Compendium of Research Project Summaries on Airborne Pollutants - 1996 to 2013

MHSC
Mine Health and Safety Council

CONTENTS

FOREWORD

The Mine Health and Safety Council (MHSC) is a public entity that is mandated, in terms of the Mine Health and Safety Act (MHSA), to advise the Minister of Mineral Resources on research programmes, regulations, standards, policies and procedures focused on minimising the occupational health and safety (OHS) risk at mines. The Council is also tasked with promoting a culture of health and safety in the mining industry.

The MHSC office executes the operational deliverables of the Council, including the provision of secretarial support to the Council and all its committees, managing occupational health and safety research programmes, finances, communications and promotions, and liaising with other statutory bodies on matters relating to occupational health and safety at mines.

MHSC provides a platform for stakeholder engagements on OHS matters.

In the South African Mining Industry (SAMI) it has been found that more deaths are still reported as a result of occupational diseases. Hence the mining sector has increasingly been giving more attention to health matters which was also as a result of the promulgation and implementation of the Mine Health and Safety Act as amended.

Considering that one of the MHSC's role in the SAMI is that of overseeing research, one such research area is termed as the Research Thrust area 6: Airborne Pollutants.

Research Thrust area 6 focusses on identifying research that will have outcomes that are aimed at improving the health of mine workers in all commodities through the identification of implementable controls for airborne hazards that will lead to the prevention of occupational lung diseases associated with exposure to dust; gases; fumes; mists and vapours. The Mine Health and Safety Act, defines an occupational lung disease as any condition listed in either the Occupational Diseases in Mines and Works Act (ODMWA) or the Compensation for Occupational Injuries and Diseases Act (COIDA).

While the elimination, control and minimising of risks associated with airborne pollutants remains a priority, projects related to respiratory protective equipment for all processes and commodities is also considered under this research area. The elimination of silicosis is a priority for the SAMI as well as diesel particulate exposure and control, and the influence of hazardous gaseous exposure on health, safety and performance.

As the MHSC, we are committed to promote OHS in the Mining Industry, including research on the prevention of occupational lung diseases.

Thabo Dube

Chief Executive Officer
Mine Health and Safety Council

December 2017

1. HANDBOOK TO REDUCE THE EXPOSURE OF WORKERS TO DUST

By Members of the Special Interest Group On Dust and Ventilation, CSIR: Mining Technology, 1996

SUMMARY:

The handbook to reduce the exposure of workers to dust flows arose out of a SIMRAC project dealing with dust in collieries. The objective was to update the previous guidelines, making them pertinent to ventilation and dust suppression systems which are presently being used on mines. In drawing up this handbook cognisance was taken of the latest technologies which are employed on mines as well as the legal framework in which these technologies are applied. The use of modern tools and instruments as well as the latest means of evaluating ventilation methods have also been included.

The handbook covers the fundamentals of dust, the measurement of dust, strategies to reduce worker exposure to dust, reducing the generation of dust and preventing dust from becoming airborne. Other topics include the use of scrubber systems to control the airborne dust water applications and reticulation networks, and ventilation practices.

Computational fluid dynamics (CFD) is rapidly becoming invaluable as a predictive and design tool as it is fast, accurate and cost effective. These computer simulations are often free from limitations imposed on analytical and experimental methods with the only limits to CFD being the speed and size of the computer, the time availability to solve the problem, and the ability to understand and model the situation, with its complex phenomena, accurately. The main purpose of CFD is not to replace experimental work, but to provide information where it is dangerous or even impossible to perform experiments. It is also a very cost effective way to examine possible solutions to a problem.

A chapter in this handbook reviews the application of CFD in evaluating and improving environmental conditions in mechanical miner headings, as well as providing a brief history of the development of the CFD model, and a discussion on a typical application. The handbook is directed at personnel on mines, allowing an understanding, not only of the problem, but also of the process which can be used to combat the occurrence of dust in workings. As this handbook is to be used by a diverse level of mine staff, ease of reading and understanding was strived for at all times.

CONCLUSION:

This handbook will serve as a reference base for those in supervisory positions, and those responsible for maintaining lower levels of dust in the occupational environment.

2. PERSONAL GRAVIMETRIC DUST SAMPLING AND RISK ASSESSMENT

By Unsted A.D., CSIR: Mining Technology, Ref: GAP 046, 1996

SUMMARY:

Shortly after the introduction of the Government Mining Engineer's (GME) programme of gravimetric dust sampling, questions were raised by industry with regard to an effective means of sampling for engineering control purposes, a possible reduction in sampling effort and a reduction in analytical costs. It was also considered that the risk calculated for levy purposes was not equitable and did not accurately reflect efforts made to reduce dust concentration and thus risk. Project SIMGAP 046 addresses the above concerns.

Extensive data sets were collected at three underground test sites as well as at an assay laboratory where a

repeat sampling exercise was conducted. At each location sampling was undertaken over a number of days and all working shifts. Sampling pumps were attached to personnel and the same personnel were sampled during each investigation. All sampling was conducted for the full working shift. At the same time stationary samples were set up at representative places.

At all the sampling sites, extremely large variations in dust concentrations were measured on a day to day and shift to shift basis. Correlation of dust concentrations between personal and stationary samples was very poor as was the correlation between quartz fractions. In addition there was a very poor correlation between personal samples in the same area during the same shift.

CONCLUSION:

Extremely large variations in dust concentrations were measured on a day to day and shift to shift basis. Correlation of dust concentrations between personal and stationary samples was very poor as was the correlation between quartz fractions. Thus, the possibility of replacing personal samples with representative, stationary samples could not be justified or recommended.

Identical sampling instruments set up in parallel yielded very similar dust loading but the quartz concentrations were uncorrelated which reinforces the perception that aerosol behaviour is far from being fully understood or predictable. Sampling pumps of different types also yielded different results when set to sample in parallel which leads to the conclusion that results reported to the GME are not always accurate.

The current sampling programme should be reviewed and replaced by a two pronged approach, one aimed at determining exposure for dose/response and epidemiological studies and the other at engineering control.

3. CONTROL OF DIESEL EXHAUST EMISSIONS IN UNDERGROUND WORKINGS

By Unsted A.D., CSIR: Mining Technology, Ref: GEN 208, 1996

SUMMARY:

Problem areas identified in a previous study (GEN 010), such as the measuring of diesel particulate matter and measuring instrument inconsistencies, for example, were investigated in this project. The likely impact of low emission fuel on diesel exhaust emissions was also evaluated.

Quantifying worker exposure to diesel exhaust aerosol in an underground coal mine depends on the ability to measure this component of respirable mine aerosol from coal dust. Such measurements are complicated by the carbonaceous nature of the diesel soot and coal dust particulate that make up the respirable aerosol.

Airborne coal samples taken in South African collieries not using diesel powered equipment showed that between 65 and 70 per cent of the coal dust is sub-micrometre in size. The analyses of all samples taken with respect to particle size distribution and mass size distributions indicate large fractions of the airborne dust to be present in the sub-micrometre ranges with fractions contributing negligibly to the mass of the total respirable dust. The results of these analyses indicate that the size selective sampling method to quantify the diesel soot component in colliery aerosols would not be applicable to South African collieries and confirmed findings in the United Kingdom. From the literature it is evident that where submicrometre particles constitute the major fraction of airborne coal dust, the detection of Diesel Particulate Matter (DPM) is not feasible with present techniques.

A number of gas monitors, selected by virtue of their relevance in monitoring diesel exhaust emissions and common usage in the mining industry, were also evaluated as part of project. From the limited tests conducted it does not appear that any of the instruments were in any way affected by increases in barometric pressures - with the exception of oxygen monitors. Instruments of the same make, all calibrated together, can produce different test results,

and readings produced in one test may not have any repeatability in a following test. A factor which could contribute to the above is the great deal of uncertainty in the absolute values of calibration gases used with these instruments.

Various acceleration tests to determine engine condition and exhaust emissions have been investigated. The technique tests to determine engine condition and exhaust emissions have been investigated.

The technique of measuring smoke or particulate in diesel exhaust during a snap acceleration test provides a simple method of judging engine condition and its contribution to unsatisfactory environmental conditions.

CONCLUSION:

Size-selective sampling would not be appropriate because the large fraction of sub-micron particulates would mask any diesel soot emissions which are predominantly sub-micron in size.

Non-respirable particles were detected on the filter media during the size-distribution investigations which could lead to incorrect assessment and reporting of respirable dust masses and concentrations.

Gas measuring instruments of the same make, all calibrated together, can produce different test results. The technique of measuring smoke and particulates in diesel exhaust during a snap acceleration test provides a simple and ready method of judging engine condition and its contribution to unsatisfactory environmental conditions. Emission levels can be better and more effectively controlled through the implementation of an engine maintenance programme than by a change in fuel formulation. Thus, there does not appear to be a technical justification to specify low emission diesel fuels.

In order to prevent the build-up of pollutants in a heading, enough air needs to be supplied to ensure that the air would travel faster than the vehicle in the heading. An exhaust ventilation system holds advantages over a forcing ventilation system.

4. ENGINEERING GRAVIMETRIC MONITORING METHODS TO COPE WITH EXCESSIVELY HIGH DUST LEVELS

By Belle B.K. and du Plessis J.J.L., CSIR: Mining Technology, Ref: COL 515, 1997

SUMMARY:

In the first-phase of the project, Oberholzer et al., (1998) developed the rationale for adapting an addition of a cowl (shield) to the existing South African cyclone for measuring dust at high concentrations. In this report, background to the reasons for sampling, rationale for adapting the sampling head, the evidence of various problems with discrepancies between instruments, the same instruments of different manufacturers, and the difficulties in evaluating these samplers are discussed.

This report, a second-phase of COL 515 project titled “Engineering Gravimetric Sampling Methods for Monitoring the Conditions of Excessively High Dust Levels-2.” The objective of the second phase of the work was to assess the results of the field trials on modified cyclones for dust measurements.

Field experience of dust measurement in South African coal mines has suggested that in very high dust concentrations, cyclones for sampling respirable dust can become overloaded (Oberholzer, 1998). In the light of studies conducted by Kenny, Baldwin and Maynand (1998) in UK, the use of a cowl (shield) attachment was favoured. The study reported to have shown that there was no significant difference in the concentration level measured between the cyclone with and without the shield. The general view of the several international opinions is that the use of the cowl will help to increase the accuracy of dust concentration measurements without increasing the bias of samples. It is further recommended that the CEN/ISO respirable curve with a d_{50} of 4 µm should be introduced as the standard.

CONCLUSION:

In overall, following conclusions were made from the current study:

- The work carried out in the field demonstrates equivalent dust concentration results from the two sampler types in different positions within the mine. The extent of the agreement between the two sets of results seems to be excellent and much better than that for results obtained in the laboratory results or in non-mining workplaces.
- From the statistical analysis (*t*-test and F-test), the mean dust concentration measured by pairs of cyclones is not significantly affected at 95 percent level of confidence.
- In other words, there is no difference between the measured mean dust concentration levels between various sampler pairs.
- From the general size distribution plots from the sample dust, we notice that the mineface respirable dust has two relative maximums, called modes and can be referred to as a bi-modal distribution.
- From the size analysis on dust samples (with and without cowl samples) of the measured dust concentrations in the range 2,37 mg/m^3 to 10,59 mg/m^3, it is seen that the sampled respirable dust contained particles greater than 10 µm, except for the BGI sampler dust (3,89 mg/m^3 concentration).
- At very high measured dust concentrations, the cowl sampler lowered the loading of large particles. From the size distribution analysis data, we can conclude that the cowl samplers are the preferred samplers for taking engineering samples at high dust concentrations.
- However, the results showed that at very high dust concentrations, there is a huge variation in both the measured dust concentration and the size distribution for a paired sample. For a pair of cowl and without-cowl samplers, for the same dust concentration levels, the evidence showed the presence of wide size distributions.
- It is thus evident that, although the dust mass collection of the samplers conforms to the requirements, the size distribution of the dust is not concomitantly accurate.
- The field study failed to conclusively determine whether the modifications made to the South African cyclone either improve or degrade its performance for the conditions tested, based on the results of the size analyses.
- From the field observations, it can be stated that the cowl sampler can be used for engineering sampling to avoid the dependence of the cyclone inlet on orientation in the collection of particles.
- The data analysis and field experience have shown that in comparison with other samplers, BGI samplers greatly reduce the amount of oversized particles deposited onto the filter from the inversion of cyclones. Also, due to the design of its cyclone inlet, the BGI sampler is not affected by orientation dependence.
- The field observations did indicate that when collecting samples closer to the face, where high concentrations of dust are present, sample handling is extremely difficult. At high dust concentrations, the probability of non-respirable particles depositing onto the filter from the grit pot is very high when the pump is switched off. However, the BGI sampler, due to its design, alleviates this problem to some extent.
- In both the laboratory and field tests, a sufficient mass of sample dust was required for analysis with the Fritsch analyser to determine the presence of non-respirable particles. This led to the conclusion that there may have been non-respirable particles in the concentrations below 5 mg/m^3 (as found from this study).The size analysis of the collected dust mass for sample concentrations greater than 5 mg/m^3 did not follow the D_{50} of either BMRC or ISO/ACGIH/CEN respirable curves.
- The cowl sampler could not be recommended for personal sampling because the results of the size analysis are inconclusive and wide-ranging.
- Finally, question of cowl under-sampling (under-estimation of dust concentration) or over-sampling (over-estimation of dust concentration) could not be resolved with confidence from size distribution data at concentrations below 5 mg/m^3 despite the insignificant differences obtained from comparison of mass concentrations alone.

From the conclusions drawn, the following recommendations for future research are proposed, although it is suggested that there should be a paradigm shift in the existing sampling procedure and instruments in the future project:

- The results were inconclusive with regard to the recommendations on the usage of adding a cowl to the cyclone in the personal sampling method. However, the use of a cowl for taking engineering samples can be recommended on the grounds that it lowers sample-handling errors, the probable reason being that in practice it reduces factors such as the wind and orientation-dependence of the cyclone inlet. At high dust concentrations, it was difficult to determine which sampler measured the "true concentration." Therefore, future field tests should incorporate the aspect of "impactor sampling" from which both the mass concentration and the size distribution of ambient particles can be accurately determined.

- Despite some of the cyclones being accepted for sampling in the industry, concerns were expressed about the cyclone performance with respect to the BMRC and ISO/ACGIH/CEN respirable curves. Fears were also expressed about whether the cyclones do follow the BMRC respirable curve under concentrations below 5 mg/m^3. In addition to the investigation, further work on recommendations for the use of the cowl sampler for personal sampling could be considered.
- Similar studies should be carried out to compare these samplers with CIP10 samplers and to investigate their variances and size distribution. The different makes of samplers should also be investigated to determine the relationship between them, not only with regard to the mass of dust collected but also in terms of the size characteristics of the dust.
- Tests should be carried out to determine the size characteristics of personal dust samples and engineering dust samples to compare with the existing DME requirements for engineering sampling.
- Immediate attention needs to be given to analysing both the compliance and noncompliance samples from the mines, which have difficulty in maintaining the 1997 DME directive. On the basis of this outcome, there needs to be clarification on the matter of performance evaluation of all the cyclones currently used in the mines.

An extensive facility, including a chamber and a particle size analyser for analysing sample mass on compliance samples of less than 5 mg/m^3, needs to be established for this serious issue of sampling. A programme needs to be established for dust sampling, measurement and data analysis for exposure assessment.

5. THE REDUCTION OF THE SAFETY AND HEALTH RISK ASSOCIATED WITH THE GENERATION OF DUST ON STRIP COAL MINE HAUL ROADS

By Thompson R.J., Visser A.T., Laboratory for Advanced Engineering Departments of Mining and Civil Engineering, University of Pretoria, Ref: COL 467, 1998

SUMMARY:

This report presents the findings of the SIMRAC (SIMCOL) research project COL467 which examines techniques to reduce the safety and health risk associated with the generation of dust on strip coal mine haul roads. The objective of this report was to develop a set of guidelines for the appropriate surface treatment selection, application and maintenance to provide a cost effective means of reducing the safety and health hazard associated with dust on strip coal mine haul roads.

The mining industry, specifically surface strip coal mine operators can use the guidelines to optimise the safety and health of surface strip coal mine transport operations, specifically through the reduction of transport related accidents and the structured recognition, evaluation and solution of dust generation problems on mine haul roads, leading to safer mining operations.

CONCLUSION:

The following conclusions and recommendations were made in the light of the findings of the research contained in this report;

A set of ideal dust palliative parameters were identified from a mining perspective, encompassing application, management and performance factors.

The management strategy recommended for any form of dust suppression was based on a user-defined level of dust defect acceptability and an average degree of palliation which can be maintained over a specified period. In general, the consensus of road-users was that a dust defect score of two represented a practical dust defect intervention level. This defect score was based primarily upon the visual effects (road safety and driver discomfort), rather than any perceived health impact.

A watering model was developed to determine individual mine road watering frequencies for the characteristic site parameter combinations during summer and winter operating conditions, for a required level of control or maximum dust defect.

A model was developed to analyse palliative cost-effectiveness (R/m2), with the aim of identifying and costing the construction, application and maintenance aspects associated with the use of chemical palliatives, compared to that of water-based suppression alone.

The average degree of palliation achieved using chemical palliatives can significantly reduce dust emissions from mine haul road, and the primary impact of these reductions would be improved visibility and safety, and in the case of open-cab trucks, an improvement in the air quality index.

It is recommended that palliatives be considered as a dust suppression system, subject to the limitations described in the research.

A mix-in establishment is recommended for a mine haul road, irrespective of palliative type, followed by spray-on maintenance reapplications. A poor wearing course material cannot be improved to deliver an adequate performance solely through the addition of a dust palliative and it is recommended that the haul road wearing course material should at least satisfy the minimum material selection specifications. If not, the inherent functional deficiencies of the material will negate any safety or financial benefit of gained from using dust palliatives.

6. THE POSITIVE IDENTIFICATION OF ASBESTOS OR OTHER FIBRES IN THE MINING OF KIMBERLITE DEPOSITS AND AN EVALUATION OF RELEVANT THRESHOLD LIMIT VALUES

By Unsted A.D. and v Vuuren D.B.J , CSIR: Division of Mining Technology, Ref: OTH 409, 1998

SUMMARY:

Dry drilling is not permissible under South African mining regulations. However, due to the physical and chemical properties of kimberlite, water has been found to have undesirable effects on blue ground, causing swelling and disintegration. Consequently, no water is used in drilling operations within blue ground pipes. This research work was carried out in conjunction with another SIMRAC project, SIMOTH 410, which investigated pollutant levels and the practice of dry drilling during the mining of kimberlite deposits. The same sampling sites were used for both projects but the sampling equipment and techniques differed. In this investigation gravimetric samplers, thermal precipitators and konimeters were used to sample for the presence of airborne fibres, whereas gravimetric samplers, tyndallometers and real time dust monitors were used for the dry-drilling investigation. In this project the gravimetric samplers were used in both continuous and intermittent mode.

Whereas the dust levels in pipe deposits were generally found to be different from those in fissure mines due to the differing mining methods and dust control measures used, fibre levels were found to be less dependent on these factors and more dependent on the geology of the deposit being mined.

Nevertheless, high background dust levels tended to mask the presence of airborne fibres. Effective dust control measures and the use of water, reduce the background dust levels thus rendering the fibres more visible in the counting fields. This effect could easily lead to incorrect conclusions when sampling results from different workplaces or mines are compared. Unlike the results obtained for the dry drilling study, no real differences in fibre levels were found between pipe deposit and fissure mines, or between dry mining and wet mining operations. It was consistently found that intermittent sampling, i.e. 10 minutes in each 60-minute period, yielded the highest fibre concentrations. This can be ascribed to the lower background dust levels

collected during these short intervals when compared to the larger mass collected with continuous samples. Under these conditions, fibres would be more visible in the counting fields as stated before. The results from the thermal precipitator and konimeter sampling were, in general, an order of magnitude lower than those from gravimetric sampling.

CONCLUSION:

It was also found that intermittent sampling, i.e. 10 minutes in each 60-minute period, yielded the highest fibre concentrations. This was felt to be due to the lower background dust levels on these samples making it easier to find the fibres during counting. The results from the thermal precipitators and konimeters were, in general, an order of magnitude lower than those from intermittent sampling. Considerable differences were found in the results for individual samples within paired samples. The necessity to collect samples in pairs is therefore apparent and is recommended. It is important to note that no fibres were detected in the downcast shaft samples and only very low concentrations in the main intake airways (0,02 f/mP).

Nevertheless, the fibre concentrations found in the main return airways were found to be 0,43 f/mP and in the upcast shaft 2,82 f/mP. These results tend to indicate a release of fibres into the workings due to mining operations. The results reported are for averages of pairs of samples and in several cases individual fibre concentrations exceeded 2 f/mP. The presence of airborne fibres was also detected at tipping and crushing operations. It is significant that several types of asbestiform fibres, i.e. chrysotile, anthophyllite and actinolite/tremolite, were found in all the mines sampled, both in the country rock and in the kimberlite excavations. However, of greater significance was the fact that NAMF constituted between 53 and 78 per cent of the airborne fibres. In effect, this means that if a fibre level of 2 f/mP is encountered, the asbestos content is likely to be between 0,4 and 0,1 f/mP.

It was also concluded that discrimination between asbestos and many other fibres using optical microscopy, was a difficult if not an unreliable means of identifying fibres - even for experienced operators or technicians. According to the literature, even with phase-contrast microscopy only about 5 to 15 per cent of the fibres visible by transmission electron microscopy can be seen, i.e. those fibres more than 2 µm long and more than 0,2 µm in diameter.

7. A CROSS-SECTIONAL STUDY TO DETERMINE THE POTENTIAL MUTAGENIC EXPOSURE FROM DIESEL EXHAUST EMISSIONS IN UNDERGROUND COAL MINES IN SOUTH AFRICA

By Dr Kay S.A., University of Witwatersrand, 2000

SUMMARY:

The health of workers exposed to diesel exhaust emissions in underground coal mines is of growing concern. The chronic effect of long term exposure to diesel exhausts is thought to be tumorgenesis due mainly to the polycyclic aromatic hydrocarbons (PAHs) contained in the emisate. To date, no reliable method exists to measure diesel emissions in the respirable zone of coal miners, nor are there any reliable biological markers to indicate exposure.

A cross sectional study was undertaken on a coal mine to determine if there was any difference in urine PAH levels between workers exposed to diesel exhaust fumes and those not exposed. Ethics clearance was obtained from the Committee for research on Human subjects (Medical) of the University of the Witwatersrand (Ref M00/10/11).

Objectives

- To determine the urine 1-hydroxypyrene level in underground coal miners exposed to diesel

exhaust emissions and in plant operators living and working on the same mine but not exposed to diesel emissions; and
- To measure the urinary cotinine of all study participants.

Methods

A coal mine in Mpumalanga, South Africa was selected to participate in the study and negotiations were held with labour and management to conduct the survey in August 2001. Workers were categorised into high and low exposure categories by the safety officer. High risk occupations were LHD drivers, bus drivers, diesel mechanics and technicians. Low risk workers were individuals who lived in the area and worked on services in the plant, services or planning where there was no occupational exposure to diesel emissions. All 40 workers exposed to diesel in two underground sections were asked to participate. From a list of 200 non exposed workers, a random sample of 40 surface, non exposed workers were asked to participate.

Workers were briefed one week prior to sample collection on the background and purpose of the survey.

Demographic data and urine samples were collected at the end of the 6th shift (end of week). Urine was collected into polyurethane vials, placed on ice and transported to an accredited laboratory where they were frozen at -18°C immediately. The urine samples were defrosted, then subjected to high pressure liquid chromatography to separate out the hydroxypyrene. The quantity of I-hydroxypyrene was determined using a fluorescent detector. Urinary cotinine level was determined on the individual urine samples to determine any potentiating effect of smoking on the PAH levels. Reference limits for non-industrial exposure for the laboratory were 0 to 0.45 :mol/mol creatinine while the limits for industrial exposure are 0.45 to 2.34 :mol/mol creatine. Cotinine is also expressed as a ratio to creatinine, with a limit of 0.7mg/g in non-smokers and and 8.6 mg/g in smokers.

The data were double punched into a personal computer and analysed with the statistica software program. As data were not normally distributed, the non-parametric, Kolmogorov Smimoff test was used to compare sample means. The Spearman rank test was used for correlation between PAH and cotinine levels.

Results

Of the 40 exposed underground workers, 2 declined to participate and 28 of the 40 selected surface workers agreed to participate as controls. Urine samples from 3 surface workers were insufficient and were discarded. All workers were male except one surface worker and ranged in age from 23 to 57 years. The results indicate that there was no statistically significant difference in the exposure to PAHs between the two groups. Two workers (diesel bus drivers) had PAH levels greater than 2 :mol/mol creatinine. The exhaust outlets are in close proximity to the drivers who do not wear protective respiratory apparatus. There was no association between smoking (cotinine) and PAH level in the urine.

Recommendations

Further research and interventions should be considered:

- To establish if bus drivers are in a particularly high risk of exposure in underground coal mines
- To introduce measures to reduce emissions from buses
- To extend the study to the non-coal mines and include other factors which may affect PAH levels
- To establish reliable methods to measure diesel particulate matter (and absorbed chemical substances such as PAHs) emissions and personal exposure in the coal and hard rock South African mining industry.

8. RANGING OPEN PATH REMOTE METHANE DETECTION/MONITORING DEVICE

Dr Kononov V.A., Spottiswoode B.S., Germishuizen F., CSIR Miningtek , Ref: GEN705

SUMMARY:

The main conclusion of project COL601 was that the method of underground open path, remote flammable gas measurement, in its existing form, does not comply with the current safety regulations. The problem with the method used lies in the fact that it provides an integrated measurement of gas concentration along the path, or, in other words, a percentage of gas concentration per metre. Therefore, it was proposed that a time Ranging Open Path Remote Sensing (ROPRES) device should be developed. This technology enables the distribution of flammable gas concentration along the open path to be determined, thus ensuring that the safety regulation requirements for routine methane monitoring and early warning are met.

The employed technology is a form of Differential Absorption Light Detection and Ranging (DIAL). In essence, short impulses of two wavelengths of infrared laser light are projected along the path of interest. This light is backscattered off the dust particles in the air and is collected by a receiving telescope. One wavelength, the primary, is matched to a strong absorption line of the gas species of interest. The other, the reference, is unattenuated by this gas but lies at a wavelength close enough to the primary wavelength to ensure that differences in transmission characteristics are negligible.

The methane concentration at any particular distance from the sources can be resolved from the two received signals by analysing their ratio at a time corresponding to that taken for the light to travel from the transmitter to the area of interest and back to the receiver.

It is impossible to apply current DIAL technology directly for use underground, as the best spatial resolution of such a system is only about 15-30 m. This limitation is due to both optical timing aspects and to a lack of backscattering particles in the atmosphere. A theoretical study was undertaken to determine the expected backscattered radiation from the dust of a typical mining atmosphere. The results of this were used to specify system requirements.

The study demonstrates that due to the substantial amount of airborne dust in the mine atmosphere and due to the advent of a new convolution-based DIAL technique, a proposed system fit for underground application (1-2m spatial resolution) is feasible. The hardware and processing software for the ROPRES system has subsequently been developed and tested in laboratory conditions.

A testing rig was designed and built in order to conduct a laboratory test of the device. The rig consists of a 8 m long 800 mm diameter rotating steel tunnel sealed at both ends with polyethylene membranes and filled with a mixture of methane and air. Fans installed in the tunnel serves to circulate the introduced dust and to provide a homogeneous methane mixture. Methane concentration is monitored by a methane sensor. A modified NLC's laboratory laser was used for testing.

Subsequent tests have confirmed theoretical results in that the amount of backscattered radiation in a mining atmosphere is sufficient for obtaining 1-2 m spatial resolution. Thus, the concept of ranging open path remote flammable gas detection/monitoring has been verified.

CONCLUSION:

As the next step, the development of an autonomous device for laboratory and underground tests is proposed.

9. INVESTIGATION OF CRYSTALLINE PHASES IN SILICA FUME

By van Niekerk W.C.A., Fourie M.H., Mouton G., INFOTOX (Pty) Ltd, Ref: SIM 020601, 2001

SUMMARY:

Despite intervention in exposure of workers to crystalline silica over many decades, silicosis remains an important occupational disease. Exposure to amorphous silica has not been regarded as a contributing factor, but a possible link with silicosis remains controversial. Silica fume, generally regarded as amorphous silica, has been associated with the development of fibrotic effects in exposed individuals. If microcrystalline phases were present, this might lead to the development of silicosis.

Microcrystalline phases are however difficult to detect with routine X-ray diffraction in the ultrafine matrix. Silica fume that appears to be amorphous in routine occupational hygiene surveys might therefore have the potential to cause silicosis because it contains a small proportion of crystalline silica.

Occupational exposure to amorphous silica generally does not show a silicotic effect. When silicosis does occur, exposures are usually mixed, with both amorphous and crystalline silica being present. A major limitation in most of these studies is the uncertain crystalline content. However, even small amounts of crystalline silica in the order of 0.1 per cent of the total amorphous content, are known to result in fibrotic effects.

Recent work on ultrafine particles has shown that their respiratory effects include inflammatory responses, while amorphous silica exposure can result in lung fibrosis. It is possible that co-exposure to ultrafine particles might sensitise the lung to silicotic effects by stimulating recruitment and activation of inflammatory cells and the amplified release of fibrogenic factors, enabling low concentrations of crystalline particles to trigger a silicotic effect. The dose-effect relationship for the development of silicosis under such conditions is not known, and it is therefore difficult to estimate an appropriate occupational exposure threshold level.

This SIMRAC study was initiated to investigate whether crystalline phases were present in silica fume and, if so, at what levels. The role of the ultrafine nature of silica fume in its overall toxicity also required clarification. Samples of airborne silica fume were collected at various locations in a typical silicon smelter plant. Transmission electron microscopy (TEM) was used to analyse the particle size, crystallinity and composition of crystalline phases present. The TEM techniques were bright field (to count particles), conical dark field (to determine the crystallinity of the particles) and EDS (energy dispersive spectroscopy) to evaluate the composition of the crystalline particles.

The TEM evidence leaves no doubt that crystalline particles are present in silica fume that forms when oxygen is bubbled through molten silicon. Less than 1 per cent of silica particles were crystalline, but its potential impact on the development of lung fibrosis should not be dismissed. The needle-shaped crystalline particles were approximately 200 nm and less in length and approximately 20 nm wide. Amorphous silica particles in all samples were smoothly spherical in shape with a diameter in the order of 100 nm and less. Silica fume can therefore be classified as ultrafine. It has now been confirmed unambiguously that small concentrations of crystalline silica can be present in amorphous silica under certain process conditions. This should affect the overall interpretation of the association between exposure to silica fume and the potential for development of silicosis.

The fibrogenic effects associated with exposure to amorphous silica fume may be transient, but remain adverse. Irrespective of the potential for development of silicosis, these facts suggest a re-assessment of exposure guidelines. In the U.S., the occupational regulating agencies (NIOSH and OSHA) have set guidelines for various amorphous forms of silica, but not for silica fume per se. The U.S. ACGIH occupational exposure guideline value for silica fume is 2 mg/m^3, but has been questioned.

The German regulating body has set a guideline (MAK) value of 0.3 mg/m^3 fine dust for several forms of amorphous silica grouped together. The South African guideline for respirable amorphous SiO_2 is 3 mg/m^3, which corresponds with the ACGIH TLV for diatomaceous earth. There appears to be insufficient justification to retain this guideline in view of the available evidence on adverse health effects of ultrafine silica fume. It is therefore apparent from this SIMRAC study that the occupational exposure guideline for amorphous silica fume should be reassessed.

10. RESPIRATORY HEALTH OF SOUTH AFRICAN COAL MINERS IN MPUMULANGA PROVINCE, EXPOSED TO RESPIRABLE COALMINE DUST

By Naidoo R., Robins T., Seixas N., University of Natal and University of Michigan (USA), 2001

SUMMARY:

The respiratory health effects of coaldust exposure have been well documented in the international literature. The relationship of coal dust exposure to outcomes such as emphysema or significant declines in lung function in the absence of CWP remains controversial. There are no previously published studies investigating the respiratory health of coal miners in South Africa. The current study was designed to investigate whether such dust related health problems present among South African coal miners.

Objectives

Specific objectives of the study included:

1. To estimate the prevalence of coal worker's pneumoconiosis (CWP), reduced levels of pulmonary function, and chronic obstructive lung disease (emphysema and chronic bronchitis) among living and deceased South African coal miners;
2. To investigate dose response relationships between these health endpoints and respirable coal dust, controlling for potential confounders such as cigarette smoking; and
3. To develop a set of evidence-based recommendations for the South African coal mining industry to address any risk for work related adverse respiratory effects.

Study Design

Parallel assessments of living and deceased coalminers were conducted. A review was conducted of all coalminer autopsies performed by the National Centre for Occupational Health between 1975 and 1997 and captured on a computer database known as PATHAUT. A validation study by 3 pathologists verified the findings in the PATHAUT database. Of the 5714 cases that were eligible for analysis, 3176 (40.93%) had exclusive coal exposure.

The assessment of the living workers was conducted on a sample of miners (including both active miners and those who had left the industry), who had been employed for at least one year in underground mining between the years 1985 and 1998 in one of three mines in Mpumalanga owned by the participating mining corporation.

A total of 896 workers participated in the study, of whom 212 were ex-miners and 684 were currently employed. Associations were investigated between measures of exposure and respiratory outcomes, based on questionnaires, lung function testing (spirometry) and chest radiographs.

Exposure estimations were derived through the use of historic dust sampling data together with dust samples collected by the research team in each of the mining operations. Cumulative exposure to respirable dust was estimated for participating miners through a combination of these historical and current exposure samples, written work histories, miner interviews and other record review.

Key Findings

Although the study found an overall moderate to low prevalence of coaldust related diseases among the study population, important dust related findings in

declines of lung function were observed. The analyses also suggested that a “healthy worker survivor effect” and a “healthy smoker effect” may have blunted the observed dose response relationship. Some of the specific key findings were:

- On autopsy, amongst those exclusively exposed to coal, the prevalence of CWP and silicosis was 6.95% and 10.22% respectively, and moderate to marked emphysema 6.45%.
- Chronic bronchitis symptoms were reported in 11.30% of the worker sample. 2.93% of workers reported having had previous TB. Ex miners reported significantly more symptoms than current miners. Prevalence of symptoms decreased with increasing cumulative lifetime dust exposure. An increase in prevalence is noted when only ex-miners are assessed.
- Better lung function outcomes were seen in current miners compared to the ex-miners and in underground workers compared to surface workers. Current smokers had better lung function than ex-smokers, with no difference seen between current and never smokers. These findings suggest both a “healthy worker effect” and “healthy smoker effect” present in the data.
- The effect of coal dust exposure on declines in lung function was equivalent to a loss of five years of breathing capacity over a lifetime of employment. This was irrespective of the
- age of the coalminer, his smoking status or past history of TB. For a 40 year old, 170cm tall man, dust exposure alone has an effect of a 1.33ml loss in FEV1 per year per mg/m^3 dust
- exposure. Over a 30 year working life period, such a coalminer has the effective breathing capacity of a non exposed worker five years older. Smoking contributed a marginally bigger loss
- of lung function amongst the miners.
- The prevalence of pneumoconiosis diagnosed by chest x-rays was 2.59%. Pneumoconiosis prevalence increased with increasing cumulative exposure. Lung function was worse for those with higher grades of pneumoconiosis.
- Autopsy diagnoses of TB was present in 5.21%, CWP: 7.37%, silicosis: 10.86%, significant emphysema: 6.45% (all emphysema: 31.33%), cancer 2.24%, among those with exclusive coal exposure. All outcomes, except TB, showed an increasing trend with increasing years of exposure. A miner in the higher exposure category had a 15 times greater chance of developing emphysema compared to a worker in a lower exposure category, adjusted for the effects of smoking.
- Smoking was associated with TB, silicosis, emphysema and cancer, with higher prevalence in ex smokers compared to current smokers. Smokers were three times as likely to have emphysema as never smokers, a risk lower than that related to coal dust exposure status.
- There was a 5.68 greater odds of silicosis amongst those with high exposure compared to low exposure. While controlling for smoking, the highest exposed workers had a 9.59 increased
- odds for developing significant emphysema. When controlling for dust exposure, current smokers had a 3.60 increased odds of developing significant emphysema compared to never smokers.
- It was concluded that under currently prevailing conditions in the South African coalmining industry, dust exposures contribute to the development of respiratory disease. The contribution of smoking to these outcomes appears to be roughly of comparable magnitude to dust.

Recommendations

Given the evidence of dust-related adverse health effects in this study, the following key recommendations appear warranted :

- Substantially increased engineering controls designed to minimise exposure.
- Statutory occupational exposure limits for exposure to respirable dust should be enforced to aid progressive reduction.
- Education campaigns for miners emphasising the hazards of exposure to respirable coal dust and the importance of cessation of smoking for those with such exposures.
- Rigorous respiratory medical surveillance programmes, as per the Mine Health and Safety Act, are instituted and maintained.
- Review of the dust sampling strategies employed on the mines.
- Further research investigation of the healthy worker and healthy smoker effects that may be influencing the data.

11. EVALUATION OF REAL-TIME AND GRAVIMETRIC-TYPE MONITORING INSTRUMENTS FOR USE IN UNDERGROUND MINES

By Belle B.K., CSIR Miningtek, Ref: HEALTH 704, 2001

SUMMARY:

Monitoring of dust in the mines is an important task and requires reliable dust-monitoring instruments. Information on routine worker dust-exposure levels using reliable dust monitors can assist both workers' and operators' awareness of the need to protect their respiratory health. However, uncertainty regarding the accuracy of dust-monitoring instruments weakens the validity of efforts aimed at monitoring and determining workers' personal exposures.

Against this background, the search for an improved or alternative instrument that will be able to measure dust-exposure levels more accurately and more reliably is continuing. In order to be able to react quickly when an unhealthy dust exposure level occurs, a near-real-time personal monitoring instrument for mineworkers is undoubtedly required. Therefore, the principal aim of this research project is to evaluate the newly available, near-real-time and respirable dust gravimetric monitoring instruments for personal sampling purposes under various South African mining conditions with regard to their feasibility as alternative/potential instruments. It is expected that this will further enhance the health and safety of the South African mine labour force by providing effective personal monitoring.

The specific objectives of the project were as follows:

- To evaluate the newly available, near-real-time and respirable dust gravimetric monitoring instruments for personal exposure assessment in order to determine whether they meet the requirements of conditions in the South African mining industry.
- To evaluate six different instruments for monitoring the respirable dust fraction, both in the laboratory and in typical underground mine conditions, viz. in coal, gold, platinum and diamond mines.
- To compare the performance of the identified instruments in terms of accuracy, the option for quartz analysis, intrinsic safety issues, and practical implications such as portability, ease of use and wearability underground.

In order to achieve the set objectives, an initial worldwide literature review was carried out on the availability of newly developed instruments and their use as personal samplers. The findings of the literature review are discussed in Section 2.9. Based on these findings, six dust monitors were selected for evaluation. They were:

1. a locally manufactured sampler,
2. the Dorr-Oliver 10 mm sampler,
3. the NIOSH RDD tube,
4. the IOM sampler,
5. the PDR and
6. the Split-2 dust monitor. All the instruments were operated according to the new CEN/ISO/ACGIH size-selective curve and the SA sampler was used as a reference sampler.

Laboratory evaluation of the instruments as area samplers was carried out in the Polley dust duct. Side-by-side comparison of the identified instruments with the SA gravimetric sampler indicated that there was a significant difference in the measured dust levels between them and the SA sampler, except for the PDR near-real-time dust monitor. Based on the criteria set for the selection of a suitable instrument and statistical analysis of the laboratory data, it was found that the PDR is potentially the best near-real-time personal dust monitor for underground applications.

Field evaluation of the instruments as personal dust-monitoring instruments, side by side in the breathing zone, was carried out in gold, platinum, coal and diamond mines. In all, eleven weeks were spent underground in these mines. It was not the intention of this study to exclude or recommend any particular type of dust-monitoring instrument for industrial use, but rather to evaluate their comparative performance,

under broadly the same conditions, as personal samplers in the field and area samplers in the laboratory.

Main findings

The following overall conclusions were drawn from this study:

- From both the laboratory and field studies, it was noted that when two samplers (the SA sampler and the Dorr-Oliver sampler) were operated according to the ACGIH/ISO/CEN size–selective curve, there was a significant difference in the measured respirable dust concentrations. From this it can be inferred that either the SA sampler overestimates or the Dorr-Oliver sampler underestimates the "true" concentration. In the USA, the Dorr-Oliver sampler is considered to give a "true" measured concentration and in South Africa, the locally manufactured Higgins-Dewell-type sampler is considered to give a "true" measured concentration. Surprisingly, when the SA sampler and the BGI sampler were compared in the coal mines as area samplers according to the ACGIH/ISO/CEN curve, it was found that there was an insignificant difference in the measured dust levels (Belle *et al*., 2001).
- The portable near-real-time dust monitor (PDR) proved to have the highest potential as a personal dust monitor for exposure assessment. Nevertheless, all the near-real-time instruments can be used for engineering control or for a quick estimation of dust levels, but using a near-real-time monitoring instrument as a stand-alone unit for compliance is not recommended. However, modifying the current PDR unit (by adding a micro-size-selective device and improving the battery life and intrinsic safety) is likely to turn the monitor into a unique near-real-time compliance instrument for personal monitoring specially suited to South African mining conditions.
- From the laboratory and field trials, it was found that the responses of most of the newly developed dust monitors were linear compared with the SA sampler over a wide range of concentrations and aerosol distributions of various dust types. These variations in the dust monitors' performance are not surprising given the wide correction factors that have to be applied since the performance of a monitor is dependent on the size characteristics of the environmental aerosol, the density of environmental dust, the wind factor, the orientation of the sampler (sensing chambers in the case of real-time monitors) and the micro environment of the workers' breathing zone.
- The RDD near-real-time dust monitor was easy to use and wear as a personal sampler under extremely harsh environmental conditions such as in hard rock mines. However, in view of the poor relationship between pressure drop and mass of dust collected on the filter, the RDD needs further fine-tuning. Further, the RDD is not recommended for use in an environment where diesel particulate matter (DPM) is present. Also, there is no confirmed procedure for evaluating the quartz content of the RDD foam dust sample.
- From the field experience, it was noted that personal sampling in the harsh conditions of underground hard rock mines is extremely difficult. Drawing rational conclusions as to the reasons for the variations in the measured dust levels is notoriously complex. It is therefore suggested that in future evaluations and comparisons of the performance of personal dust samplers in the workplace should be carried out on a rotating 'mannequin'.
- The study has gathered a large amount of data on personal dust-monitoring instruments and built up considerable expertise on the subject. The identified instruments were successfully evaluated and new research directions that should be pursued for developing a near-real-time monitoring instrument have been determined. The project has led to technical knowledge and to know-how on the feasibility and practicality of providing information on the use of personal samplers in some of the harsh conditions underground.
- Finally, this study has generated a wealth of unique information and experience related to the evaluation of newly available dust-monitoring instruments for personal sampling purposes and to the difficulties encountered in some of the deepest and hottest mines in the world.

Main recommendations

The following recommendations are made based on the extensive laboratory and field study:

- The ACGIH, CEN and ISO have called for a harmonised approach worldwide to dust sampling in accordance with the same international size-selective sampling conventions. This study has shown that when the two size-selective samplers were operated according to the new ISO/CEN/ ACGIH curve, the result was a significant difference in the respirable dust concentration level measured. It is against this background that the South African mining industry and allied industries should resolve to carry out basic and pragmatic research into defining the detailed penetration characteristics (aspiration efficiency) of the SA sampler for the size fractions of respirable dust. Side-by-side comparison of the BGI cyclone and the Dorr-Oliver cyclone according to the new respirable dust curve may lead to an understanding of why the SA sampler's measurements vary from the "true" concentration.

- In past decades, researchers used the MRE 113a, which followed the Johannesburg (BMRC) curve, as a benchmark "true sampler" because it was based on health studies. Ideally, samplers with penetration characteristics that "exactly" follow the respective size-selective curves should provide "true" concentrations (Vincent, 2002). However, there is no single physical sampler that precisely duplicates the theoretical size-selective curve. Owing to the differences observed, the study identifies the need for consensus on a "true SA sampler" which will operate according to the proposed new size-selective curve for international sampling harmonisation.
- In South Africa, no study has yet been carried out to determine how closely non-ideal SA samplers conform to either the BMRC or ISO/CEN/ACGIH size-selective curves when used in the field. Furthermore, the DME (1997) does not provide any guidelines as to which of the samplers conform to the specified collection efficiencies of either the BMRC or the ISO/CEN/ACGIH curve. Also, a draft guideline should be developed for the South African mining industry based on the results of recommended research and investigations into acceptance criteria for overseas instruments and, if necessary, the development of "secondary acceptance parameters" for specific samplers should be pursued.
- The study highlights the lack of infrastructure for applied aerosol research for the mining industry. What is lacking in this field at present is a well-established state-of-the-art centre for aerosol sampler testing to cater for the needs of the local mining industry and allied industries. This need is emphasised by the considerable current research outputs in the field of aerosol sampling research from various universities, laboratories and research institutes in European, North American and some South East Asian countries. In view of the needs of the local mining industry, southern Africa needs to take a quantum leap in this area. Such a centre would acquire various sampling instruments, which could be used for comparing the test results from a wide range of manufactured dust-monitoring instruments and would facilitate the calibration of these instruments. Informal exchanges between dust experts have demonstrated that the "need for worldwide interaction" still exists. Therefore, the establishment of this centre would lift South Africa's and the region's capacity in dust research and should be regarded as a national priority. This should be the strategic aim of the Advisory Committee for the future of dust measurement and control research.
- Use of area sampling as an alternative to personal sampling in extremely harsh conditions such as deep gold mines should be reviewed, based on the practicality of such sampling and the quality of the exposure data obtained.
- Further work is needed to develop suitable test facilities and methods in consultation with overseas research agencies (Vincent, J., NIOSH, MSHA). Some of the shortcomings identified in this study should be regarded as pointing a way forward for better understanding of personal sampling in mines.

12. DIESEL PARTICULATE EMISSIONS IN THE SOUTH AFRICAN MINING INDUSTRY

van Niekerk W.C.A., Simpson D., BSc, Fourie N.H., Mouton G., CSIR Miningtek, Ref: SIM 020602, 2001

SUMMARY:

Exhaust fumes of diesel driven vehicles are a complex mixture of noxious gases and diesel particulate matter (DPM). In 1988 the National Institute for Occupational Safety and Health (NIOSH) recommended that diesel exhaust emissions be regarded as a "potential occupational carcinogen", and stated that reductions in workplace exposure would reduce cancer risks. The US Environmental Protection Agency (USEPA) regards DPM amongst the top twenty air pollutants of concern for environmental exposure. Exposure in the mining industry is of particular concern because sometimes air concentrations are much higher than environmental levels, even exceeding concentrations as high as 2 mg/m3, which is a thousand times higher than a typical environmental level . In addition, inhalation exposure is not to DPM in isolation, but includes other fine and ultra fine particles resulting from normal mining activities, as well as polynuclear aromatic hydrocarbons (PAHs) that adsorb onto the particulates. These co-exposures may represent a serious health risk.

Some European countries (Germany and Switzerland), as well as Canada and the United States, have adopted regulations that limit the exposure levels of diesel particulate matter in the workplace. However, it appears that controversy still exists regarding the compound to be measured, e.g. elemental carbon, organic carbon, or total carbon. In the United Kingdom there is at present no regulatory limits for DPM. British Columbia, New Brunswick, Quebec and Ontario have adopted a level for respirable combustible dust (RCD) to represent exposure to diesel particulates. The complexity of the chemical and physical composition of diesel exhaust emissions make the assessment of exposure and health risk a challenging task.

The South African mining industry shares the global concern regarding occupational exposure to diesel particulate matter and it's associated health effects, but at present there is no occupational exposure limit (OEL) or other guidelines regarding DPM in the workplace. A primary concern about diesel particulates in South African mines is that levels of exposure have never been quantified properly. Methods used in this endeavour have produced results that were not reproducible, and whatever was measured could not be unambiguously related to diesel particulates. Therefore, the level of health risk to workers associated with exposure to diesel particulates is not known and can therefore not be managed effectively.

In addition to this problem of quantification of exposure to particulates, there are also concerns about potential exposure to polynuclear aromatic hydrocarbons (PAHs), which are common products of incomplete combustion and are known to adsorb readily onto a carbon substrate. The extent to which workers are exposed to PAHs adsorbed onto diesel particulates is not known.

A large volume of scientific information is available in the open literature on the toxicology and health effects associated with inhalation of diesel particulates. It has been the intention of this study to present a concise review of the available publications with the aim of highlighting the status of knowledge and understanding in the field, to form a basis for decision-making about control of occupational exposure and institution of regulations in this regard.

Assessment of sampling and analysis methods that are currently in use to quantify exposure to diesel particulates was identified as an essential step early in the study. The automotive industry generally uses a gravimetric method to quantify particulate emissions. However, it is difficult to quantify particulate emissions at levels in workplace air using a conventional gravimetric balance because the amount of particulates collected on filter samples for assessment of occupational exposure is very small. A primary objective in this study has been to identify the most appropriate sampling and analytical methods and to validate the procedures. Occupational exposure surveys in selected mines were integrated with this assessment process, to establish current levels of exposure to diesel particulates. The primary outputs of the study were therefore to establish an appropriate sampling and analytical technique and to assess current levels of exposure to diesel particulates in

South African mines.

Based on these findings, recommendations were to be made with regard to the need for the implementation of exposure control measures.

Three candidate mines were identified for testing of the sampling and analytical techniques. A pilot study was conducted in a coalmine, after which more comprehensive studies for quantification of exposure to diesel particulates and PAHs were done in one coalmine and one hard rock goldmine. Some measurements in another goldmine and in two platinum mines were later added to the programme.

Three types of methods were used to determine diesel particulate matter:

- A Rupprecht and Patashnick (R&P) Series 5400 Ambient Carbon Particulate Monitor that has the capability of direct sampling was used for quantification of elemental carbon associated with diesel particulate matter in ambient air.
- A laboratory-based Horiba Mexa 1370PM Super Low Mass PM Analyser was used to analyse diesel particulate matter captured on filters fitted to personal samplers of the type most commonly used to collect dust and other particulate matter in mines.
- A size selective sampler was used to differentiate between elemental carbon associated with diesel emissions and carbon particles from other sources, e.g. coal dust present in coalmines.

Exposure to PAHs was shown to be insignificant. The investigation confirmed that determination of elemental carbon was the preferred method for quantification of exposure to diesel particulate emissions. It was clear from the results of personal sampling using the Horiba Mexa 1370PM instrument for quantification that exposure in some of the mines exceed the international guidelines significantly. The validity of the Horiba measurements was confirmed by comparison of duplicate samples with analyses conducted by the Health and Safety Executive (HSE) in the UK. Furthermore, good agreement in readings was obtained between the Horiba instrument and the R&P direct-reading analyser, which provided additional confidence in the analyses. Therefore, for the first time, it has now been shown that exposures in some of the South African mines are high, at such levels that health effects associated with diesel particulates may occur. These findings indicate the need for the assessment and possible introduction of measures to reduce emissions and exposure, and the requirement for introducing regulations for the control of exposure to diesel exhaust emissions in South African mines.

13. ROAD HEADER ENVIRONMENT CONTROL (PHASE I, II AND III)

By Belle B.K., Hole B.J., Van Zyl F., Du Plessis J.J., CSIR Miningtek, Ref: COL 603, 2001

SUMMARY:

The primary objective of the Road Header (RH) Environmental Control project (COL 603) is to minimise the dust exposure of workers while maintaining adequate ventilation conditions in RH headings in order to optimise the working environment of mine workers. The constantly high dust levels at the road header (RH) operator's position prompted the Department of Minerals and Energy (DME) to issue a directive enforcing a 5 mg/m^3 dust-concentration level at the position of the RH operator. The main objective of this project was to find ways of controlling the environment to ensure that dust and methane levels are kept within the regulation requirements.

The project was conducted in three phases. During the first phase, an extensive literature review of past international and South African research on best ventilation and dust-control practices was carried out by IMCL (UK) and CSIR Miningtek (South Africa). In the second phase of the project, studies were carried out in a surface gallery at IMCL, UK. From this work, recommendations were made on the most effective way to control dust and methane in a road header heading.

The third phase of the project consisted of evaluating the ventilation and dust-control systems (as proposed from the surface work) underground. Two systems were evaluated: System 1: Bank 2000 Road Header Dust Control System without a wet-head, System 2:

Bank 2000 Road Header Spray System with a wet-head. The underground tests were carried out by the CSIR Miningtek team.

CONCLUSION:

The results obtained during the trials of the systems at Bank Colliery, South Shaft were encouraging for both the dust-control systems (DCS), with all the individual elements operational, constantly keeping the dust-concentration levels below the 5 mg/m3 design criterion that the measured methane concentrations were below the permissible volume concentration level of 1,4% CH4.

The average engineering dust-concentration levels at the RH operator's position for the two systems (1 and 2) are 3,82 and 2,69 mg/m3 respectively.

To achieve these results consistently the following has been identified as potential factors that can render the DCS ineffective:

1. It is extremely important that the DCS's spray configuration and individual components be properly manufactured, installed (orientated), operated, and maintained in order to achieve these results consistently. These include spray blocks, sprays, water supply pressure, and water flow rate
2. The quality of the spray nozzles needs to be consistent with the design parameters. From underground observations, the general quality of the spray nozzles appeared to be quite variable, particularly with respect to the final orifice hole that was drilled into the thin sheet-metal plate. Visual inspection of a number of nozzles revealed a range of problems including angled drilling of the holes, elliptical orifices and the presence of burrs. These defects cause problems such as incorrectly aligned sprays, gaps in spray coverage and a generally 'streaky' appearance to the spray.
3. Maintaining an air velocity of at least 1,0 m/s in the last through road (LTR) to maximise fresh air entrainment into the heading.
4. Training of section personnel on the function and concept of each component of the DCS for correct operation and maintenance.

14. DUST CONTROL FOR THICK-SEAM COAL MINES

By Belle B.K., CSIR Miningtek, Ref: COL 807, 2001

SUMMARY:

Project COL 807 was formulated to find ways of keeping down the dust in thick-seam coal operations to concentration levels of less than 5 mg/m^3 and to minimise the dust exposure of workers while maintaining adequate ventilation conditions along the coal face. A directive of the South African Department of Minerals and Energy (DME, 1997) required the dust-concentration level to be reduced below 5 mg/m^3 at the operator's position. The principal objectives of the project were:

1. to carry out an international literature survey of thick-seam wall mining dust-control techniques and their applications,
2. to evaluate the present performance of the dust-control system on the Joy shearer, and
3. to recommend alterations to the existing system or to propose a new dust-suppression system.

CONCLUSION:

Reviews of international literature on thick-seam coal dustcontrol techniques have indicated that longwall dust-control is still a problem area worldwide and broad dust-control techniques are available. However, mine-specific and technical aspects of the control mechanisms are not reported in detail.

The most common method for controlling the airborne dust in wall mining is the use of water sprays mounted on the shearer cutting drums. Techniques implemented for the control of shearer-generated dust include high drum-water flow rates, improved cutting techniques, shearer-clearer type external water spray systems and radio- remote control.

The majority of the wall dust-control techniques have been developed in the USA for low seam wall mines and their application is specific to low to medium coal seam heights.

Results from the preliminary field trials in South African wall mines (Series-1 trials), have indicated that the average Airborne Respirable Dust (ARD) concentration at the sampling stations exceeded the DME directive (1997) of a limit of 5 mg/m3. Similarly, the personal dust concentration levels are above the compliance level of 2 mg/m3.

The partially implemented CSIR-recommended Kloppersbos Shearer Spray Curtain (KSSC) system (Series-2 trials) resulted in significant improvements (> 50%) in dust levels The engineering concentration levels were below the DME directive of less than 5 mg/m 3, except at the tailgate position.

The shield dust is the second major contributor of dust as observed in the tailgate engineering dust levels, as well as the personal sample values.

In the quantitative risk assessment of a shortwall operation, using the field data, dust has been identified as both an explosion and a health risk. The risk rankings for explosions and health are 2 and 1 respectively.

15. EVALUATION OF NEWLY DEVELOPED REAL-TIME AND GRAVIMETRIC DUST-MONITORING INSTRUMENTS FOR PERSONAL DUST SAMPLING FOR SOUTH AFRICAN MINES

By Belle B.K., CSIR Miningtek, Ref: HEALTH704, 2001

SUMMARY:

Monitoring of dust in the mines is an important task in terms of Section 12.2 and 12.3 of the Mine Health and Safety Act (MHSA) of 1996 and therefore requires reliable dust measuring instruments.

Information on routine worker dust-exposure levels using reliable dust monitors can assist both workers' and operators' awareness of the need to protect their occupational respiratory health. However, uncertainty regarding the accuracy of measurement of dust monitoring instruments weakens the validity of efforts aimed at monitoring and determining workers' personal exposures. Against this background, the search for an improved or alternative instrument that will be able to measure dust-exposure levels more accurately and more reliably is continuing. In order to be able to ascertain the magnitude and range of dust levels and to react in accordance with the MHSA (1996) when an unhealthy dust exposure level occurs, a real-time personal monitoring instrument for mineworkers is undoubtedly required.

The specific objectives of the project were as follows:

- To evaluate the newly available, real-time and respirable dust gravimetric monitoring instruments for personal exposure assessment in order to determine whether they withstand the harsh environmental conditions (heat, humidity and working area) in the South African mining industry.
- To evaluate six different instruments for monitoring the respirable dust fraction, both in the laboratory and in typical underground mine conditions, viz. in coal, gold, platinum and diamond mines.
- To compare the performance of the identified instruments in terms of accuracy, the option for quartz or elemental analysis, intrinsic safety issues, and practical implications such as portability, ease of use and the ergonomics surrounding wearability of the instruments underground.

In order to achieve the set objectives, an initial worldwide literature review was carried out on the availability of newly developed instruments and their use as personal samplers. The findings of the literature review are discussed in Section 2.9 of the main report. Based on these findings, six dust monitors were selected for evaluation. They were: (1) a locally manufactured gravimetric sampler, (2) the Dorr-Oliver 10 mm sampler, (3) the National Institute of Occupational Safety and Health respirable dust dosimeter (RDD) tube, (4) the Institute of Occupational Medicine (IOM) sampler, (5) the Personal Data

Ram (PDR) and (6) the Split-2 dust monitor. All the instruments were operated according to the new Comite' European de Normalization /International Standards Organization /American Conference of Governmental Industrial Hygienists (CEN/ISO/ACGIH) size-selective curve and the South African (SA) sampler was used as a reference sampler.

Laboratory evaluation of the instruments was carried out in the Polley dust duct. Side-by-side comparison of the identified instruments with the SA gravimetric sampler indicated that there was a significant difference in the measured dust levels between them and the SA sampler, except for the PDR real-time dust monitor. Based on the criteria set for the selection of a suitable instrument and statistical analysis of the laboratory data, it was found that the PDR is potentially the best real-time personal dust monitor for underground applications. Field evaluation of the instruments as personal dust-monitoring instruments, side by side in the breathing zone, was carried out in gold, platinum, coal and diamond mines. In all, eleven weeks were spent underground in these mines. It was not the intention of this study to exclude or recommend any particular type of dust-monitoring instrument for industrial use, but rather to evaluate their comparative performance, under broadly the same conditions.

CONCLUSION:

The portable real-time dust monitor (PDR) proved to have the highest potential as a personal dust monitor for exposure assessment. Nevertheless, all the real-time instruments can be used for engineering control or for a quick estimation of dust levels, but using a real-time monitoring instrument as a stand-alone unit for compliance is not recommended.

The RDD real-time dust monitor was easy to use and wear as a personal sampler under extremely harsh environmental conditions such as in hard rock mines. However, in view of the poor relationship between pressure drop and mass of dust collected on the filter, the RDD needs further fine-tuning. Further, the RDD is not recommended for use in an environment where diesel particulate matter (DPM) and moisture is present. Also, there is no confirmed procedure for evaluating the quartz content of the RDD foam dust sample.

From both the laboratory and field studies, it was recognized that when two samplers (the SA sampler and the Dorr-Oliver sampler) were operated according to the ACGIH/ISO/CEN size–selective curve, there was a significant difference in the measured respirable dust concentrations. From this it can be inferred that either the SA sampler overestimates or the Dorr- Oliver sampler underestimates the "true" concentration.

The identified instruments were successfully evaluated and the project has led to technical knowledge and to know-how on the practicality of providing information on the use of personal samplers in some of the harsh conditions underground.

16. INHERENT RESPIRABLE DUST GENERATION POTENTIAL (IRDGP) OF SOUTH AFRICAN COALS

By Phillips H.R., Belle B.K., University of Witwatersrand, Ref: SIM 020604, 2003

SUMMARY:

Project SIM020604 was formulated to determine the Inherent Respirable Dust Generation Potential (IRDGP) of various South African coal types from various provinces and its use in dust exposure assessment. The objective was to quantify the amount of inherent respirable dust that becomes airborne from a particular coal type, rather than the respirable crusher product or its size distribution.

The epidemiological findings on the relationship between coal rank and development of Coal Workers' Pneumoconiosis (CWP) led to numerous studies on coal types and generation of respirable dust. Internationally, a number of laboratory studies have been conducted on the relationship between coal characteristics and respirable dust generation. No literature relating rates of CWP in South African mine workers with coal rank has been found. Also, no study has yet been done in South Africa to determine the inherent respirable dust generation potential (IRDGP) of various coal seams or coal types.

Therefore, any new information acquired through such a study could be used in future to investigate the relationship between the exposure levels, dust types and the disease rate among South African coal miners from a long-time perspective.

The IRDGP test facility was built at the Kloppersbos research centre. The laboratory test facility comprised a roll crusher located at the intake end of a 0.9 m high by 1.2 m wide wood framed hard board sheet rectangular wind tunnel 8.0 m long. An exhaust fan and a dust collector were located at the discharge end of the tunnel. The rollcrusher used for the study was similar to the specifications used by NIOSH in their dust generation research study. The research study carried out experimental work that resulted in critical information on dust type and IRDGP for the first time for South African coals.

CONCLUSION:

In summary, the following conclusions are made from the IRDGP data of the test coal samples:

- For the first time, a clear delineation of coal types (Bituminous and Anthracite) that possess the most inherent respirable dust generation potential was possible. Apart from a small amount of semi-anthracite found in Kwa Zulu Natal, most of the South African coal is of the semi-bituminous type. Typical range of volatile matter of coal is between 25% and 31%, while ash content is 10% to 24%.
- There is no conclusive relationship between different coal seams (1, 2, 4 and 5) and inherent respirable dust generation potential (IRDGP). The majority of the mine operators are currently exploiting coal from seam 2 and 4.
- Average coal crushing time of coal samples for the study indicated that the crushing time decreases in the order of seams 1 to 5. Kwa Zulu Natal coals took the highest crushing time during the tests when compared to the other coal seams and coal types. The reasons can be attributed due to inherent coal properties of high rank anthracite coals.
- Measured IRDGP of Limpopo coal was less than commonly occurring seam 2 and seam 4 coals in Mpumalanga province.
- Inherent silica content of South African coal seams indicated that average inherent silica for the test coals was 3.54%. Similarly, historically analysed airborne coal dust samples for quartz has indicated that they were below the limit of detection of X-ray spectrometer. However, caution must be exercised when assessing exposure specifically in the presence of sandstone bands and roof-bolt operators.
- Statistical Analysis of Variance (ANOVA) results of the study indicated that coal rank influences the IRDGP of coals ($p = 0.000$). There is no conclusive relationship between different coal seams (1, 2, 4 and 5) and IRDGP ($p = 0.373$) as they are all of semi-bituminous type.
- Based on the measured respirable dust data of the South African coals, it can be concluded that majority of the coal mining operation provinces such as Mpumalanga, Free State, Limpopo have on average similar IRDGP, while Kwa Zulu Natal coal samples which are semi-anthracite type coal have greater IRDGP.

17. QUANTIFICATION OF DUST GENERATING SOURCES IN GOLD AND PLATINUM MINE

By Biffi M., Belle B.K., CSIR Miningtek, Ref: GAP802, 2003

SUMMARY:

This report outlines the findings of a study performed to establish the respirable dust generation characteristics of a number of mining activities. A series of thirty-eight tests were performed on five mines in order to establish the respirable dust generation rates linked to activities presumed to be hazardous in this respect.

The aim of this study was to identify prominent dust sources that occur in hard rock mines and to characterise these by means of on-site measurement of dust generations. The activities identified for the studies were drilling, scraping, tipping, crushing and rock transfer. The study indicates that dust generation rates are activity dependent and that geological areas contribute to the silica content of the dust.

The results indicate that higher levels of mechanization lead to higher generation rates. In addition blasting has been confirmed to generate massive amounts of dust. These points need to be considered in view of developments in modern mining methods that consider the use of mechanised methods together with increased blasting intensity. The results are summarised in the table below.

In order to determine the inherent crystalline silica content of dust sources, stope rock samples from all the identified mines were analysed. The analysis of both type of samples indicated a variation of silica content. In the platinum mines visited inherent silica content was less than 1% while in the gold mines this varied between 9 and 39%. Similarly, a total of 38 airborne gravimetric respirable dust samples collected in various identified samples were analysed for silica content. The platinum mine dust samples contained silica content of less than 0,2% while in the gold mines this varied between 4,5 and 57% showing consistency between inherent silica content and airborne silica. Knowledge of this information together with the generation rates from different processes are important in assessing the risk of exposure to these and to decide on the most adequate means of controlling this hazard. The size characterization of respirable dust collected on the dust filter was not possible due to instrument limitations.

Ore transport, transfer and drilling are the greater contributors to respirable dust generations in more conventional operations. The correct use of water seems to control the dust generations effectively. However, alternatives are required in order to avoid the increased use of water underground as this might lead to other hazards and increased operational costs. The suggested combinations of dust control components and research topics discussed in Section 6 would enable the mines for effective protection of workers from harmful respirable dust as well as projections for future work.

Mine	Mine Type	Dust Source	Dust Levels [mg/m³] Min	Max	Avg	Crystalline Silica [%]
1	Gold [West Wits]	Intake	0.09	1.57	0.46	9.92
		Tips	0.23	0.65	0.49	
		Transfer boxes	0.59	0.81	0.70	
		Return airway	0.49	1.77	0.88	
		Development	0.34	8.19	1.76	
		Stope tips	0.58	0.87	0.73	
		Stope face	0.57	1.40	0.89	
2	Gold [Vaal]	Intake	0.02	0.73	0.29	39.05
		Tips	0.06	5.65	1.41	
		Transfer boxes	0.74	3.99	2.19	
		Return airway	0.69	14.12	4.62	
		Stope tips	0.41	4.22	1.69	
3	Platinum [Western limb, BIC]	Intake	0.10	0.36	0.20	0.45
		Tips	0.02	0.59	0.30	
		Transfer boxes	0.22	1.49	0.53	
		Return airway	0.63	3.47	1.73	
		Development	0.76	1.88	1.23	
		Stope tips	0.59	2.63	1.31	
		Scraping	0.71	1.51	1.19	
4	Platinum [Western limb, BIC]	Intake	0.09	0.84	0.34	0.45
		Tips	0.07	0.34	0.21	
		Conveyor belt	0.01	0.90	0.39	
		Return airway	0.44	1.69	1.06	
		Shaft	0.01	0.27	0.15	
		Development	0.48	2.09	1.23	
		Stope face	0.28	1.01	0.71	
		Scraping	0.25	0.92	0.54	
5	Diamond [Gauteng]	Intake	0.03	1.54	0.57	0.45
		Drilling	0.44	0.44	0.44	
		Loading	3.28	16.14	8.45	
		Crusher	5.61	8.63	7.12	
		Return airway	1.44	2.07	1.75	

18. IDENTIFICATION OF HEALTH HAZARDS IN MINERAL PROCESSING PLANTS RELATING TO CHRONIC EXPOSURE TO MULTIPLE CHEMICALS

Dr van Niekerk W., Dr Fourie M., Simpson D., Retief W., van Niekerk W., Mouton G., INFOTOX (Pty) Ltd, Ref: HEALTH 804, 2003

SUMMARY:

The entire Health 804 project is presented on a CD-ROM, and it is therefore appropriate that this report provides only an executive summary of the contents.

Project Health 804 is an extension of Projects Health 603 and Health 709. Health 603 focussed on health hazards associated with heavy metals in 15 types of mineral processing plants, and Health 709 addressed the issue of silicosis in silicon smelters. The studies highlighted that assessment of exposure to heavy metals provides an incomplete picture of potential health risk if a more holistic view of total chemical exposure is not taken. For example, it is incomplete to assess exposure to heavy metals without considering the impacts of the dust or acid mists in which the metals are carried, or the presence of sulphur dioxide together with calcium oxide. The plant surveys conducted under Project Health 603, and especially Health 709, played an important role in observing these issues, and the methodologies that were developed provided an essential framework for making occupational health risk assessment and management in mineral processing plants more complete, relevant, and useful. The approaches used in the previous projects were therefore used and expanded to cover the major chemical hazards associated with routine operations in mineral processing plants. Health 804 was designed as an extension to Health 603, expanded to include the issue of silicosis associated with Health 709, and the cyanide gold extraction process was added.

The project has been designed to produce an interactive CD-ROM. Within the software recorded on the CD, links were created from process flow sheets of the mineral processing plants to relevant information on chemical hazards and potential occupational health risks in the various nodes of the processing plants. Because all potential users of the CD-ROM might not have access to the Internet, information sheets on toxicology and methods to monitor and manage occupational health risks were recorded. Because it is anticipated that Internet access will become more and more available in the future, and because toxicological information and some other data are updated from time to time, links to relevant international websites were also recorded on the CD. The data are in the public domain and this report has no commercial interest or value. Links to websites of commercial companies in the field of occupational hygiene were not included, but these can be accessed through the ASOSH website.

Mineral processing plants consist of operations that are unique to a particular type of activity such as the bio-leach process for gold recovery, and certain unit operations that may be common to different plants such as spray painting and degreasing. The process flow diagrams developed form a good basis for refinement to include all the chemical hazards relating directly to the processes. In addition, more general unit operations can be cross-referenced between industries where they are employed. The mineral processing plants covered in Health 804 are:

- Carbon steel process with blast furnace and basic oxygen furnace;
- Carbon steel process with direct reduced iron and electric arc furnace;
- Typical copper recovery circuit;
- Typical ferrochromium production process;
- Typical ferromanganese production process;
- Bacterial oxidation circuit for the pre-oxidation of refractory gold ores;
- Carbon-in-pulp circuit for gold recovery;
- Typical gold cyanide leach process;
- Nickel, copper, and cobalt refining process;
- Typical phosphate rock production process;
- Platinum group metal refining;
- Silicon smelter process;
- Typical stainless steel process;
- Typical titanium dioxide production process;
- Vanadium pentoxide production: the salt-roast process;
- Vanadium slag production process; and
- Typical circuit for zinc recovery from concentrate.

The following generic unit operations have been described:
a) Abrasive blasting;
b) Asbestos;
c) Brazing and soldering;
d) Casting;
e) Coal burning;
f) Metal surface cleaning;
g) Degreasing;
h) Electroplating;
i) Flocculants;
j) Hot forging;
k) Machining;
l) Grinding, polishing, buffing;
m) Oils, greases and waxes;
n) Painting;
o) Welding,
p) The Sõderberg electrode; and
q) Diesel vehicles.

Following the concept of process flow diagrams, each type of mineral processing plant was divided into a set of unique and generic unit operations. Potential exposure points were identified for the range of chemicals of interest. The flow diagrams were not intended to represent specific plants of companies that assisted in providing information, but the data were presented in generic context. Therefore, specific plants and companies are not referred to.

For the toxicological assessment, criteria documents of the National Institute for Occupational Safety and Health (NIOSH), the American Conference of Governmental Industrial Hygiene, the US Environmental Protection Agency (USEPA), the World Health Organisation (WHO), various textbooks, and journals in the open literature were studied. Close to 200 toxicology charts were produced. Toxicity classifications were made with regard to target organs, to give an idea of where multiple chemicals could have additive effects on the same target organ system.

The following classification of target organ systems was used:
1. Renal system;
2. Nervous system;
3. Liver;
4. Gastrointestinal tract;
5. Respiratory tract;
6. Haematopoietic system;
7. Bone;
8. Endocrine system;
9. Muscle;
10. Eye;
11. Skin;
12. Cardiovascular system;
13. Immune system;
14. Reproductive system, and
15. Others where the above systems could not be clearly associated.

A general structure for occupational health risk management has been included under the main menu, including guidelines for monitoring and quality assurance. South African exposure guidelines are listed in the toxicology charts.

All the information was compiled on a CD-ROM in a format that allows interaction and guidance through the various process steps, linking the various elements that are relevant in the hazard identification, exposure assessment, and risk quantification. Information available to the public on websites has been downloaded and incorporated into the SIMRAC electronic document. Since the information is the work of agencies of the United States Government, the United Kingdom and elsewhere, and in the public domain, SIMRAC does not have copyright on those items, which shall remain in the public domain. The format of the CD-ROM will enable a person to work through the chemical hazards associated with a mineral processing plant, linking to the background information to understand the concepts, thereby achieving a more holistic view of health hazards and risk management.

However, it remains the responsibility of the Managements of the mineral processing plants to employ occupational hygienists and medical professionals to implement their monitoring and health risk management strategies.

19. SIMRAC SILICOSIS CONTROL PROGRAMME- PHASE 1

By Dr. Stanton D.W., Dr. Mbekeni C., Mr Rowe D., Prof. Ross M.H.,, CSIR, Ref: SIM 02-06-03, 2003

SUMMARY:

In 2002 SIMRAC established a long-term project to eliminate silicosis in the South African Mining industry (SIM 02-06-03). Phase 1 of this project was to scope the Phase 2 research required to work towards eliminating silicosis and included two regional workshops on silicosis elimination and a National Workshop.

Research efforts aimed at the elimination of silicosis in the SA mining industry will be long term and will require considerable funding and resources. Collaboration will be required from a broad range of personnel in the industry including management, health and safety personnel, human resources, employees, government and trade unions.

The primary objective should be reducing dust at source by means of improved engineering control. This will require the identification of the best practices to control the various dust sources underground and on the surface. Those responsible for dust control need to be fully aware of the engineering controls required to reduce dust generation to minimise exposure.

To properly monitor and evaluate the progress in dust control the industry needs to ensure that reliable and valid dust exposure and medical surveillance data are collected and reported. The analysis of this data should provide a better understanding of the health risk associated with silicosis and exposure to silica dust.

Current awareness and education programmes for employees on silicosis control will have to be considerably enhanced and appropriate refresher training implemented.

20. INHERENT RESPIRABLE DUST GENERATION POTENTIAL (IRDGP) OF SOUTH AFRICAN COALS

By Phillips H.R., Belle B.K., University of Witwatersrand, Ref: SIM020604, 2003

SUMMARY:

Project SIM020604 was formulated to determine the Inherent Respirable Dust Generation Potential (IRDGP) of various South African coal types from various provinces and its use in dust exposure assessment. The objective was to quantify the amount of inherent respirable dust that becomes airborne from a particular coal type, rather than the respirable crusher product or its size distribution.

The epidemiological findings on the relationship between coal rank and development of Coal Workers' Pneumoconiosis (CWP) led to numerous studies on coal types and generation of respirable dust. Internationally, a number of laboratory studies have been conducted on the relationship between coal characteristics and respirable dust generation. No literature relating rates of CWP in South African mine workers with coal rank has been found. Also, no study has yet been done in South Africa to determine the inherent respirable dust generation potential (IRDGP) of various coal seams or coal types.

Therefore, any new information acquired through such a study could be used in future to investigate the relationship between the exposure levels, dust types and the disease rate among South African coal miners from a long-time perspective.

The IRDGP test facility was built at the Kloppersbos research centre. The laboratory test facility comprised a roll crusher located at the intake end of a 0.9 m high by 1.2 m wide wood framed hard board sheet

rectangular wind tunnel 8.0 m long. An exhaust fan and a dust collector were located at the discharge end of the tunnel. The rollcrusher used for the study was similar to the specifications used by NIOSH in their dust generation research study. The research study carried out experimental work that resulted in critical information on dust type and IRDGP for the first time for South African coals.

CONCLUSION:

In summary, the following conclusions are made from the IRDGP data of the test coal samples:

- For the first time, a clear delineation of coal types (Bituminous and Anthracite) that possess the most inherent respirable dust generation potential was possible. Apart from a small amount of semi-anthracite found in Kwa Zulu Natal, most of the South African coal is of the semi-bituminous type. Typical range of volatile matter of coal is between 25% and 31%, while ash content is 10% to 24%.
- There is no conclusive relationship between different coal seams (1, 2, 4 and 5) and inherent respirable dust generation potential (IRDGP). The majority of the mine operators are currently exploiting coal from seam 2 and 4.
- Average coal crushing time of coal samples for the study indicated that the crushing time decreases in the order of seams 1 to 5. Kwa Zulu Natal coals took the highest crushing time during the tests when compared to the other coal seams and coal types. The reasons can be attributed due to inherent coal properties of high rank anthracite coals.
- Measured IRDGP of Limpopo coal was less than commonly occurring seam 2 and seam 4 coals in Mpumalanga province.
- Inherent silica content of South African coal seams indicated that average inherent silica for the test coals was 3.54%. Similarly, historically analysed airborne coal dust samples for quartz has indicated that they were below the limit of detection of X-ray spectrometer. However, caution must be exercised when assessing exposure specifically in the presence of sandstone bands and roof-bolt operators.
- Statistical Analysis of Variance (ANOVA) results of the study indicated that coal rank influences the IRDGP of coals ($p = 0.000$). There is no conclusive relationship between different coal seams (1, 2, 4 and 5) and IRDGP ($p = 0.373$) as they are all of semi-bituminous type.
- Based on the measured respirable dust data of the South African coals, it can be concluded that majority of the coal mining operation provinces such as Mpumalanga, Free State, Limpopo have on average similar IRDGP, while Kwa Zulu Natal coal samples which are semi-anthracite type coal have greater IRDGP.

21. ASSESSING THE OCCURRENCE OF FUNGI, INCLUDING OPPORTUNISTIC PATHOGENS IN THE MINING ENVIRONMENT

By Dr Pohl C., Dr van Heerden E., University of the Free State, Ref: SIM 030602, 2004

SUMMARY:

Several studies have been conducted regarding the presence of fungal spores in the air in residential and occupational areas. This is the first study regarding this topic in the mining environment. With the high number of HIV infected people working in the mines in South Africa, the impact of fungi - especially as opportunistic pathogens - on the health and productivity of the workers needs to be assessed.

The aims of this study were to determine airborne fungal load in the air present in the mine, to identify the fungi present in the air and, with this knowledge, to speculate on the impact of the identified isolates on the health of miners.

The results indicate that three of the sampled sites in the mine contain significant numbers of airborne fungi. The first such site was next to an auxiliary extraction fan, which may act as a concentrator for airborne fungal spores from the rest of the mine. The other two

sites had high dust concentrations and human activity, which may all contribute to the higher fungal load in the air. At one site, the presence of wooden support structures may serve as a substrate of several fungal genera.

Although most of the isolates identified in this study were not human pathogens, we believe they may still have a negative impact (either as opportunistic pathogens or allergens) on workers exposed to them for prolonged periods. This is especially true for workers who are immunocompromised.

CONCLUSION:

We recommend that the levels of dust in areas where high human activity occur be controlled as far as possible and that the wooden structures in the mine be treated to prevent the growth and sporulation of fungi.

22. PILOT STUDY TO DETERMINE THE EXTENT AND NATURE OF OCCUPATIONAL EXPOSURE TO AIRBORNE POLLUTANTS ASSOCIATED WITH CLAY MINING AND BRICK-MAKING

By Spies A., Naicker N., NIOH, Witwatersrand University ,2006

SUMMARY:

The study set out to:

- To identify typical airborne pollutants associated with clay-mining and brickmaking
- To assess the potential impact on the occupational health of mining and factory staff
- To recommend the need for further research, and strategies for improvement, monitoring and reporting
- To recommend, where necessary, the need and potential for the elimination, control and management of hazards, exposure and pollution

The clay brick production industry has been identified as a major source of air pollution in developing countries (1). However, there is only one study into the dust exposure in the clay mining and brick making industry in South Africa. The environmental impacts of the clay brick-making industry in South Africa have tended to be ignored. It is often assumed that because they are small these industries have little impact.

For this reason the Clay Brick Association approached the Mine Health and Safety Council to investigate the nature and extent of occupational exposure in the brick-making industry. The pilot study was commissioned to assess the potential risk associated with clay mining and brick-making and identify any need for further focused research or interventions.
Due the nature of the clay mining and brick manufacturing process, particulate matter is the primary pollutant emitted by brick plants. The main source of particulates (dust) is the materials handling procedure, which generally includes mining, drying, grinding, screening, and storing and kiln firing would result in emission of combustion products (e.g., NOX, CO) which would vary in composition, depending on the fuel source.

Sulphur Dioxides may also be emitted during this firing process. During the study qualitative measurements were taken for airborne particulates, SO_2, CO, CO_2, and NOx. Ground level dust concentration in the workplace depends upon the location, nature of activity, calm/windy conditions as well as weather. In calm conditions the dust level could be 0.3-1.3 mg/m^3 in no activity zones.

Dust levels in areas around the kiln while it is being fired were between 28-33 mg/m^3. In windy conditions the dust level on the top and around the kiln might be considerably higher, even in the absence of the above activities, due to dust. Although, the main focus of the study was to identify the airborne hazards, a number of other non airborne hazards were observed. These included, noise, ergonomic problems, and heat stress.

23. REPORT ON INSPECTION AND ENFORCEMENT AROUND THE WORLD WITH REGARD TO SILICOSIS PREVENTION

By Nundlall N.R., Baker A., Mark D., NIOH and HSL, 2006

SUMMARY:

In the field of Occupational Health and Safety, the more difficult aspect to regulate and quantify is occupational health, since many health effects are rarely immediate, and result from a cumulative exposure to pollutants over a long period. Periodic medical surveillance allows identification of the onset of symptoms or signs of disease, potentially enabling both re-deployment and early management of the individual to reduce the exposure and prevent, or slow down, the progression of the disease. However silicosis, a debilitating but preventable disease, may not always be detected early enough and primary prevention must be regarded as the best practice option.

This report reviews available information on enforcement strategies in some of the mining countries around the world with regards to worker exposure to respirable crystalline silica for regulatory compliance purposes. The report therefore does not consider compliance with regard to other interventions such as medical surveillance, training and engineering controls.

The guideline for a mandatory Code of Practice (COP) on Airborne Pollutants issued by the Mine Health and Safety Inspectorate (MHSI) of South Africa to protect and improve the health of employees, by monitoring and reducing their exposure to airborne pollutants, provides a good basis for assessing their exposure. In terms of reducing employees' exposure to pollutants, the responsibility is placed solely on the employer. A Code of Practice produced by each mine is required to describe the control measures currently in place to protect the workforce and to identify any additional measures that require to be instituted in order to reduce risks. The MHSI must then monitor compliance by the employers against the requirements of the guidelines to ensure the effective implementation of these control measures.

A brief snapshot of the mining industries' contribution to the economy of the different countries has been included, where available. Of the eight countries studied, the majority have 'outcomes-based' rather than prescriptive health and safety legislation for their mining industries.

The exception to this is the USA. In the RSA and the UK the legislation is formulated nationally and is applied exclusively through a national inspectorate. An intermediate approach is used by the USA, whereby the MSHA produce national prescriptive legislation on behalf of the Department of Labor. Individual states have certain powers to modify the legislation for their own area of jurisdiction and state agencies can also undertake inspections. It is considered that the prescriptive position in the USA enables the states to undertake these individual functions, largely using a checklist approach, particularly in regions which have many smaller operations that may be geographically scattered.

Australia is in a unique position in that it now utilises the Robens 'duty of care' approach to mining (and other) legislation. This is managed at the state level rather than at national level. However, this approach has no guarantee of providing uniformity of standards across the country, and approaches to health surveillance can vary across the various states. In Canada, occupational health and safety legislation also tends to be enacted and enforced at individual state level. India has a similar system to South Africa with respect to the exposure classification bands relative to the occupational exposure limit: the South African approach was molded on the UK model.

The RSA position is that the MHSI intends to have national 'duty of care' legislation, operated through a national body, which will lead to uniform standards in mines. One of the key concerns is whether standards at the small and micro mines can be improved without

more prescriptive guidance and whether the situation can be improved by the use of approved agencies. Currently the MHSI is reliant on the mining industry for self-monitoring worker exposure to respirable crystalline silica. The data received by the regulator have not yet been independently verified.

One of the outcomes of the Industry workshop held at the National Institute for Occupational Health (NIOH) was that the industry was assessed as being fairly satisfied with the current airborne pollutants monitoring programme issued by the Department of Minerals and Energy (DME). The current dust sampling programme was based on a collective effort of the state, labour unions and the employer through their tripartite collaboration. The concern, however, has been the level of training/awareness of the requirements provided by the state and industry prior to the implementation of the programme. This is evidenced by the number or errors seen on the statutory returns to the DME.

It is clear from the review that the Mine Health and Safety Inspectorate needs to urgently develop independent verification methods to verify data supplied via the statutory returns and also an enforcement method to ensure compliance with the regulated occupational exposure limit.

24. EXPOSURE TO AND EFFECTS OF CARBON MONOXIDE IN DEEP UNDERGROUND MINES

By Gulumian M., Masoka X., Schutte P.C., CSIR, Ref: SIM 05 06 01, 2006

SUMMARY:

Carbon monoxide is a colourless, odourless, tasteless gas that is slightly less dense than air. It is a product of incomplete combustion of carbon-containing fuels and is also produced by some industrial and biological processes.

Carbon monoxide is absorbed through the lungs and the concentration of carboxyhaemoglobin (COHb) in the blood at any time will depend on several factors. When in equilibrium with ambient air, the COHb content of the blood will depend mainly on the concentrations of inspired carbon monoxide and oxygen. However, if equilibrium has not been achieved, the COHb concentration will also depend on the time of exposure, pulmonary ventilation, and the COHb originally present before inhalation of the contaminated air. All of these factors will play an important role in the occupational exposure to carbon monoxide in South African mines.

The objective of this study was to establish the physiological effects of exposure to carbon monoxide (CO) under conditions of work stress in underground mines and the suitability of existing CO exposure limits. In order to achieve this objective literature reviews of the basic physiology of carbon monoxide uptake by the body and of the scientific and pathophysiological basis of CO occupational exposure levels were conducted. The literature reviews were followed by an assessment of the suitability of CO exposure limits used in the South African mining industry at present.

International regulatory agencies have implemented the scientific approach to derive health-based standards for CO. The health effects are reviewed in criteria documents to determine a COHb concentration as a Biological Exposure Index (BEI) that will correspond to an ambient concentration of CO using the Coburn equation. Standards were then derived which are considered to be protective for individuals against a specific critical health effect of CO.

Exposure for eight hours to the recently proposed levels of 35 ppm proposed by the National Institute of Occupational Safety and Health (NIOSH) producing a COHb level of 5%, is said to be protective against

asymptomatic cardiovascular diseases in workers engaged in sedentary activity, but would provide no margin of safety for workers with clinical symptoms of coronary heart disease (CHD).

Exposure for eight hours to 25 ppm as proposed by American Conference of Government Industrial Hygienists (ACGIH) USA producing a COHb level of 3.5%, with the proviso that 25 ppm should not be exceeded at any time during work shift, will maintain cardiovascular work and also will be effective in minimizing behavioural changes and providing a margin of safety for particularly susceptible workers, including pregnant workers and those with respiratory diseases. However, both of these standards are not considered to be protective for those who smoked as well as for those with increased work load at high temperatures and at high altitudes and therefore a decrease in duration of exposure is recommended.

Since the two Occupational Exposure Limit (OEL) values of 30 ppm and 50 ppm of CO, recommended by the South African Department of Minerals and Energy (DME), did not accompany a corresponding BEI for CO, the rearranged Coburn equation recommended by NIOSH was used to calculate the approximate COHb levels that may result from ambient CO levels of 30 ppm and 50 ppm.

If a value of < 5% COHb, recommended by NIOSH, is considered as a benchmark concentration not to be exceeded in order to be protective against CHD, a time-weigted average occupational exposure limit (TWA-OEL) of 30 ppm recommended by the DME will be protective only for sedentary workers and not for those conducting light and heavy work. A TWA-OEL of 50 ppm will certainly not be protective for all workers.

If a lower value of < 3.5% COHb, recommended by ACGIH, is considered as a benchmark concentration not to be exceeded in order to minimise the potential for adverse neurobehavioral changes as well as to maintain cardiovascular work and exercise capacities of healthy workers, a TWA-OEL of 30 ppm as well as a TWA-OEL of 50 ppm will not be protective for all workers.

The above results suggest that exposure limits based on the physiological responses of sedentary individuals under "ideal" conditions of acceptable environmental temperature and barometric pressure cannot be expected to be valid under conditions of increased physical work loads with concomitant increased pulmonary ventilation rates.

From the literature it is evident that the transport of CO between the airway openings and red blood cell haemoglobin, its concentration, rate of formation and elimination of COHb are all controlled by physiological (e.g. alveolar ventilation and cardiac output) and physical (e.g. mass, transport and diffusion) processes, governed by physicochemical laws, particularly Fick's first law of diffusion. Furthermore, during exercise, the relative rate of CO binding increases more for myoglobin than for haemoglobin.

CO will diffuse from blood to skeletal muscle, producing an increase in the concentration of carboxymyoglobin in both skeletal and cardiac muscles. The subsequent reduction in the oxygen-carrying capacity of myoglobin might have a profound effect on the supply of oxygen to these tissues. The increase in binding of CO to myoglobin during exercise is shown to occur even at low levels of CO (2-2.5% Hb-CO).

From the literature it is also evident that a combination of thermal stress and exposure to CO will reduce physical work performance because of the production of higher levels of COHb, while the interactive effects of heat, physical work, and CO exposure will change cognitive task performance. These findings suggest that heat stress may be an important determinant of changes in physical work performance as well as cognitive performance when combined with exposure to CO.

As health effects of CO may actually be mediated by physical stressors such as work load and temperature and by other risk factors such as smoking and the health status of workers, it is recommended that all variables that affect the outcome of the Coburn equation, individually as well as in combination, be further investigated to assess their effects on the suitability of TWA-OELs proposed for the South African mining work environment. This research could be in the form of a desktop study, using the Coburn equation to predict outcomes based on risk factors typical of South African. The predictions could then be used to establish TWA-OELs for CO that will be protective and will provide a margin of safety for all workers operating under South African mining environmental conditions.

25. AN INVESTIGATION INTO THE SURFACE ACTIVITY OF AIRBORNE PARTICLES IN THE GOLD MINING ENVIRONMENT

By Gulumian M., Semano M., Komane P., Khoali L., Malindi M., Matiwane N., Vallyathan V., Wallace W.E., National Institute for Occupational Health (NIOH), South Africa; National Institute for Occupational Safety and Health (NIOSH), U.S.A., Ref: SIM 02 06 05, 2006

SUMMARY:

Surface activity of representative settled bulk mine dust samples collected from ten mines located within three provinces in South Africa as well as their < 20 mm size-separated fractions were studied using a number of in vitro test systems. These included the ability to generate the hydroxyl radical, to initiate lipid peroxidation and also to induce damage to DNA. The physicochemical properties such as surface area, elemental composition and alpha quartz content of these particles were also assessed.

It was found that dust samples collected from these mines and their size separated fractions were not equal in initiating these toxic reactions. Accordingly, it is proposed that equal masses of these dust particles will not translate into equal doses of exposure. Recommendations are therefore made to take this variability in toxicity of mine dust in establishing a more relevant dose response relationship of exposure to pathological effects. Additional toxicological tests involving the assessment of surface elemental contamination of dust particles with iron will further assist in establishing the latter relationship.

26. ADVERSE HEALTH IMPACTS ASSOCIATED WITH DUST EMISSIONS FROM GOLD MINE TAILINGS

By Andraos C., Gulumian M., NIOH, 2013

SUMMARY:

It is believed that pollution related to gold mine tailings storage facilities (TSFs; mine dumps) may pose risk to surrounding communities. For this project, the application of a health risk assessment paradigm will scientifically investigate a cause-effect relationship, if any, between exposure of nearby communities to gold mine tailings dust and adverse health effects experienced by these communities.

It is hypothesised that the higher the exposure of communities to ambient particulate matter (PM) emitted from TSFs, the higher the incidence of respiratory diseases associated with exposure to toxic dust.

The achievements for year 2 of this project involved:

1. assessing the hazardous nature of dust particles emitted from TSFs,
2. assessing the exposure levels of surrounding communities surrounding TSFs and
3. assessing the prevalence of adverse health effects in surrounding communities.

The TSFs studied included Durban Roodepoort Deep (DRD; West Rand), Crown Gold Recoveries (CGR; Central Rand), ERPM (East Rand), ERGO (Far East Rand) and Anglo Gold Ashanti (AGA; Stilfontein), Vaal River Area.

Hazard Identification

The risk assessment paradigm requires that the compound or particle in question be assessed for its hazardous properties in order to determine whether exposure to the compound or particle may cause an increase in the incidence of adverse health effects in humans. The hazardous nature of tailings dust was determined by physicochemical characterisation and in vitro toxicity assessment. The analysis revealed the presence of particles in the respirable- and nano-range, which is known to be more toxic once inhaled. The dust can be classified as mesoporous material exhibiting low surface areas and blockage of surface pores. Despite low surface areas, the dust showed toxicity in human bronchial epithelial BEAS- 2B cells as well as high surface activities in their ability to produce free radicals.

Exposure Assessment

Environmental PM dispersion monitoring: The Grimm counter was set up to measure tailings PM concentrations in surrounding areas of the DRD, CGR and ERPM TSFs during the windiest months September-October, based on seasonal variation analysis. Results showed that the average daily limit of 180 µg/m^3 was exceeded eight times during the sampling period at the DRD site.

The limit was also violated three times and six times at the CGR and ERPM sites, respectively (not shown). These dust generating events leading to elevated PM concentrations well above the limit showed that ambient air quality is compromised for surrounding populations.

Personal sampling: Personal sampling was conducted on school children in surrounding communities to calculate the actual respirable concentration of tailings PM. As expected, the concentrations of particles collected at experimental schools (0.948 mg/m^3) were on average higher than that of the control schools (0.163 mg/m^3).

Epidemiology - Cross-sectional study: A cross-sectional study of surrounding communities was conducted using the International Study of Asthma and Allergies in Childhood (ISAAC) and American Thoracic Society (ATS) questionnaires for school children and the elderly, respectively. Results showed that the prevalence of asthma in school children was three times higher in experimental communities, compared to control communities. In addition, the elderly in experimental communities showed

higher prevalence of asthma, hay fever, bronchitis emphysema, arrhythmia, pneumonia, and myocardial infarction, compared to control communities.

CONCLUSION:

The results from year 2 together with the results from Year 1 will be used in our risk assessment paradigm to establish a correlation between exposure to mine tailings dust and respiratory diseases in surrounding communities.

Notes:

“Every Mine Worker returning from work unharmed everyday. Striving for Zero Harm.”

MHSC
Mine Health and Safety Council

T: 011 655 1797 | **F:**011 656 1578

145 Western Service Road
Western Wood Office Park
B7 Maple Place
Woodmead

www.mhsc.org.za