Noise and dust emissions from non-metal mining activities: analysis of suitable techniques of measurement, prediction and control

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Noise and Dust Emissions from Non-Metal Mining Activities: Analysis of Suitable Techniques of Measurement, Prediction and Control

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ABSTRACT

The paper deals with the activity program and the preliminary results of a research work commissioned by IReR Research Centre and Regione Lombardia to the Department of Land, Environment and Geotechnologies of Politecnico di Torino. The aim is to define measurement, analysis and control criteria for the emission of chemical and physical pollutants from non-metal mining industries, with particular reference to noise and airborne particulates. Such emissions are related to health risks and annoyance problems, both for the working crews and the neighbouring population, and so, in order to get an effective sustainability of the industry, suitable reduction methods and assessment tools are required. A simple technique for the evaluation and forecasting of both the emission levels and deriving impact has been tested at different mining and quarrying sites, considering their differences in terms of layout and exploitation method, the latter ascribed to a series of main typologies as present in Lombardia region.

FORWARD

The growing social attention to environmental issues has been finding in Europe a reply in many norms, which rule the productive activities. In particular, among other industrial sectors, mining is often a matter of concern of local communities because of the potential and real impacts on environment and landscape.

Furthermore, taken into account the high population density of Italy, and in particular in some Northern regions such as Lombardia (EU-25 = 110 inhab/km^2; Italy = 190 inhab/km^2; Lombardia = 380 inhab/km^2), the latter being also a very industrialized area, mining activity should be very carefully planned and managed, in order to minimize health risks and annoyance problems for the local population, and environmental damages [2] [3].

- general health, annoyance and environmental problems due to the emission of noise and airborne particulate from extractive sites;
- main typical sources of the aforesaid pollutants, and the most adopted methods of control and reduction.

The second step of 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, pollutant emissions and propagation data, besides testing the applicability of a "speedy" 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 after an in-depth statistical study of the situation in Lombardia, and the final selection was carried out in cooperation with the Regional Mining Bureau.

In order to get representative data, the selection considered the following criteria, because of their influence on pollutant emissions 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:

- general industrial data (industrial size, mining exploitation methods, work organization);
- adopted technologies, equipment, machinery and main fittings, with their technical characteristics;
- pollution levels, both at workplaces and toward the surrounding areas (here are also collected, where available, the data from previous noise and dust measurement campaigns);
- pollutant sources identification and description, and the already adopted control measures.

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 particular features of the pollutant source and the features of the environment in which the pollutant is emitted. The field data are 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 and airborne particulate in real situations.

The last step of the work will 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 and dust control measure and simple tools to assess the potential impact of new mining sites will be made available for the competent regional bureau.

As far as the last steps are concerned, the research is still in progress; the activity so far performed and the obtained results are presented and discussed in the following chapters.

ON SITE MEASUREMENT CAMPAIGN

Mining site selection

It could be useful to recall that the Italian Mining Law (art. 2 R.D. n. 1443 29/07/1927) draws a distinction between "mines" and "quarries" depending on the exploited minerals and rocks: for example, mining of marl for cement involves the "mine" status, while the "quarry" status is in force if limestone for cement is mined. Actually, there are not evident technical and technological differences between "mines" and "quarries", and so, being the difference basically administrative, they are not significant for the purposes of the research.

Referring to the Lombardia situation, open cast exploitations are the majority (about 90% of 550 active sites) and they are almost equally divided in hillside and plain localisation. Sand and gravels quarries are the most frequent (more than 300), followed by dimension stone quarries (about 150); marl and limestone mining is also well represented.

The sensitivity to noise and dust emissions depends on the land uses around the mining site. Considering as important "sensitive facility" the presence of inhabited places, it must be highlighted that more than 48% of mining sites lies within 500 m from dwellings, and just 1% is located more than 5 km far from the closest inhabited place.

Given this general situation and in agreement with the Mining Bureau, the in site measurement campaign of noise and dust emissions has been limited to open cast mines and quarries, selecting five sites representative of the main regional mining sectors (aggregates, natural stones and industrial materials) and topographic layouts. The location of the selected sites and a short description of their characteristics are reported in Figure 1 and Figure 2.

	Municipality and Province	Topographic layout	Exploited Material	Mining technology
1	Ternate (VA)	Hill side	Marl	Explosive + Excavator
2	Costa Masnaga (LC)	Plain	Marl	Ripper + Explosive
3	Botticino (BS)	Hill side	Marble	Diamond wire + Explosive
4	Mediglia (MI)	Plain (wet pit)	Aggregates	Floating grab dredger
5	Peschiera B. (MI)	Plain (wet pit)	Aggregates	Floating suction dredger

Figure 1: Localization and short description of mining sites where measurement campaigns have been done.

Figure 2: Pictures of the selected sites. From the left: the marl mine (2); the natural stone quarrying basin (3); the aggregate quarry (5).

Identification of emission sources

In the present research, only extraction and first processing phases, which take place in the mining site (eg. 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 airborne particulate concentration such to impact the surrounding environment are listed in Table 1.

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.

Table 1: The activities which should generally be controlled as potential sources of dust and noise emissions.

As far as noise is concerned, sources 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…).

Mining dust is generally a direct result of mining and processing activities involving some form of ground disturbance or mechanical handling of the mined materials, in combination with air movement. As far as dust emission is concerned, it can be categorised as “fugitive”, and the sources may be described as localised or diffused. Blasting, truck loading, crushing and conveyor transfer within the process plant are usually readily localised. Diffused sources typically are arising from relatively large areas such as waste rock dumps, pits, stock piles, etc... is represented by Linear sources, such as haul roads, represent another category of diffused sources.

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 producers.

Measurement procedure

The aims of the on-site measures are summed up in the following points: 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 site, in order to populate the regional data base and especially to test the results of some predictive models; to directly assess the efficiency of some emission reduction practices.

Given the experimental character of the campaign, aimed to provide rough preliminary data, it has not been possible to carry out measures following all the prescriptions of the national laws about noise and dust monitoring.

Noise

On site noise emission have been measured along ideal alignments, whose location depends on the local possibilities given by mine topography. At least 3 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, on the left).

Each alignment consists of 3 integrating sound level meters (eg. B&K 2222), which simultaneously record the noise emission on a Digital Audio Tape recorder (eg. SONY TDC - D10PROII) (Figure 3, on the right).

A 15 minute recording time has been considered suitable to characterise 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.

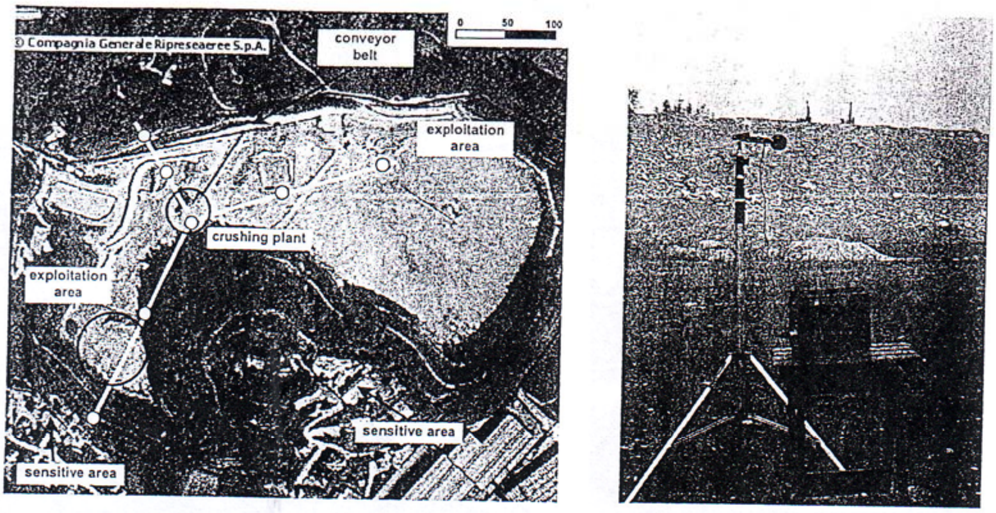

Figure 3: **On the left, aerial photo of the site n°2 (marl mine); the alignment and the microphones locations used for the noise survey are reported. On the right, a recording station (sound level meters + digital recorder) in the site n°1.**

Generally the maximum sound power level, as measured under specified conditions, is given for single plants and machines (eg. loaders, excavators, etc…) according to the EC Directives (eg. Directive 2000/14/EC), but often the actual emission has been directly assessed on site.

Airborne dust

Emission of dust in the environment has been assessed through the measurement of the concentration in air of particulate ($\mu g/m^3$). Active monitoring systems have been adopted: during a sampling period of some hours, particles are captured on a special filter (25 mm filter diameter, 0.8 µm pores diameter) as air is drawn through by an air pump with constant pre-set flow rate (Figure 4, on the right). On site, 4-5 devices, simultaneously working for a period of at least 5 hours per day, are located with the aim of intercepting the dust "plume" created by mining activity, considering also the position of potential sensitive areas. Usually, one sampling station is positioned in the centre of activities and the others along the border of the mining area, depending on the prevalent wind direction (Figure 4, on the left). Given the need of locating the instruments in not always easily accessible places, portable air pumps (flow rate = 3 dm^3/min), commonly used for the monitoring of workers' exposure to airborne dust, have been adopted. Whenever possible, a stationary air pump, with higher flow rate (> 5 dm^3/min), has been used too. Of course, the main environmental parameters, as temperature, pressure, humidity and wind speed and direction, have been recorded in different moments of the monitoring work.

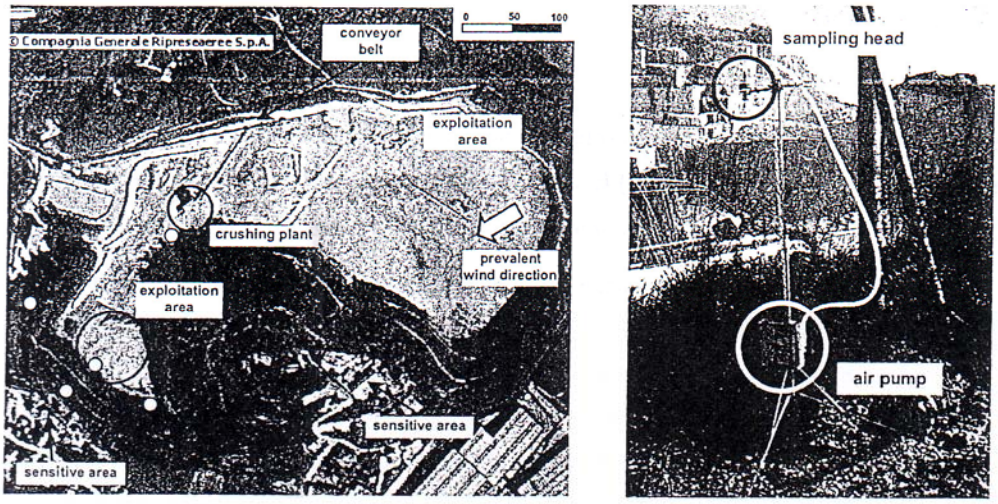

Figure 4: On the left, aerial photo of the site n°2 with the location of the dust monitoring devices. On the right, a dust monitoring station during the campaign in site n°3.

FIRST RESULTS AND ANALYSIS

Pollutant emission, dispersion patterns and impacts are difficult to predict due to the wide range of activities that may rise them, and often to the lack of reliable emission factors, together with the decisive influence of local climatic and topographic features.

Many predictive models are available, but their results should be carefully transferred to on-site application. In facts, the more complex is the model, the more accurate should be the key inputs the model rely on, mainly referring to climatic local condition.

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.

One of the aims of the present research work has then been the development of a simple predictive system for noise and dust emission, able to provide a rough but acceptable relationships between the different site activities and the pollutant levels, and movement patterns around the site.

The output of such tools 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. This step of the research is not yet concluded, and verification of the models reliability is now in progress.

Noise

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.

Depending on site and sources features some of the experimental data show a decay similar to the one typical of free field propagation conditions (1), while in other situations the presence of secondary sources (e.g. truck transit – Figure 5) or the spatial distribution of the main sources themselves can make very difficult the definition of a precise decay pattern: a problem to be carefully taken into account when provisional models are used.

$$SPL = SWP - 20 \cdot \log(r) - 11 \qquad (1)$$

where:

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

Site	Activities/Sources	Noise levels - Leq (dB(A))	Location	Notes
1 – 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	
2 – Marl mine (plain context, pit layout; see Figure 3) 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	
2 – Marl mine (plain context, pit layout; see Figure 3) 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)	

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

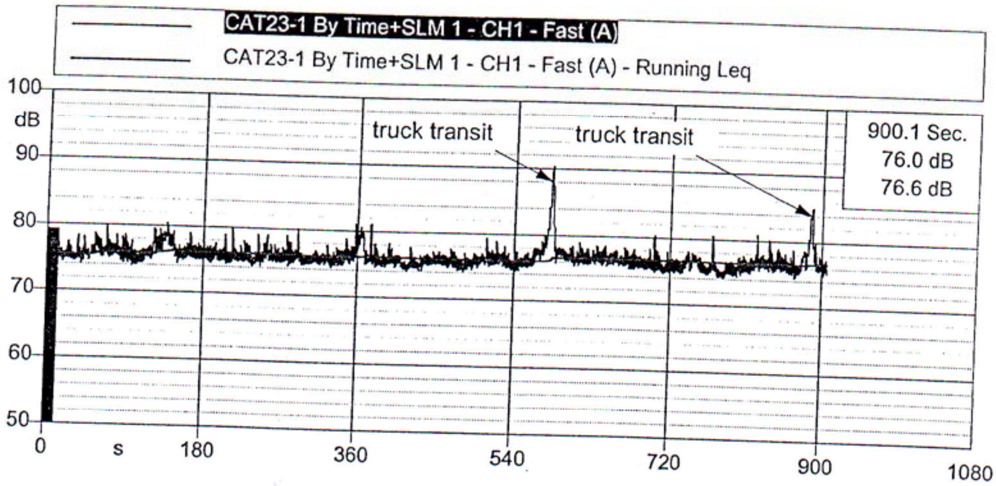

Figure 5: **Time history graph recorded in Site 5 (aggregate quarry); the sound level meter was placed 20 m from the main source (processing plant), but the presence of a secondary source (truck transits) may affect the recorded noise level.**

Airborne dust

A gravimetric analysis of the sampling filters have been carried out in laboratory in order to evaluate the airborne particulate concentration, and some optical microscopy analysis have also been made to get some info on the size and the composition of the collected particles.

As an example, the results of the measurement at 3 sites are reported in Table 3.

<table>
<tr><th rowspan="2">Site</th><th rowspan="2">Activities / Sources</th><th colspan="2">Airborne particulate concentration</th><th rowspan="2">Notes</th></tr>
<tr><th>(µg/m³)</th><th>Location</th></tr>
<tr><td rowspan="4">1 – Marl mine (hill side exploitation, pit layout)</td><td rowspan="4">Drilling (2 hydraulic drillers) Loading (1 excavator – 2 dumpers) Transport by dumpers (4 dumpers)</td><td>P1 = 50</td><td>Downwind, in the unpaved square at the entrance of the mine; 20 m from the haul road, frequent dumpers transit</td><td rowspan="4">sampling time: 5 h
average temp.: 7.6 °C
avg. rel. humidity: 50%
wind speed: < 1 m/s
wind dir: NW → SE</td></tr>
<tr><td>P2 = 16</td><td>Downwind, in a rehabilitated area, 350 m from the activity area where drilling and loading of marl are performed</td></tr>
<tr><td>P3 = 29</td><td>Downwind, in a rehabilitated area, 200 m from activity area, at the bottom of the pit</td></tr>
<tr><td>P4 = 95</td><td>Windward, on a mining level, 100 m from the activity area</td></tr>
<tr><td rowspan="4">3 – Marble quarries (hill side exploitation)</td><td rowspan="4">Drilling & Blasting Diamond wire cutting Truck transit Material handling by loaders and excavators Rock crushing (static plant in a damp dawn area)</td><td>P1 = 121</td><td>Crosswind, in a quarry square where offices are located; 50 m from the blocks squaring by diamond wire</td><td rowspan="4">sampling time: 7 h
average temp.: 11 °C
avg. rel. humidity: 50%
wind speed $_1$: < 0.6 m/s
wind speed $_{2,4}$: < 1 m/s
wind speed $_3$: 0 m/s
wind dir: SE → NW</td></tr>
<tr><td>P2 = 406</td><td>Downwind, in a dominant place on the works areas; just below (20 m) material handling is made by loaders and excavators</td></tr>
<tr><td>P3 = 356</td><td>Downwind, on the main haul road (paved) where all the trucks and quarry vehicles transit</td></tr>
<tr><td>P4 = 60</td><td>Windward, on the same haul road, but behind a vegetated mound</td></tr>
</table>

5 – Aggregate quarry (plain quarry wet pit)	Extraction by floating suction dredger Belt conveyors transport Aggregate processing plant Loaders and truck transit Material handling Stock piling	P1 = 232	Downwind, along the border of the quarry, on a vegetated mound, 300 m from the processing plant and stockpiling area, 50 m from the entrance (frequent truck transit)	sampling time: 4 h average temp.: 9.5 °C avg. rel. humidity: 51% wind speed: > 1.5 m/s wind dir: SE → NW
		P2 = 162	Downwind, along the border of the quarry, on a vegetated mound, 200 m from the processing plant and stockpiling area	
		P3 = 122	Crosswind, along the border of the quarry, on a vegetated mound, 150 m from the processing plant and stockpiling area	
		P4 = 297	Crosswind, in the paved quarry square, 50 m from the processing plant and stockpiling area	

Table 3: Some results of dust measurement at different sites.

First of all, it is important to point out that dust emissions have been monitored for a relatively short time (4-7 hours) and during the working hours. As a consequence, the measured concentration are higher than what would be measured according to the national directives, which refer to at least 24 hours of continuous monitoring, hence including night time when, in the selected sites, activities are stopped.

Anyway, the achieved results can be considered of acceptable significant reference base for the purposes of the research. The contemporary presence of point and diffuse sources and the strong influence of local topography and site features confirm the difficulty to find out a general prediction tool for dust emissions. Long term estimations by computer modelling could provide a certain reliability (eg. 70-80 % of predictions fall within +/- 40% of the annual average site measurements [6]), but short-term dust concentration and deposition rates under "worst-case" conditions are not consistent. Inaccurate estimations of the many variables involved could make the model useless.

A Gaussian dispersion model, appropriately modified to recognise plume depletion through particulate fall-out depending on wind turbulence, is confirmed to well describe the dust diffusion at sites characterised by a simple topography and constant climatic factors. A first prediction of the expectable dust concentration at different distances from the source, along the prevailing wind

$$c = A \cdot r^{-B} \qquad (2)$$

where:

referring to a conventional concentration of 100 mg/m^3 at a distance of 10 m

c = airborne dust concentration (mg/m^3); r = distance from the source (m)

A = 15000; B = 2.17 according to Sutton;

A = 3200; B = 1.50 according to Pearson;

A = 1000; B = 1 according to Zurlo-Frigerio, this being the most conservative.

Once selected the curve that best fits to the locally collected data, it is possible to assess the expectable concentration at a given distance from the mining site (eg. data recorded at the site n. 1 well fit to the curve proposed by Sutton).

CONCLUDING REMARKS

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.

It could be useful to recall some general issues deriving from risk management theory, which may be extended to the practices of emission reduction:

- 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

- 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.

A short list of "good practices", analysed in the research, is reported in Table 4.

Some of them refer to the planning stage, within which emission management issues should be reflected; some others refer to the integration of dust and noise control provisions into work practices.

Activity / Source		Noise (N) and Dust (D) reduction / control practices
Topsoil and overburden removal - handling		Restrict the duration of the activity and not plan it in particularly dry or windy periods Restrict exposed surfaces (D) Seal and seed soil storage mounds as soon as is practicable or spray them with water regularly (D) Minimise material handling
Extraction	General	Locate and orientate working faces to intercept and reflect noise away from sensitive areas (N) Locate and orientate working faces so that they are not in wind "chutes" or susceptible to strong winds (D) Incorporate buffer zone and/or create vegetated or artificial barriers to protect sensitive areas
	Drilling & Blasting	Use dust extraction devices for drilling equipments (D) Stem properly the blasting holes Avoid blasting in windy hours
Loading / unloading of rock materials		Reduce drop heights wherever practicable Use "smart" reversing alarms (N) Spray with water loading and unloading zones (D)
Transport within the site		Optimise the location of haul roads or belt conveyors in order to shield emissions towards sensitive areas Create vegetated or artificial barriers to protect sensitive areas Plan operations to minimise vehicle journeys and idling times
		Use alternatives to on-site vehicle movements, if practicable, such as covered conveyors or pipelines Cover existing conveyors Use of rubber lining in chutes, dumpers, transfer points (N)
		Keep the gradient of haul roads as low as possible (N) Keep surfaces of haul roads as smooth as feasible Use water bowsers or water sprays to suppress dust on haul roads in dry weather Restrict vehicle speed
Processing - crushing		Locate dust and noise generating activities where maximum protection can be obtained from topography, woodland or other features or create screening barriers Protect from wind and spray feeding and exit points (D) Enclose processing plants
Loading / unloading and stockpiling		Locate stockpiles in protected areas or create screening barriers Minimise material handling Reduce drop heights wherever practicable Install silencers and other retrofit devices to reduce noise output; use "smart" reversing alarms (N) Spray with water loading and unloading zones (D)

Table 4: Common noise and dust generating activities in open cast exploitations and main reduction / control practices. The selection of low emission equipments

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