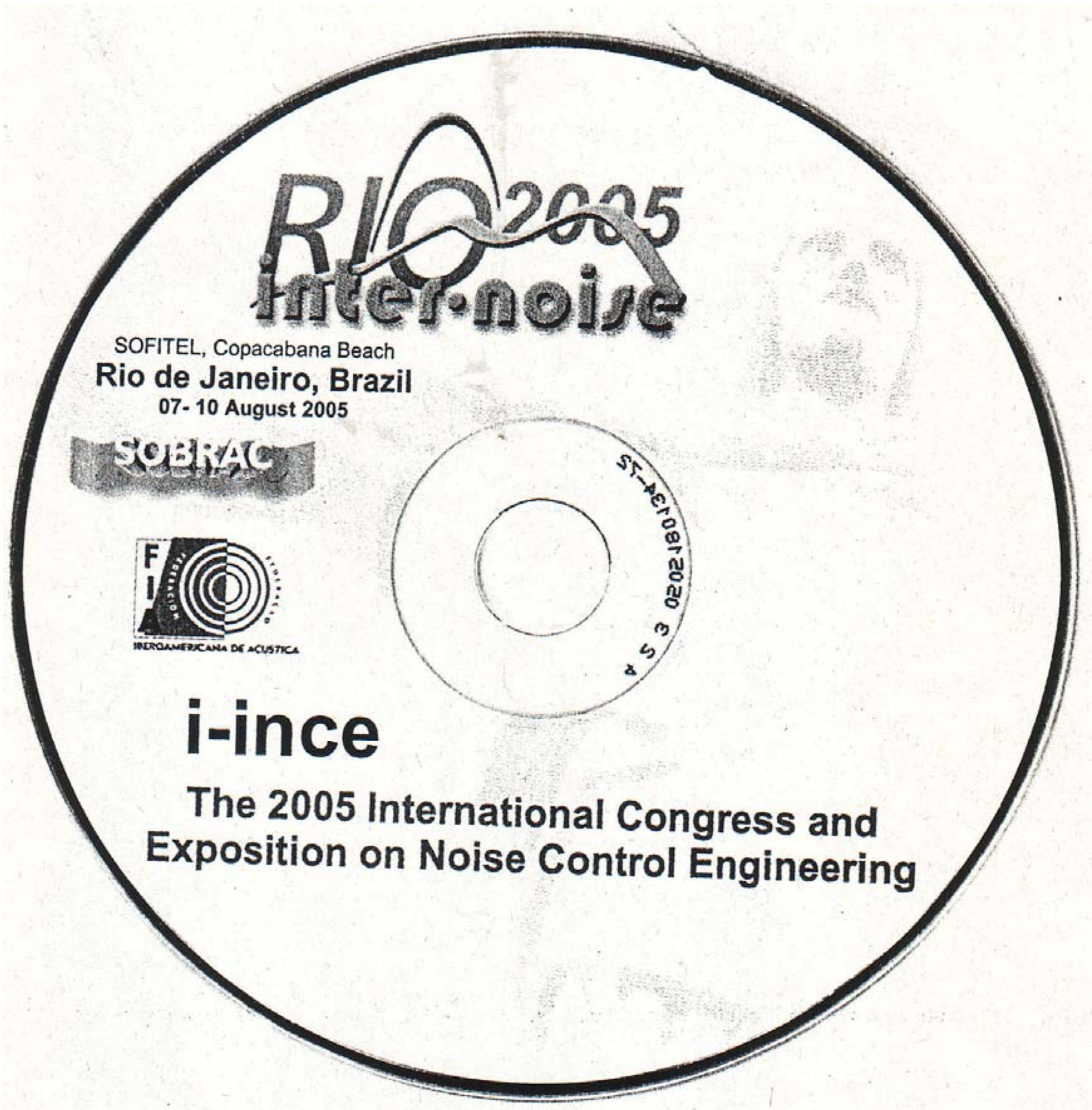

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A Simplified Measurement and Analysis Approach for the Assessment of the Environmental Noise from Mining Activities

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Abstract Mining & quarrying activities provide essential row material for industry, but, due to their features, they may involve environmental impact and substantially interfere with human activity. Hence, in order to get an effective sustainability, asides from the obvious compliance to the enforced law requirements, a compulsory step is to identify the best evaluation techniques and suitable reduction methods for pollutant emissions.

Nevertheless, unlike other industrial activities, the mining operations imply a continuous modification of the interested area and of the general working layout: therefore, a fast, effective, repeatable and low cost emission analysis technique in needed.
The paper refers on the main results of a research work aimed to identify a simplified but effective technique for the measurement and analysis of environmental noise impact and aimed to forecast the expectable noise due to new mining operations start ups or to the development of the existing ones.

As a first step, both a data base of the emitted sound power and a direct measurements technique (based on measured SPL over enveloping surfaces on reflecting plane) have been set up to evaluate the noise generated by the most common sources in a series of different scenarios. Simple corrective factors, drawn from direct in site measurements, are proposed in order to take into account, in each special situation (e.g. mining technique, equipment, work organization, mined material characteristics and site features), the parameters recognized as substantially influencing the noise propagation rate, and discussed in comparison with noise propagation models derived from adaptation of the ISO 9613-1/2 1993 method.

Next step is the set up of a database of impact mitigation measures (from literature and direct experience): the expectable noise reduction can then be evaluated together with the economical aspects, so that the analysis can be developed taken into account also the sustainable development criteria.

1. FOREWORD

Mining activities can be considered as important resources both in terms of material extracted and occupation (also for related activities) but, for their own nature and features, they may strongly impact environment and population. It has therefore become a must that planning and development should answer to the present needs without compromising future resources and environment.

The emission of noise (together with other chemical and physical pollutants) from industrial sites is nowadays a general concern in our country, and it must be managed both in terms of more and more stringent official regulations and in terms of total quality management of the productive processes. These same principia should be applied in particular at the extractive activities, in an approach of sustainable development, as stated by the EC recently issued standards [3] [4].

Nevertheless, extraction of mineral resources, besides being an important source of employment and economic wealth in many areaș, is so far essential for the needs of society [1]. Hence, a policy tending to the general closure of mining activities in our Countries, with the consequent transfer of the problem to less "protected" Countries, is no more a sustainable option: an effective balance between socio-economic development and environmental protection should be pursued.

In some parts of Italy the problem is very critical, the density of population and settlings is very high, therefore also production sites and industries are numerous and they can strongly impact environment and human activities. As a consequence, any productive activity needs to be carefully planned and managed, in order to reduce, both for workers and neighboring population, risks and annoyance phenomena [2].

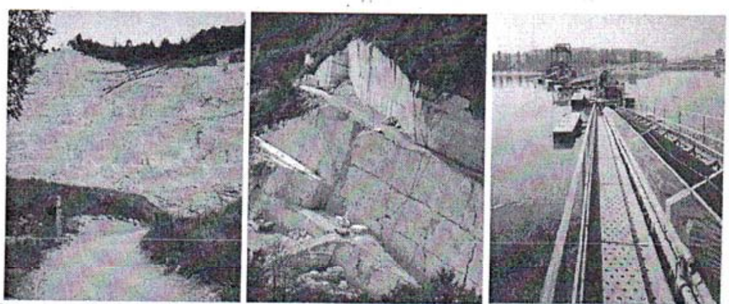

Figure 1: Different typologies of mining activities. From the left: a quarry for industrial minerals, a dimension stone quarry, an aggregate quarry.

2. AIM OF THE RESEARCH

From the previous considerations it appears clear that it is necessary an in-depth study focused on both the identification of correct technologies and methods for mining exploitation and the evaluation of efficiency and effectiveness of the available control measures. First necessary step of this study is the understanding and the evaluation of noise propagation, in order to estimate impact level of noise emissions towards exposed areas.

Nowadays, a series of measurement and analysis methodologies are available, to study pollutant emission from industrial activities; in particular for noise emissions, a number of complex provisional computer based methods can be used to estimate the propagation of sound waves from a source.

Unfortunately, to give reliable results, these methods need a very detailed set of input data (about the source, its position, site topography, acoustical features of all surfaces along the path of propagation, ...) in order to take into account all parameters involved in noise behaviour, but, for its own nature, mining exploitation is a continuously evolving activity and both sources and acoustic field (due to environment modifications) can noticeably change in space and time, so that, when the study is completed, the situation described by the provisional method can completely differ from the real situation. In fact the proper management of such data needs detailed and long-term monitoring, which is not often available, especially in the planning stage of a mining activity.

For these reasons, computer models may be very effective for the in-depth analysis of specific cases, but they are not necessarily the best tool for more general assessment activities and "routine" control of mining emissions.

A research program is presented, with the aim to give a simplified measurement and analysis approach for the assessment of noise emission from mining activities, able to provide rough but acceptable relationships between the different site activities and the pollutant levels. The approach is based on fundamental laws of applied acoustics and, through some simplification, it allows the evaluation of active sources at a given distance from mining site.

All obtained data are collected in a computer-based database, which contains all info about noise measurement campaigns and extraction sites features. The output of such tool may provide suggestion both at the planning stages, on the mine layout and technology selection, and at the mining stages, on the critical situations and possible reduction methods. The unavoidable uncertainties, due to such a simplified approach, can be overcome by the process of continuous updating of the proposed database, in order to link experimental noise measurement data with typical features of the site, used technologies, extracted material, etc... . A sure advantage of the proposed method is the possibility to carry out an evaluation methodology able to permit simple and repeatable measurement campaigns and analysis, in order to check the noise emission trend during the time.

3. THE RESEARCH PROGRAM

After a first extended literature analysis of case histories focused on modern mining methods and technologies, general health, annoyance and environmental problems due to the noise emission from extractive sites, main typical noise sources and the most adopted control methods; the research work consisted of an on-site measurement campaigns, aimed to a direct data collection for the analysis of the cross references among mining techniques and technologies, emissions and propagation data, besides testing the applicability of the described fast monitoring system and evaluating the effective results of the adopted reduction techniques.

A series of mining sites, different as to exploitation technique and general layout was identified. In order to get representative data, the selection considered the following criteria, because of their influence on noise emission and propagation:

- features of material to be extracted (aggregates, natural stones, industrial minerals) and mining technologies (explosives, mechanical, transports, etc…);
- features and topography of sites (surface or underground, hillside or flat area quarry, distance from sensitive areas).

A data collection form, to be implemented in a software based database, was organized to get detailed info on the selected mining activities and to input the measured emission data; the requested info is grouped into homogeneous classes referring to the different aspects of the research (e.g. general industrial data, as industrial size, mining exploitation methods, work organization, adopted technologies, equipment, machinery and main fittings available noise levels, both at workplaces and toward the surrounding areas from previous measurement campaigns, sources characterization, and the adopted control measures, ...).

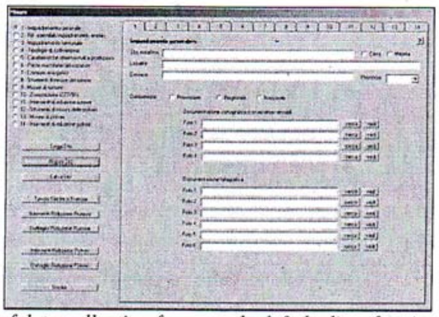

Figure 2: General layout of data collection form, on the left the list of topics contained in the database

The results of the analysis and processing of the collected data are related to the sites characteristics (topography, extracted material, vegetation cover, etc...), to the measurement conditions (e.g. particular meteo conditions) and, where available, to other experimental results got in similar situations, in order to get reliable models of the relationship between specific features of the pollutant source and the features of the environment in which the pollutant is emitted. The data from in site measurement campaigns are then compared with the output of simplified numerical prediction methods, in order to identify the critical and essential parameters that can be used to correctly simulate and forecast the behaviour of noise in real situations.

The last step of the work can lead to the issuing of a "best practice" guideline on technical and organizational solutions aimed to the reduction of pollutant emissions. General criteria through which evaluate the effectiveness of noise control measure and simple tools to assess the potential impact of new mining sites will be made available for the competent regional bureau.

3.1 In site measurement campaigns

The in site measurement campaigns of noise emissions have been limited to open cast mines and quarries, selecting five sites representative of the main mining sectors (aggregates, natural stones and industrial materials) and topographic layouts.

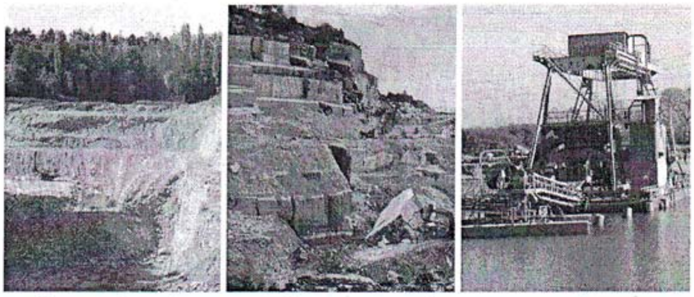

Figure 3 Pictures of some selected sites. (a marl mine, a natural stone quarrying basin, an aggregate quarry)

In the present research, only extraction and first processing phases, which take place in the mining site (e.g. crushing and screening), have been analysed. The major sources of emissions hardly can be identified in single points, because different machines contemporarily operate, and different activities are usually performed at the same time. Typical activities which are likely to produce noise levels and able to impact the surrounding environment are listed in Table 1.

Table 1 The activities that should generally be controlled as potential sources of noise emissions.

Activity / Source	Description
Preparatory works and deposit exposing	Provision of road access, site offices and compound, and usually some mineral processing facilities. Overburden grubbing and topsoil stripping in order to reach the exploitable deposit; relocation in proper areas of the stripped material.
Extraction	Removal (or cutting for ornamental stones) of a volume of ore body. Preliminary operation are usually needed, and different technologies can be adopted according to the deposit features and the material characteristics.
Handling and transport	Loading material by shovels, excavators, etc. and transport, within the mining area, by haul truck, dumpers, conveyor belts, etc.
Processing	Size reduction and selection of extracted material. Different technologies are used depending on the material characteristics and further processing operation.
Site reclamation	All the operation associated with mining site to return the area to a prescribed acceptable environmental state. Such works take place before, during and after the mineral extraction.

Noise sources in exctraction activities can be continuous or intermittent: processing plants, generators, conveyor belts, etc… are continuous sources; blasting, engines starting, loading and unloading operations, etc… are typical intermittent sources. The following main categories of noise sources, which take part in the activities described in Table 1, can be pointed out: explosives blasting; excavation machines (drillers included); transport machines and plants; static or mobile processing plants; other fittings (generators, compressors, etc…).

The aims of the on-site measurements can be summarized in: to test the feasibility and reliability of a procedure which can be performed in a relatively short time (1-2 days per site), at reasonable costs and without interferences with the regular mining activities; to get direct data of emission levels from different types of mining sites, in order to populate the data base and especially to test the results of some predictive models; to directly assess the efficiency of some emission reduction practices.

In each selected site, a detailed inventory of all the sources has been drawn up, collecting also all the available information and data from project documents and machinery manufacturers; a particular measurement procedure has been set up for noise level measurement, as described below (of course the described procedure can't be used to fulfil to national laws prescriptions about noise monitoring, due to the specific aim of the same proposed procedure); for moving sources a special method has been developed to give info about sound power emission (as described in 3.2).

On site noise emission have been measured along ideal alignments, whose location depends on the local possibilities given by mine topography. At least 4 alignments have been made in each site, in order to cover the main propagation direction of the noise, from the "core" of the activity/source area toward the closest sensitive areas (Figure 3). Each alignment consists of 3 integrating sound level meters (e.g. B&K 2222), which simultaneously record the noise emission on a Digital Audio Tape recorder (eg. SONY TDC - D10PROII) (Figure 4).

A 15 minute recording time has been considered suitable to characterize a series of activities, still allowing to repeat many measures in just one day. The survey has been carried on during normal production working hours, avoiding rainy days and unusual atmospheric conditions. Anyway, during each line, the main environmental parameters, as temperature, pressure, humidity and wind speed and direction, have been carefully recorded.

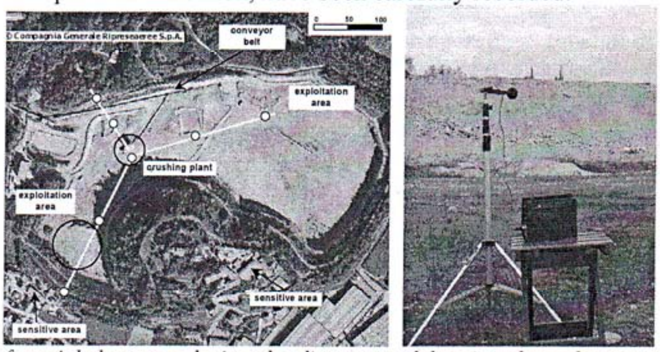

Figure 4 On the left, aerial photo a marl mine; the alignment and the microphones locations used for the noise survey are reported. On the right, a recording station (sound level meter + DAT recorder).

To test the repeatability of the procedure, the measurement campaigns were repeated in different situations (used machinery and specific operations performed) showing a good stability of measured noise levels, in the following a series of 5 measurement results performed in the same position is presented.

L_{eq} (1) = 62.3 dB(A)

L_{eq} (2) = 64.3 dB(A)

L_{eq} (3) = 61.2 dB(A)

L_{eq} (4) = 63.9 dB(A)

L_{eq} (5) = 64.4 dB(A)

3.2 Sound power measurements

In the evaluation of machinery noise emission, one of the most important parameter is sound power level, because of its relation only with sources features, without influence of the environment [6]. Generally the maximum sound power level, as measured under specified conditions, is given for single plants and machines (e.g. loaders, excavators, etc…) according to the EC Directives (e.g. Directive 2000/14/EC), but often the actual emission has to be directly assessed on site. In fact noise generated from machinery strongly depends on features as prevailing working conditions, activity patterns, cycles times, worked materials, used tools and equipments, maintenance policies (e.g. if periodic maintenance policy is considered, real exposure levels can be significantly far from the ideal estimates for most of the time), etc... so that noise emission data supplied from the machinery manufacturer can be very different from the real ones, for various operating scenarios (which can significantly differ from reference test condition).

A specific sound power evaluation method has been set up, deriving from an adaptation of ISO standards on soud power determination (ISO 6395, ISO 6396, ISO 3744); a series of static and dynamic test were performed and real working conditions are simulated.

According to ISO 3744 requirements, the source is placed on reflecting surface and the measurement positions of sound pressure levels are defined on a emisphere of suitable dimensions in relation with the machine dimensions (special care is due to avoid any obstacle whitin a distance of 3 times of radius of the measurement surface); the influence of environmental factors is taken into account and a condition is requested to have background noise at least 10 dB less than sound deriving from the machine under test. In particular the dynamic tests are developed with the machine moving (at a defined velocity) along the emisphere diameter and each dynamic cycle is repeated 3 times during the test.

Sound power level is then derived form relations:

$$L_{WA} = L_{pAeq,T} - K + 10\log\frac{S}{S_0} \text{ dB(A)} \qquad (1)$$

where:

$$\overline{L_{pAeq,T}} = 10\log\left[\frac{1}{n}\sum_{i=1}^{n} 10^{0,1 L_{pAeqi}}\right] \text{ dB(A)} \qquad (2)$$

and: L_{pAeqi} is the sound pressure level at the measurement point i, n is the number of measurement points, K is an environmental correction factor, S is the measurement surface area and $S_0 = 1$ m^2.

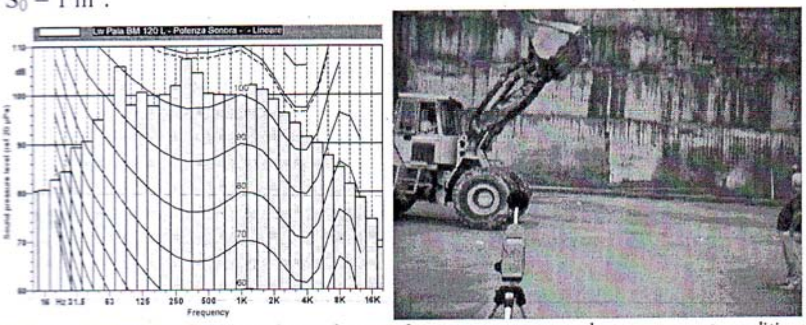

Figure 5 An example of measured sound power frequency spectra and measurement conditions.

3.3 First results and analysis

The recorded data have been analysed and the typical acoustical descriptors have been derived; for each measurement point, time history, equivalent level (Leq) and frequency spectra are traced, in order to compare the noise characteristics along the described alignments. All data concerning measurement campaigns are listed in a suitable form of the database (Figure 6), with detailed info about measuring parameters, environmental conditions and active sources (the list of active machinery is requested together with the actual operation they were performing during each measurement).

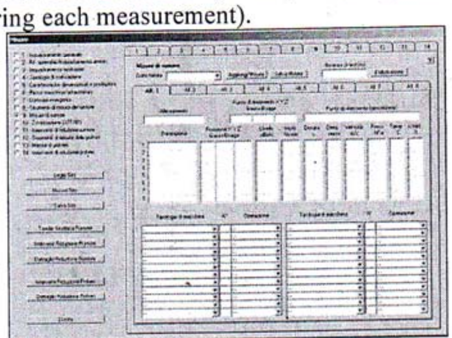

Figure 6 The data collection form for measurement campaigns.

Depending on site and sources features, some of the experimental data show a decay similar to the one typical of free field propagation conditions (3), while in other situations the presence of secondary sources (e.g. truck transit – Figure 7), the spatial distribution of the main sources themselves or the presence of important absorbing or reflecting surfaces can make the definition of a precise decay pattern very difficult: a problem to be carefully taken into account when provisional models are used.

$$SPL = SWP - 20 \cdot \log(r) - 11 \text{ [dB]} \quad (3)$$

where:
SPL = Sound Pressure Level (dB); SWL = Sound Power Level of the source (dB); r = distance (m)

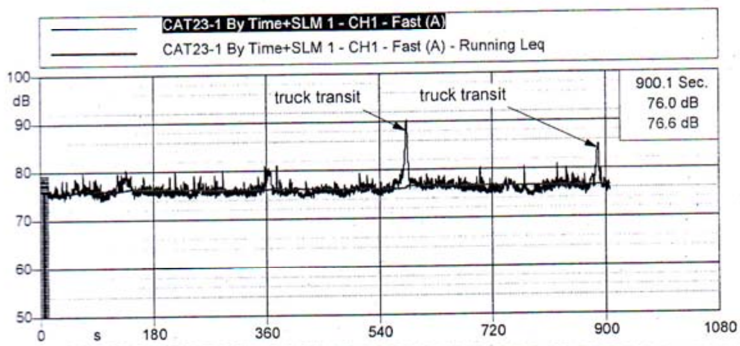

Figure 7: Time history graph (in aggregate quarry) the sound level meter was placed 20 m from the main source (processing plant), but the presence of a secondary source (truck transits) may affect the noise level.

A series of experimental results are listed in table 2 with some considerations on parameters influencing real noise propagation patterns.

Table 2: Some results of noise measurements at different sites.

Site	Activities/Sources	Noise levels - Leq		Notes
		(dB(A))	Location	
Marl mine (hill side exploitation, pit layout)	Drilling (2 hydraulic drillers) Loading (1 excavator – 2 dumpers) Transport by dumpers (4 dumpers)	L1 = 67.7	On the level above the main activity area, 20 m from it	The level in L2 is not far from the value predictable applying the free field propagation law (50.2 dB(A)). The grass cover on the rehabilitated face proves to be effective in reducing reverberation phenomena.
		L2 = 54.1	On the same level, next to the rehabilitated face, 150 m from main activity area	
Marl mine (plain context, pit layout) First alignment	Crusher Handling material by 1 loader and 2 trucks Excavator working at the front Driller and ripper discontinuously operating	L1= 75.1	At the bottom of the pit, 10 m from the crusher	Levels in L2 and L3 are much higher than free field predictions (50.2 and 48.9 dB(A) respectively). The presence of secondary sources and a reverberating space (rock faces) rise noise levels to 15-18 dB over the ideal situation.
		L2 = 68.0	Along an haul road, 175 m from the crusher	
		L3 = 64.5	At the border of the mining area, on a rehabilitated bench, 205 m from the crusher	
Marl mine (plain context, pit layout) Second alignment	Crusher Handling material by 1 loader and 2 trucks	L1= 77.6	At the bottom of the pit, 10 m from the crusher	Levels in L2 and L3 are much higher than free field predictions (57.6 and 51.6 dB(A) respectively). The presence of secondary sources (L2) and a reverberating space (rock faces) (L3) rise noise levels to 16 dB over the ideal situation.
		L2 = 73.5	On the top of a big pile, 100 m from the crusher (5-10 m from handling material activity)	
		L3 = 67.4	At the bottom of the pit, 200 m from crusher (truck transit)	

The basic equation for the determination of sound pressure levels along sound propagation path is derived from Iso 9613-1/2:1996 (Attenuation of Sound During Propagation Outdoors):

$$SPL(f) = SWL(f) + D_1(f) - A(f) \text{ dB} \quad (4)$$

where sound pressure level (SPL) and sound power level (SWL) are taken into account with the influence of source directivity ($D_1(f)$) and attenuation factors ($A(f)$).

For a simplified estimate the obtained results are also compared with typical noise propagation patterns derived from theory (with reference to the extreme situation of free field and diffuse field) and some estimates of sound levels at a different distance form the extraction site are proposed (based on best fit curve obtained from experimental data).

4. CONCLUSION

Reduction measures for chemical and physical pollutant from extractive sites must be included in the general management process of the activities, with particular reference to minimization of health & safety risk and annoyance sources. These points are strictly connected and so effective results can be achieved only considering, since the planning stage, all the critical aspects.

Recalling some general issues deriving from risk management theory, which may be extended to the practices of emission reduction, (in particular the following requirements: eliminate the emission; reduce the emission, if it can not be eliminated; do not simply move or transfer the emission; maintain over time the achieved results; up date in case of modification of production cycle or used technologies); to make such principles operating, the following stages can be undertaken along the "life cycle" of a mining site:

- assessment of existing baseline emission level, independently of the mining activity;
- identification and characterisation of mining emission sources;
- measurement or prediction of the emission levels expectable near the mine site and evaluation of the potential to effect human health and the environment;
- analysis of the local parameters that can affect (positively or negatively) the emission impact;
- identify and implement the most suitable mitigation measures and site design modifications;
- assess the achieved results through predictive models and verify them through a monitoring program.

The proposed methodology, applied in a wide range of extraction site typologies and for repeated measurement campaigns during the time, can help to identify the critical and essential parameters that can be used to correctly evaluate the behaviour of noise in real situations in order to forecast noise propagation patterns in similar situations.

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