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Respirable Dust Management in Deep Level South African Gold Mines

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Synopsis

The paper describes a dust risk assessment and management methodology for underground mines that was adopted to facilitate the implementation of a process used to control, minimise and ultimately to eliminate the associated health risk to which employees may be exposed.

Areas of high dust generation and/or exposure, as highlighted during the risk assessment on a typical underground gold mine, are identified and controls discussed. Dust measuring technologies are questioned. The way forward in preventing ill health associated with dust exposures is also discussed.

1. Introduction

As required by "section 11(1) and (2) of the Mine Health and Safety Act (Act 29 of 1996), as amended, risk assessments must be done on all possible health hazards. This includes the dust health hazard.

Section 4.4.4 (page 46) of the Leon Report stated that:

> "A safe working environment will remain a goal
> which cannot be reached so long as
> the fundamentals of occupational health
> are not more widely understood…"

This paper will explain the process that is being followed by a typical underground gold mine in managing the Dust Occupational Health Risk.
i.e. the utilisation of an appropriate dust concentrations evaluation and recording system which is used to control, minimise and ultimately eliminate the associated health risks associated with dust exposure.

Silicosis and tuberculosis are two lung diseases listed in the Occupational Diseases in Mines and Works Act (Act 208 of 1993). Silicosis occurs as a result of exposure to silica dust particles [3] that are small enough to reach the alveoli of the lung. Exposure to silica dust can also increase susceptibility to tuberculosis. [4]

> "While our historic preoccupation with the recognition of occupational diseases and the compensation of workers have value in their own right, we must focus on prevention."
> May Hermanus, Chief Inspector of Mines – October 2001 [1]

The main sources of dust and dust generation in underground mines have been well defined and documented by both Mine Ventilation Engineers [5] and Research Organisations, such as SIMRAC (Safety in Mines Research Advisory Committee). These sources include dust generation from blasting operations, rock cutting and loading, raise and blind hole boring equipment, drilling operations, transportation of rock and ore tipping at transfer points.

For numerous years the mining industry has been developing methods to control dust concentrations liberated by these sources. Although controls were implemented, these were not always maintained. In some instances so called "best practice" controls were implemented and the same controls later proved to be totally ineffective.

Without the resources to inspect each dust control mechanism on a daily basis it became apparent that a holistic approach was required to monitor and control dust concentrations in the underground environment.

2. Dust Management System

During February 2002 AngloGold reviewed its safety and health thrusts. During this meeting Dust was identified as one of the strategic thrust areas. The AngloGold Dust Steering Committee was tasked to lead AngloGold in the management of dust exposures.

The AngloGold Dust Steering Committee was established during 1998 and pioneered the implementation of "HEG's" (Homogeneous Exposure Groups), based on ventilation districts, to determine dust exposure profiles, instead of the previously used Statistical Populations, based on mining sections. This committee's vision is to achieve a quantum reduction in dust exposure in AngloGold, thereby achieving a significant improvement in the long-term health outcomes of employees.

To achieve its vision the Dust Steering Committee adopted an "Effective Dust Management Program" philosophy (figure 1) [10] to ensure a holistic approach.

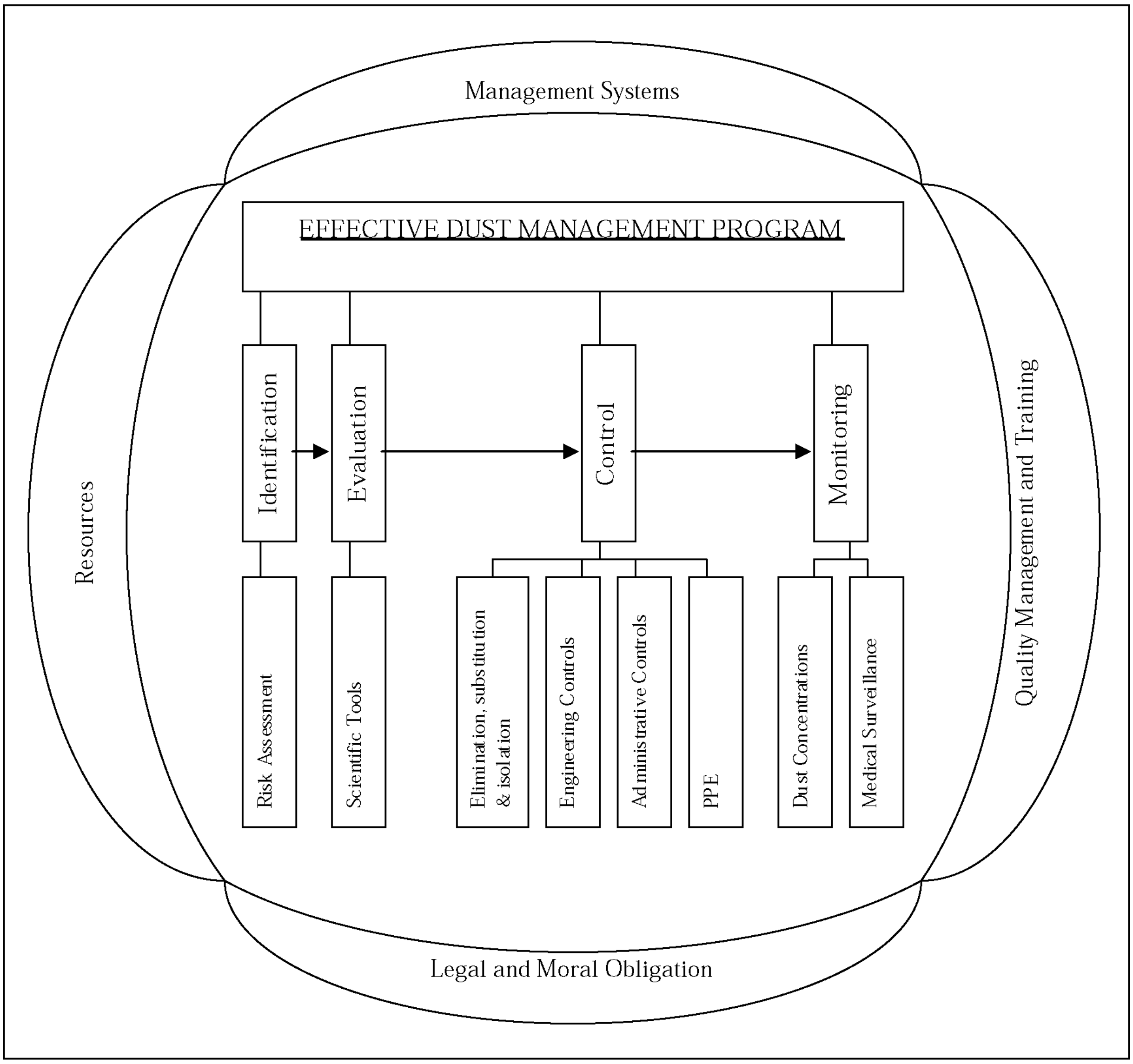


Figure 1: "Effective Dust Management Program" philosophy.

The Dust Steering Committee consists of the Head of Occupational Environment Safety and Health (O-ESH), the Manager Occupational Environment, the Occupational Hygiene (Dust) Specialist, the Consultant Occupational Health, a Senior O-ESH Representative from a deep level mine and a Senior O-ESH Representative from the Metallurgical plants. The main function of this committee is to determine strategic direction and ensure the implementation of the dust management program.

A Dust Technology and Innovation Supporting Team was also established, headed by the Dust Specialist. The team consists of representatives (Mine Occupational Hygienists) from each of the South Africa Region Business Units. This team meets on a monthly basis and information and practice from all levels within the organisation and industry is shared, evaluated and (if appropriate) adopted for implementation throughout AngloGold SA Region.

The establishment of these two committees not only ensures proper implementation of appropriate technologies but also ensures clear communication between the executive level and mine operational level (Management, Employees, Unions and Associations).

3. Dust Risk Assessment Methodology

The risk assessment caters for underground respirable particulate only.
To facilitate a systematic approach (enhancing quality management) the risk assessment consisted of three very distinct phases, namely: [2]

Phase 1:
- The determination of background dust concentrations
- The determination of areas and activities dust concentrations

Phase 2:
- The identification of critical occupations
- The analyses and survey of critical occupations

Phase 3:
- The development of a new personal dust monitoring strategy
- The establishment of a computerised system to link measured exposures to employees' medical records
- The development of a new dust control method
- The development of a dust control code of practice

3.1 Phase 1

3.1.1. Determine Background Dust Concentrations.

The background dust load was established during an "off" weekend, when there were (nearly) no activities that could give rise to elevated dust concentrations. The background dust concentration was determined by placing gravimetric dust sampling instruments at the intake and return air side of all major areas, e.g. surface bank, shaft stations, start of haulage, end of haulage, stope intake and stope return, etc.

The results were used to identify areas with elevated dust concentrations and this in turn was one of the indicators used to alter or improve existing dust control methods.

3.1.2 Determine Areas and Activities Dust Concentrations.

This survey was done by using continuous monitoring dust measuring instruments, e.g. Hund tyndalometer. The instruments were placed at exactly the same locations as those used during the "Background" survey. Activities and any identified dust sources were recorded at time intervals. By analysing this information it was possible to establish which activities result in an increase (or decrease) in dust concentration. Once again the information was used to investigate and implement better dust controls. These surveys were conducted during day shift and night shift.

3.2 Phase 2.

3.2.1 Identify Critical Occupations.

This was done by using the previous year's medical information and by:

- Obtaining a detailed list of all persons submitted for pneumoconiosis (PN) certification during the previous year.
- Calculating the percentage of each occupation submitted for PN certification based on the total number of persons employed in the occupation.
- Ranking the occupations from highest to lowest percentage.

3.2.2 Analyses and Survey of Critical Occupations.

This was done by conducting a task analysis of identified occupations whilst taking continuous dust measurements with a continuous dust measuring instrument. The location, tasks performed and any identified dust sources are recorded at time intervals.

It was established that high dust levels occur at certain areas or due to certain tasks being performed. This resulted in more reliable information being available to investigate and implement improved dust control methods. These surveys were also conducted during day shift and night shift.

3.3 Phase 3.

3.3.1 Develop a New Personal Dust Monitoring Method.

The continuous dust monitoring was done by utilising the current gravimetric dust sampling equipment and by implementing the following strategy.

A percentage of the "highest exposed occupation" in each HEG were issued with gravimetric dust sampling instruments for the purpose of continuous monitoring.

The percentage / number of continuous monitoring instruments to be issued and the frequency thereof, was calculated in accordance with internationally acceptable NIOSH methods.

The determination of HEG's is based on areas with similar dust concentrations within a ventilation district,

e.g. Stopes on the intake air side (fresh air) of the ventilation district fall into one HEG, stopes on the return air side (used air) fall within another HEG, stopes where different mining techniques is used is yet another HEG, etc.

A special investigation is called for, should the trend of continuous monitoring results indicate a Time Weighted Average (TWA) respirable dust concentration above the set TWA limit/target.

Such a special investigation is done in accordance with the method as described up to this point. All results, findings, recommendations and action plans implemented are recorded and filed for possible future use.

4. Dust Management Methodology

4.1 Introduction of a new dust monitoring method.

The new personal dust monitoring method has been implemented at all AngloGold South Africa Region Business Units as from October 2001. This method mainly incorporates the establishment of ventilation districts (sampling areas) and activity areas (Homogeneous Exposure Groups) within these ventilation districts.

4.2 Link to Personal Dose Register.

A computerised Integrated Risk Management System (IRMS) was developed to assist AngloGold in managing its health and safety risks. The dust-monitoring module of this program was also revised to include all airborne pollutants, including toxic gases and vapours. It also addresses all the requirements of the Department of Minerals and Energy's "Guideline for the compilation of a mandatory Code of Practice for Airborne Pollutants". [6]

Personal monitoring sample results are entered into this program on a daily basis. The program is then utilised to update employees' personal occupational hygiene exposure records (on a monthly basis) and to generate engineering control reports (discussed in detail later in this paper).

4.3 Develop New Dust Control Methods.

By using the latest respirable dust concentration information, the HEG's are ranked from highest to lowest respirable dust concentration. The mine staff then investigate and decide (various other considerations taken into account) if and to what extend corrective action plans needs to be implemented. This ranking is revised at least once a year in order to re-prioritise the high-risk areas.
The progressive respirable dust concentrations TWA value for each of the worst five high risk HEG's is then monitored on a monthly basis to evaluate the effectiveness of any implemented corrective action plans.

By only addressing the worst five HEG's (reducing the respirable dust concentrations) the average respirable dust concentration of the mine also decreases. This is done on an ongoing basis to reduce the respirable dust concentrations to within acceptable limits.

4.4 Key Result Indicators

Four main key result indicators where identified, namely:

- Percentage of employees exposed to total respirable dust concentrations above 1 mg/m^3
- Percentage of employees exposed to total respirable dust concentrations $\geq$ 0,5 to 1 mg/m^3
- Percentage of employees exposed to total respirable dust concentrations below 0,5 mg/m^3
- Average total respirable dust concentration.

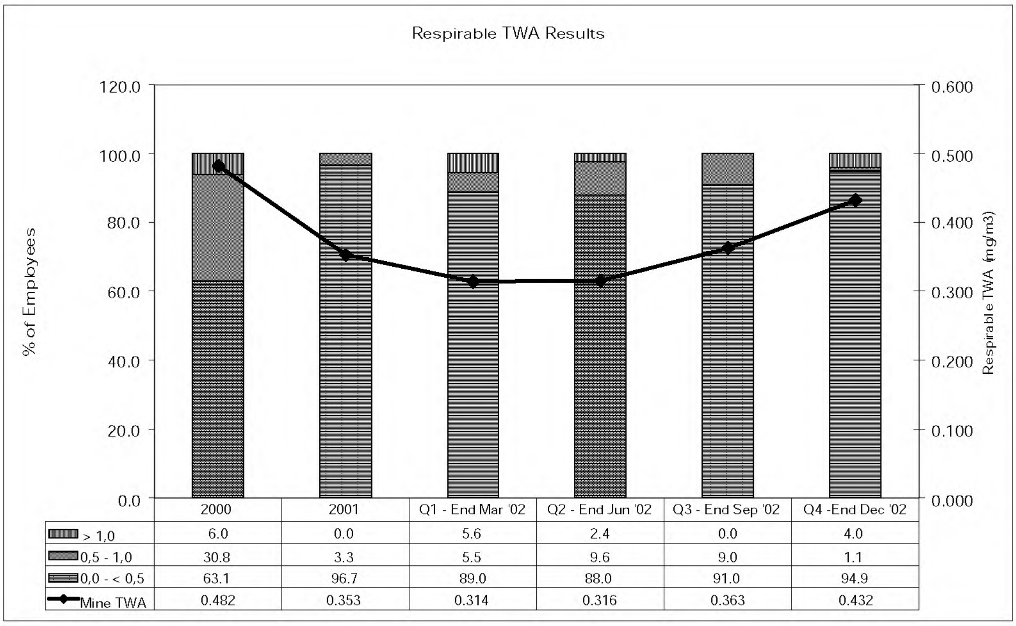
It must be noted that these indicators are for total respirable dust concentrations and not just for a specific pollutant such as alpha quartz. The use of total respirable dust as an indicator facilitates proactive management of dust concentrations, as no delay for pollutant analysis results are required.

These indicators are monitored on a monthly and quarterly basis for each Business Unit, each ventilation district (sampling area) within the Business Unit, and each HEG within each ventilation district.

This information is then utilised to monitor the results of any implemented controls and track dust exposure trends at operational level, to identify any problem areas. For example, if we interpret the information presented on figure 2 it is evident that:

- the controls implemented to reduce dust exposures in "high" dust exposure areas (more than 1 and more than 0,5 mg/m^3) are rendering the required results, but:
- Overall dust concentrations are on the increase. If not addressed, it may result in overall "high" dust exposures.

By viewing the same information for each ventilation district the "problem" ventilation district can be identified. Similarly, by viewing the same HEG information for the problem ventilation district, the problem HEG can be identified and corrective action plans can be formulated (after proper area investigation).



	2000	2001	Q1 - End Mar '02	Q2 - End Jun '02	Q3 - End Sep '02	Q4 -End Dec '02
> 1,0	6.0	0.0	5.6	2.4	0.0	4.0
0,5 - 1,0	30.8	3.3	5.5	9.6	9.0	1.1
0,0 - < 0,5	63.1	96.7	89.0	88.0	91.0	94.9
Mine TWA	0.482	0.353	0.314	0.316	0.363	0.432

Figure 2 – Quarterly Total Respirable Dust Results

4.5 Targets.

To achieve the company's vision, (i.e. "To halve the exposures levels in 5 years") it was essential that the following respirable dust concentration targets be achieved.

- First Target - To reduce the average TWA value to 0,40 mg/m^3 by the end of 2001.
- Second Target - To reduce the average TWA value to 0,25 mg/m^3 by the end of 2003.
- Third Target - To reduce the average TWA value to 0,20 mg/m^3 by the end of 2005.

5. Results obtained from the new personal dust measuring method (Old vs New)

5.1 1998 (Old Method)

At the end of 1998 the mines' survey results (based on the then DME prescribed gravimetric dust sampling method) indicated that:

- No employee was exposed to alpha quartz concentrations above the internationally acceptable Threshold Limit Value (TLV) of 0,1 mg/m^3.
- The highest exposed employees (0,2 %) where only exposed to concentrations up to half that of the TLV.

5.2 1999 onwards (New Method)

At the end of 1999 the mines survey results (based on the new personal monitoring method) revealed that:

- 15,1 % of the employees where exposed to alpha quartz concentrations above the TLV of 0,1 mg/m3.
- The highest exposed employees (0,5 %) where exposed to concentrations 3 to 4 times higher than the TLV.

This was obviously unacceptable and a concerted effort was made to reduce these over-exposures. By employing the methodologies (as explained in this paper) the over-exposures reduced from 15,1 per cent in 1999, to 6,5 per cent in 2000, to 4,1 per cent in 2001 and to 2,5 per cent in 2002, with no over-exposures during the last quarter of 2002.

This reduction in percentage of employees over exposed is of major importance. Not only is the company providing a healthier work environment, but this should also result in a long-term benefit to the company as compensation and treatment costs should also start to decline in years to come.

The improvement of dust concentrations was achieved by implementing the strategy as discussed up to this point.

5.3 Comparing the old with the new

Table I represents a comparison of the old dust control methodology with the new.

ISSUE	OLD	NEW
Statpop / HEG	Based on Mining Section	Based on ventilation district
Remedial Action Investigation	• Based on AQI (reactive) • Require one additional sample and interview	• Based on TWA trend forecast and targets (proactive) • Full investigation of area, occupation and tasks
Calculated Risk	• Used for levy determination • Used as engineering control indicator	• Used as dosage determination • Used as engineering control indicator
Targets	Nil	5 year plan
Dust control method	Not scientifically (± 6 month delay)	Formal scientific method (proactive)
Personal Dose Register	Inadequate information	Specific objective
Code of Practice	Not required	• Specific objective • Based on survey outcome & international best practice

Table I

6. High dust generating areas

The background and areas and activities surveys revealed the following high dust generating areas:

- Intake airways (Including vertical shafts)
- Backfill spillage's
- Shaft Ore Pass systems
- Horizontal ore transport

7. Auditing /Evaluation

Gravimetric dust sampling results are mainly used to measure the company's dust performances and also to direct remedial and technology initiatives. A comprehensive dust auditing protocol has been formulated and implemented. The purpose of this annual audit is to maintain good quality management and thus also accurate statistics.

The following issues are evaluated:

- Measuring equipment (Maintenance, calibration, etc)
- Statistical analysis of Homogeneous Exposure Groups (2 Standard Deviations at 95% confidence level)
- Sampling methodology (Correct classification of ventilation districts and HEG's)
- Integrated Risk Management System (IRMS) Dust and Hygiene modules
- Reporting (Appropriate level, follow-up, etc)
- Remedial action (Reduction of "high" exposures)
- Technology and Innovation (Implementation of new initiatives)

8. Employee hygiene register

This requirement is addressed by the implementation of the IRMS Airborne Pollutants and Hygiene Register modules.

9. Interesting discoveries / findings during implementation of controls

9.1 Footwall treatment

Scientific tests were conducted on the flammability and evolution of gases during combustion, toxicity and corrosivety (on various footwall treatment products) and these proved to be within acceptable limits. The tests were conducted to ensure that the utilisation of these products would not result in the introduction of other health and safety risks.

Most footwall treatment products consist of Molasses or Sugar compounds, which also contains Lignosulphonate. Lignosulphonate is an additional binding agent added to the Molasses. Once applied the binding effect of the product is visible on the footwall.

A project was conducted to establish the dust allaying effect of these products. The underground working levels selected were those with the highest air velocities and highest tramming-traffic. Gravimetric sample positions were selected and samples were taken at the selected points before the application and again after treatment with the dust allaying products.

This project proved the effectiveness of the products to control footwall dust.

9.2 Dust Filtration

Each type of fabric bag dust filter (currently utilised) was tested to determine its fractional dust filtering efficiency and dust holding capacity (7,8). It was decided to determine the fractional dust filtering efficiency as small dust particles (< 1µm) are capable of entering the deeper regions of the respiratory tract. Even if a high overall dust filtering efficiency (all particle sizes) is maintained it is still possible for large quantities of small particles to pass through the filter (and enter the respiratory track). The fractional dust filtering efficiency was determined by utilising instruments that could count the number of dust particles within a specified dust size category. A summary of the main findings is depicted in figure 3.

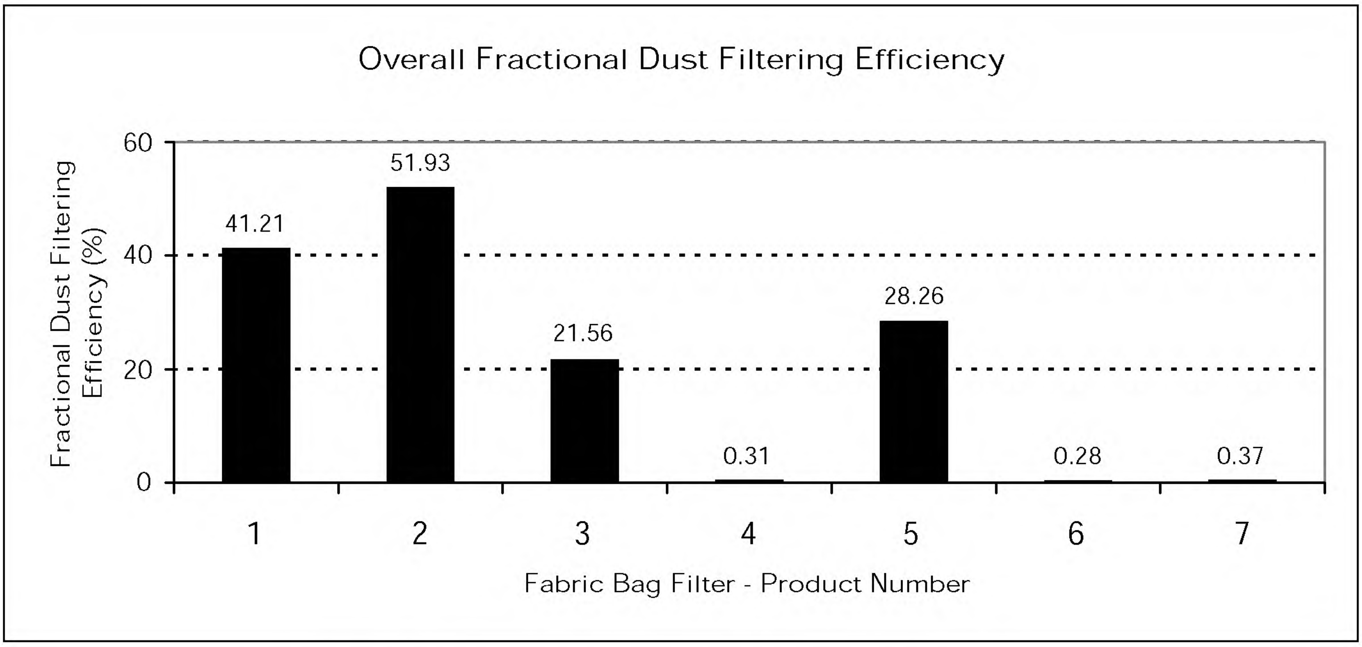


Figure 3 – Overall Fractional Dust Filtering Efficiency

This initial investigation would suggest that fabric dust filters (currently in use) have no meaningful effect on the elimination of harmful airborne pollutants. In perusing the test data, it becomes apparent that the combination of pre-filtration with high efficiency secondary filtration offers the best prospects for success in the underground environment.

9.3 Administrative Controls

Numerous administrative controls are already implemented (blasting schedules, re-entry periods, etc) to prevent exposure to the harmful contaminants generated by blasting operations.

It is of utmost importance that the effectiveness of these controls be audited on an ongoing basis. A theoretical simulation revealed that persons exposed to blasting fumes for only 30 minutes at a typical dust concentration of 90 mg/m^3 will receive a Time Weighted Average (TWA) exposure of 5,63 mg/m^3 for the shift (assuming no exposure for the remainder of the shift), compared to the international limit of 1 mg/m^3. It also begs the question: "What is the long-term health effect of frequent short-duration high-concentration exposures?"

9.4 Respiratory Protective Equipment (RPE)

Because of a variety of ergonomic constraints, the 'Personal Protective Equipment route' should always be regarded as the last resort in any strategy designed to protect employees from workplace hazards.[9]

To gain the maximum benefit of any intended PPE, the most fundamental issue is employee acceptance. This was a complex requirement and also the single most important motivation for conducting a RPE field trial. The primary purpose of the trial was to assess ergonomic acceptance of RPE for different realistic scenarios. It is of no use to issue employees with the best and most costly RPE, if they do not want to wear it. Eight different types of respirators (1360 units) were evaluated.

The results of the trail indicated that employees prefer to use valve fitted disposable RPE. The majority of employees working in critical occupations or employed in areas with "high" dust concentrations preferred half-mask, non-disposable RPE.

9.5 Real-time Dust Monitor

The objective of the Real-time Dust Monitor Project is to design an automated monitoring system for measurement of airborne silica dust. This instrument must also have an alarm capability that can be used to warn employees when "high" dust concentrations are experienced. Employees can then withdraw from the affected area until normal conditions have been restored. Meetings held with international leaders in the instrument-manufacturing field revealed that the technology does not yet exist for this objective to materialise.

9.6 Effect of (Hydropower) water jetting on dust concentrations

Two water jets were in operation at the time of the investigation. Gravimetric dust samples (used to monitor the panel dust conditions) were taken for 15-minute periods. The forces created by the 2 water jets were adequate to hamper the designed ventilation flow as it reversed the ventilating airflow direction.

The 2 operating water jets resulted in an 86,7 per cent (0,341 to 0,636 mg/m^3) increase in stope dust concentrations and a 433 per cent (0,341 to 1,818 mg/m^3) increase in panel dust concentrations.

This increase in dust concentrations was mainly due to:

- The reversal of the ventilating airflow direction. Thus not sufficient dilution ventilation is available (in the panel) to reduce the dust concentration.
- The lack of proper watering down practice. The hanging wall is washed by using the water jet guns. This practice is deemed by the stope team as adequate watering down, as the water used to clean the hanging wall also falls onto the footwall.
- The dust kicked up by the "pressure wave" of the water jet.

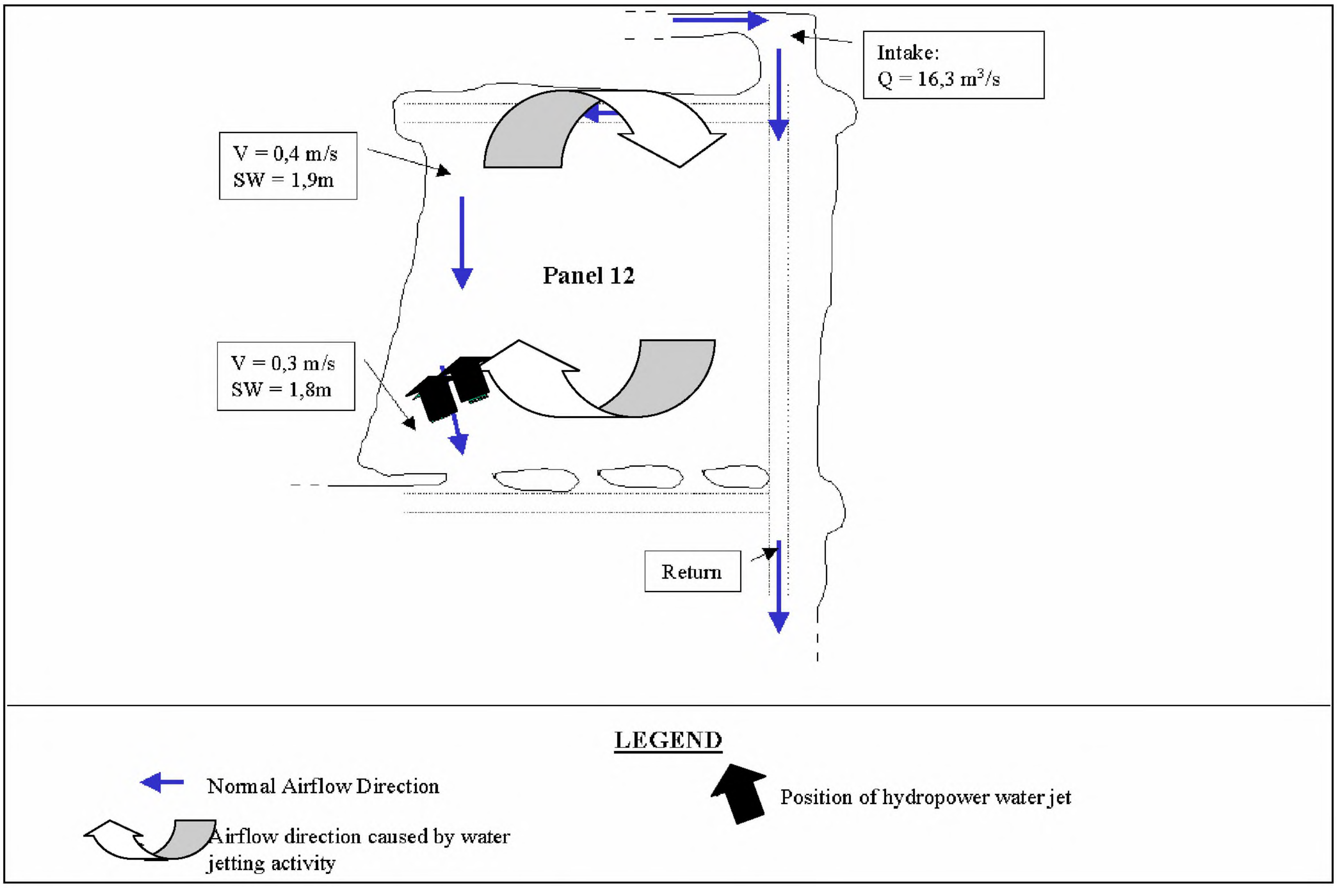


Figure 4 – Water Jetting Project

10. Conclusion

It should be apparent that the management of dust (airborne pollutants) in the underground environment is no small order. Implementation of a dust management program (as described in this paper) will certainly assist Mine Management to better manage the dust health risk.

Some immediate issues (actions that can be / were immediately implemented / reinforced) are:

- Regular watering down of intake airways
- Watering down on re-entry (from intake side where possible)
- Dust filter plants to be regularly cleaned and maintained
- Respiratory protection to be worn by persons at or involved in tipping operations, sweeping, water jetting, filter plant cleaning / maintenance, etc.
- Ore pass controls (finger controls, chutes, tip covers, etc) to be in working order at all times.
- Settler efficiency to be rigorously maintained
- Ventilation controls to be rigorously maintained.

Only dedication, commitment and enthusiasm by all stakeholders (Management, Employees, Unions and Associations) will result in reduced dust concentrations thus reduced medical outcomes.

11. Acknowledgement

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