Informative document

Mine Workers Exposure to Noise and Vibrations

Produced for SOREDEM
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CANMET Mining and Mineral Sciences Laboratories (CANMET-MMSL)
CANMET Mining and Mineral Sciences Laboratories are key stakeholders to Natural Resources Canada's mining technology sector. CANMET-MMSL has long been recognized internationally for the excellence of their technology of mining and mineral processing, and for their leadership in the design of technological solutions to reduce environmental responsabilities and improve the health and safety of mine workers.

Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST)
Firmly established in Quebec since 1980, the IRSST is a private non-profit organization. Its Board of Directors is made up of an equal number of employer and worker representatives, making it a bipartite body. The Commission on the health and safety of Quebec (CSST) provides most of its funding from the contributions that it collects from employers. The mission of the IRSST is to contribute, through research, to the prevention of occupational accidents and occupational diseases as well as to the rehabilitation of affected workers. IRSST also, provides laboratory services and expertise to the action network public health prevention and safety and ensure the dissemination of knowledge.

SOREDEM
Members of the Quebec Mining Association (QMA) have established, in January 1992, the mining research and development society SOREDEM. The non profit organisation, was given the mandate to promote the emergence of new technologies in underground mines in Quebec to increase the competitiveness of these enterprises on the international market and develop safer conditions in the workplace. SOREDEM consists of mining companies, members of the QMA, which finance research. The Company coordinates projects with researchers from several institutions and research organizations.

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Foreword

This document was prepared under a project carried out jointly by CANMET-MMSL, the IRSST and SOREDEM in order to draw a general picture of the exposure of miners to vibration and noise.

Problematics
Health problems related to vibration and noise are among the main causes of work-related compensations in mines. Although no Canadian regulations could force employers to limit the exposure of their workers to vibration, the mining research and development society SOREDEM decided to address the problem by including vibrations among their research priorities.

Document objective
This document was written with the main objective of distributing up to date information about mine workers exposure to noise and vibration. It presents a summary of the information found in the litterature and obtained during the measurement campain performed in SOREDEM member mines in 2009.

Who was this document written for?
This document is intended primarily for preventionists and occupational health and safety related personnel in mines. They can find basic information, calculation methods, typical vibratory and noise levels and tools to assess exposure of workers in their company to vibration and noise. Practical examples are presented in Annexes 1 to 4.

Managers, buyers and supervisors are also invited to consult the document to make informed choices in relation to equipment and tasks assigned to workers.

Finally, operators concerned about their health, can consult the document in order to estimate if the noise and vibration levels to which they are exposed are likely to affect their long-term health.

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SECTION 1: Vibrations

As in many industrial environments, the vibrations are omnipresent in the mining industry. They may have a negative impact on the health of workers and it is important to understand its amplitude in order to lay the appropriate preventive actions.

This section provides basic knowledge on vibration, their effect on health, regulations, measuring equipment and methods, as well as calculation methods and maximum recommended daily exposures.

What are vibrations?

Vibrations are mechanical oscillations of an object or tool. The vibrations affecting the workers are divided into two types according to their mode of action, **whole-body vibration** and **hand-arm vibration**.

Is there a regulation on vibrations?

The Canada Labour Code stipulates that the employer must ensure that the levels of ventilation, lighting, temperature, humidity, sound and vibration are in accordance with prescribed standards[1]. Otherwise it does not define exposure limits. Most provinces, including Quebec, does not address vibratory exposure in their regulations.

British Columbia is the only province defining limits of exposure to whole-body vibration and hand-arm vibration. It also defines the obligation of the employer to take measurements and in case the vibrations exceed the recommended limits, inform the employee of possible effects on their health and develop a plan to reduce vibration. New Brunswick only defines the limits for exposure to hand-arm vibration. Nunavut and the Northwest Territories require employers to provide gloves, shoes and anti-vibration seat when necessary, without establishing exposure limits.

The worlds mostly used regulation is Directive 2002/44/EC of the European Parliament. This directive is implemented across the European Union and is often used as reference to other regulations. It defines action values and limit values for hand-arm vibration and whole-body vibration.

[1] Canada Labour Code, L.R.C. 1985, c. L-2, art. 125

What are the effects of vibration on health?

The effects of vibration on health of individuals are not immediate and vary from one worker to another. Time from first exposure to the appearance of symptoms is called the latency. Some damage caused by vibrations is permanent while others are reversible.

Whole-body vibration

The whole-body vibrations are transmitted to the operator by the seat or the floor. Epidemiological studies of long term exposure to whole-body vibration showed higher frequency of back pain, disk herniation and early degeneration in the spine[2]. The prolonged sitting posture and torsion of the trunk during exposure to whole-body vibration are additional risk factors.

According to The Canadian Center for Occupational Health and Safety, whole-body vibration can cause fatigue, insomnia, stomach problems, headache may also contribute to a number of circulatory, bowel, respiratory and back disorders[3].

[2] INRS, Vibrations et mal de dos, ED 6018, février 2008, p. 24
[3] http://www.cchst.ca/oshanswers/phys_agents/vibration/vibration_effects.html#_1_4

Hand-arm vibration

Hand-arm vibrations are transmitted to the operator by the hands when using vibrating tools or controls. The most known health disorder associated with hand-arm vibration is Raynaud's disease also known as white hands disease. The symptoms of this disease are aggravated by cold and moisture. The chart shown in Figure 2 allows us to estimate the latency period for the appearance of the first stage of Raynaud's disease according to the daily vibration exposure to hand-arm vibration A(8). The example presented on the graph allows us to estimate that 10 % of workers will develop the first state of Raynaud's disease after 4 years at a daily exposure at 5 m/s^2.

Figure 1: Hand affected by Raynaud's disease[4]

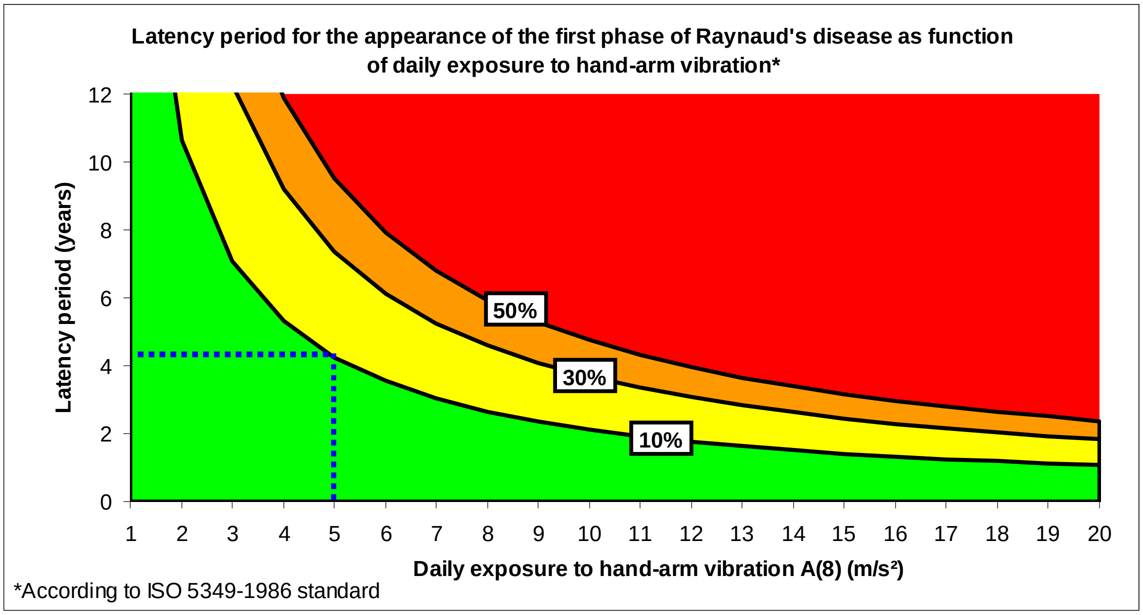

Figure 2: Chart of the latent period on Raynaud's disease.

Among other occupatioal diseases that could be caused or aggravated by hand-arm vibrations; we find musculo-skeletal syndrome, carpal tunnel and tendonitis.

[4] http://en.wikipedia.org/wiki/Raynaud's_phenomenon

Vibration measurements

As well as making noise measurements, vibration measurements can be taken directly by the companies or through consultants. In some jurisdictions, like Europe for example, this practice is regulated. This section presents the basic knowlegde required for taking vibration measurements in business. It is strongly recommended to consult the documents given as references before starting a measurement campaign.

Instruments

There are two types of systems for evaluating worker's exposure to vibration. The first type consists of a data acquisition system that records complete vibration data. In this case, external software is used to perform detailed analysis. This type of system is mainly used by researchers and consultants. A system of this type has been used for vibration measurements taken in mines within the project that is behind this document.

A second type of device, the vibration dosimeter is much better suited to the needs of the mining industry. Like a noise dosimeter, the device does not record the full data, but rather calculates various values to calculate exposure. This type of device, very compact, can be slipped in the pocket of the worker whose exposure must be evaluated. The two most popular models are the Larson Davis HVM100 and Bruel & Kjaer Type 4447, shown in Figure 3.

Figure 3: Vibration dosimeters

Both types of systems, the acquisition system and the vibration dosimeter are used with the same type of sensor such as a miniature tri-axal accelerometer. This usually takes the form of a cube and has a size smaller than one centimetre. Depending on the source of vibration to evaluate, it can be mounted using various mounting accessories such as collars, screwed or magnetic adapters, or then again mounted in a cushion for the

Evaluation of seats. A tri-axial accelerometer type and various mounting accessories are shown in Figure 4.

Figure 4: Example of a tri-axial accelerometer and mounting accessories

Wireless integrated vibratory dosimeters recently appeared on the market. In these systems, electronic components that allow recording of vibratory levels are integrated to the sensor. Once activated by a computer, they are autonomous and they reccord vibratory levels automatically. They are therefore particularly well suited for industrial vibratory dosimetry.

During this project, we tested the EVEC[5] wireless integrated whole body dosimeter for whole body vibration. This apparatus uses a Bluetooth connexion to configure the sensors and transfer data to a personal computer or pocket assistant. The system includes two sensors, one for the seat and the other for the floor that can be used simultaneously. It is therefore suitable to evaluate suspension seat performance. I should be noted that results obtained from this system are similar to those obtained with conventional commercial devices.

Figure 5 : Système EVEC pour vibrations globales du corps

At least two manufacturers are currently working at the development of integrated wireless dosimeters for hand-arm vibration. These autonomous dosimeters are inserted between fingers and work like the EVEC system described earlier. One should otherwise remain cautious with this type of dosimeter because the sensitivity range and the mounting method are not adapted to all mining equipment. Trials with a pre-production prototype were performed and showed that it was inappropriate for the measurement of the vibration level of pneumatic rockdrills. It is strongly recommended to perform a comparative test with a conventional apparatus before purchasing and using a system of this type.

[5] http://www.body-vibration.eu/en/evec_human_vibration_meter_en.aspx

The positioning of accelerometers

Vibratory measurements are usually performed in three locations which are hands, seat and floor. The accelerometers must be installed according to the orientations shown in Figure 6.

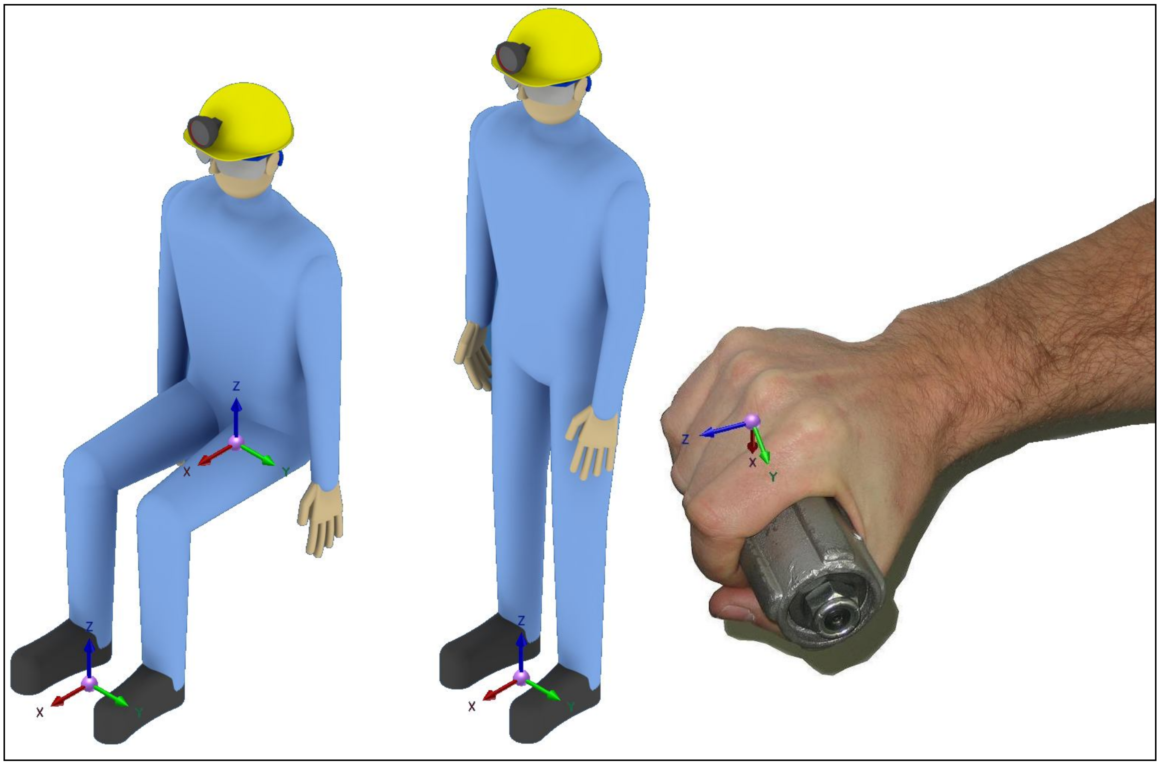

Figure 6: Orientation of accelerometers

Harmful frequencies and weighted acceleration

The frequency of vibration, expressed in Hertz (Hz), is the number of oscillations per second. For a given acceleration, the displacement is lower for high frequencies.

The different organs of human bodies react differently depending on the frequency of vibration. For example, the small movements associated with high frequencies are absorbed through the skin and soft tissues are not transmitted to the spine. On the opposite of the spectrum, vibrations of very low frequency, although associated with large displacements do not affect the hands as they follow the movement as a whole.

Therefore, there is a range of vibration frequencies having a greater impact on the human body. Weighting curves have been developed to take into account this phenomenon and give more weight to frequencies that affects the body. The ISO 5349 standard defines the weighting curve W_h used for hand-arm vibration (X, Y and Z). ISO 2631 defines the weighting curve W_k for the Z-axis of whole body vibration and W_d for axes X and Y for whole-body vibration.

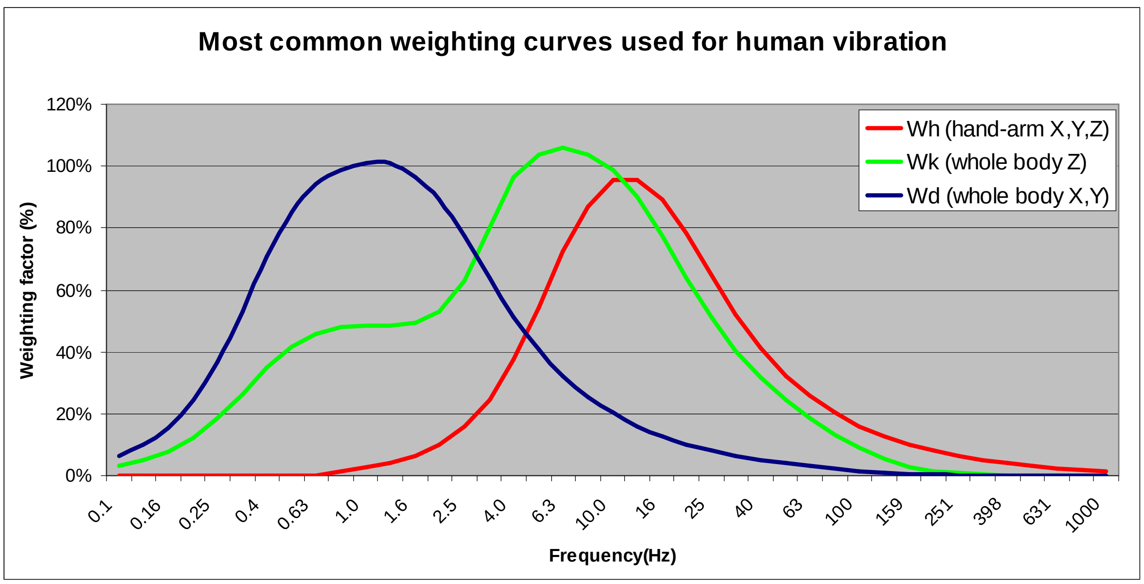

Figure 7: Main weighting curves used in human vibration.

The weighting curves are programmed into devices such as vibration dosimeter. One should not forget to select the proper weighting curve before taking measurements.

Interpretation of results

In this section, the basic calculations to interpret the results of a vibration dosimeter will be explained. These calculations can be performed using the vibration levels presented in Section 3 to estimate the exposure of a worker according to his daily tasks.

Calculation of daily exposure to hand-arm vibration: A(8)

The acceleration weighted by $\mathbf{W_h}$ curve is represented by the symbols $\mathbf{a_{hvx}}$, $\mathbf{a_{hvy}}$ and $\mathbf{a_{hvz}}$. To evaluate the effect of vibration in the three axes on the hand-arm system, we calculate the total value of weighted acceleration $\mathbf{a_{hv}}$ as follows:

$$a_{hv} = \sqrt{(a_{hvx})^2 + (a_{hvy})^2 + (a_{hvz})^2}$$

Daily exposure **A(8)** is the weighted acceleration normalized for 8 hours. It is expressed in m/s². When the worker performs several tasks, the daily exposure associated with each task is denoted $\mathbf{A_i(8)}$.

To calculate the daily exposure from the weighted acceleration and duration of a task, use the following formula:

$$A_i(8) = a_{hv} \times \left(\frac{T}{8}\right)^{0.5}$$ where T : exposure duration in hours

To obtain the time required to reach a certain level of exposure, we isolate T in the previous formula to get:

$$T = 8 \times \frac{A(8)_{cible}{}^2}{a_{hv}{}^2}$$

Finally, to calculate the total daily exposure from daily exposure associated with various tasks, use the following formula:

$$A(8) = \sqrt{(A_1(8))^2 + (A_2(8))^2 + (A_3(8))^2 + \ldots}$$

A calculation example is presented in Annex 1.

Calculation of daily exposure to whole-body vibration: A(8)

This procedure can be applied to assess risks to a workers health whose vibrations are transmitted to the body by the seat or the floor.

The frequency-weighted acceleration according to $\mathbf{W_d}$ curve for x and y axes is represented by symbols $\mathbf{a_{wx}}$ and $\mathbf{a_{wy}}$. The frequency-weighted acceleration according to the $\mathbf{W_k}$ curve for z axis is represented by the symbol $\mathbf{a_{wz}}$.

For whole-body vibration, we independently calculate daily exposure for each axis ($\mathbf{A_x(8)}$, $\mathbf{A_y(8)}$ **and** $\mathbf{A_z(8)}$ **)**. The equivalent total daily exposure is the greatest value obtained. When the worker performs several tasks, partial daily exposures associated with each task are recorded $\mathbf{A_{ix}(8)}$, $\mathbf{A_{iy}(8)}$ **and** $\mathbf{A_{iz}(8)}$. Caution, a factor of 1.4 for the x and y axes must be applied for the calculation of whole-body vibration daily exposure.

$$A_{ix}(8) = 1.4 \times a_{wx} \times \sqrt{\frac{T}{8}} \qquad A_{iy}(8) = 1.4 \times a_{wy} \times \sqrt{\frac{T}{8}} \qquad A_{iz}(8) = a_{wz} \times \sqrt{\frac{T}{8}}$$

where: T is the exposure duration expressed in hours.

The different tasks are combined according to each axis, using the following formulas:

$$A_x(8) = \sqrt{(A_{1x}(8))^2 + (A_{2x}(8))^2 + (A_{3x}(8))^2 + \ldots}$$
$$A_y(8) = \sqrt{(A_{1y}(8))^2 + (A_{2y}(8))^2 + (A_{3y}(8))^2 + \ldots}$$
$$A_z(8) = \sqrt{(A_{1z}(8))^2 + (A_{2z}(8))^2 + (A_{3z}(8))^2 + \ldots}$$

Finally, the daily exposure corresponds to the largest values obtained for the different axes:

$$A(8) = \max\left(A_x(8), A_y(8), A_z(8)\right)$$

A calculation example is presented in Annex 2.

Calculation of the dose of whole-body vibration: VDV

The value of the vibration dose **VDV**, is an alternative method to calculate the total daily exposure to whole-body vibration. It is based on a quadratic summation that gives more weight to impacts. As in the case of calculating A(8) for whole-body vibration, calculation of **VDV** must be performed for each axis and the maximum value should be taken.

The value of the vibration dose calculated by the device takes into account the length of the measurement. For the same vibration level, the longer the exposure time, the higher the **VDV** is. It is therefore necessary to correct the **VDV** according to the total duration of the worker exposure during a work shift by using the following formula (note the factor 1.4 for the x and y axes):

$$VDV_{\exp,i,x} = 1.4 \times VDV_{i,x}\left(\frac{T_{\exp}}{T_{mes}}\right)^{\frac{1}{4}}$$

$$VDV_{\exp,i,y} = 1.4 \times VDV_{i,y}\left(\frac{T_{\exp}}{T_{mes}}\right)^{\frac{1}{4}}$$

$$VDV_{\exp,i,z} = VDV_{i,z}\left(\frac{T_{\exp}}{T_{mes}}\right)^{\frac{1}{4}}$$

or: T_{exp} = Exposure duration (h)
T_{mes} = Measurement duration (h)

When the worker performs several tasks during a shift, you can combine partial VDV as follows:

$$VDV_x = \left(VDV_{\exp,1,x}{}^4 + VDV_{\exp,2,x}{}^4 + VDV_{\exp,3,x}{}^4 + \ldots\right)^{\frac{1}{4}}$$

$$VDV_y = \left(VDV_{\exp,1,y}{}^4 + VDV_{\exp,2,y}{}^4 + VDV_{\exp,3,y}{}^4 + \ldots\right)^{\frac{1}{4}}$$

$$VDV_z = \left(VDV_{\exp,1,z}{}^4 + VDV_{\exp,2,z}{}^4 + VDV_{\exp,3,z}{}^4 + \ldots\right)^{\frac{1}{4}}$$

The value of the vibration dose for the worker is the maximum value obtained for the different axes:

$$VDV = \max\left(VDV_x + VDV_y + VDV_z\right)$$

A calculation example is presented in Annex 3.

Maximum recommended level : A(8) and VDV

Directive 2002/44/EC of the European Parliament defines action and limit values for hand-arm and whole-body vibration. Levels prescribed by this recent Directive are based on recommendations of reference bodies such as the International Organization for Standardization (ISO) and the American Conference of Governmental Industrial Hygienists.

In jurisdictions where this Directive is implemented, the action value is the value at which the employer must take the following actions:
-determine and evaluate the risks
-taking measures to eliminate or reduce exposure
-train and inform the worker
-monitor the worker's health

Also in jurisdictions subject to this Directive, the limit is the legal limit for daily exposure to which an employee may be subjected.

Below the action value, risks to the workers health has not been clearly demonstrated and/or objectively observed. Between value and action limit value, potential risks to the workers health have been documented. Beyond the limit value, the long term effects on the health of workers are very likely.[6]. Table 1 shows the action and limit values specified by the Directive 2002/44/EC of the Eurpean Parliament.

	Hand-arm	**Whole-body**	
	A(8)	**A(8)**	**VDV**
Action value	2.5 m/s²	0.5 m/s²	9.1 $m/s^{1.75}$
Limit value	5 m/s²	1.15 m/s²	21 $m/s^{1.75}$

Table 1: Recommended exposure limit

Note that for whole-body vibration, the European Directive 2002/44/EC allows the use of daily exposure **A(8)** or vibration dose **VDV** to set exposure limits.

The crest factor is the ratio of peak acceleration compared to the effective value of the signal (rms value). It is given by most vibration dosimeters. A high crest factor is associated with the presence of impacts and shocks. The effect on health of impacts and shocks is possibly underestimated by the daily exposure method **A(8)**. Therefore, for tasks where there is presence of shocks and impacts (crest factor > 9), it is recommended to use the vibration dose **VDV**[7].

[6] ISO 2631-1 : 1997
[7] ISO-2631-1:1997

Spreadsheet tools

Excellent spreadsheet tools are available for free on the Internet. The HSE, a government agency of the United Kingdom, publish on his website two free Excel spreadsheets to calculate workers exposure to whole-body and hand-arm vibration.

http://www.hse.gov.uk/VIBRATION/hav/vibrationcalc.htm

http://www.hse.gov.uk/VIBRATION/wbv/calculator.htm

SECTION 2: Noise

Problematic related to noise in the mining industry has long been known and the hearing protector is associated with the mining industry in like manner as the miner's lamp.

Section XV of the Quebec regulation respecting occupational health and safety[8] deals with noise. It defines, amongst others, the maximum exposure to which a worker could be exposed. It also defines the obligation of the employer, in a company with 50 employees or more to make noise measurements for any job where the maximum exposure is likely to be exceeded.

As mining companies are subject to this law, they usually employ qualified staff members to perform the actions required by law.

This document does not cover the basics knowledge related to sonometry. Instead, it was chosen to bring to your attention some important concepts.

[8] Regulation respecting occupational health and safety, O.C. 885-2001, 2001 G.O.

Where to find the basics of sonometry

The Canadian Center For Occupational Health and Safety has a complete website (http://www.cchst.ca) presenting a wealth of information related to industrial hygiene. This site contains, among others, two sub-sections of particular interest that deal with noise exposure in the workplace.

The first section (http://www.cchst.ca/oshanswers/phys_agents/noise_basic.html) popularizes the basics of sonemetry under forms of questions/answers. The following questions are being developed:

- What are sound and noise?
- Why is noise an important workplace hazard?
- How can I tell if my workplace is too loud?
- What are some properties of noise that can be measured?
- What are pitch and frequency?
- What is sound pressure?
- What is sound pressure level?
- What is sound power?
- What is the relation between sound pressure and sound power?
- What kinds of noise are there?
- What are A-weighted decibels?
- What are basic rules of working with decibel (dB) units?
- How are noise levels added?

The second section (http://www.cchst.ca/oshanswers/phys_agents/noise_auditory.html) discusses auditory effects on noise in developing the following topics:

- What kinds of health effects can be caused by exposure to noise?
- What are examples of auditory health effects?
- What are the characteristics of noise-induced permanent hearing loss?
- Does aging affect hearing?
- What are some other causes of hearing loss?
- How is hearing loss measured?
- How is the amount of hearing disability measured or expressed?
- What is an example of a hearing disability calculation?
- What is the relationship between noise exposure and hearing loss?

Legal Exposure Limits in Canada

Noise exposure limits are defined similarly in all Canadian provinces regulations. A maximum exposure level allowed for 8 hours and an exchange rate is given in dBA. The exchange rate is the amount by which the permitted sound level may increase if the exposure time is halved.

Jurisdiction	Maximum Permitted Exposure Level for 8 hours (dBA)	Exchange Rate (dBA)
Colombie-Britannique	85	3
Alberta	85	3
Saskatchewan	85	3
Manitoba	85	3
Ontario	85	3
Québec	90	5
Nouveau-Brunswick	85	3
Nouvelle-Écosse	85	3
Île-du-Prince-Édouard	85	3
Terre-Neuve et Labrador	85	3
Territoires du Nord-Ouest	85	5
Nunavut	85	3 or 5
Yukon	85	3

Table 2: Noise exposure limits by province

It should be noted that Quebec is the most permissive jurisdiction with a maxmum permitted exposure of 90 dBA for 8 hours and an exchange rate of 5 dBA.

Quebec regulation on health and safety expects that the level of maximum permissible exposure will be reduced to 85 dB from a later date determined by regulation under section 223 of the Health Act and Safety (RSQ, c. S-2.1).

Articles 134 and 135 of the regulation on health and safety of Quebec also defines the number of impacts permitted by shifts in the level of noise in dB linear and the calculation method for combining different levels of impact.

Actual protection vs NRR

Article 137 of the Regulation respecting occupational health and safety of Quebec states that any hearing protector provided to a worker shall reduce the noise such that the worker is no longer exposed to noises that exceed the maximum permitted level. It is not specific as to how to evaluate a worker's exposure to noise when wearing hearing protectors. The proposed method is a simple method for estimating a worker's exposure to noise. Please note that there are alternative, more complex methods, to estimate with greater precision, a workers exposure to noise.

The approved hearing protectors NRR rating (Noise Reduction Rating) which can be used to estimate the level of protection provided. The NRR value was developed to be used to calculate the noise level in dBA under the protector by subtracting the NRR from the noise level expressed in dBC. As the regulations in all Canadian jurisdictions set exposure limits in dBA, measures are often taken using this weighting.

To estimate exposure in dBA from the sound level in dBA and the NRR value, subtract 7 dB from the NRR indicated.

The NRR value is obtained from laboratory tests in which hearing protectors are placed over the heads of subjects, by technicians in ideal conditions. Usually, the level of production in the workplace is always lower. Many studies have been conducted to measure the actual attenuation of hearing protectors[9]. To reflect the actual attenuation of hearing protectors, NIOSH (National Institute for Occupational Safety and Health) recommends that the labelled NRR be reduced by the following factors for various types of protection:

NRR reduction recommended by NIOSH to reflect the actual protection in the workplace		
Earmuffs	subtract 25%	$NRR_{reduit} = 0.75*NRR$
Formable earplugs	subtract 50%	$NRR_{reduit} = 0.50*NRR$
All other plugs	subtract 70%	$NRR_{reduit} = 0.30*NRR$

Table 3: NRR reduction recommended for estimation of the actual level of protection.

For example, to estimate the effective noise exposure of a worker, expressed in dBA, use the following formulas from noise levels measured in dBA or dBC using a sound level meter or noise dosimeter:

$\text{Exposition (dBA)} = \text{dBC} - NRR_{\text{réduit}}$

$\text{Exposition (dBA)} = \text{dBA} – (NRR_{reduit} – 7)$

[9] http://www.cdc.gov/niosh/docs/98-126/chap6.html

Effect of dual protection

When earplugs and earmuffs are worn simultaneously, the level of protection increases. The increased level of total protection is not directly equal to the sum of the levels of protective earplugs and earmuffs. To estimate the effect of dual protection, it is recommended to add 5 dB of attenuation to the protection level offered by the most protective device.

Effect on removing the hearing protectors for short periods

The removal of hearing protectors for even short periods has a very negative effect on the actual level of protection offered. The reasons most often cited for removing a hearing protector are discomfort and difficulties to communicate due to excessive attenuation.

Table 4 shows the actual level of protection offered for different values of attenuation hearing protector according to the period during which the protector is removed.

Actual attenuation of hearing protector(dB)	Equivalent level of protection (dB) offered if during a period of 8 hours if the protection device is removed during :					
	5 min	10 min	15 min	30 min	45 min	1 h
30	19.4	16.6	14.9	12	10.2	9
25	18.7	16.2	14.6	11.8	10.1	8.9
20	16.9	15.1	13.9	11.4	9.9	8.7
15	13.8	12.9	12.1	10.4	9.1	8.2
10	9.6	9.2	8.9	8.1	7.3	6.7

Table 4: Protection according to the period of withdrawal of hearing protectors

By observing the table, one can realise that there is no advantage using a hearing protector with a high attenuation it must be retired, even for short periods, to communicate. For example, the act of removing a hearing protector with an attenuation of 25 dB for only 15 minutes during an 8 hour shift lowers the real level of protection to below 15 dB. It would be more advantageous to use a hearing protector with a lower attenuation, but allowing the worker to communicate.

The best hearing protection is not necessarily the one that offers the greatest attenuation; in fact, it is the one that the worker will wear continuously.

Calculation of daily exposure for multiple tasks

Caution: There are many calculators on the Internet that allow calculation of the daily exposure for multiple tasks. However, the majority use the formulas based on an exchange rate (factor of bisection) of 3 dB.

The following method allows us to calculate the noise exposure dose for each task. Doses must be added to determine if the employee exceeds the limit of daily exposure corresponding to 100%.

L: effective noise level during the task (dBA)
T: duration of the task (hours)
$L8_{max}$: maximum permissible level for a period of 8 hours (90 dBA in Quebec)
C_{eq}: exchange rate (5 in Quebec)

$$DOSE(\%) = \frac{T \times 10^{\left(\frac{.3*L}{C_{eq}}\right)}}{8 \times 10^{\left(\frac{.3*L8_{max}}{C_{eq}}\right)}} \times 100$$

To verify compliance with current regulations of Quebec, by replacing C_{eq} by 5 and $L8_{max}$ by 90, we obtain the following simplified formula:

$$DOSE(\%) = \frac{T \times 10^{(0.06 \times L)}}{20095} \quad \text{(if } C_{eq} = 5 \text{ and } L8_{max} = 90\text{)}$$

An example of calculation is presented in annex 4.

Maximum recommended daily exposure

Most research reports indicate that there is a risk for the workers health as soon as exposure exceeds 85 dBA for a period of 8 hours. Moreover, most research reports also indicate that to properly assess the effect of noise exposure on human hearing loss, an exchange rate of 3 should be used. That's why most jurisdictions use these values in their regulation.

The simplified formula for calculating the dose of daily exposure to noise causing long-term hearing loss becomes:

$$DOSE(\%) = \frac{T \times 10^{(0.1 \times L)}}{25298221} \quad \text{(if } C_{eq} = 3 \text{ and } L8_{max} = 85\text{)}$$

SECTION 3: Vibration and Noise levels of mining equipment

This section presents the vibration levels of mining equipment to identify the tasks that are potentially problematic.

Several factors may influence the level of vibration equipment. The condition of equipment, field conditions and operator are among the parameters having the greatest influence on results. In literature, it is therefore not uncommon to encounter very different vibration values for the same type of equipment.

We must therefore carefully use the results presented in this section. It is strongly recommended to measure the vibration exposure of workers in cases considered potentially problematic.

There are few data in literature on the vibration levels of various mining equipment. Therefore, a measurement campaign was conducted in SOREDEM mines to obtain or confirm the vibration levels of chosen mining equipment. Tables 5 and 6 summarizes the vibration and noise levels recorded during the measurement campaign in the SOREDEM mines. Required exposure duration to attain action and limit exposure values defined by the European directive can also be found in these tables.

Detailed results are presented available through SOREDEM.

Vibratory levels of mining equipment, as found in the literature, are presented at Annex 5.

WHOLE BODY VIBRATION (measurement into SOREDEM member mines)									
Task	Daily exposure				Dose de vibration VDV				Bruit
	Aw average (m/s²)	Standard deviation	Taction (h)	Tlimit (h)	VDV8 average	Standard deviation	Taction (h)	Tlimit (h)	dBA
Travelling - Utility truck (boom truck, concrete truck), solid tires, pneumatic seat	1.40	0.21	**1.0**	**5.4**	29.6	4.7	**0.1**	**2.0**	89
Travelling - LandCruiser (average front and rear cabin)	0.75	0.09	**3.6**	**>8**	15.0	2.2	**1.1**	**>8**	-
Travelling - 5 ton locomotive (average seat and floor)	0.91	0.16	**2.4**	**>8**	19.6	3.3	**0.4**	**>8**	91
Travelling - MineCat 100PC (driver)	1.60	0.02	**0.8**	**4.1**	34.7	0.5	**0.0**	**1.1**	103
Travelling - RTV	0.72	0.03	**3.9**	**>8**	13.8	0.8	**1.5**	**>8**	-
Travelling - Kubota 5740 (driver)	1.01	0.05	**2.0**	**>8**	29.0	8.7	**0.1**	**2.2**	101
Drilling - Jumbo drill	0.11	0.06	**>8**	**>8**	5.6	5.9	**>8**	**>8**	76-105
Drilling and bolting - Bolter	0.16	0.13	**>8**	**>8**	4.8	6.0	**>8**	**>8**	105
Drilling and bolting - Alimak platform	0.59	0.21	**5.7**	**>8**	11.8	3.4	**2.8**	**>8**	-
Drilling and bolting - Scissor lift	0.23	0.20	**>8**	**>8**	6.3	7.3	**>8**	**>8**	-
Drilling and bolting - Aluminium scaffolding (section that holds the leg of the drill excluded)	1.35	0.14	**1.1**	**5.8**	24.8	7.8	**0.1**	**4.1**	122
Mucking - Scooptram	1.08	0.26	**1.7**	**>8**	22.3	5.1	**0.2**	**6.3**	83-105
Mucking - Muck machine *	3.42	0.56	**0.2**	**0.9**	97.2	21.9	**0.0**	**0.0**	117
Mucking – CAVO*	2.62	0.18	**0.3**	**1.5**	65.8	7.4	**0.0**	**0.1**	115
Grading - Road grader	0.73	0.11	**3.8**	**>8**	15.1	3.3	**1.0**	**>8**	101
Legend : **less than 1 hour** / **between 1 and 4 hours** / **between 1 and 4 hours** / **more than 8 hours**									
*Standing may contribute, in a limited manner, to attenuate the effect of vibrations. However, these very high recorded levels are a major concern.									

Table 5: Whole body vibrations levels recorded during measurement campaign in SOREDEM member mines

HAND-ARM VIBRATION (measurement into SOREDEM member mines)					
Task	Daily exposure				Noise
	Aw average (m/s²)	Standard deviation	Taction (h)	Tlimit (h)	dBA
Travelling with MineCat 100PC (steering)	2.58	0.04	**7.5**	**>8**	103
Travelling with RTV (steering)	3.05	0.40	**5.4**	**>8**	-
Travelling with Kubota 5740 (steering)	2.63	0.25	**7.2**	**>8**	101
Drilling with jumbo drillForage (controls)	1.83	0.19	**>8**	**>8**	76-105
Pneumatic rockdrill with anti-vibration handle	9.19	0.48	**0.6**	**2.4**	117
Pneumatic rockdrill with conventional handle	21.84	0.50	**0.1**	**0.4**	117
Road grader operation (steering)	2.27	0.45	**>8**	**>8**	101
CAVO (handle)	2.08	0.03	**>8**	**>8**	115
Legend :	**less than 1 hour**	**between 1 et 4 hours**	**between 4 and 8 hours**	**more than 8 hours**	

Table 6 : Hand-arm vibrations levels recorded during measurement campaign in SOREDEM member mines

Graphs of daily exposure were produced for whole body vibration for each category of equipment. On these graphs, it is possible to see the extent of the distribution of measures and the risk area as function of the number of hours of exposure. A comment is added for each category of equipment.

Travelling - Utility truck (boom truck, concrete truck), solid tires, pneumatic seat

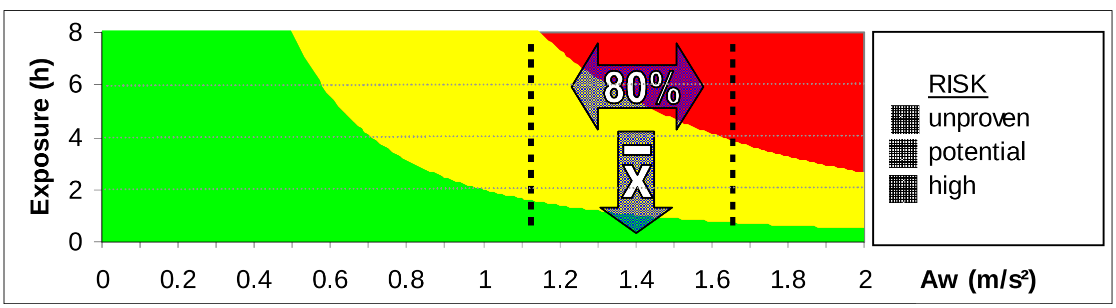

Figure 8: Daily exposure: Utility truck

A boom truck and a cement truck, both equipped with solid tires and a pneumatic seat were evaluated. The measured levels were similar. In both cases, the suspension seat helped to reduce the vibration level by between 10 and 25 percent.

Travelling - LandCruiser (average front and rear cabin)

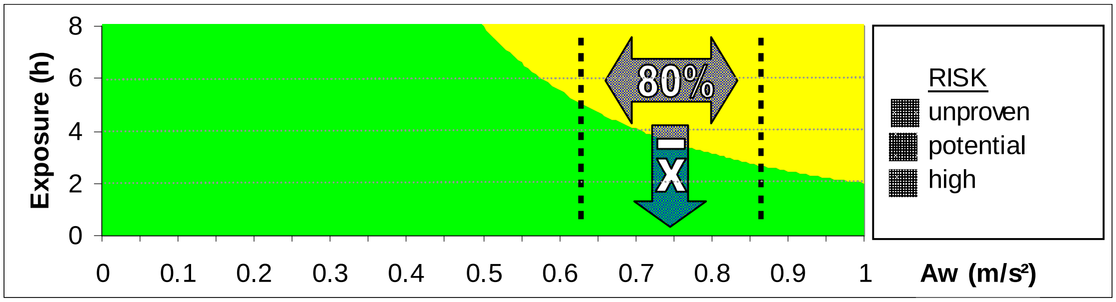

Figure 9: Daily exposure: LandCruiser

Vibration levels among the lowest for a personnel transportation vehicle. The action value is reached after about 2.5 to 5 hours of daily exposure.

Travelling - 5 ton locomotive (average seat and floor)

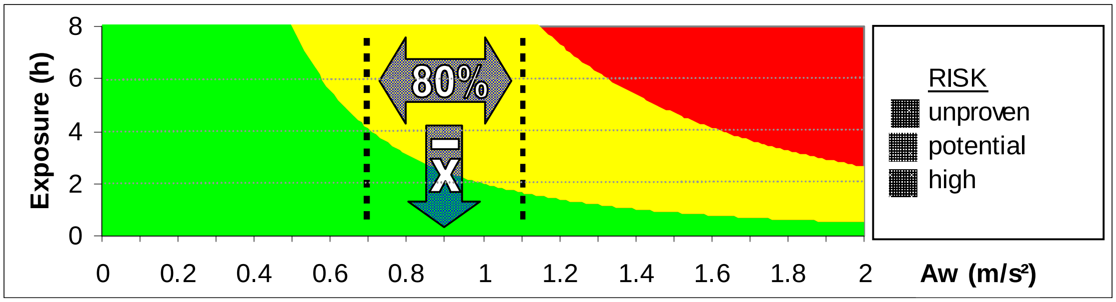

Figure 10: Daily exposure: 5 tons locomotive

Comparable levels, with or without cars. The action value is reached between 1.75 and 4 hours. In all cases, it remains under the limit.

Travelling - MineCat 100PC (driver)

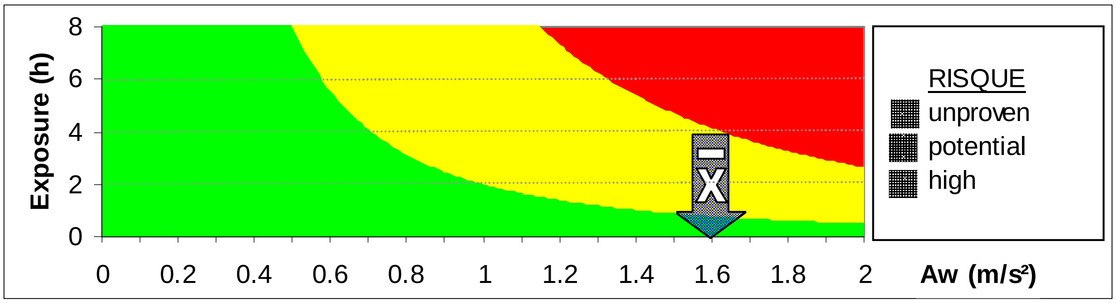

Figure 11: Daily exposure: MineCat 100PC

Vibration level recorded at the driver's position. The levels recorded in the rear seats are even higher (1.84 m/s²). The action value is reached in under an hour. The limit value is reached after about 4 hours of exposure.

Travelling - RTV

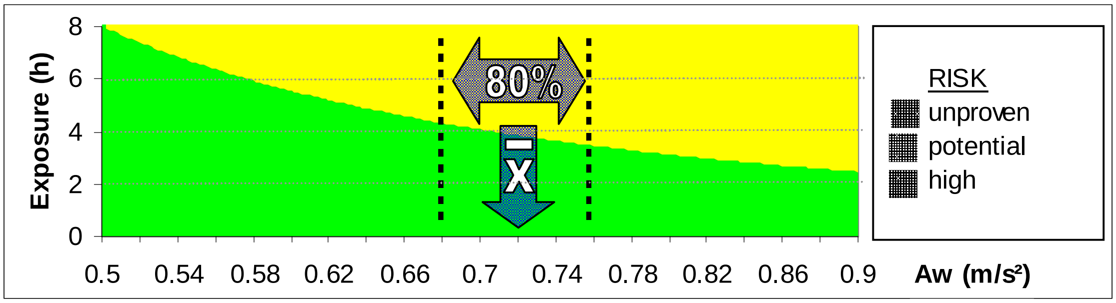

Figure 12: Daily exposure: RTV

The levels recorded are amongst the lowest for a vehicle to transport employees. The action value is reached after about 4 hours of daily exposure.

Travelling - Kubota 5740 (driver)

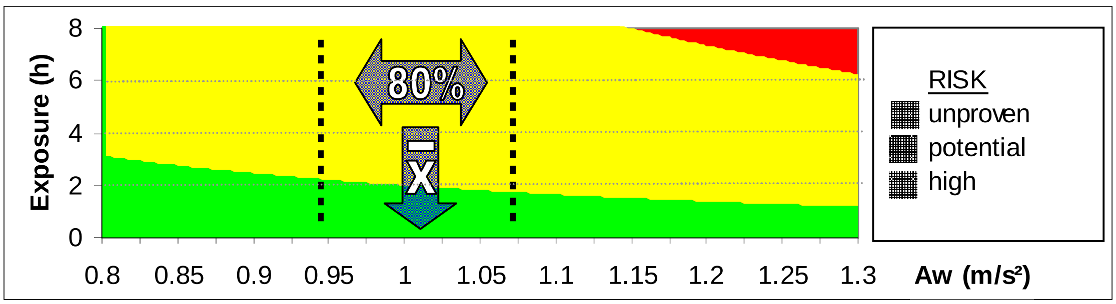

Figure 13: Daily exposure: Kubota 5740

Intermediate level of vibration compared to other vehicles of staff transportation. The action value is reached after about 2 hours. It remains under the limit value for an 8 hour shift.

Drilling - Jumbo drill

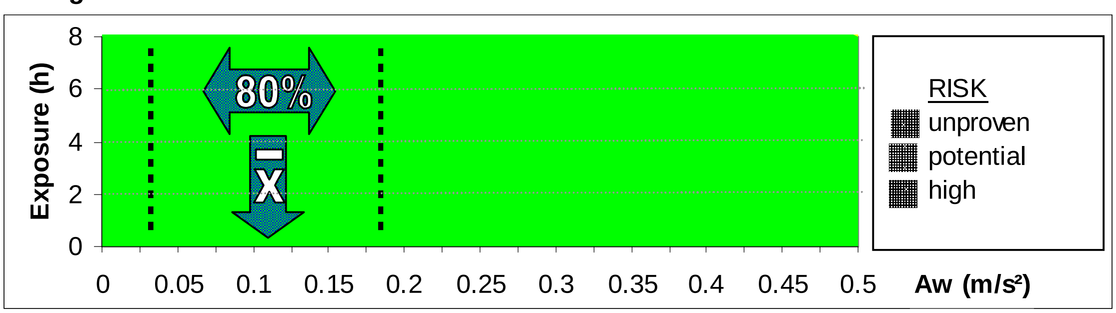

Figure 14: Daily exposure: Jumbo drill

Two jumbo drills were evaluated. One with a cabin isolated from vibrations, and a conventional jumbo. In both cases, the vibration levels recorded did not pose a health risk to operators.

Drilling and bolting - Bolter

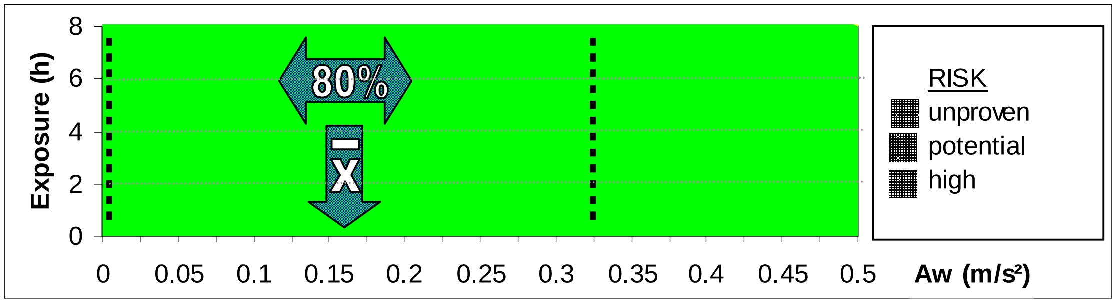

Figure 15: Daily exposure: Bolter

Non-problematic task on whole-body vibration level for both pieces of equipment assessed.

Drilling and bolting –Alimak platform

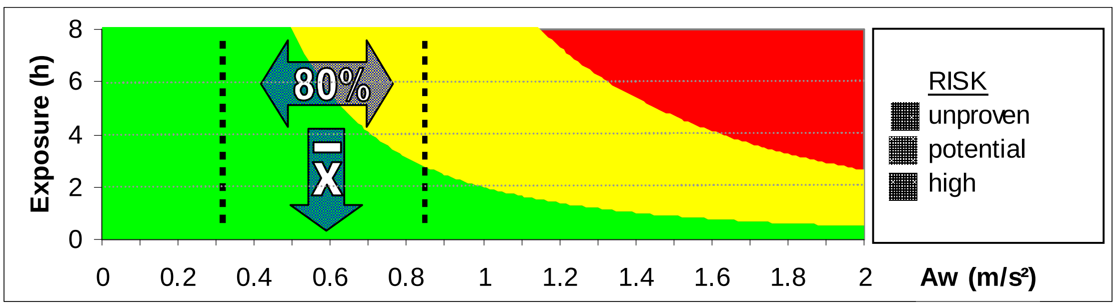

Figure 16: Daily exposure: Alimak

Two Alimak were evaluated. The levels obtained were not problematic for a typical shift.

Drilling and bolting - Scissor lift

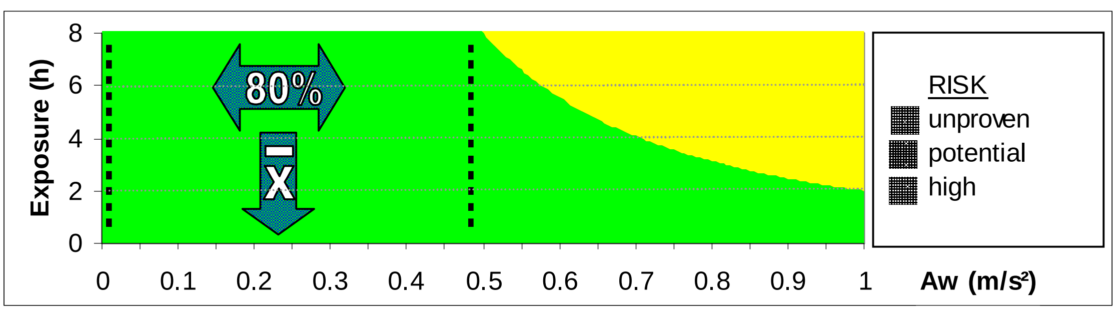

Figure 17: Daily exposure: Scissor lift

Non-problematic task level of whole-body vibration for equipment assessed.

Drilling and bolting - Aluminium scaffolding
(section that holds the leg of the drill excluded)

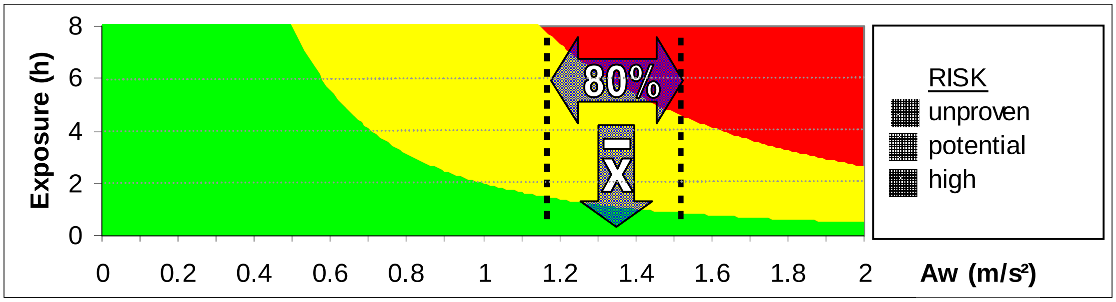

Figure 18: Daily exposure: Aluminium scaffolding

Measurements were made on the section adjacent to the section where the jackleg is supported. The action value is reached after about 1 hour of exposure.

Mucking - scooptram

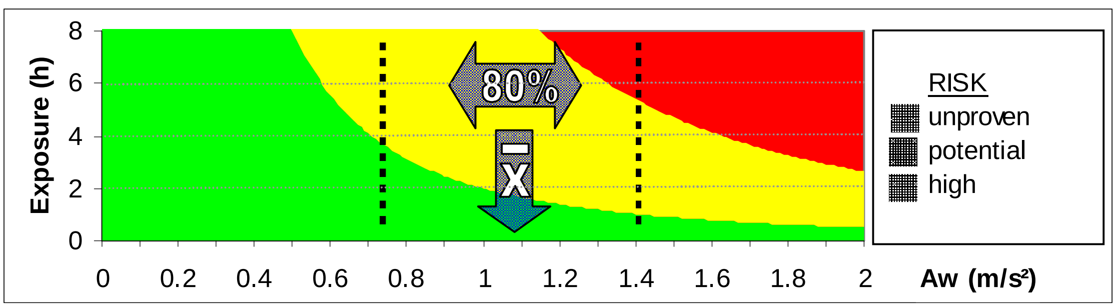

Figure 19: Daily exposure: Mucking with scooptram

Six scooptrams with capacities ranging between 3.5 and 15 cubic yards have been evaluated. No trend can be found as function of the capacity of the machine. The recorded levels vary greatly as function of the condition of the gallery and ore to be excavated.

Mucking - Muck machine

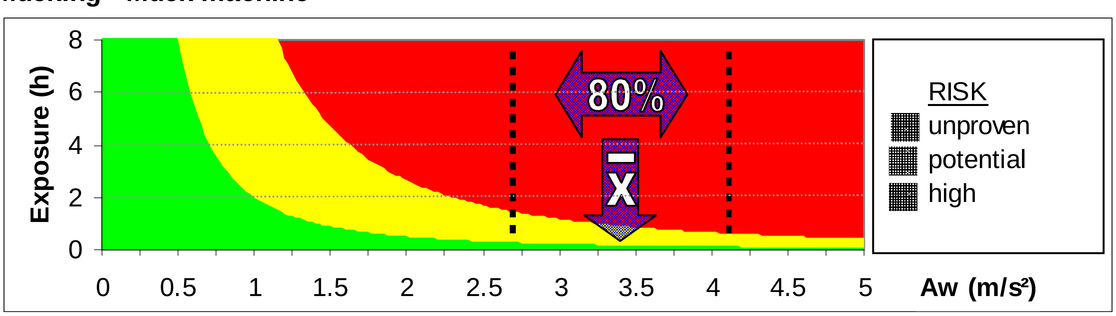

Figure 20: Daily exposure: Muck machine

Highest vibration level observed during the measurement campaign. The limit value based on daily exposure A(8) is reached after about 1 hour. It would be prudent to limit time exposure to workers using this equipment.

Mucking – CAVO

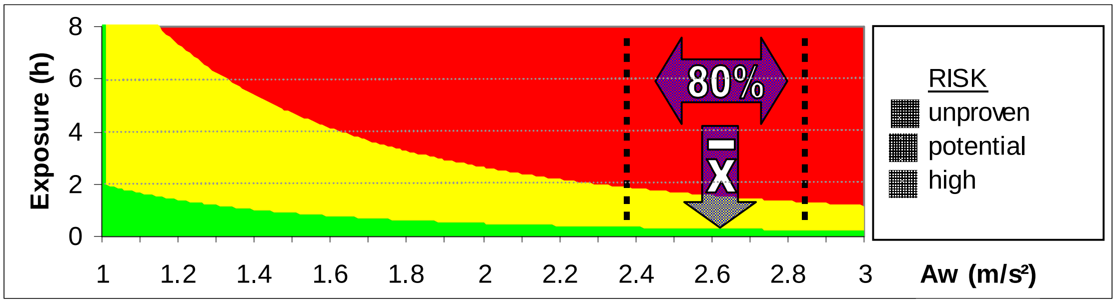

Figure 21 : Daily exposure: CAVO

Second vibratory level mostly observed during the last measurement campaign. The action value is reached after only a few minutes. The limit value based on daily exposure A(8) is reached in less than two hours. It would be prudent to limit time exposure to workers using this equipment.

Grading - Road grader

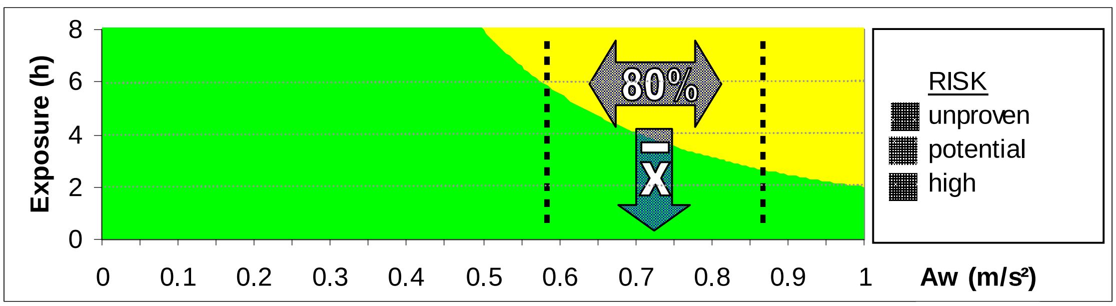

Figure 22: Daily exposure: Grader

Two graders were assessed in the context of the measurement campaign. In both cases, the vibration levels were similar. In all cases, levels remain below the limit value for an exposure time of 8 hours.

Note on the use of pneumatic rockdrills

The vibratory level of pneumatic rockdrills is extremely high. A worker that is exposed to the vibrations of the handle reaches the action exposure limit after a period of only 6 minutes and the limit value after 25 minutes. An anti-vibration handle, which allows reducing the vibratory level by approximately 60%, has been developed. Work aiming at improving the reliability of the handle is currently ongoing. If this handle reaches the market, it will reduce the vibratory level to about 9.2 m/s² which would allow a worker to be exposed for about two hours before reaching high risk zone. Figure 24 shows the graph of daily exposure to hand-arm vibration for pneumatic rockdrills equipped with a conventional and an anti-vibration handle.

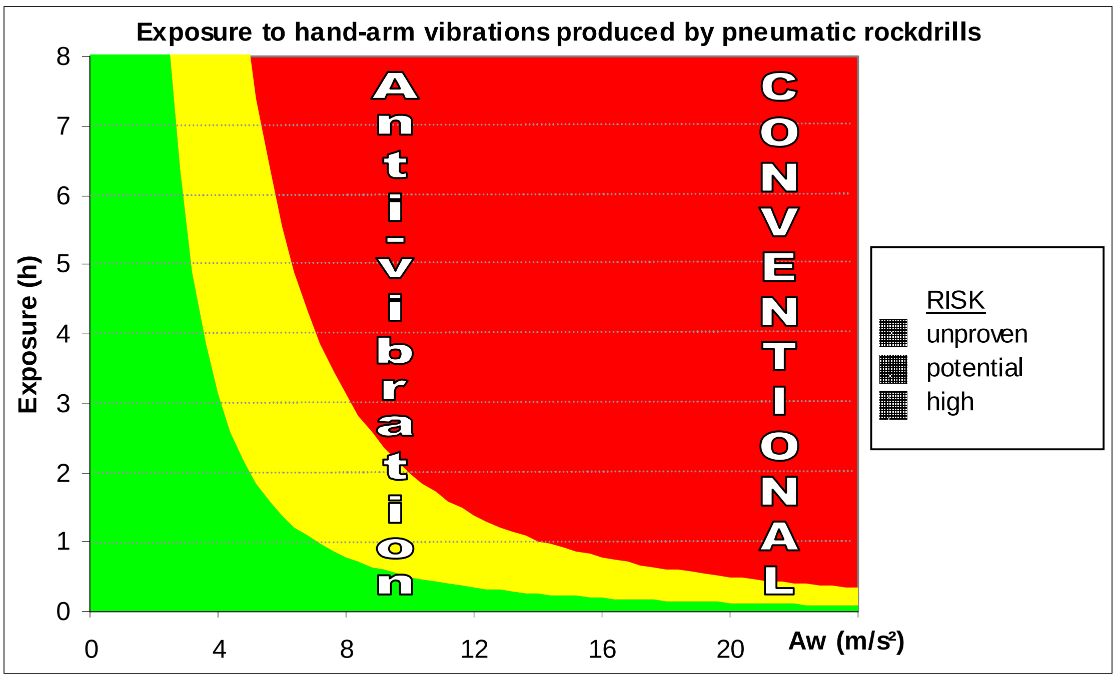

Figure 23: Daily exposure: Pneumatic rockdrills

Note on suspension seats

Improper or poorly adjusted suspension seat can significantly increase the vibration level and therefore the health risk for the operator. It is important that the seat is adjusted to the weight of the operator and that it does not reach travel limit during normal operation of the vehicle. Of the six scooptrams that were evaluated, 4 seats were amplifying the vibration levels.

The seats that attenuated the vibration levels were pneumatic suspension seats.

Loader	Floor		Seat		Attenuation seat	
	RMS	VDV8	RMS	VDV8	RMS	VDV8
1	1.17	22.06	1.45	28.00	-24%	-27%
2	0.74	18.53	0.83	18.44	-12%	0%
3	0.61	17.14	0.86	22.17	-41%	-29%
4	0.70	15.46	1.00	19.75	-43%	-28%
5	1.50	35.21	1.38	26.34	8%	25%
6	1.26	33.49	0.98	18.88	22%	44%

Table 7: Scooptrams seat attenuation

SECTION 4: References and Tools

DIRECTIVE 2002/44/CE

Description of the document: Text of the European regulation on the minimum health and safety requirements regarding the exposure of workers to the risks arising from vibrations (2002, pdf, 7 pages)

Google key words: 2002/44/CE en pdf

Guide to good practice on whole-body vibration

Description: Guide to good practice, produced by the INRS, with a view to apply the Directive 2002/44/CE of the European Parliament. (2006, pdf, 65 pages)

Google key words: INRS whole-body vibration guide

Guide to good practice on hand-arm vibration

Description: Guide to good practice, produced by the INRS, with a view to apply the Directive 2002/44/CE of the European Parliament. (2006, pdf, 65 pages)

Google key words: INRS hand-arm vibration guide

Vibrations et mal de dos

Description: Portion of the INRS web site is devoted to vibration and back pain in the workplace. This section is not available in english.

http://www.inrs.fr/dossiers/vibrationsdos.html

SST Answers- Physical Agents

Description: The Canadian Center for Occupational Health and Safety contains a section called *SST Answers* that responds to a host of questions about health and safety at work. The Physical Agents section responds to many questions about noise and vibration.

http://www.cchst.ca/oshanswers/phys_agents/

HSE-Vibration at Work

Description: HSE, a government agency of the United Kingdom devotes an entire section of its website to vibration in the workplace. There is a lot of information as well as two Excel spreadsheets allowing to calculate the daily exposure to whole-body vibration and hand-arm vibration.

http://www.hse.gov.uk/vibration/

Annex 1: Example of daily exposure calculation of hand-arm vibration - A(8)

Scenario:
We want to evaluate if a worker is exposed to excessive hand-arm vibration. During a typical shift, the worker is exposed to hand-arm vibration when performing two tasks:

Task	**T (h)**	$\mathbf{a_{hvx}}$	$\mathbf{a_{hvy}}$	$\mathbf{a_{hvz}}$	$\mathbf{a_{hv}}$
A	2	2	3	4	5.4
B	0.5	5	6	12	14.3

In the literature, we can directly find the values of a_{hv}. If we proceed to the measure in the three axes, we must combine the values as follows to obtain a_{hv} :

$$a_{hv} = \sqrt{(a_{hvx})^2 + (a_{hvy})^2 + (a_{hvz})^2}$$

task A : $a_{hv} = \sqrt{(2)^2 + (3)^2 + (4)^2} = 5.4$

task B : $a_{hv} = \sqrt{(5)^2 + (6)^2 + (12)^2} = 14.3$

Daily exposure associated to each task is calculated as follow:

$A_i(8) = a_{hv} \times \sqrt{\frac{T}{8}}$ or T : exposure duration expressed in hours

Thus $A_A(8) = 5.4 \times \sqrt{\frac{2}{8}} = 2.7$ and $A_B(8) = 14.3 \times \sqrt{\frac{0.5}{8}} = 3.6$

Daily exposure of the two tasks combined is calculated as follows:

$A(8) = \sqrt{(A_1(8))^2 + (A_2(8))^2 + (A_3(8))^2 + ...}$ thus $A(8) = \sqrt{2.7^2 + 3.6^2} = 4.5$

The daily exposure value **A(8)** of 4.5 exceeds the action value of 2.5 but is below the set limit of 5 prescribed by the Directive of the European Parliament. It is therefore recommended to take actions to limit worker exposure and monitor his condition because there are potential long term health risks.

If we want to determine the duration of the task B required to achieve a value share of 2.5, we must use the following formula:

$T = 8 \times \frac{A(8)_{target}{}^2}{a_{hv}{}^2}$ thus $T = 8 \times \frac{(2.5)^2}{(14.3)^2} = 0.25 \text{ hours} = 15 \text{ minutes}$

Annex 2 : Example of daily exposure calculation to whole-body vibration - A(8)

Scenario:
We want to evaluate if a worker is exposed to excessive whole-body vibration. During a typical work shift, the worker is operating two vehicles that are transmitting vibration to the operator through the seat:

Task	Exposure duration T (h)	a_{wx}	a_{wy}	a_{wz}
A	3	.20	.45	.60
B	1	.55	.30	.90

The first step is to calculate the daily exposure for each axis of each task using the following formulas (note the factor 1.4 for the x and y axes):

$$A_{ix}(8) = 1.4 \times a_{wx} \times \sqrt{\frac{T}{8}} \qquad A_{iy}(8) = 1.4 \times a_{wy} \times \sqrt{\frac{T}{8}} \qquad A_{iz}(8) = a_{wz} \times \sqrt{\frac{T}{8}}$$

Task	$A_{ix}(8)$	$A_{iy}(8)$	$A_{iz}(8)$
A	.17	.39	.37
B	.27	.15	.32

You then calculate the total exposure for each axis using the following formula:

$$A_x(8) = \sqrt{(A_{1x}(8))^2 + (A_{2x}(8))^2 + (A_{3x}(8))^2 + \ldots} = \sqrt{.17^2 + .27^2} = 0.32$$

$$A_y(8) = \sqrt{(A_{1y}(8))^2 + (A_{2y}(8))^2 + (A_{3y}(8))^2 + \ldots} = \sqrt{.39^2 + .15^2} = 0.42$$

$$A_z(8) = \sqrt{(A_{1z}(8))^2 + (A_{2z}(8))^2 + (A_{3z}(8))^2 + \ldots} = \sqrt{.37^2 + .32^2} = 0.49$$

The daily exposure corresponds to the largest value, thereof 0.49, obtained for the Z axis. This value is below the action value (0.5), therefore no significant risk has been clearly demonstrated.

Annex 3 : Example of vibration dose calculation of whole-body vibrations - VDV

Scenario:
We suspect that the employee of the scenario in Annex 2 is subject to impacts from the suspension seat which frequently comes into abutment. We therefore decided to calculate the vibration dose of whole-body vibration – **VDV** for this case.

Note: vibratory dosimeters provide values of **VDV** and **A8**, it is therefore not necessary to repeat measurements.

Task	**Measurement time T_{mes} (h)**	**Exposure duration T_{exp} (h)**	**$VDV_{i,x}$**	**$VDV_{i,y}$**	**$VDV_{i,z}$**
A	0.75	3	2.42	5.03	11.93
B	.5	1	6.52	3.19	9.67

The first step is to correct the VDV obtained by the device according to the exposure duration of workers during a shift using the following formulas (note the factor 1.4 for the x and y axes):

$$VDV_{\exp,i,x} = 1.4 \times VDV_{i,x}\left(\frac{T_{\exp}}{T_{mes}}\right)^{\frac{1}{4}}$$

$$VDV_{\exp,i,x} = 1.4 \times VDV_{i,x}\left(\frac{T_{\exp}}{T_{mes}}\right)^{\frac{1}{4}}$$

$$VDV_{\exp,i,z} = VDV_{i,z}\left(\frac{T_{\exp}}{T_{mes}}\right)^{\frac{1}{4}}$$

Task	**$VDV_{exp,i,x}$**	**$VDV_{exp,i,y}$**	**$VDV_{exp,i,z}$**
A	4.80	9.95	16.87
B	10.86	5.30	11.50

Then you have to calculate the VDV for each axis by combining partial VDV associated to each tasks using the following formula:

$$VDV_{axis} = \left(VDV_{\exp,1,axis}{}^{4} + VDV_{\exp,2,axis}{}^{4} + VDV_{\exp,3,axis}{}^{4} + \ldots\right)^{\frac{1}{4}}$$

thus

$$VDV_x = \left(4.80^4 + 10.86^4\right)^{\frac{1}{4}} = 10.96$$

$$VDV_y = \left(9.95^4 + 5.30^4\right)^{\frac{1}{4}} = 10.15$$

$$VDV_z = \left(16.87^4 + 11.50^4\right)^{\frac{1}{4}} = 17.72$$

The vibration dose for the worker correspond to the largest value, thereof 17.72, obtained for the Z axis. This value is between the value of action (9.1) and the limit value (21) for the **VDV**. It is therefore recommended to take measures to limit a worker's exposure and to monitor his condition, because there are potential long term health risks.

Annex 4: Example of daily sound exposure calculation for multiple tasks

Scenario: We want to determine if exposure of a worker exceeds the limits prescribed by Quebec regulations on health and safety and if the exposure dose is likely to affect long term hearing health of the worker. Surveys conducted with a sound level meter were used to determine noise levels associated with each task performed by the worker during a typical work shift.

Task	Sound levels dBA	Daily exposure in hours	Protection used
A	105	2	Earmuffs – NRR 27
B	116	1	double protection earmuffs-NRR27 and formable earplugs-NRR29
C	86	3	no protection

The first step is to determine the noise levels to which the worker is exposed at the completion of each task.

$NRR_{reduced}$ (earmuffs) = NRR x 0.75 = 27 x 0.75 = 20.25
$NRR_{reduced}$ (formable earplugs) = NRR x 0.50 = 29 x 0.50 = 14.5
$NRR_{reduced}$ (formable earplugs and earmuffs) = max (20.25, 14.5) + 5 = 25.25

Exposure (dBA) = dBA – ($NRR_{reduced}$ – 7)

thus $Exposure_{TaskA}$(dBA) = 105 – (20.25 – 7) = 91.75 dBA

$Exposure_{TaskB}$(dBA) = 116 – (25.25 – 7) = 97.75 dBA

$Exposure_{TaskC}$(dBA) = 86

The legal exposure dose associated with each task is calculated as follows:

$$DOSE_{legal}(\%) = \frac{T \times 10^{(0.06 \times L)}}{20095}$$ (simplified formula for C_{eq} = 5 and $L8_{max}$ = 90, Quebec)

$$DOSE_{legalA}(\%) = \frac{T \times 10^{(0.06 \times L)}}{20095} = \frac{2 \times 10^{(0.06 \times 91.75)}}{20095} = 31.8$$

$$DOSE_{legalB}(\%) = \frac{T \times 10^{(0.06 \times L)}}{20095} = \frac{1 \times 10^{(0.06 \times 97.75)}}{20095} = 36.4$$

$$DOSE_{legalC}(\%) = \frac{T \times 10^{(0.06 \times L)}}{20095} = \frac{3 \times 10^{(0.06 \times 86)}}{20095} = 21.6$$

The total daily dose of sound exposure for the worker is equal to the sum of the doses associated with each task.

$$DOSE\ (\%) = DOSE_A + DOSE_B + DOSE_C = 31.8 + 36.4 + 21.6 = 90\,\%$$

The worker is exposed to 90% of the maximum prescribed exposure dose by the current version of the law on health and safety of Quebec.

If we want to determine whether noise exposure can affect long-term hearing health of a worker, we must repeat the calculation of the noise exposure dose using C_{eq} = 3 and $L8_{max}$ = 85:

$$DOSE_{health}(\%) = \frac{T \times 10^{(0.1 \times L)}}{25298221} \text{ (if } C_{eq} = 3 \text{ and } L8_{max} = 85 \text{)}$$

$$DOSE_{healthA}(\%) = \frac{T \times 10^{(0.1 \times L)}}{25298221} = \frac{2 \times 10^{(0.1 \times 91.75)}}{25298221} = 118$$

$$DOSE_{healthB}(\%) = \frac{T \times 10^{(0.1 \times L)}}{25298221} = \frac{1 \times 10^{(0.1 \times 97.75)}}{25298221} = 235$$

$$DOSE_{healthC}(\%) = \frac{T \times 10^{(0.1 \times L)}}{25298221} = \frac{3 \times 10^{(0.1 \times 86)}}{25298221} = 47$$

$$DOSE_{health}(\%) = DOSE_{healthA} + DOSE_{healthB} + DOSE_{healthC} = 118 + 235 + 47 = 400\,\%$$

Because the calculated dose exceeds 100%, we can conclude that it is likely to affect the long term hearing health of the worker.

Annexe 5 : Vibration levels from literature

WHOLE BODY VIBRATION LEVELS FROM LITERATURE

Sources	Legend
1-Whole-body vibration on construction, mining and quarrying machines, HSE, research report 400, 2005	less than 1 hour (red)
2-T. Eger, A. Salmoni, A. Cann, R. Jack, Whole-body vibration exposure experienced by mining equipment operators. Occupational Ergonomics, 6:121-127, 2006.	between1 and 4 hours (orange)
3- A. Salmoni, T. Eger, P.-É. Boileau, Evaluation of whole-body vibration, seat design and performance, and sitting posture in large mobile equipment. Final Report, WSIB Grant #03-049, 2006.	between 4 and 8 hours (light yellow)
4-J.L. van Niekerk, P.S. Heyns, N. Heyns, J.R. Hassall, The measurement of vibration characteristics of mining equipment and impact percussive machines and tools. Final report, Safety in Mines Research Advisory Commitee (South Africa), Project number GEN 503, 1999.	more than 8 hours (green)
5-J. Village, J.B. Morrison, D.K.N. Leong, Whole-body vibration in underground load-haul-dump vehicles. Ergonomics, 32(10):1167-1183, 1989	
6-guide normalisé ISO TR 25398:2006	

Description	Aw average (m/s²)	Taction (h)	Tlimit (h)	Reference
Bulldozer	1.96	0.5	2.8	2
Bulldozer	0.9	2.5	>8	6
Bulldozer	1.45	1.0	5.0	1
Bulldozer (A)	2	0.5	2.6	4
Bulldozer (B)	0.78	3.3	>8	4
Articulated Truck	0.7	4.1	>8	4
Scissor truck	0.72	3.9	>8	2
Skid Steer Loader	0.58	5.9	>8	1
Loader	0.61	5.4	>8	4
Chargeuse sur pneus	0.9	2.5	>8	6
Loader Cat 950F	0.59	5.7	>8	1
Loader Cat 970F (loading cars)	0.96	2.2	>8	1
Loader Cat 970F (general work)	0.7	4.1	>8	1
Scooptram	0.54	6.9	>8	4
Scooptram (big)	1.04	1.8	>8	3
Scooptram 3.5 yd³	1.4	1.0	5.4	5
Scooptram 3.5 yd³ (A)	1.12	1.6	>8	2
Scooptram 3.5 yd³ (B)	2.01	0.5	2.6	2
Scooptram 5 yd³	0.69	4.2	>8	5
Scooptram 6 yd³	1.34	1.1	5.9	5
Scooptram 7.0 yd³ (B)	0.67	4.5	>8	2
Scooptram 8 yd³	0.94	2.3	>8	5
Scooptram (small)	1.62	0.8	4.0	3

Backhoe Loader	0.8	**3.1**	**>8**	6
Backhoe Loader (loading)	0.71	**4.0**	**>8**	1
Backhoe Loader (digging)	0.29	**>8**	**>8**	1
Jumbo Drill	0.18	**>8**	**>8**	2
Locomotive (seated)	0.58	**5.9**	**>8**	2
Locomotive (standing)	0.76	**3.5**	**>8**	2
Locomotive (underground diesel)	0.24	**>8**	**>8**	4
Grader	0.8	**3.1**	**>8**	6
Grader	0.79	**3.2**	**>8**	2
Excavator (<25t)	0.8	**3.1**	**>8**	6
Excavator (>25t)	0.5	**8.0**	**>8**	6
Dipper shovel (loading truck)	0.74	**3.7**	**>8**	1
Dipper shovel (moving)	1.04	**1.8**	**>8**	1
Bolter	0.45	**>8**	**>8**	2
Muck Machine	1.02	**1.9**	**>8**	2
CAVO	2.29	**0.4**	**2.0**	2
Dump Truck (articulated, 25 t)	0.92	**2.4**	**>8**	1
Dump truck (rigid, 80 t)	0.37	**>8**	**>8**	1
Dump Truck (articulated)	0.9	**2.5**	**>8**	6
Dump Truck (rigid)	0.9	**2.5**	**>8**	6
Dump Truck (underground 16 t)	1.2	**1.4**	**7.3**	2
Dump Truck (surface, 150 t)	0.28	**>8**	**>8**	2
Dump Truck (surface, 150 t)	0.37	**>8**	**>8**	2
Tractor (personnel transportation)	1.09	**1.7**	**>8**	2

Table 1 : Whole body vibration levels from literature

HAND-ARM VIBRATION FROM LITTERATURE				
Sources			**Legend**	
1-Guide to good practice on Hand-Arm Vibration, INRS, 2006			(red)	less than 1 hour
2-J.L. van Niekerk, P.S. Heyns, N. Heyns, J.R. Hassall, The measurement of vibration characteristics of mining equipment and impact percussive machines and tools. Final report, Safety in Mines Research Advisory Commitee (South Africa), Project number GEN 503, 1999.			(orange)	between 1 and 4 hours
3-Côté Charles, Rapport de recherche sur les aspects ergonomiques des véhicules sous terre, mai 2007			(light yellow)	between 4 and 8 hours
			(green)	more than 8 hours

Description	Aw average (m/s²)	Taction (h)	Tlimite (h)	Source
Bit sharpener (A)	4.5	2.5	>8	2
Bit sharpener (B)	1.5	>8	>8	2
Concrete Breaker	14	0.3	1.0	1
Concrete Breaker (A)	21.7	0.1	0.4	2
Concrete Breaker (B)	24.7	0.1	0.3	2
Concrete Breaker (C)	28.7	0.1	0.2	2
Concrete Breaker (D)	18.1	0.2	0.6	2
Concrete Breaker (E)	23.6	0.1	0.4	2
Concrete Breaker (F)	19.3	0.1	0.5	2
Boom Truck (steering)	0.77	>8	>8	3
Dump Truck (A)	0.76	>8	>8	3
Dump Truck (B)	0.87	>8	>8	3
Scooptram (A)	0.36	>8	>8	3
Scooptram (B)	0.35	>8	>8	3
Scooptram (C)	0.3	>8	>8	3
Lift truck	0.74	>8	>8	3
Impact Wrench	7.5	0.9	3.6	1
Impact Wrench	11.7	0.4	1.5	2
Vibratory Rammer	10.7	0.4	1.7	1
Rammer (A)	17.1	0.2	0.7	2
Rammer (B)	10.0	0.5	2.0	2
Clearing saw	3.8	3.5	>8	1
Jeep	0.66	>8	>8	3
Grinder	5.5	1.7	6.6	1
Pneumatic Grinder	1.8	>8	>8	2
Percussive Drill	12.4	0.3	1.3	1
Chainsaw	6	1.4	5.6	1
Tractor (Agco Allis, steering)	0.99	>8	>8	3
Tractor (Agco Allis, steering)	0.76	>8	>8	3
Tracteur (Kubota, steering)	0.51	>8	>8	3

Tableau 2 : niveaux de vibration main-bras provenant de la littérature