

# THE CURRENT STATE OF QUANTIFYING RECEPTOR ANNOYANCE RELATED TO LOW FREQUENCY NOISE IN THE ENVIRONMENT

David C. DeGagne and Mark L. Hamm

Alberta Energy & Utilities Board  
640 Fifth Avenue S.W.  
Calgary, Alberta T2P 3G4

## ABSTRACT

Environmental noise from energy industry facilities in Alberta is regulated by the Alberta Energy and Utilities Board (EUB), as described in the *Noise Control Directive, ID 99-8*. *ID 99-8* is the fourth edition of a comprehensive policy and guide, which has adopted A-weighted energy equivalent sound levels ( $L_{Aeq}$ ) as the measurement system with sound pressure level criterion for a receptor location. With the receptor being some distance from the energy industry noise source, the high and mid-frequency components can dissipate or be absorbed by air and ground conditions, leaving mostly low frequency noise. Consequently, A-weighted measurements do not reflect the full annoyance potential of the remaining industrial noise. This paper examines the current state of research, begun by the EUB in 1995, to quantify potential receptor annoyance and meet the current noise control directive's technical approach.

## SOMMAIRE

Le bruit environant, provenant des usines de l'industrie énergétique de l'Alberta, est régulé par le EUB comme indiqué dans la Directive du Contrôle de bruit *ID 99-8*. *ID 99-8* est la 4<sup>ème</sup> édition d'une police et d'un guide complet qui ont adopté des niveaux de son d'énergie équivalente pondérée ( $L_{Aeq}$ ) comme système de mesure comprenant un critère de niveau de pression du son pour la location d'un récepteur. Le récepteur étant à une certaine distance de la source du bruit de l'industrie énergétique, les composants de haute et moyenne fréquence peuvent être dissipés ou absorbés par l'air et l'état du sol, ne laissant pour la plus part que des sons de basse fréquence. En conséquence, les mesures pondérées-A ne représentent pas le dérangement potentiel total du bruit industriel résiduel. Cet article examine le status actuel des recherches, commencées par le EUB en 1995, pour mesurer le dérangement potentiel des receveurs et respecter l'approche technique de la directive actuelle du contrôle de bruit.

## 1.0 INTRODUCTION

The current Alberta Energy and Utilities Board (EUB) *Noise Control Directive, ID 99-8*, uses A-weighted energy equivalent sound level ( $L_{Aeq}$ ) as the measurement system to determine the compliance of an energy industry facility. However, A-weighting does not provide accurate free field measurements of low frequency noise (LFN). Typical LFN for energy industry related noise is in the range of 21-500 Hz. Furthermore, research has been conducted in the field of psychoacoustics to determine specifically how humans respond to LFN. The relevant psychoacoustic research to date has focused primarily on physical and mental health issues related to LFN and differences in response to LFN between genders. The psychoacoustic effects are explored in greater depth later in this paper.

Although the EUB directive attempts to minimize the negative impacts of energy industry facility noise on people living near them, it has been recognized for a number of years that some method of quantifying the annoyance level of LFN was necessary. For this reason, the EUB has been conduct-

ing research, on a limited basis, since 1995 into understanding how different measurement systems work and how they might be used within the directive. The most promising methods that were the focus of research are Loudness, C-weighted minus A-weighted sound pressure levels, and a range of other methods such as B and D-weighting, which were somewhat effective in assessing LFN. The research information will be used to modify the measurement requirements within the Noise Control Directive to account for LFN.

## 2.0 ASSESSMENT

Before the research could be conducted and relevant information gathered, the scope of the legislation had to be ascertained. The Noise Control Directive applies to industrial energy facilities throughout Alberta. It contains precise environmental standards regarding industrial noise to which these facilities must adhere. It was designed to ensure minimal annoyance within communities and the environment. Therefore, the methods that were researched had to apply to the far field, where the sound was assumed to come from a point source some distance away. Noise is assumed to reach

the listeners' ears only from the direction straight ahead, in the open air (or non-reflecting environment).

Research was conducted with the primary intent of properly measuring or quantifying the impact of LFN. Air, ground, and obstacles absorb sound as it proceeds to travels. This is known as the attenuation of sound. The absorption of sound in air varies with humidity and temperature. However, although these factors change quite drastically throughout the seasons in Alberta, they will, in turn, counteract one another, resulting in having little effect on noise levels in the field. Furthermore, the noise in the survey fields (receptor location) will be dominated by low frequencies. Low frequency sounds have much longer wavelengths than do high frequency sounds, allowing higher frequency noise to be absorbed more readily. Typically for rural Alberta, where most energy facilities are located, the ground that the noise travels over consists of a mixture of acoustically hard (i.e., asphalt roads), soft (i.e., grasslands), and very soft (i.e., forest) surfaces. Therefore, whatever noise reaches the survey field from an energy facility consists mostly of LFN.

### 3.0 METHODOLOGY

#### 3.1 A-weighting

All sound weighting methods were developed in an attempt to alter the measured signal in a similar fashion as the human hearing mechanism. The method of A-weighting was specifically developed for human response to low sound levels. All of the different weighting techniques compress sound from a broad range of frequencies into a sound pressure level (SPL) at middle frequency (1000 Hz). However, when a measured sound spectrum has tonal components of 250 Hz or less, A-weighted Leq ( $L_{Aeq}$ ) measurements delete low frequency sound energy disproportionately to its impact on humans. Also, A-weighting methods are level dependent. This means that this accuracy depends on the SPL.

Another significant flaw prevalent in A-weighted SPLs is that they do not account for the effects of mutual masking among the components in a complex sound.

It is clear that when the sound is dominated by LFN, an alternate measurement method to A-weighting is required. Unfortunately, there are only a limited number which have the potential capability to deal with this problem. The growing prevalence of public concern about environmental noise demands timely action. There is no doubt that the next EUB review of the noise directive will need to seriously consider implementing the outcome of this important research.

#### 3.2 C-weighting

The method of C-weighting was specifically developed for human response to high sound levels. It is comparable to A-weighting except for between the 0 to 250 Hz range. C-weighting does not delete low frequency sound energy to the same extent that A-weighting does. On its own, C-weighting is suitable for assessing LFN. It can also be used along with A-weighted SPLs to determine the existence of LFN. The method of dB(C) minus dB(A) has been adopted throughout many countries in Europe in order to quantify LFN more efficiently. However, Europe uses this method more so in building regulations than in the free field. The general rule in some European countries is that a dB(C) minus dB(A) measurement greater than 15 dB requires that LFN be assessed. However, this significant difference hardly identifies a LFN problem. This is due to the high slope of the hearing threshold towards lower frequencies, implying that the low frequencies may be below threshold.

If C-weighting were to be implemented within *ID 99-8*, it could be done in two ways. The first way would be to include a dB(C) minus dB(A) standard that if exceeded would require the original  $L_{Aeq}$  value to undergo a Class C adjustment factor to account for LFN. For example, if the dB(C) minus dB(A) value was between 13 and 15, the  $L_{Aeq}$  value could be adjusted by +2 dB. This is purely an arbitrary example and more research would have to be conducted to implement an appropriate Class C adjustment factor. Although this might assess LFN more accurately than a standard dB(A) reading, it also has some negative aspects. The most apparent being that the implementation of such a Class C adjustment factor would render some field measurement equipment obsolete. Three options to assess this problem are obvious. First, if the field surveyor is currently using a sound level meter capable of measuring dB(A) or dB(C) readings but unable to store both at the same time (i.e., B&K 2231, B&K 2236), two sound level meters would have to be used in order to measure dB(A) readings and dB(C) readings simultaneously. The second option is to purchase a sound level meter capable of storing dB(A) and dB(C) measurements simultaneously (i.e., B&K 2260). A third option is to record the survey via a high fidelity VHS tape and replay the survey sounds to a sound level meter capable of measuring dB(A) or dB(C), but not both at the same time. When the survey is replayed, the weighting that was not used in the field would be recorded so that a dB(C) minus dB(A) value could be calculated. Whatever the case, implementing a Class C adjustment factor to incorporate a dB(C) minus dB(A) calculation would likely double equipment costs or the time required to analyze the survey data.

The second way that C-weighting could be implemented into *ID 99-8* is to replace the current standard of A-weighted

SPLs. This change would redefine the Noise Control Directive, but would also account for LFN to some extent in doing so. A new SPL would have to be sought and appropriate changes to the adjustment factors would have to be calculated. The predominant negative issue that would arise if C-weighting was implemented into the Noise Control Directive would be that all past dB(A) measurements would become invalid.

### 3.3 Loudness

The proper method to determine loudness is described under ISO 532 Method B (Zwicker's Method). Method A (Stephen's Method) also provides a measure of loudness but is less commonly used than Method B. Method B can be determined in terms of loudness (sones – GD or GF) or loudness level (phons – GD or GF). Loudness is based upon an internationally standardized set of equal loudness contour lines. Selected phon contour lines can be inverted to obtain A, B, and C weighting curves. Loudness seems to provide an efficient means for approximating LFN. However, research now suggests that loudness may not be a good indicator of LFN annoyance. This results from the fact that loudness levels can be relatively high, while perceived annoyance can be very low.

A Class C adjustment to A-weighted energy equivalent sound levels was proposed as a way to assess LFN within the scope of *ID 99-8*. This is probably the most feasible way of including loudness into the Noise Control Directive, and it would account for LFN in survey data to some extent. However, by including such an adjustment factor, some negative issues arise. The methods for calculating loudness are very complex, time consuming, and tedious. This could mean that a significant amount of extra time would be added to the normal time that it takes to analyze survey data under the regulations of *ID 99-8*. Programs such as B&K BZ7113 are readily available to calculate loudness given one-third octave band readings and would help in calculating a Class C adjustment factor. An option to calculating loudness would be to purchase sound level meters that measure loudness, but this would be costly and less realistic.

### 3.4 Other Methods

In addition to A and C-weighted SPLs have been the only two weighting scales mentioned, other weighting scales exist. B-weighting was developed specifically for human response to moderate sound levels. This is not a common weighting network but could possibly be the best weighting scale to account for LFN within the free field. It does not delete low frequency energy levels to the extent that A-weighting does, but its relative response to low frequencies is still less than that of C-weighting. B-weighting has under-

gone very little research and virtually no equipment exists which could measure  $L_{B\text{eq}}$  values. Therefore, B-weighting would be an impractical way to account for LFN.

Other weighting networks exist but would not apply for the assessment of LFN within the free field. D-weighting was specifically developed for noise around airports. While D-weighting does not delete much low frequency energy, it does boost the high frequency range between 1000 and 12,000 Hz. This weighting network has been researched, but has not been adopted by any international standards group. G-weighting is specifically designed for infrasonic noise (0 - 20 Hz). Other weighting networks have also been designed for very specific purposes.

Stephens' Mark VI method, as described by ISO 532 Method A, is another method for calculating loudness. This method utilizes physical measurements obtained from spectrum analysis in terms of octave bands and is specifically recommended for simplicity. However, Stephens' method can only accommodate measurements within a diffuse sound field and is, therefore, inadequate for use within the Noise Control Directive.

Some countries in Europe have designed maximum LFN levels for each octave band and incorporated them into their regulations. For example, Sweden's Health Authorities developed indoor LFN building regulations with the following sound pressure limitations for low frequency sound pressure levels measured at a receptor location:

Frequency [Hz]	$L_{A\text{eq}}$ [dB(A)]
31.5	56
40	49
50	43
63	41.5
80	40
100	38
125	36
160	34
200	32

A system such as this could be incorporated into the EUB Noise Control Directive. However, research and experimentation must be conducted in order to determine proper values that would represent annoyance levels for communities affected by industrial energy facilities. One disadvantage to such a system is that such regulations may be difficult to comply with. The more regulating sound level values that are incorporated into the Noise Control Directive, the more insignificant each number becomes. If a method such as this were to be incorporated into the Noise Control Directive, the EUB would have to conduct an annoyance level survey in

order to create regulations applicable to Alberta residents. A statistically significant number of rural Albertans would need to be surveyed and tested to establish some level of confidence in the outcome, not an easy or inexpensive task.

Establishing regulations similar to those in Sweden is a proven way to account for LFN in a sound survey. This method would not require the additional measurement equipment or computer program changes. Also, A-weighting would still be retained within the scope of the Noise Control Directive and, therefore, few changes would have to be made to the directive. Furthermore, the extent to which C-weighting and loudness accounts for LFN is a disputed issue, even though regulations such as Sweden's have been successful in addressing LFN problems within their country.

## 4.0 PSYCHOACOUSTICS

### 4.1 Human Response to LFN

As mentioned previously, the purpose of researching psychoacoustics is to establish the need to address LFN specifically within the Noise Control Directive. This research has focused primarily on physical and mental health issues related to LFN and the differential response to LFN between genders.

As industry grows larger, the effects of noise grow more and more out of control. At the same time, peoples' expectancies for their quality of life increase. When these two facts coincide, the issues related to LFN problems grow exponentially.

The fundamental characteristic of LFN is that of "intrusiveness." After much research, it has been suggested that LFN contributes to annoyance responses by:

1. creating a sensation of pressure in the ear,
2. periodically masking effects on medium and high frequency sound with a strong modulation effect that can disturb normal conversation, and
3. by creating secondary vibrating effects typically experienced within homes.

Analysis of documented noise complaints would seem to be consistent with the above suggestions. With continuous exposure to LFN, behavioral dysfunction such as

- a) task performance deterioration,
- b) reduced wakefulness,
- c) sleep disturbance, headaches, and irritation, can occur.

LFN does not need to be considered "loud" in order for it to cause such forms of annoyance and irritation. One significant characteristic of LFN is that it is found to be more dif-

ficult to ignore than higher frequency noise. Individuals suffering from LFN annoyance have been known to describe it as

- i) omnipresent,
- ii) impossible to ignore,
- iii) worse indoors (due to the effects of vibration),
- iv) unable to locate, and
- v) difficult to tune out.

Unlike high frequency noise, LFN is difficult to suppress. Closing doors and windows in attempt to diminish the effects of LFN make the noise worse, due to the propagation characteristics of LFN and the low-pass filtering effect of structures. Individuals often become irrational and anxious as attempts to control LFN fail, serving only to increase the individual's awareness of the noise.

There is quite a significant difference between genders in their response to loudness. Experiments conducted by N. Broner and H. G. Leventhall concluded that males tend to react to loudness with a significantly higher response than females do. The annoyance response remains similar between genders, although males seem to be less sensitive to low noise levels and more sensitive to high noise levels than females.

## 5.0 CONCLUSIONS

The current Noise Control Directive fails to properly account for the presence of LFN in survey data. This is primarily due to the use of A-weighted energy equivalent sound levels, which do not accurately account for LFN. The psychoacoustic research that was conducted has shown that LFN can have serious negative effects on an individual's quality of life. For this reason, the EUB is committed to implement appropriate regulations that will suitably account for LFN.

To date, the most practical methods for further investigation and eventual incorporation into the Noise Control Directive remain Loudness (as described by ISO 532 Method B), C-weighting (including dB(C) minus dB(A)), and appropriate maximum SPLs for one-third octave bands below 200 Hz.

## 6.0 REFERENCES

- [1] 'ID 99-8: Noise Control Directive', Alberta Energy and Utilities Board (October 1999)
- [2] ISO 532, 'Acoustics – Method for Calculating Loudness Level', (1975)
- [3] H. Moller, T. Watanabe, 'Low Frequency Hearing Thresholds in Pressure Field and in Free Field', Journal of LFN and Vibration, Vol. 9, No. 3 (1990)

- [4] K. D. Kryter, 'The Effects of Noise on Man', Academic Press Inc., Second Edition (1985)
- [5] R. Hellman, E. Zwicker, 'Why Can a Decrease in dB(A) Produce an Increase in Loudness?', Journal of the Acoustical Society of America, Vol. 82, No.5 (1987)
- [6] H. Moller, 'Comments to Infrasounds in Residential Area – Case Study', Journal of LFN and Vibration, Vol. 14, No. 2 (1995)
- [7] K. Holmberg, U. Landstrom, A. Kjellberg, 'Low Frequency Noise Level Variations and Annoyance in Working Environments', Journal of LFN, Vibration and Active Control, Vol. 16, No. 2 (1997)
- [8] E. B. Magrab, 'Environmental Noise Control', John Wiley and Sons Inc. (1975)
- [9] D. C. DeGagne, J. G. Farquharson, 'The Application of Loudness in Environmental Noise Legislation for the Energy Industry', Inter-Noise '95 (July 10-12 1995)
- [10] M. Lydolf, H. Moller, 'Proceedings of the 8th International Meeting on LFN and Vibration', Multi-Science Publication, Gothenburg (June 3-5 1997)
- [11] J. R. Hassall, K. Zaveri, 'Acoustic Noise Measurements', Bruel & Kjaer (1988)
- [12] N. Broner, H. G. Leventhall, 'Annoyance Loudness and Unacceptability of Higher Level Low Frequency Noise', Journal of LFN and Vibration, Vol. 4, No. 1 (1985)
- [13] S. Benton, 'Measurement Challenges in Assessing the Annoying Characteristics of Noise. Is Low Frequency Noise a Special Case?', Journal of LFN and Vibration, Vol. 16, No. 1 (1997)
- [14] L. E. Marks, 'Recalibrating the Auditory System: The Perception of Loudness', Journal of Experimental Psychology: Human Perception and Performance, Vol. 20, No. 2 (1994)

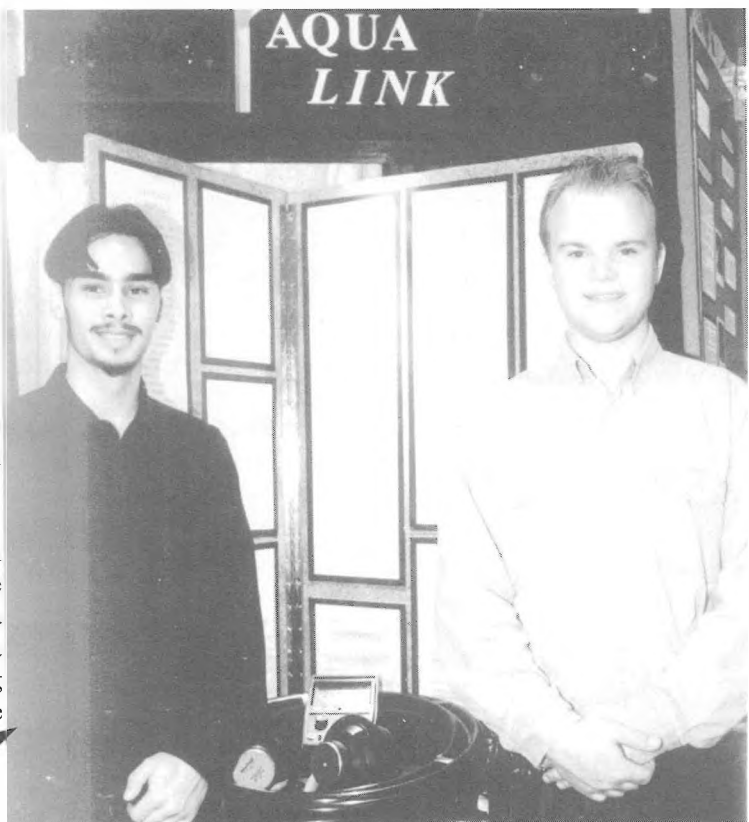
### Canada Wide Science Fair Canadian Acoustical Association - Special Award

Over 428 students participated in this year's Canada Wide Science Fair in Edmonton winning \$130,000 in cash, cholarships, trips and other prizes. The students are selected from regional fairs that take place across the country. The fair was attended by judges, delegates, officials, guests, visitors, as well as thousands of visitors. The nine day event consisted of two days of judging, an opening and closing banquet, an awards ceremony, tours, public viewing of projects, cultural activities, seminars, and workshops.

The Canadian Acoustical Association provides an award for the best project in acoustics. The award is \$400 plus a one-year subscription to Canadian Acoustics. The students also receive a certificate.

This year the prize was awarded to Allan Kaufman and Kodie Tober. Allan is from Clyde AB and Kodie is from Fawcett AB. Both attend St. Mary School and are in Grade 12. Their project was entitled "Aqua Link". It examined the viability of conducting acoustic signals by means of aquatic wave impulse conversion.

*Alan Kaufman (L) and Kodie Tober (R)*



# ***Gunnar Rasmussen Acoustic Solutions:***

***Precision Acoustic Measurement Instrumentation***



***Condenser Microphones and Preamplifiers  
Intensity Probes  
Outdoor Microphones / Hydrophones  
Calibration Instrumentation and Accessories***

**G.R.A.S.**  
Sound & Vibration

***Represented in Canada by***

**NOVEL DYNAMICS INC.**  
.....  
Dynamic Test and Analysis Systems

***Integrated Solutions from World Leaders***

Novel Dynamics Inc.  
Phone 519-853-4495 Fax 519-853-3366  
Email: [metelka@aztec-net.com](mailto:metelka@aztec-net.com)  
Ottawa Office 613-599-6275 Fax 613-599-6274