

# SMRAC

**SAFETY IN MINES RESEARCH ADVISORY COMMITTEE  
ANNUAL REPORT 2001/2002**



## ***SIMRAC: Facilitating health and safety research in the South African Mining Industry***

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**W**ithin the framework of the Mine Health and Safety Act, SIMRAC's mission is to facilitate and manage research that will significantly improve health and safety conditions associated with mining operations in South Africa.

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**T**he Safety in Mines Research Advisory Committee, known as SIMRAC, was established in terms of Section 29 (9) (a) of the Minerals Act (Act 50 of 1991), with the principal objective of advising the Mine Health and Safety Council on the determination of the health and safety risk on mines, and the need for research into health and safety on mines based on the risk.

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SIMRAC also identifies research projects to reduce the identified health and safety risks on mines, and determines the cost and priorities of such projects, concludes agreements for carrying out such projects, imposes a levy to fund such research, monitors the progress on these projects and communicates the results of research to all parties concerned.

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Since 1995, SIMRAC has been constituted on a tripartite basis: the employers, employees and regulatory authorities are represented on committees. This tripartite structure followed the recommendations of the Leon Commission of Inquiry to investigate health and safety in the industry. The report highlighted the fact that efforts to improve health and safety in the workplace are most effective when they take cognisance of the needs of all the affected parties.



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## FOREWORD



May Hermanus.

***As SIMRAC enters its 10th year of operation, the mining industry can look back on a important decade in advancing the health and safety of the many thousands of workers employed in this industry.***

**E**stablished in 1992 in terms of the Mine Health and Safety Act, SIMRAC can certainly be proud of the many significant developments emanating from its research programme. These developments have been profiled over the years in this annual report and range from the introduction of improved support systems and design methodologies through to the development of lung reference tables, hearing conservation programmes and stone dust barriers.

Equally of note, however, is how responsive SIMRAC is to its stakeholder and market needs and to the changes in the mining sector. Over the years, considerable emphasis has been placed on establishing and maintaining a strategic direction for SIMRAC research to ensure that it meets not only the needs of the industry today, but also the challenges this industry will face in the future. This has been facilitated by ongoing strategic planning which addresses both the long-term strategic research objectives of SIMRAC and the optimisation of the efficiency of the organisation itself. Important advances achieved over the years include true tripartite representation on the SIMRAC committees and a streamlined committee system.

Further improvements to the committee system were implemented during the year under review. These are covered in detail on page 9 of this report. However, briefly, significant changes include enhancements to the project and programme administration resulting in, amongst others, the replacement of the unwieldy SIMRAC sub-committee system by SIMPROSS progress meetings and presentations, and the assigning of responsibility to the SIMPROSS Programme Managers to monitor progress, assess contractual conformance and recommend payments to contractors. Other changes include the use of external experts, advisers and

auditors; and the appointment of technology champions and incentives for host mines.

Turning to the research programme, important developments over the years have included increased focus on the so-called "softer" issues, namely occupational health, the human factor and ergonomics, while still recognising the importance of engineering, and specifically rock engineering, issues. Despite the incomplete data available, it is widely accepted in the mining sector that the burden of occupational diseases on workers and their communities is now greater than occupational injuries, the rate and severity of which is already unacceptably high.

The research programmes for the year under review and for the coming year also reflect the changing face and needs of the mining industry. For example, projects included cover occupational health issues associated with female mine workers and the impact on the platinum industry of greater mining depths and associated issues of increased seismicity.

The past year saw a significant change in the structuring of the research programme into nine major thrust areas for increased focus on the research needed to overcome persistent barriers to improved occupational health and safety performance in the mining industry. These areas include behavioural safety; rockfalls; rockbursts; explosions and fires; machinery and transport systems; airborne pollutants; physical hazards; occupational diseases and special projects.

The effective transfer of the technology and knowledge developed through the research programme has been highlighted as an important issue requiring attention and in which SIMRAC has made great strides in recent years. Not only has the communication of the results being considerably enhanced with, for example, the introduction of regular newsletters and product launches and seminars, but increased emphasis has also been placed on packaging these research findings in a user-friendly and accessible format.

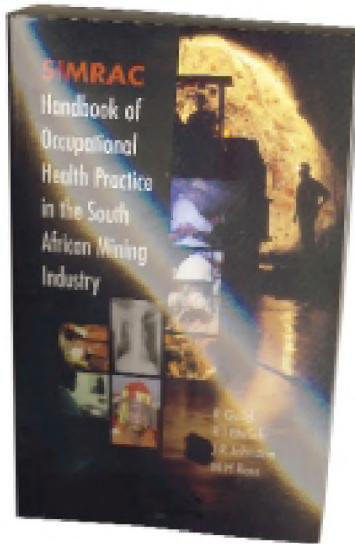
The number of guidelines and handbooks published recently bears testimony to SIMRAC's commitment to maximising the benefit to the mining industry of its research programme. Last year saw the launch of two particularly important handbooks, the Coal mining rock engineering handbook and a Handbook of Occupational Health Practice in the South African Mining Industry. This latter handbook could not have been more appropriately timed in view of the occupational hygiene regulations and guidelines that are to be promulgated and which will complete the regulatory framework for safeguarding the health of workers employed in South African mines. The wealth of experience captured in this handbook should serve as an up-to-date resource for managers and practitioners charged with giving effect to our legislation. It also marks an important break with the past in terms of focusing on prevention and not narrowly on recognition of occupational disease and compensation.

Being involved in a system such as SIMRAC which is dedicated to improving the lives of our workforce is an invaluable experience for me personally. Without a doubt, despite the advances made in recent years, much more must be done to protect the health and safety of workers as well as the communities exposed to hazards emanating from workplaces.

I would like to thank the SIMRAC committee members, SIMPROSS and the researchers for their support and contribution to a safer and healthier workplace.

May Hermanus  
Chief Inspector of Mines





*SIMRAC co-ordinates a comprehensive health and safety research programme with many of the outputs of the research projects already in application within the mining industry, as practical tools or to guide further work in areas ranging from technology development to reviews of regulations and legislation. A number of these outputs were launched during 2001/2, and these together with others are highlighted below.*

## **Handbook of Occupational Health Practice in the South African Mining Industry. HEALTH 612/HEALTH 713**

**T**his handbook provides managers, union officials, engineers, health and safety practitioners and occupational medical and hygiene practitioners with practical tools to prevent occupational illness and disability. Information on the identification, assessment and control of hazards and related diseases in the mining industry has been integrated into a single authoritative manual that contains best practice guidelines for use as a practical guide, an audit tool, a planning tool, a reference document, and an educational tool.

## **Coal mining rock engineering book. COL 606**

**T**he publication 'Rock Engineering for Underground Coal Mining' was launched to provide mine managers, underground supervisors and engineers, who have not had in-depth rock engineering training, with a highly practical guide. The handbook covers fundamentals, roof support, pillar design, subsidence - the first real treatment of this issue in a handbook in South Africa, legal issues, multiple seam mines, and high extraction methods.

*Left: Nielen van der Merwe, Duncan Adams and Bernard Madden with the newly published Rock Engineering book for coal mines in South Africa.*



## **Horizontal stresses in coal mines. COL 802**

**A** major study into the role of horizontal stress in the coal mine roadway roof found that that, whilst horizontal stress is undoubtedly present within the coal measures, it is not a significant geotechnical constraint to mining. The one area where horizontal stress was clearly at work was in the guttering and, ultimately, instability within the skin of the immediate roadway roof. A possible method of reducing this potential is "slotting" of the immediate roof.

## **Demonstration of prototype face area support systems. GAP 813**

**P**rototypes of two unique systems with the potential to significantly improve safety in terms of reduced rock-related hazards were demonstrated in a mock-up stope. A "walking stope support" has been developed based on a concept which produces a continuous range of 600 to 1200 mm advance. The roof support system consists of two similar support units connected to each other by two cranks. Each unit consists of a 210 x 1200 mm headboard supported by a "wishbone" structure (top and bottom leg) and a self-contained loading/yielding mechanism that keeps the legs apart.

## **Shallow and open cast mining. OTH 501/602**

**T**he safety and stability of shallow or open cast mines has been given added impetus with the formulation of a design methodology for pillars in areas of variable surface topography and for the design of stable stope panels that will provide the necessary safe environment for underground personnel working in stopes.

In addition, a handbook has been published which emphasises the use of rock mass classifications for the evaluation of stability and support requirements and covers rock mass characterisation, rock mass classification, evaluation of stability in underground and open pit or quarry operations, and determination of support requirements.





## TECHNOLOGY TRANSFER HIGHLIGHTS

### Dust control for thick-seam wall mines. COL 807

**T**rials of a CSIR-recommended Kloppersbos Shearer Spray Curtain system showed significant improvements (> 50 %) in dust levels with engineering concentration levels of below the DME directive of less than 5 mg/m<sup>3</sup>, except at the tailgate position, being achieved. Use of this system is incorporated in recommendations aimed at overcoming the thick-seam wall mine dust problems.

### Design of mine layouts on planar reefs. GAP 722

**T**he MINF boundary element code was developed to simulate seismic catalogues that are similar to observed seismicity and to enable mine planners to plan for the future on the basis of expected seismicity. When calibrated for local conditions, this capability has greater potential for planning different mine layouts *in situ* than using traditional criteria based on numerical modelling alone. The sudden drop in the strength of failed and unfailed rock causes both natural earthquakes and mining-induced seismic events. MINF simulates mining in small steps, and uses estimated strength of intact and previously failed rock, the dynamic strength during the event itself, a growth model whereby slip must grow contiguously and the final long-term strength to simulate seismicity.

### Safe design of water barrier pillars. COL 702

**B**arrier pillar design charts (hydraulic) have been established to enable engineering estimates to be made of the barrier pillar width, tolerable water compartment head or roadway pumping rate required to manage water ingress into workings. An easy-to-use guidebook containing a series of hydraulic design charts has been developed for coal measure strata to aid anyone involved in the management of water on South African underground coal mines.

### Best Practice: Conveyors. GEN 701

**R**ecommendations on the best design, installation, maintenance and operation of conveyor belts cover both material conveyors and man-riding conveyors used underground and on surface. The recommendations are designed to impact on aspects important to a safer working environment. It is evident that an entire culture change is required in the mining industry and that safety of the workers is the shared responsibility of individuals and the employers.

### Ergonomics of locomotive design. GAP 704

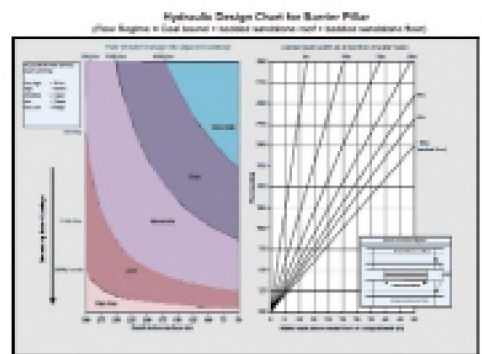
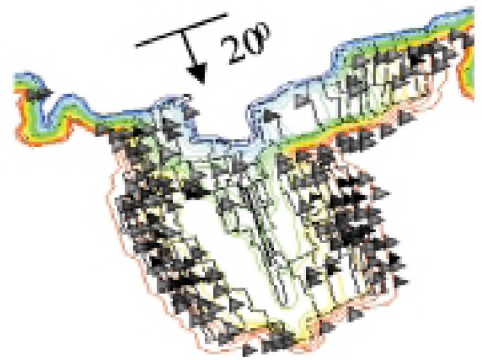
**S**afety aspects of the existing fleet of mine locomotives and rolling stock in South African gold and platinum mines that could be improved through ergonomics interventions have been identified and an ideal design has been formulated. The ergonomics assessment of the existing fleet of mine locomotives highlighted various deficiencies in the design of the working system, most typically at the operator-machine interface. Poorly designed workstations make the operator's tasks more difficult and thus render him more error-prone.

### Hand Arm Vibration Syndrome (HAVS) in South African gold mines. HEALTH 703

**A** sustainable capacity to diagnose HAVS has been created through research into determining the prevalence of HAVS in gold miners. The prevalence and severity of HAVS was found to be low and to be associated with operating rock drills. Eight per cent of the subjects investigated had neurological and vascular symptoms, 5 % had neurological and 2 % had vascular symptoms.

### Doctoral study on ionizing radiation. HEALTH 619

**T**he Cape Technikon conferred its first doctoral degree for a dissertation on the effects of exposure to continuous low doses of ionising radiation on bats, work which was partly sponsored by SIMRAC. The study found the effects of radiation emanating from disused Monazite mines in the Northern Cape on the endangered Cape bat, *Rhinolophus capensis*, to include signs of dose dependent DNA damage, evidence of abnormal bone structure and a marked decrease in osteoid mineralisation which is an indicator of myelodysplastic syndrome, a progenitor to haematopoietic malignancies.





## HEALTH AND SAFETY STATISTICS

The long term health and safety performance of different mining sectors presented graphically in this section was compiled using the South African Mines Reportable Accident Statistical System (SAMRASS) database. Information on occupational health performance, as captured in the SAMODD database, is currently insufficient to allow for meaningful analyses.

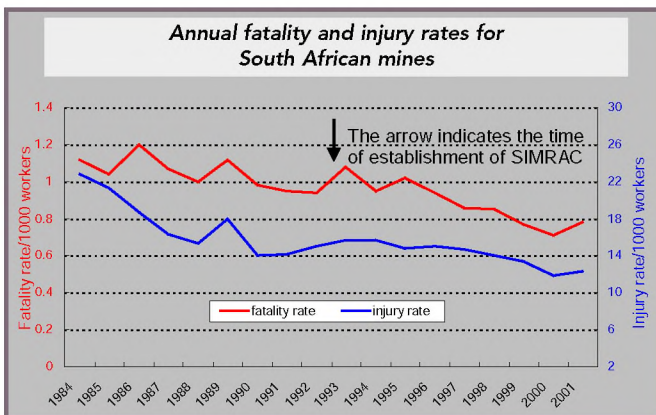
There are currently 51 different commodities being mined which have been categorised into four mining sectors, namely, gold, platinum, coal and other mines. Analysis of the statistics shows that the long-term performance of occupational safety in the South African mining industry has improved

consistently, but the short-term trend has shown no significant improvement. The main contributors to fatalities and injuries are rockfalls, rockbursts and transport systems. Explosions, fires and rockbursts continue to represent the main causes of multiple fatality accidents, the frequency of which has decreased over the last 10 years from eight incidents resulting in 60 fatalities in 1991, to three incidents resulting in 17 fatalities in 2001.

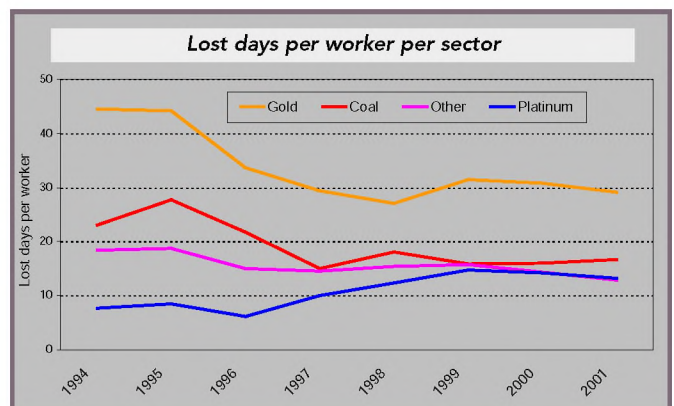
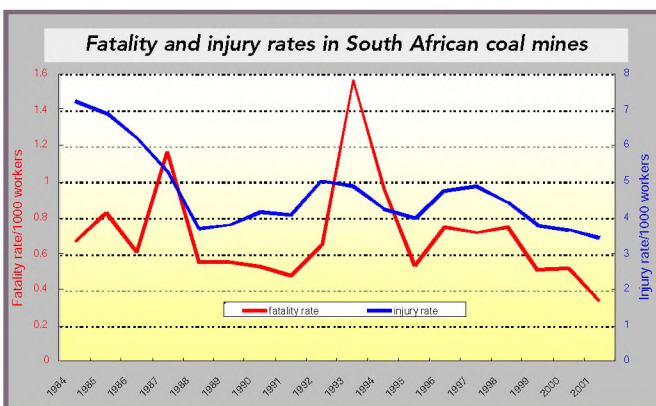
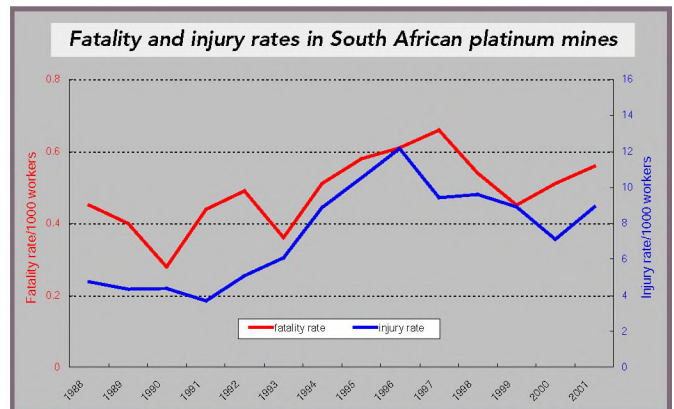
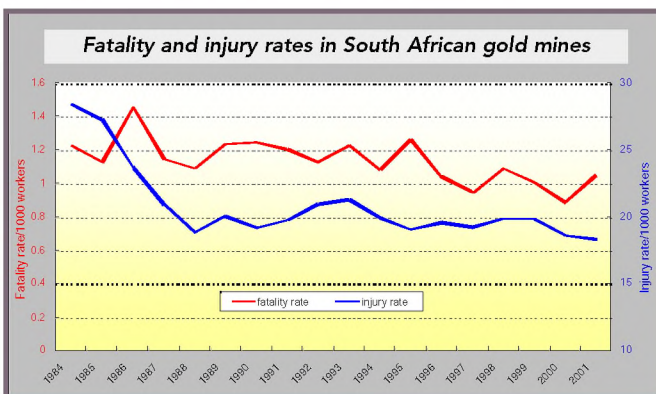
Trends in occupational health performance can currently not be fully assessed due to the lack of measurement criteria and performance indicators in the mining industry and statutory institutions. However, the influence of HIV/AIDS continues to exacerbate morbidity and mortality. The number of cases of tuberculosis (TB) per 1000 autopsies has increased from 51 in 1990 to 161 in 2000 and the estimated TB fatality rate in the gold mining industry is 2,5 per 1000 compared to an accident fatality rate of 1,0 per 1000 workers employed.

Accidents and fatalities in different mining sectors during 2001. Figures in brackets represent data for 2000

| Sector       | Fatalities       |            | Injuries             |            | Total lost-days/worker |
|--------------|------------------|------------|----------------------|------------|------------------------|
|              | Number           | % of total | Number               | % of total |                        |
| Gold         | 192 (173)        | 64         | 3 546 (3372)         | 72         | 29,1 (30,8)            |
| Coal         | 17 (31)          | 6          | 213 (171)            | 4          | 15,9 (16,6)            |
| Platinum     | 50 (46)          | 17         | 795 (638)            | 16         | 14,3 (13,1)            |
| Others       | 39 (35)          | 13         | 386 (332)            | 8          | 14,4 (12,0)            |
| <b>Total</b> | <b>298 (285)</b> |            | <b>4 940 (4 729)</b> |            |                        |

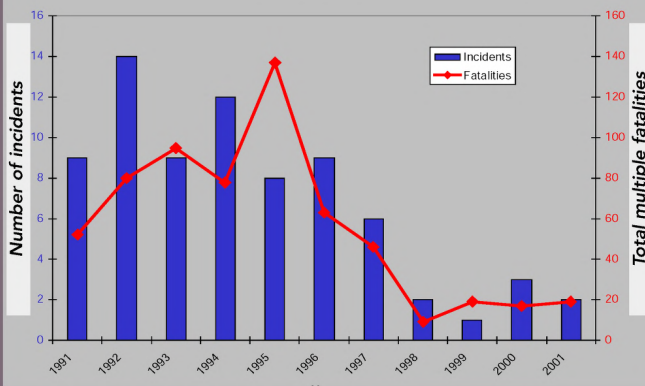


Graphs and tables giving a detailed breakdown of health and safety trends, according to mining sector, are presented on pages 6, 7 and 8.

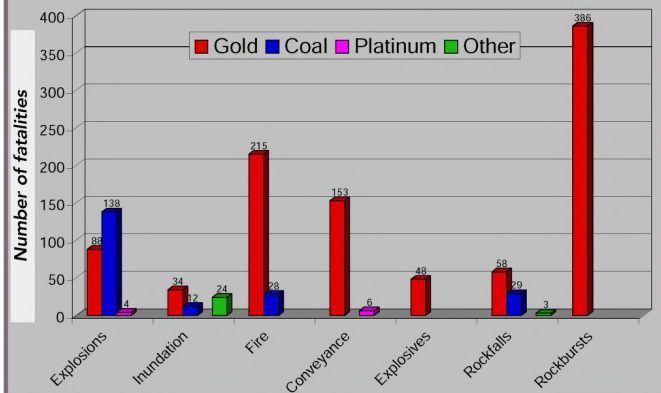




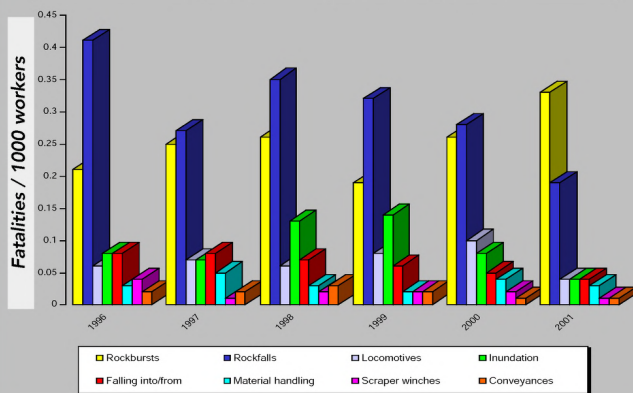
**Incidents resulting in 4 or more fatalities**



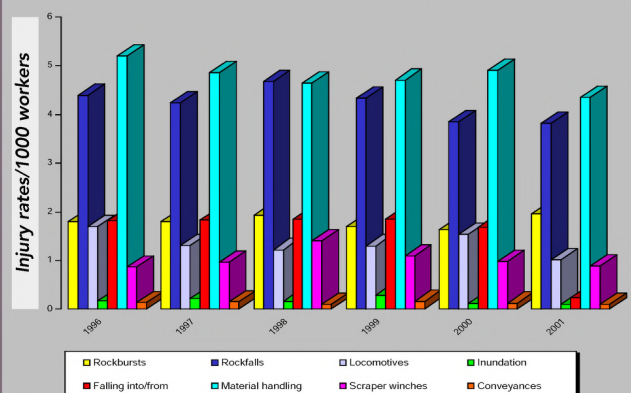
**Incidents resulting in multiple fatalities (4 or more) 1984 – 2001**



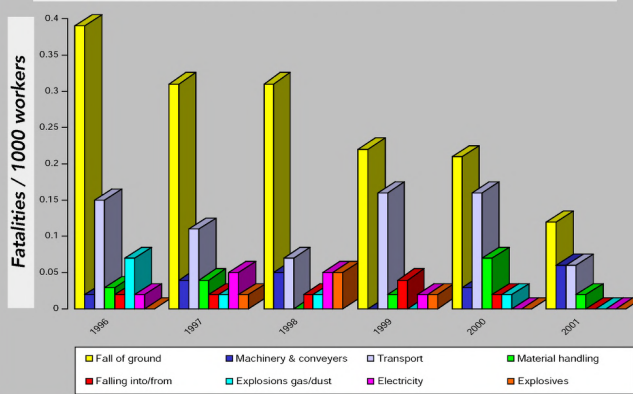
**Fatality rate in the gold mining sector**



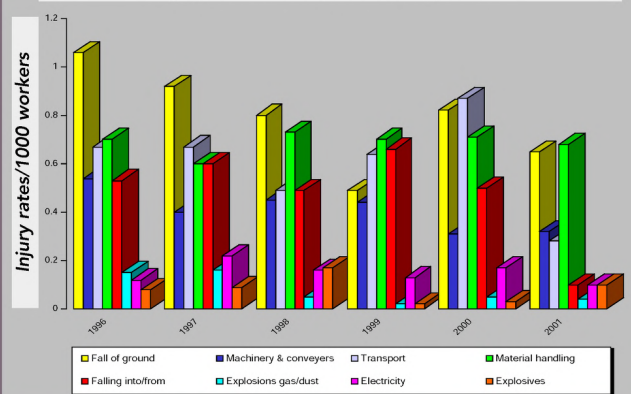
**Injury rate in the gold mining sector**



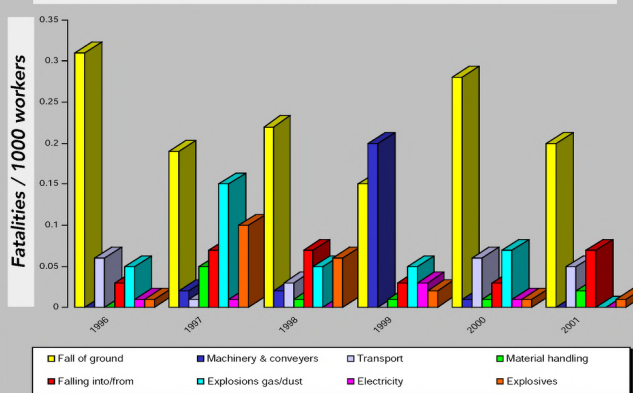
**Fatality rate in the coal mining sector**



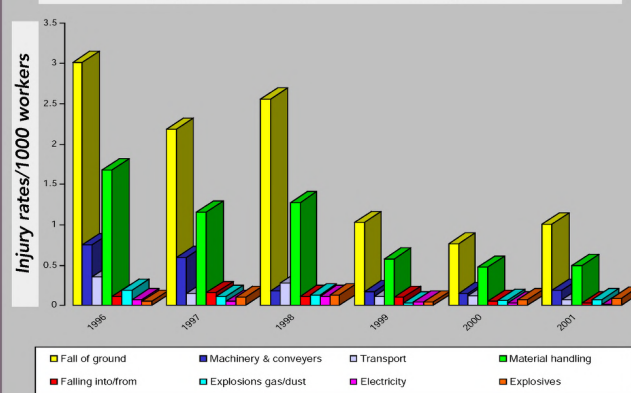
**Injury rate in the coal mining sector**



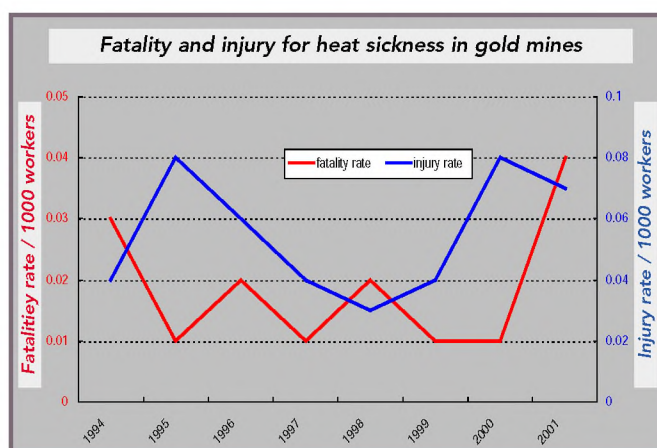
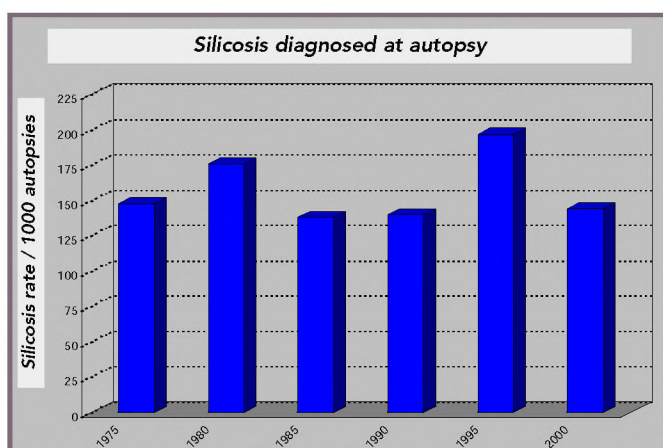
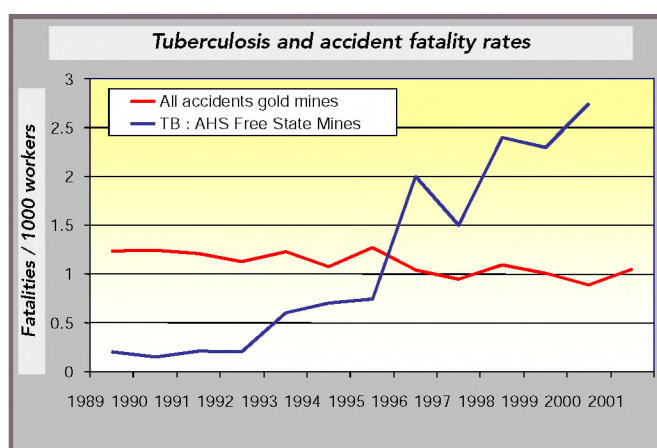
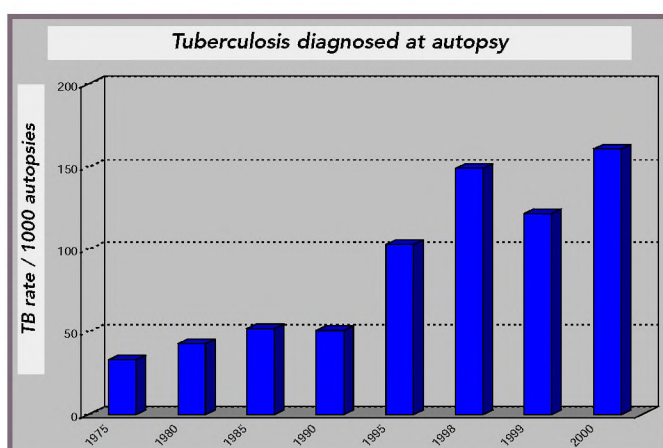
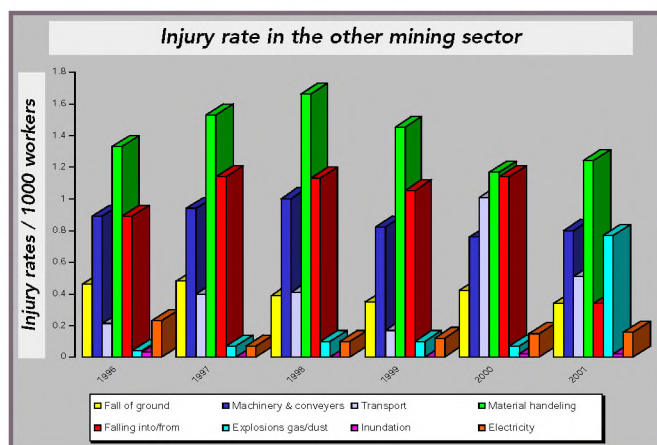
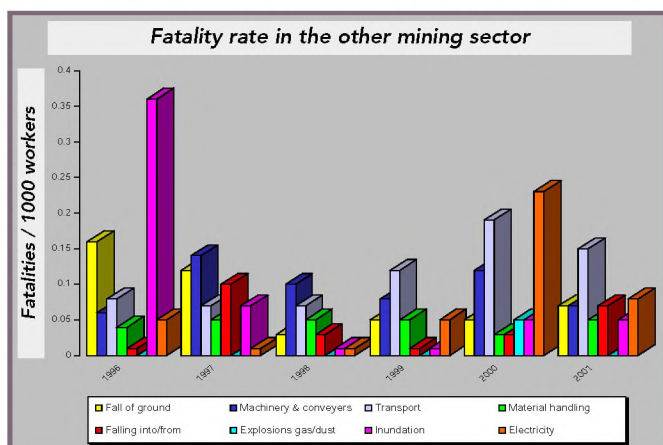
**Fatality rate in the platinum mining sector**



**Injury rate in the platinum mining sector**



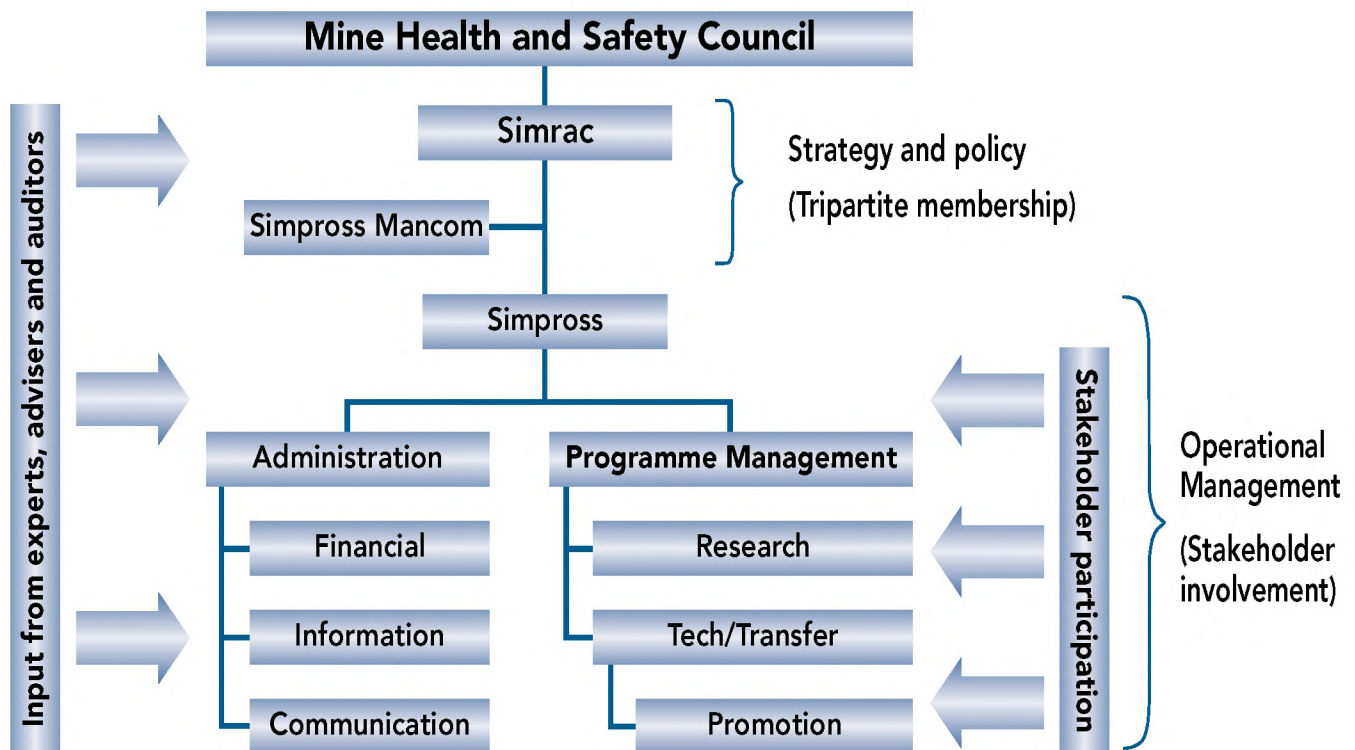
## HEALTH AND SAFETY STATISTICS (CONTINUED)



Worker exposure to airborne pollutants for various commodities for 2001 unless otherwise stated

| Commodity    | Number of mines 2001<br>(Number that submitted results) | Number of workers employed in 2001 | % of workers exposed to AQI $\geq 1,0$ 2001 (2000) | Compensation in R million 2000 (1999) |
|--------------|---------------------------------------------------------|------------------------------------|----------------------------------------------------|---------------------------------------|
| Gold         | 53 (40)                                                 | 103 313                            | 6,65 (6,62)                                        | 82,69 (49,11)                         |
| Platinum     | 15 (15)                                                 | 95 603                             | 0 (1,03)                                           | 2,68 (0,75)                           |
| Coal         | 73 (60)                                                 | 33 969                             | 28,92 (30,94)                                      | 1,93 (1,56)                           |
| Asbestos     | 0                                                       | 0                                  | 0 (0)                                              | 25,54 (9,91)                          |
| Other mines  | 140 (93)                                                | 20 620                             | 4,40 (4,23)                                        | 9,07 (3,84)                           |
| <b>TOTAL</b> | <b>281 (208)</b>                                        | <b>253 505</b>                     | <b>6,94 (8,52)</b>                                 | <b>121,91 (65,19)</b>                 |





*SIMRAC has adopted a new organisational structure and operational procedures with changes being made to the following:*

- project and programme administration;
- the use of external experts, advisers and auditors; and
- the appointment of technology champions and incentives for host mines.

#### Project and programme administration

**S**IMPROSS will be responsible for expediting the approved annual programme, monitoring the financial status, including levy payments, and reporting on relevant administrative matters. Projects will be clustered into new thrust areas to be managed by SIMPROSS Programme Managers.

SIMPROSS progress meetings and presentations have replaced the unwieldy SIMRAC sub-committee system.

Programme Managers will monitor progress, and assess contractual conformance and recommend payments to contractors.

#### The use of external experts, advisers and auditors

**P**ermanent committees of the Mine Health and Safety Council have been advised that the use of professional facilitators should be considered to

enhance the effectiveness of tripartite forums that require specialised technical skills.

SIMRAC has ratified the use of experts, expert panels, facilitators and auditors and will continue to make use of such services to render the new organisational structure practicable.

The sustained input from industry participants, who are not only experts, but are also closely involved with end-user needs, research priorities and implementation of research results, will be required. Commitment will also be sought from all stakeholders in the South African mining industry to ensure that ongoing input is maintained from their representatives.

#### Incentives for participating mines and champions

**T**he principle of compensation for participation in SIMRAC projects will be negotiated with mining groups before formalising any procedures and policies. Some general guidelines are:

- The selection of a participating host mine or technology champion will only be considered once SIMRAC has ratified the development of a detailed research project proposal;
- Mine and champion involvement must be formalised with a guarantee of compensation at the completion of the research project for expenses incurred during the period of participation;
- Mining and industry champions may be invited to attend meetings and discussions.

## Safety In Mines Research Advisory Committee (SIMRAC)

Mr PB Botha (Chairperson)  
Dept of Minerals & Energy (right)

Mr N Ndiweni (State Convenor)  
Dept of Minerals & Energy

Mr D Rowe  
Dept of Minerals & Energy

Mr MM Zondi  
Dept of Minerals & Energy

Mr NG Mojapelo  
Dept of Minerals & Energy

Dr A Parsons (Employers Convenor)  
Chamber of Mines (right)

Dr FA Rander  
Chamber of Mines

Mr DH Diering  
Anglogold

Mr SJR Allan  
Gold Fields Ltd



Mr DJ van Niekerk  
Kumba Resources

Mr JJ Henning  
UASA

Mr MB Ddubula (Labour Convenor)  
National Union of Mineworkers (right)

Mr E Gchilitshane  
National Union of Mineworkers

Mr PR Moroakgosi  
De Beers Consolidated Mines



## SIMPROSS Management Committee (MANCOM)

Mr PB Botha (Chairperson)  
Dept of Minerals & Energy

Mr N Ndiweni (State Convenor)  
Dept of Minerals & Energy (right)

Dr MJ Gouws  
Chamber of Mines

Mr DJ van Niekerk  
Kumba Resources

Mr JJ Henning  
UASA



## SIMPROSS

**SIMRAC Project Support Services (SIMPROSS)**  
*undertakes administrative, secretarial and communications functions on behalf of SIMRAC.*

**F**unctions include facilitating programme and project management and contract awarding processes and functions, as well as procedures to establish technology transfer, communications and information strategies. Paul van der Heever, the SIMPROSS research manager, is supported by Duncan Adams, rock engineering programme manager, Mary Ross, occupational health programme manager, and

Alec Gumbie, engineering programme manager. The programme managers provide project management support for the three disciplines and are also involved with risk analyses, technical input and technology transfer. Financial support functions, such as levy invoicing and project payment procedures, are also undertaken by SIMPROSS on behalf of SIMRAC.

SIMPROSS conducts an extensive technology transfer programme which includes regular newsletters, an annual review, a web site from which SIMRAC reports can be downloaded, and individual product launches and seminars.



SIMPROSS staff (standing l to r): Elsie Zinsser, Duncan Adams, Adiel Badrodien, Cecile Gomes, Remember Moraba; (seated l to r): Johannes Lithebe, Noeleen Woods, Cheryl Jones, Paul van der Heever, Mary Ross and Alec Gumbie.



*The SIMRAC research programme is aimed at addressing research needs to overcome persistent barriers to improved occupational health and safety performance in the mining industry. SIMRAC has identified and formulated a research programme for 2002 that is comprised of the following nine major thrust areas:*

## Behavioural safety

**R**ecommendations are required on developing a pervasive occupational health and safety culture in the mining industry which cover the relationship between risk-taking behaviour outside the workplace and risk-taking behaviour in the workplace.

- Safety culture in the South African mining industry Sim 02 01 01
- Industrial Technology, rights and politics of transformation Sim 02 01 02
- Alcohol study HEALTH 712

## Rockfalls

**R**ockfalls are the single largest contributor to safety related fatalities in the South African mining industry in all mining situations from shallow to ultra deep mines. Emphasis should be on eliminating, controlling or minimising the risk of rockfalls in the face area and in tunnels that access the mineral deposit or in the roadways created in the ore body.

- Development of an effective 'pinch' bar Sim 02 02 01
- Determination of remote stresses in the rock mass Sim 02 02 02
- Effective support for tabular stopes Sim 02 02 03
- Effective support for tabular stopes Sim 02 02 04
- Investigation into support systems in South African collieries Sim 02 02 05
- Guidelines for the design and testing of thin sprayed linings Sim 02 02 06
- Technology transfer of strata control knowledge Sim 02 02 07
- The use of tendon support in tabular stopes Sim 02 02 08
- Joint orientations, spacings and lengths Sim 02 02 09

- Corrosion on the behaviour of steel fibre reinforced shotcrete Sim 02 02 10
- 3-D analyses of stress and strain distribution Sim 02 02 11
- Database of pillar collapses suitable for statistical analysis Sim 02 02 12
- Trial training in strata control GAP 851
- Rating system for coal mine roofs COL 812

## Rockbursts

**R**ockbursts are the second largest contributor to accident-related fatalities in gold mines. The depth of mining is increasing and a concomitant increase in seismicity and associated rockbursting is anticipated. Different reef types show different trends in terms of fatalities and this requires greater understanding and, if necessary, individual strategies. Modelling dynamic rock fracturing and seismicity on mines may be one of the most significant tools for understanding rock mass behaviour more comprehensively and in real time in order to take proactive decisions.

- New criteria for rock mass stability and control using integration of seismicity and numerical modelling Sim 02 03 01
- Proactive approaches to rock mass stability and control Sim 02 03 02
- Guidelines for safe extraction of remnants Sim 02 03 03
- Improved seismic locations and location techniques Sim 02 03 04
- Testing of stope support systems under dynamic loading Sim 02 03 05
- Stope face fracturing/bursting and the effect of face support Sim 02 03 06
- Calibration of integration ready numerical models Sim 02 03 06
- Preconditioning at varying stoping widths GAP 811

## Explosions and fires

**T**he consequences associated with flammable gas explosions, coal dust explosions and fires are significant. Projects relating to eliminating, controlling and minimising the risk of explosions and fires in mines will be considered, as well as projects relating to emergency preparedness and response, and monitoring of risk areas.

- Training package to reduce the risk of gas explosions Sim 02 04 01
- Inertisation of inbye and outbye

## CONTRACTED RESEARCH AGENCIES

### 2001/2002

- Advantage Consulting
- AECC
- Aurum Health Research
- BBE
- CSIR
- GA Fourie & Associates
- Grootegeluk Colliery
- Groundwork Consulting
- Hands on Mining
- Hearing Centre
- Infotox
- ISSI
- Lapheka Care
- LGI
- NCOH
- Mechanical Testing & Measurement
- Mine Engineering Consulting
- Mintek
- OEHRU
- OMCURU
- SRK
- Strata Engineering
- Turgis Technology
- University of Cape Town
- University of Pretoria
- University of the Witwatersrand

### 2002/2003

- Advantage Consulting
- ATD
- Aurum Health Research
- CSIR
- Grootegeluk Colliery
- Hearing Centre
- HS Design
- Infotox
- ISSI
- Itasca
- Lapheka Care
- MRC
- NCOH
- OEHRU
- OMCURU
- RCT
- SIGRA
- Siyazi
- SRK
- Turgis Technology
- University of Cape Town
- University of Natal
- University of Pretoria
- University of Stellenbosch
- University of the Witwatersrand



areas computer package

Sim 02 04 02

- Evaluate and test active machine mounted explosion systems Sim 02 04 03
- Ranging open path remote methane detector Sim 02 04 04
- Prevention of spontaneous combustion of coal discards COL 713

## Machinery and transport systems.

A high degree of risk is associated with the use of transport systems and machinery such as conveyors, scrapers, fixed machines, tools and equipment. Areas highlighted by sectoral mine accident statistics include trackless mobile machinery and conveyors in coal mines, "other" mines and platinum mines, and scrapers and shaft conveyances in gold mines.

- Test modified detaching hooks and need to develop safer hooks Sim 02 05 01
- Factors affecting driver alertness Sim 02 05 02
- Re-railing of underground rolling stock Sim 02 05 03
- Ergonomics of machinery and transport Sim 02 05 04

## Airborne Pollutants

A major improvement in the health of miners in all commodities would be achieved by the control of airborne hazards. As a partner in the WHO/ILO initiative, SIMRAC is

prioritising the elimination of silicosis in the South African mining industry. Additional areas of interest are diesel particulate exposure and control and the influence of hazardous gaseous exposure on health, safety and performance.

- Measurement of ultrafine silica exposure in fumes Sim 02 06 01
- Diesel exposure measurement and reduction Sim 02 06 02
- Silica control [Phase 1] Sim 02 06 03
- Dust generation potential of South African coal seams Sim 02 06 04
- Real time dust measurement HEALTH 704

## Physical hazards

Physical agents include noise, vibration, temperature, illumination and radiation. SIMRAC has targeted noise and vibration for innovative research to complement previous research conducted in these areas.

- Evaluation of new methods for NIHL screening and diagnosis Sim 02 07 01
- Body cooling garments Sim 02 07 02
- Vibration – seating Sim 02 07 03
- Best practices to prevent adverse effects of noise and vibration HEALTH 806
- Vibration absorber for rock-drill GAP 726
- Finalisation of the quiet rock drill GAP 801

## Occupational diseases

One focus area identified by the Mine Health and Safety Council is the effect of HIV/AIDS on occupational disease. Of particular concern is the combined effect of HIV/AIDS and Silicosis on Tuberculosis. Other diseases of interest are asthma and skin disease.

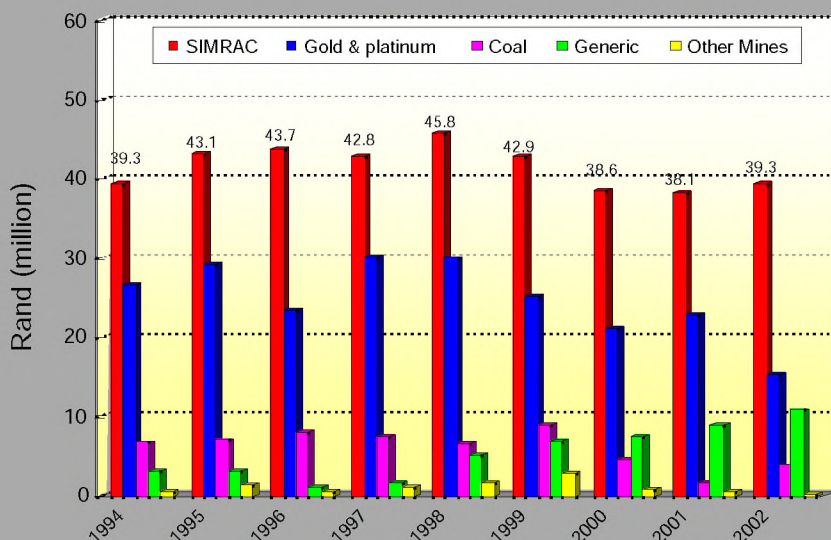
- Development of x-ray reading skills in the mining industry Sim 02 08 01
- TB management in the South African mining industry Sim 02 08 02
- Silicosis surveillance programme Sim 02 08 03
- Musculoskeletal disorders PhD Sim 02 08 04
- TB prevention HEALTH 701
- Sputum study HEALTH 705
- Lung disease / exposure HEALTH 606
- MMR study GEN 534

## Special projects

- A additional topics identified by SIMRAC that require investigation or surveys include: the "handling of material" and "slipping and falling", chemical hazards, ergonomics and the occupational-physiological interface.
- Effects of nutrition and housing provision on occupational health and safety Sim 02 09 01
  - Historical documents regarding health and safety Sim 02 09 02
  - Occupational handbook on safety practice in South Africa Sim 02 09 03
  - Slipping, falling and manual handling accidents Sim 02 09 04
  - The evolution of South African mining research Sim 02 09 05
  - Occupational health services on small mines HEALTH 809

Note: New projects are now listed according to thrust areas, unlike the earlier numbering system using an alphanumeric order based on commodities. The new numbering system of six digits, for example 02 01 01, refers to the specific year of the project, i.e. 2002, the first thrust area, 01, i.e. Behavioural safety, and the number of the project in that thrust, namely 01.

### Annual funding allocations





*The programme for gold and platinum mining addressed the main contributors to fatalities and injuries specific to these mining operations. Within the rock engineering risk area, the work ranged from fundamental research through to development of support technologies and review of past work. Within the engineering risk area, the priority areas included illumination, reducing the potential for vibration-induced disorders, winding operations and dust control.*

## **\*GAP 601a** Experimental and theoretical investigations of mining induced fracturing

**T**his project was jointly funded by AngloGold Technology, the Innovation Fund and SIMRAC and had two objectives: fundamental research into the dynamic processes of the seismic rock mass response to mining, and development, testing and transfer of technology for routinely monitoring this response with unparalleled resolution.

Research focused on analysis of complexity including system susceptibility, non-linear phase space reconstruction, triggering of seismicity and reaction-diffusion models. The theoretical basis was established for tap-tests, in which seismic responses to production blasts are used to assess seismic hazard; and mode-switching, in which short term seismic deformation is controlled through optimal sequencing of panels.

The technology component focused on high-frequency seismic sensors, improved underground modems and continuous seismic monitoring. This work gave rise to high resolution seismic monitoring, in which hundreds of events with magnitude above -2.0 are consistently recorded daily in section 336 of TauTona mine, and is the state-of-the-art in seismic monitoring. Additional modes of data acquisition were also developed. The available QS technology can now simultaneously record triggered seismograms for mine seismology, summarised micro-crack information for evaluation of rock mass response to blasting within the hour and ground motion parameters for a complete damage history of vital structures.

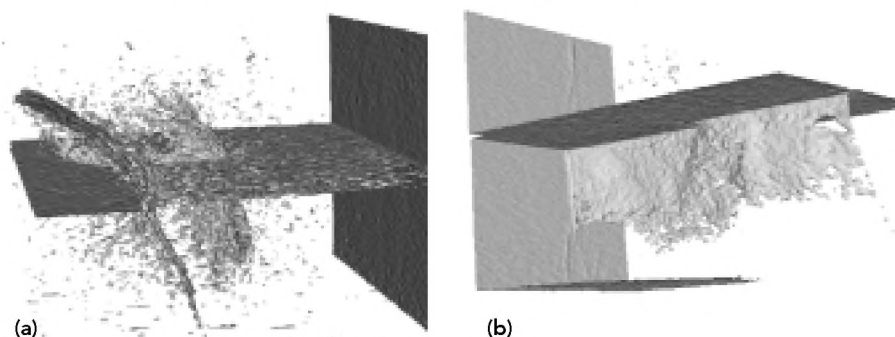
## **GAP 601b** Experimental investigation of fundamental processes in mining induced fracturing and rock instability

**T**he application of fundamental knowledge of rock mass deformation mechanisms to modelling stope-scale problems has been the focus of recent

research to assess how this knowledge may be used to control and engineer the mechanics of the fracture zone.

The development of techniques to enable small-scale (AE) sensors to be used as velocity transducers has allowed test results from small-scale samples to be interpreted with currently available moment tensor inversion methods and to deduce micro-event source sizes and mechanisms. These studies have shown that laboratory scale frequency-magnitude statistics are compatible with mine and even earthquake scale observations and motivate the relevance of small scale testing to the understanding of stope scale damage processes.

Underground measurements have indicated that, in the Vaal Reef, hangingwall-parallel stress relaxation can be significant following the advance of the mining face. This emphasises that the choice of the mining rate can be used to control the effectiveness of clamping stress in the hangingwall. Relationships were established between time-dependent closure rates, mining rate and the distance to the stope face. This provides a practical quantification of the closure rate behaviour that can be used in the evaluation and design of stope support units.



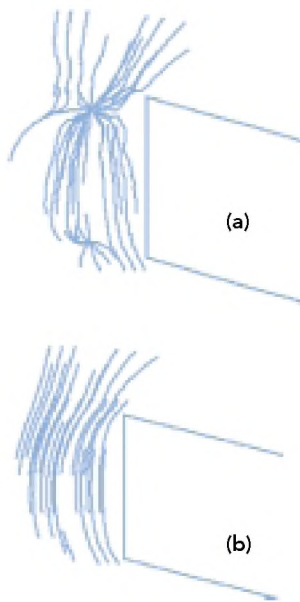
*Analysis of the fracture patterns by x-ray scans of the rock samples found that the fracture surface forms initially at the stressed edge of the slot outline and progressively changes shape away from the plane of the opening to follow the average orientation of the stressed edge. The images above show three-dimensional reconstructions of the fracture pattern in an Elsburg quartzite block with a lead-lag of 20 mm (a) and with a lead-lag of 10 mm (b). The superimposed white lines denote the lead-lag panel layout.*

Assessments of the feasibility of predicting the time to failure of rock samples in uniaxial loading showed that before, or just at, the point of failure, one dominant cluster of connected mesh elements emerges in the sample. This suggests that any prediction of the failure time requires not only a record of seismic activity but, also, information relating to the evolutionary formation of internal damage clustering. Slip weakening models have been developed to simulate size effects and to investigate the stability of mine layouts. The results suggest that the critical value of the weakening parameter may be used as a novel layout evaluation criterion.

A major output has been an extensive study of the interaction of seismic waves with underground openings and the analysis of wave propagation through fractured rock, which has led to methods to quantify dispersion behaviour in numerical models. It was also shown that the computer code WAVE can be used to reproduce measured wave attenuation effects



near the surface of an underground tunnel. In addition, hangingwall block loosening can be promoted by the interaction of surface waves with such blocks.



A simplified method for the simulation of blast-induced fracture growth was introduced into the DIGS code, and showed that the stability of the fractured hangingwall can be strongly affected by blasting and by the amount of gas penetration into the mining induced fractures and pre-existing discontinuities. Simulation results of a production blast show (a) that with a high pressure blast, the fractures initially grow radially from the shot hole, until the pressure has dropped and the fracture directions are subsequently controlled by the stress state surrounding the free face. (b) When the blast pressure is low, the fracture directions are controlled by the existing stress state and correspond to results expected from "smooth" blasting techniques.

## GAP 603 Fundamental aspects of the integration of seismic monitoring with numerical modelling

The concept of integrating observational data with mining-oriented numerical modelling has emerged as the next logical step in the development of more reliable computer-based methods for treating the problems of rock mass stability and damage.

The most important feature of an integrated numerical model is the ability to take real data, as provided by a seismic monitoring system, and use this data as an additional input for solving a forward problem about the evolution of the physical state of the modelled rock mass. However, not every numerical model currently in use in the South African mining industry is suitable for integration with real seismic data.

A study was performed aimed at revealing the potential of the software packages currently in use by the South African gold mining industry to be upgraded to integrated models. Special attention was paid to the ability of different models to emulate the basic patterns of mining-induced seismicity. In particular, it was concluded that the ability of a model to reproduce the power-law behaviour of the size distribution of local seismicity is not a decisive factor in selecting the models which are best suited for integration. On the other hand, the deviations from the

above-mentioned trend seem to be more informative about the state of the rock and an integration-ready model should be capable of emulating such characteristic deviations from the underlying power-laws.

Recommendations for developing and using integrated models for the needs of the mining industry have been made, namely that special care must be taken in specifying the initial state of the modelled rock mass. This implies that a suitable stress-modelling module may be added as a part of the integrated software.

## GAP 709 The meaningful use of peak particle velocities at excavation surfaces for the optimisation of the rockburst support criteria for tunnels and stopes

An important criterion in the design of rockburst resistant support for stopes and gullies is the peak particle velocity at excavation surfaces that such support will be subjected to in a dynamic event. To quantify the peak particle velocities in various geotechnical areas, a Peak Velocity Detector (PVD) was developed and 17 sites, including PVDs and 8-channel Ground Motion Monitors, were successfully established.

A seismic data set comprising all seismic events, recorded by the mine seismic network at TauTona Gold Mine since 1996, was compiled. A procedure for filtering the seismic events with respect to their location was also developed.

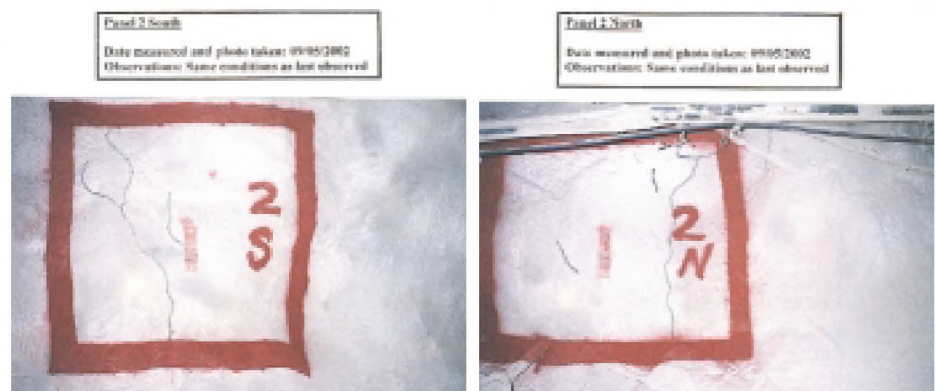
Using a fatality database for all accidents in the South African gold mining industry, an evaluation of the dynamic response of the most common support types applied at the Ventersdorp Contact Reef, Carbon Leader and Vaal Reefs was carried out.

The effect of a passing Rayleigh wave on the stability of a hangingwall, discretised by fractures and joints, was also investigated. This led to the development of a procedure for determining whether or not keyblocks will be displaced relative to the surrounding hangingwall rock mass as a Rayleigh wave passes.

## GAP 710 Underground verification of deflection performance of fibre reinforced shotcrete

The need for underground verification of the performance of fibre reinforced shotcrete, subject

Condition of panels in the test sites with reinforced shotcrete.





to high stresses, convergence and dynamic loading, was identified in terms of providing an *in situ* performance comparison between fibre and mesh reinforced shotcrete; confirmation that the fibre reinforced shotcrete performance matches that of the mesh reinforced shotcrete under large deformations; a comparative performance of various types of fibre reinforced shotcrete; and a comparative performance of fibre reinforced shotcrete of various thicknesses.

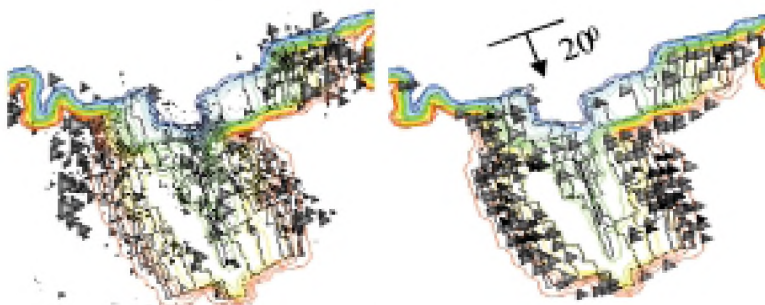
The performance of various types of shotcrete was monitored in an appropriate experimental field site where the maximum expected magnitude of a seismic event for the region was 3.8. Several large seismic events were recorded near the field test site, but no increase in deformation could be linked with any of these seismic events.

The four test sites with the various reinforced shotcretes remained stable in the estimated field stress of 140 to 145 MPa with a stress change of 10,9 MPa. The mesh-reinforced shotcrete exhibited the maximum closure measured of 56 mm as well as a higher crack density in the southern panel.

## **GAP 722** A methodology and computer program for applying improved, inelastic ERR for the design of mine layouts on planar reefs

Use of the mine layout design criteria of ERR (Energy Release Rate), APS (Average Pillar Stress) and ESS (Excess Shear Stress) has not provided a good control of seismicity. It has become apparent that more complex models of rock mass behaviour are needed. Furthermore, such models should be integrated with observed seismicity of recent mining to enable better estimates of future expected seismicity within a rock mass of uncertain geological structures, strength and virgin stress conditions.

A computer code that simulates seismicity in three dimensions on a shaft-wide scale, and with properties similar to those of observed seismicity in space, time and source properties, is being developed for mine layout design on the Carbon Leader and Ventersdorp Contact Reefs. The methodologies and the program MINF write synthetic catalogues of seismic events as actual mine outlines are advanced, and provide the most realistic mimicking of near-reef seismicity. They also allow for multi-parameter comparisons between modelled and observed seismicity.

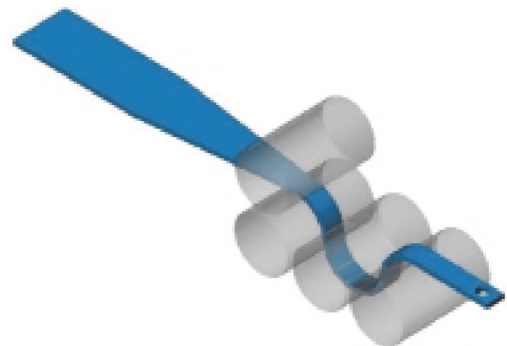


History of two years of mining at 3 km depth and observed (left) and modelled (right) seismicity associated with this mining. Symbol sizes are proportional to Magnitude.

## **GAP 725** Development of a design procedure for the use of 'dynamic cyclic bending' deceleration systems

The deceleration system takes the shape of a series of inline rollers, through which a steel strip is threaded. The end of the strip is then attached to a cable or other device and pulled. This action forces the strip to be drawn through the rollers, bending and unbending to conform to the path set. This bending and unbending motion dissipates kinetic energy in the form of strain energy, which is a resulting resistive force to the motion drawing it between the rollers. These systems can thus be applied in the form of linear brakes or deceleration systems.

The research requirement was thus to develop a methodology that could be used to calculate the required dimensions and specifications of such a deceleration system. This study concentrated on the use of these systems in the mining industry in the case of an 'under-wind', which is when the skip overshoots the stopping point and connects the shaft bottom at speed.



Deceleration systems take the shape of a series of inline rollers, through which a steel strip is threaded.

A 1/10th scale model of a shaft was used to simulate an 'under-wind' condition. Accelerations were measured and a preliminary code was written to predict the deceleration performance via theoretical calculations. The data acquired from the scale testing was compared to the preliminary theoretical predictions and results were favourable. The program has subsequently been improved and the prediction has become more accurate, a finding that was supported with the use of a dynamic FEA program to further test the capability of the prediction program.

The next step to finally test the reliability of the developed theoretical prediction program is to build and test a full-scale model and a site has been investigated.

## **GAP 726** Development of a vibration absorber for rock-drill vibration attenuation

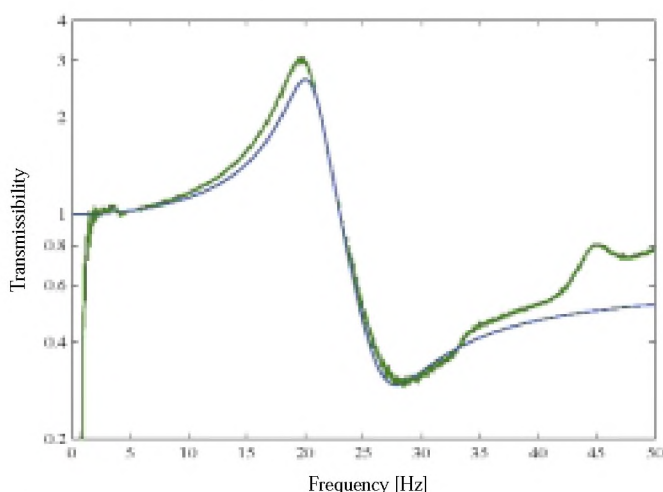
In a recent survey of the vibration characteristics of mining equipment and impact percussive tools it was concluded that operators of hand-held equipment in South



African mines are at risk of vibration-induced disorders. These diseases may lead to vascular and neurological disorders, which may cause crippling injury to the hands and fingers.

Several methods exist to reduce the extent of vibration transmitted. It has been demonstrated that vibration absorbers may be very appropriate for such applications and may substantially reduce the transmitted forces. However, the application of vibration absorbers to rock drill applications where operating frequencies change constantly poses serious and conflicting challenges. Small, lightweight and robust designs are required at very competitive cost. For an application where mass is a critical design constraint, innovative designs utilising mechanical or hydraulic amplification may be employed. Such devices introduce geometrical variables that may be utilised to tune the isolation frequencies by effectively changing the absorber mass.

Two devices have been built and tested extensively. The first utilised the addition of a second degree of freedom to make it easier to tune the absorber. The second used a heavy tungsten slug to reduce the size of the absorber while still tuning it by changing the pressure in an air spring.



Transmissibility curve at 215 kPa.



A heavy tungsten slug was used to reduce the size of the absorber shown above while still tuning it by changing the pressure in an air spring.

## GAP 802 Quantification of dust generating sources in gold and platinum mines

**P**ast research on respirable dust has focused on the exposures of workers and on issues related to the measurement of workers' exposures. Characterising the dust produced during different activities during mining operations has not enjoyed similar emphasis. This analysis is of importance as a first step in devising effective and efficient measures to control this hazard at source. Data is being gathered which includes a quantification of generation rates as a function of various activities. This will enable the characterisation and ranking of some of the more prominent and common dust sources at points associated with relevant mining activities in South African gold and platinum mines.

## GAP 803 Develop discard criteria for non-spin wire ropes

**P**revious research has led to discard criteria for mine hoisting ropes that are part of SABS0293 - 1996 "Condition assessment of steel wire rope on mine winders". Some of the discard criteria stipulate that a rope must be taken out of service if a given number of wires are broken. However, it has been shown that there is no technology with which internal broken wires can be counted with sufficient accuracy. This has led to the proposal that a correlation be sought between the strength of multi-layer ropes and the signals obtained during a magnetic test. If such correlation exists, then a discard criterion could be that magnetic signal level at which the rope strength is no longer adequate.

However, no sample could be obtained from a multi-layer rope that was discarded because of internal broken wires. It has therefore been decided that a conservative discard criterion be proposed if there are very few winders on which the ropes accumulate internal broken wires. A survey has shown that there may be only one or two winders where this is the case.

## GAP 804 The role of illumination in reducing risk to health and safety in South African gold and platinum mines

**A**lthough 'insufficient illumination/visibility' is rarely cited as the primary cause of an accident, a number of accidents, for example slip/trip/fall incidents and machine collisions, may well have been prevented if sufficient lighting had been provided. Poor design of visual environments can induce errors caused by an inability to see properly as well as confusion, illusions and disorientation and visual discomfort and headaches.

The many variables that need to be considered to ensure a safe and healthy visual environment have led to a diverse range of current worldwide illumination and visibility standards. A review of current standards, and research and developments relevant to illumination and visibility in gold and platinum mines was therefore undertaken to update and supplement corresponding information elicited for coal mines in a previous SIMRAC project.



The review provided an indication of the impact that poor standards of illumination and visibility have on safety and performance, and identified a range of factors that must be considered to ensure a safe visual working environment. A self-contained set of recommendations for the gold and platinum sectors was produced to allow direct and effective action to be taken at both corporate and individual mine level to improve the visual working environment. The recommendations are not prescriptive, and each situation must be subjected to a specific risk assessment.

## **GAP 806** An investigation into the conditions under which HFC134a may become flammable

**A** catastrophic failure of an underground refrigeration plant, retrofitted with HFC134a (or R134a) refrigerant (Tau Tona 1999), highlighted the need to investigate and understand conditions under which HFC134a may become dangerous or explosive. HFC134a has been rated as non-flammable and non-toxic at standard temperatures and pressures by both American and European standards.

Previous research which investigated the flammability of HFC134a at elevated temperatures and pressures concluded that HFC134a can become flammable at temperatures exceeding 280 °C at standard pressure or in a 34 % oxygen enriched atmosphere (at standard temperature and pressure). A small quantity of combustible substances (6,5 % propane for example) was shown to reduce the lower flammability limit of a propane/HFC134a/air mixture.

The literature review and findings of the Tau Tona accident report identified a single possible scenario whereby an HFC134a/lubricant/air mixture may become explosive. The mechanism involved the escape of HFC134a/lubricant past the over heated bearing surfaces of a failing compressor. Experimentation that realistically replicated the likely scenario was used to explore this possibility. However, no flammability was observed, and it was concluded that too many variables exist (presence of lubricant, additives and hot metal catalysts) to positively state the exact mechanism for the cause of the Tau Tona explosion. Guidelines for the safe use of HFC134a underground were drawn up.

## **GAP 810** Performance of various types of containment support under quasi-static and dynamic loading conditions

**F**atalities in tunnels account for some 20 % of all rock-related fatalities within the mining industry and it is therefore critical to optimise the performance of support systems in order to reduce the incidence of these fatalities.

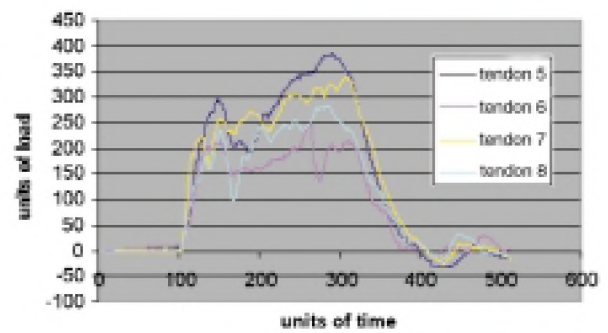
In order to quantify the lack of compatibility between typical yielding tendons and the other support components, which is the main cause of support failure, tunnel support systems, comprising various combinations of tendons, mesh and lacing, were subjected to quasi-static and dynamic loading. In addition, stress concentrators, which caused localised

and premature mesh failure, were identified and means to overcome these problems suggested. Dynamic recording of forces and accelerations allowed for unique and detailed monitoring of the processes taking place during the impacts.

*Result of an impact from a mass of 3 tons travelling at a speed of 5 m/s (37,5 kJ).*



*Dynamic tendon forces during the impact.*



*Result of a static load of around 40 tons.*



## **\*GAP 811** Criteria for preconditioning at varying stopping widths in different geotechnical areas

**P**revious research showed preconditioning to be very effective in minimising facebursts and increasing productivity. Wherever it was implemented properly, preconditioning also resulted in improved hangingwall and face conditions as well as better fragmentation and improved worker morale. In addition, the technique was found to be cost effective due to the increased face advance per blast. However, it was also observed that, following a successful implementation and the withdrawal of the implementation team from the site, preconditioning activities tended to be terminated.

Initially, the favourable results that had been obtained from these preconditioning experiments have not, on their own, been enough to bring about the



widespread utilisation of preconditioning as routine practice in faceburst prone mining areas. While many of these implementations were considered to be successful as they confirmed the very positive research results, some of them were reported as unsuccessful.

In particular, it was reported that the recommended method of preconditioning is ineffective in high stoping width areas. In order to investigate the potential shortcomings and to test the effectiveness of the technique in these areas, two preconditioning experiments were carried out in a Ventersdorp Contact Reef stope and a Carbon Leader stope.

The reasons for failure and the critical success factors for the implementation of preconditioning were identified and, based on the results obtained, the guidelines for the best implementation of preconditioning were updated and a structured implementation process was proposed.

## **GAP 813a The design and development of an effective support system for tabular stopes in gold and platinum mines**

**S**ince the majority of rock-related fatalities ( $\pm 55\%$ ) occur in the immediate vicinity of the stope face, there is a need to develop a support system concept that addresses the deficiencies in current stope support systems, and that will significantly reduce fatalities in the stope face area in the short to medium term. Previous research identified the deficiencies of current stope support systems to include poor area cover, poor installation practices, and poor face area support during cleaning.

A linked prop and headboard system, named the remotely advanced headboard system, was identified as having the highest potential to significantly improve safety in the face area, while seemingly being a practical system that should not be difficult to implement and maintain. A prototype remotely advanced headboard system was designed and manufactured and initial laboratory tests on the beams indicated that plastic deformation is unlikely to occur up to loads of 20 tons.

The system, which is based on a concept that produces a continuous range of 600 to 1200 mm advance, makes use of a headboard that incorporates a force apportioning lever so that the prop force is shared between the beam and a metal pad, therefore limiting the force carried by the relatively weak beam. The beams only carry sufficient load to provide rockfall protection while the aggregate beam and pad are sufficient to control rockburst energy. In the system, the temporary support hinges on the forward headboard of the support system via a link-bar. This concept gives the temporary support more stability and could be installed by one operator.

*Schematic of prototype remotely advanced headboard system.*



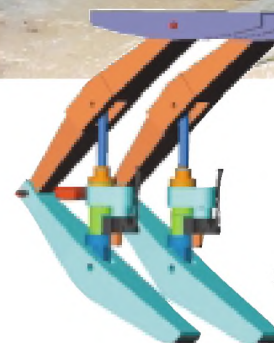
## **GAP 813b Effective roof support for tabular stopes**

**T**he objective of this project was to develop and surface test an effective roof support system in the face area of tabular stopes and to do a risk assessment of the system.

The roof support system consists of two similar support units connected to each other by two cranks. Each unit consists of a 210 x 1200 mm headboard supported by a "wishbone" structure (top and bottom leg) and a self-contained loading/yielding mechanism that keeps the legs apart. The system yields to both slow and sudden stope closure by a combination of elastic deformation in the wishbone structure and a pressure relief valve. Rapid yielding is mainly accommodated by the flexibility of the "wishbone" structure, and this also gives the system the necessary rebound, since stopes do not only undergo monotonic closure during a seismic event. The system is therefore more likely to stay in place, providing support resistance and energy absorption during the critical moments of the rockburst.

To move the system forward, one support unit is collapsed and then hangs from the other by the two cranks. The collapsed unit is then manually cranked forward and re-loaded. Surface tests reveal that three minutes are required to move the system forward by 900 mm. Typically, 20 wishbone support units will be installed in a 30 m panel, and will take two persons one hour to move forward a distance of 900 mm. The support system can be tailored to meet specific mining parameters such as stoping width and average face advance per blast.

Testing of the prototype on surface in the laboratory and in a mock-up stope, and a risk analysis identified certain areas that need to be addressed in order to implement the new support system safely underground.



*Schematic of roof support system and roof support system in mock-up stope.*



## \*GAP 816a Review of past research areas – stope and gully support

This project involved a critical review of past research funded by SIMRAC in the areas of stope and gully support, and in other areas relevant to such support. Knowledge gaps, in which further research would be of value; research outputs that are now in use in the mining industry; and research outputs that have potential for use in the mining industry, but that are not yet in use, were identified.

## GAP 816b Review of past research areas - seismology and mine layout design

SIMRAC has managed research on behalf of the mining industry since 1993. Since there is concern that the industry may not have implemented many of the results, six projects in the area of seismology and mine layout design were selected for evaluation of their level of implementation in industry.

It was established that research outputs are being implemented where they are perceived to add value, and the level of research implementation is higher than is perceived by the observer. Overall there is a high level of awareness in the industry of SIMRAC research, although it is often associated with the contractor who did the work.

The study established that the future research strategy in this area should be aimed at developing seismic monitoring techniques with particular emphasis on the accurate quantification of seismic parameters such as location and size. Real-time seismic monitoring should then be developed, concentrating on accurate automatic seismic event location technology.

## GAP 818 Realistic dynamic testing of stope face support systems

A number of methods offer potential for preventing the collapse of fractured rock from the essentially unsupported roof area between individual support units. These include the use of long headboards on hydraulic props as a means of increasing the areal coverage of the support units; the use of simple mesh straps sandwiched between the tops of adjacent conventional timber elongates and the hangingwall surface above, as a relatively cheap and expendable means of linking individual support units and supporting potentially loose blocks between them; and, for the same purpose, using more appropriately engineered linkage systems that might be more expensive but are potentially re-useable where conditions permitted.

These alternatives were tested in the dynamic stope support test unit and the results indicated that long headboards are only partially effective as a means for eliminating falls of rock from between individual support units. With increasing length the potential for rotational instability becomes a potential hazard. The system of simple mesh straps linking timber elongates showed some promise in reducing falls of rock between timber props. Indications were that the strength

needed to be increased considerably and the yielding mechanism made more positive. The more sophisticated, potentially re-useable collar-and-web device appeared to be effective at moderately high values of input energy. Further work is needed to establish its upper limit of capacity. Two tests on pack support showed that large fluid-filled diaphragm-type pre-stressing devices show a potential for rotationally-unstable behaviour which might tend to promote collapse under certain conditions. However, more analytic and experimental work is needed to examine this tendency.



(a)



(b)



(c)

Progression of test in the dynamic stope support test unit: (a) shows possibly 100 milliseconds after impact of 140 kJ striking at  $4.8\text{ms}^{-1}$  (note vapour expelled from the south west prop), (b) shows all blocks collapsed except above each 400 mm headboard and (c) shows significant sliding of centre four blocks in the east beam and in the west beam.



## GAP 820 Infrared thermography of loose hangingwalls

The application of Infrared Thermography (IR) for the detection of loose rock in hard rock mines has considerable potential for application in South African mines due to the high rock temperatures and relatively low temperature of the ventilation air.

Tests on IR were conducted on platinum and gold mines and samples of the most common rocks present in the mines were tested in the laboratory to quantify their emissivity. It is recommended that this method could be used within two to three days after blasting in South African hard rock mines.

The IR radiometers currently available on the market are not able to provide reliable operation in the harsh underground environment, particularly in deep gold mines. They also cannot be used in a potentially explosive atmosphere. Also, commercial devices are usually designed to provide a very narrow measurement angle. However, when the method is used for the identification of loose rock, a much wider angle or measuring area is required.

Therefore, a commercial IR radiometer was modified into a portable mine-worthy, intrinsically safe device. Initial testing showed the modified IR radiometer to provide better results than the

commercially available instrument. It should be noted that IR Thermography/Radiometry could also be used for other aspects of mine safety, such as condition monitoring of mechanical and electrical/electronic equipment.

## GAP 821 Assessment of seismic risk in the Bushveld Complex platinum mines

With increased mining depths, the platinum mines are also experiencing increased levels of seismicity. Work was therefore carried out to assess the seismic risk in the Bushveld Complex platinum mines and to provide guidelines for regional and local support in areas where the seismic risk is considered to be high.

Seismic data from some recently installed seismic networks were analysed and highlighted a significantly increased risk with mining at depth (down to -2000 m), and with larger mined out areas.

Potholes, a feature unique to the Bushveld Complex, do not show as increasing the potential for larger seismicity. The deteriorated ground condition experienced when approaching potholes, however, does enhance the likelihood of 'shakedown' damage and therefore increases the probability of an undesirable consequence (an increased risk of experiencing seismic-related damage/injuries).

An industry workshop on local support requirements in areas of higher seismic risk resulted in the specification of support requirements. A maximum design parameter for yielding support in terms of the ground motion velocity was determined to be 1 m/s and seismic monitoring provided confirmation of this specification.

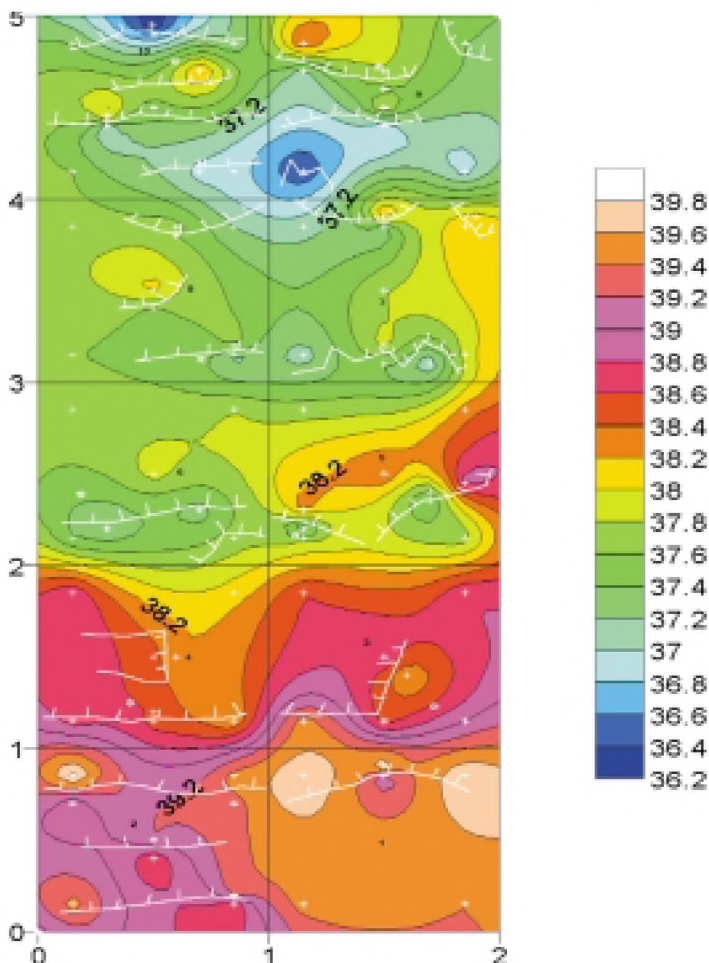
A single example of the need for better regional support was demonstrated in a practical example where an abutment pillar greatly reduced the closure rate and seismicity in an area of mining down-dip from an extensively mined-out area.

## GAP 822 Assessing and evaluating acoustic techniques for 'making safe'

Seismic techniques provide a potentially valuable method for instantly detecting hazardous rock conditions in a quantifiable way. Therefore, investigations were carried out to evaluate the propagation of seismic energy in the immediate skin around an underground excavation to assess whether seismic techniques can detect changes in hangingwall integrity in gold and platinum mines.

An assessment of the Acoustic Energy Meter (AEM) showed that, from a theoretical point of view, the AEM has application potential in the gold and platinum mines, provided that the correct frequencies are introduced into the rock mass and that the technical specifications of the instrument are such that the required frequencies are measured to correctly interpret the reflected seismic energy. The AEM determines the position and extent of sub-surface hazards by quantifying the decay time of seismically-induced oscillations, and has been applied in coal mines with a fair degree of success.

The accuracy of the AEMs was determined using a



Infrared thermography image of hangingwall. Note that the cooler temperatures indicate areas suspected to have loose rocks.



calibration table and the device also underwent surface and underground trials. The surface trials, which were done on unweathered andesite rock, showed that the AEM detects slightly open discontinuities up to 0,8 m inside the rockwall, but does not detect tight discontinuities beyond 0,3 m into the rockwall. The AEM results on the gold mines showed that the device could detect open discontinuities up to 0,5 m into the hangingwall at Tau Lekoa, 0,65 m into the hangingwall at Mponeng Mine and approximately 0,7 m into the hangingwall at South Deep. The AEM results on the platinum mines showed that the AEM can detect open discontinuities up to approximately 0,7 m depth at Bleskop and Eastern Platinum Mines, 0,9 m depth at Frank Shaft and approximately 0,3 m depth at Waterval Mine.



Training Material for Acoustic Energy Meter

## GAP828 Examine the criteria for establishing the small span small pillar concept as a safe mining method in deep mines

**A**s a result of investigations by a Deepmine project into the criteria required for successful mining of hard rock at ultra-deep depths, it was found that bord and pillar (small span small pillar) as a mining method presented very favourable results, from a safety point of view.

After comparing the small span small pillar (SSSP) method with other known and practiced deep mine mining methods, it was found that the problem areas could be overcome. Investigating non-rock engineering as well as rock engineering criteria proved,

in most cases, the SSSP method to be a safer mining method and, from an economic point of view, it compares well with the other known and practiced mining methods.

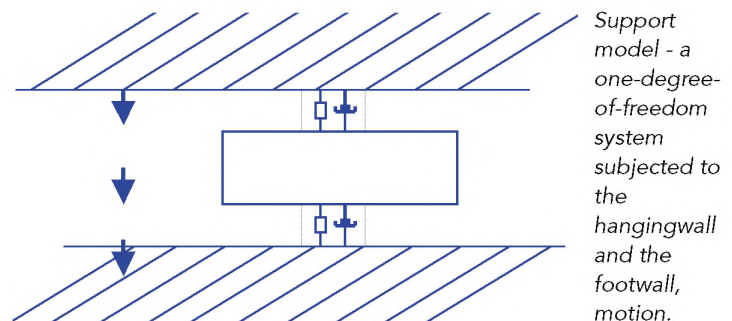
## GAP 836 Investigation into effects of steel wire rope specimen length on the breaking force for a constant diameter and construction of steel winding rope

**T**he destructive testing of steel wire rope specimens forms a crucial part of the decision making process concerned with the safe use of such ropes to hoist men, materials and rock from mines. The regulations governing the use and testing of these ropes include references to several parameters that describe the engineering properties of the rope, and are based on the destructive test of a sample of nominal length of the rope. The derivation of this nominal length appears to be relatively arbitrary, and this project therefore aims to assess whether variations do exist.

From a literature search, it can be seen that the physical lengths used to conduct tensile tests on wire rope specimens appear to have a historical nature. However, it was concluded that differing stress regimes will occur across the length of a rope, a situation that is vastly different from those existing in a relatively short test specimen. In the extreme, if the sample is too short, end effects may well predominate across the entire sample, and not indicate the stress regime at the mid-length section of a deep wind.

## GAP 845 Interaction between stope support and ground motion in the hangingwall and footwall

**M**onitoring of strong ground motion in the hangingwall, footwall and support units at Mponeng Mine showed the strongest monitored ground motion to be caused by an event of magnitude 1,8 at a distance of less than 40 m with a peak ground acceleration, PGA, of 170 m/s<sup>2</sup>, a peak ground velocity, PGV, of 1,2 m/s and a final displacement of 31 mm.



A reasonable model of support was developed to predict deformation of the support under seismic load. It is assumed that the response of the stope support can be adequately simulated using a one-degree-of-freedom system, SDOF, developed for support under multiple excitations. It was found that the support response may be simulated using the SDOF model



when the PGA is in the range 18 - 100 m/s<sup>2</sup>. For this data, the model showed the maximal value of the stiffness is 120 000 kN/m and it is associated with a relatively small deformation of 1 mm measured at the middle of the support and the very large viscous damping attenuation. The ground motion caused elastic deformation, however, a small inelastic component of the motion could be introduced as well.

The ground motion monitor showed that a peak ground velocity of 1,2 m/s is responsible for permanent deformation of 23,6 mm in the upper part of the support. The data showed that the timber pack does not deform as one uniform block and the difference in ground motion between the hangingwall and footwall has an effect on the way the pack is deformed. An equation governing the model with two or three degrees of freedom with multiple excitation was developed.

A theoretical basis for the estimation of energy absorbed by a support unit using data recorded in the support unit, hangingwall and footwall was given: the damping and yielding influence the manner in which energy is dissipated. The energy is dissipated by viscous damping in the elastic system and by viscous damping and yielding in the inelastic system. The values of the kinetic and strain energy are generally small compared to the damping and hysteretic energies at the end of the record.

The response of the support to strong ground motion has radically different characteristics in comparison to its response to weak ground motion. Therefore, parameters of weak ground motion cannot be used as an indicator of support behaviour under strong ground motion as they are quantitatively different and the full waveform should be studied instead.

**\*GAP 846 Investigate the rock mechanics aspects of potholes in the platinum mines, their contribution to poor ground conditions, and if proactive identification is possible**

**R**elatively little effort has been directed towards understanding the mechanisms of falls of ground in the platinum mines. One factor identified as having a major influence on the occurrence of falls of ground is mining near potholes and therefore work was carried out on the effect of potholes on ground conditions in platinum stopes.

In order to gain a better understanding of the effect, a comprehensive literature survey and interviews with platinum mining personnel were carried out. The literature survey revealed that there has been a very limited study of the geotechnical aspects of potholes and almost no cohesive record of the identifiable characteristics of potholes. On the other hand, interviews with mining personnel indicated that there is a good local understanding of the pothole phenomenon and that set rules of how to handle potholes once they are intersected are in place.

Detailed mapping of 14 underground sites indicated that there are no easily recognised features that can be used to predict the presence of potholes ahead of excavations that are universally applicable across all mines and all reefs. However, there are

specific indicators that are common. It is suggested, therefore, that instead of relying on a single feature to indicate the presence or absence of a pothole, a checklist of the features, prepared in this project, should be used.

**GAP 849 Improved understanding of the use of short tendons for stope support under rockfall and rockburst conditions (Phase I)**

**T**he use of rockbolt support in South African gold mines is well established, but its application in stopes is uncommon, and is limited to stabilisation of ground to prevent rock falls. Practical limitations on bolting imposed by production and geometric constraints are such that only bolts shorter than the stoping width can be installed in a single production cycle. While it is highly probable that bolts extending through the entire fractured region in the hangingwall would be beneficial, it is not known whether shorter bolts would contribute significantly.

The aim of this project was therefore to determine whether the introduction of short bolts into a stope hangingwall would increase the stability of the hangingwall beam. A simple physical 1/10th hangingwall model was constructed out of concrete, with properties scaled accordingly, and numerical modelling was employed in generating and analysing hangingwall models representing three generic hangingwall types: the VCR, Vaal Reefs and Carbon Leader.

The primary finding of the work was that the installation of short bolts can have a beneficial effect on the strength, stiffness and energy absorbing capacity of the stope hangingwall. The bolting pattern must be such that bolts intersect discontinuity planes involved in failure of the beam. It was shown in the various generic hangingwall models that failure most often occurs on discontinuities which span the model, whether they are shear fractures or subvertical jointing. It was suggested that alternating the orientations of bolts in a single row will provide resistance along as many of the discontinuity planes as possible.

**GAP 851 Trial training in strata control for underground workers**

**I**n-depth assessments of accident records in gold and platinum mines indicate that an improved understanding of rock mechanics among production and service personnel will improve worker safety in relation to the rockburst and rockfall hazard. To date, however, rock engineering-related courses have been mainly aimed at rock engineering personnel, mine management and senior production personnel. It is therefore desirable that a course suited to less senior production and service personnel, up to shift supervisor level, be implemented.

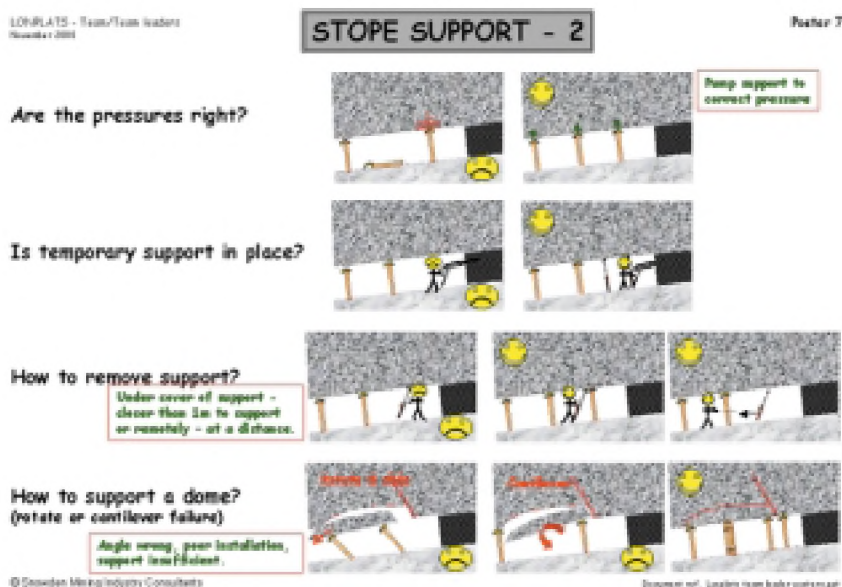
While recently completed SIMRAC projects provide a sound framework to perform effective training at the required level in gold and platinum mines, the results of the research need to be tested and proven, and effectively communicated, before they can be generally accepted.

\* Report not yet approved. Work ongoing.



A trial implementation of purpose-developed training content according to guidelines drawn up under the previous projects found that the introduction of basic strata control knowledge to the team leaders directly, and to the rest of the workers indirectly, made a significant improvement in terms of hazard recognition and the method of coping with the bad ground conditions.

Positive results were recorded from the implemented training intervention exercise, and the positive impact of this method was evident. However, training alone (even using an appropriate methodology) is not sufficient for success, as positive organisational influences are required, such as availability of all specified or required safety items.



Poster training material used for strata control training

## \*GAP 852 Experimental validation of a mine-wide continuous closure monitoring system as a decision-making tool for gold mines

A significant decrease in the number of rock-related fatalities in deep gold mines has not been achieved to date, with one possible reason for this apparent failure being the lack of in-stope instrumentation to continuously monitor the behaviour of the rock mass. Recent SIMRAC projects indicated that continuous stope closure measurements will greatly enhance the design parameters and hazard prediction tools available to rock mechanics engineers and will enable the generation of daily closure maps of the entire mine, indicating possible hazardous conditions and also areas where the existing support design may not be adequate.

In a previous project it was concluded that the hardware for such a system can be developed and many components already exist. The current work therefore aims to install a system underground to collect enough data to verify the concept and obtain evidence of the value of such a system as a decision making tool for management.

\* Work still ongoing.

## GAP 857 Learning outcomes and effective communication techniques for hazard recognition learning programmes in the transportation thrust area

The brief of this research was to identify the hazards associated with underground track-bound transportation on gold and platinum mines, to describe the learning that is necessary to recognise these hazards, and to determine the most suitable techniques for transferring this learning to individuals.

In-depth observation of training practices at three different mining Groups led to the conclusion that workers are well trained and are generally competent to work safely underground. However, a highly complex set of organisational, environmental and individual

factors interact in a variety of ways to ultimately determine the way people perform. Measuring and understanding this interaction is key to designing learning programmes that will significantly impact on safety performance. Essential to acceptable safety performance were found to be individual self-confidence and the operational competence to perform assigned tasks. This insight allowed the most appropriate learning areas for various occupational categories to be identified.

Many current training programmes on mines were found to have value, although most were used in an ad hoc manner without a concrete understanding of what they were addressing.

## GAP 858 Application of indirect stress measurement techniques (non-strain gauge based technology) to quantify stress environments in mines

Reliable values of *in situ* stress are essential for the valid modelling of mine layouts. Available non-strain gauge methods were reviewed as potential practical techniques and it was found that a number of methods could be attractive in this mining environment:

The most suitable method of *in situ* stress measurement is the use of Kaiser effect gauging, with the Kaiser effect change point being determined by means of acoustic emission monitoring. This method is applicable to both greenfield sites as well as existing mining operations. Other potentially suitable methods include estimation of *in situ* stresses, using the existing *in situ* stress database and observations and interpretations of failure around openings. Sleeve fracturing appears to be well suited for routine measurement of *in situ* stress since 20 to 30 tests can be carried out in a day and the fracture can be induced in the borehole at any desired direction. Back analysis of *in situ* stresses uses deformations measured around excavations as a result of changes in the geometry of that or adjacent excavations.



*Hazards specific to coal mining operations cover the rock engineering, engineering and occupational health risk areas. Priority areas are support, layout and design, dust and spontaneous combustion.*

## **COL 701 Inertisation strategies and practices in underground coal mines**

**T**he process of managing the risk of underground explosions requires not only engineering controls, but consideration of other aspects such as the human factor and management influence. At present, there are very few processes that incorporate these aspects into the risk assessment and management process.

Apart from a fundamentally well-designed engineering control process, there should also be methods for auditing implementation and using the controls. As the probability of a hazard occurring is directly proportional to the period of time that the control system cannot cope, auditing systems should also encompass changing conditions, trends and rates.

Work was therefore carried out to develop an inertisation strategy for use in the in-bye areas of South African underground fiery collieries, based on an evaluation of worldwide best practice and an adaptation of these methods for use in current conditions. It was concluded that any inertisation strategy must be based on an efficacious Hazard Identification and Risk Assessment (HIRA), the risk treatment steps prescribed by the relevant articles of the MHSA and be composed of an appropriate selection (portfolio) of RTTs capable of eliminating, controlling and/or minimizing the significant health and safety hazards/risks identified and assessed as part of the mine's HIRA.

## **COL 713 Prevention of spontaneous combustion of backfilled plant waste material**

**O**pen pit coal mines generate millions of tons of plant discards per annum. This material still contains carbonaceous material and is susceptible to spontaneous combustion, which liberates harmful products, amongst which are benzene related aromatics that have been linked with cancer. Previous research resulted in the construction of a probability model to enable the selection of the most likely backfilling method to provide a safe and practical way to store discard material in the worked out area of the mine in such a way as to prevent spontaneous combustion.

The method selected involves backfilling in pre-built compartments, which is based on the hypothesis that, when using compartments, oxygen will only be allowed from surface, and the compartment's walls will protect the slopes. The fixed width and height of the compartments as well as the constant stacking rate will allow exposure of the cross-walls' slope for a very short time only. Sealing the surface of the backfilled compartment adequately, in conjunction with a safe rate of stacking, and flooding the most reactive material with water will further prevent the risk of

spontaneous combustion.

This method is being tested in the worked out area of the mine with results to date showing very stable conditions from backfilling in pre-built compartments. Temperatures within the backfilled material have remained stable, below the theoretically-predicted temperature within all compartments, and the gases show no problem with respect to spontaneous combustion within the backfilled material.



*Interburden backfilling at Grootgeluk mine, three months apart.*

## **COL 802 Survey of horizontal stresses in coal mines from available measurements and mapping**

**T**he role of horizontal stress in the coal mine roadway roof has received a significant amount of attention in South Africa. This project attempted to provide an overall assessment of its significance to benefit both mine operators and strata control professionals alike.

From site inspections of underground coal mines in the Witbank and Highveld coalfields, and the assessment of a number of actual stress measurements at several mine sites, the major conclusion from the study is that, whilst horizontal stress is undoubtedly present within the coal measures, it is not a significant



*Mining conditions associated with adverse horizontal stress effects (Australia).*

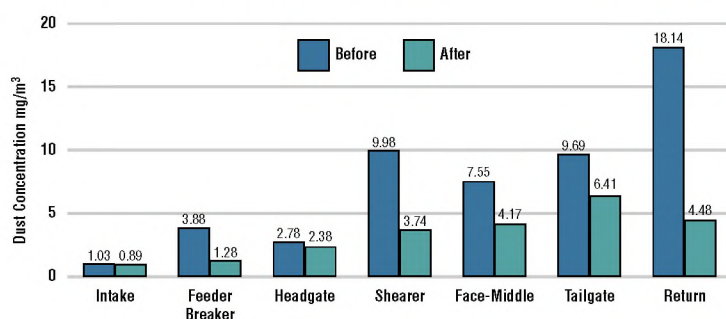


geotechnical constraint to mining. This conclusion is well supported by the efficiency of the continuous miner development operations that were inspected. Such operations would be constrained to a much higher degree if horizontal stress were a primary controlling factor of roadway roof stability.

The one area whereby horizontal stress was clearly at work was in the guttering and, ultimately, instability within the skin of the immediate roadway roof. Whilst this was not a major production constraint, it does represent a potential safety threat, especially in high seam workings where even small pieces of falling material can inflict serious injuries. A possible method of reducing the potential for guttering and associated skin instability is "slotting" of the immediate roof.

### COL 807 Dust control for thick-seam wall mines

A directive of the Department of Minerals and Energy (DME, 1997) requires the dust-concentration level to be reduced to below 5 mg/m<sup>3</sup> at the operator's position. However, results from preliminary field trials in South African thick-seam wall mines indicated that the average Airborne Respirable Dust (ARD) concentration at the sampling stations along the wall face exceeded the DME directive. Similarly, the personal dust concentration levels are above the compliance level of 2 mg/m<sup>3</sup>.



Dust concentration levels (8-h period) before and after implementation of the CSIR-recommended Kloppersbos Shearer Spray Curtain system. It can be seen that the partially implemented system resulted in significant improvements (> 50 %) in dust levels with engineering concentration levels below the DME directive, except at the tailgate position.

In order to overcome the thick-seam wall mine dust problems, a number of broad areas of change were recommended including maintaining an average face air velocity of 2,5 m/s; implementing the Kloppersbos Shearer Spray Curtain dust-control system; installing and evaluating the efficiency of the physical shield curtains hanging from the shield in reducing worker exposure; and using a custom-built scrubber system fitted on to the shearer.

### COL 810 The impact of geotechnical factors on the secondary extraction of coal in the Witbank and Northern Highveld coalfields, specifically related to safety

Many of the problems experienced during the extraction of coal are directly related to

geological disruptions in the continuity and quality of the seam. Work is therefore being carried to identify those geotechnical factors impacting on secondary coal extraction in the Witbank and Northern Highveld Coalfields and to quantify these factors with respect to resource / reserve classification and to safety.

It was found that those factors that are critical for safety reasons are also important with regard to the financial feasibility of any secondary coal extraction operation. Geotechnical factors affecting safety can have major monetary implications, potentially far beyond that of any actions required to prevent the risk and / or restore the mining environment after a safety-related incident has occurred. Therefore, certain factors will prevent the upgrading of a resource to reserve status, while others may have a similar effect if unexpected coal losses occur during mining.

Standing water bodies, spontaneous combustion (the geology, coal and mining components), the competency of the roof, the condition of pillars, the time elapsed since the primary extraction, and the presence of dykes and sills are the most critical geotechnical factors in terms of safety, mining method selection, open cast and underground operations and potential adverse effects on the resource / reserve classification.

### COL 812 Rating system for coal mine roofs

Many rock engineering departments in South Africa use locally developed rock mass classification systems to evaluate the condition of the roof, but these are sometimes descriptive in nature and undocumented and in most cases restricted in use to the specific mine. This project attempted to overcome the problem by evaluating and documenting all the existing systems that are used in South Africa and others that have been developed in other countries, and proposing the way forward for the development of a system that could be used universally on South African collieries.

The literature review of all existing systems highlighted that in the mining industry the Q and RMR classifications form the basis of many empirical design methods as well as of failure criteria used in many numerical modelling programs. Application of these systems in South African mines has been limited due to lack of acceptance of the techniques from the industry. The CMRR promises to overcome most problems associated with application of rock mass classification systems to coal mining. However, certain modifications need to be applied to the system due to different conditions to South African coals.

The investigation into the rating systems being used in South Africa highlighted that roof rating systems are being used mainly for planning purposes, and not to determine the changing conditions underground.





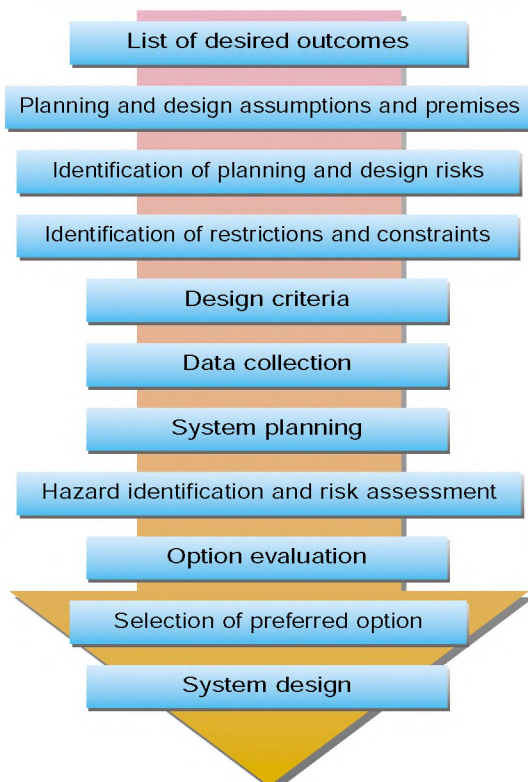
Impact splitting was found to be effective for South African conditions.

Impact Splitting Tests, Section Performance Rating and Physical Risk Ratings systems developed in South Africa were found to be the most effective and appropriate for South African conditions. They can distinguish different roof conditions necessary for initial planning and support design. They can also be used for identifying changing conditions while mining and determining the best response to the different conditions. These systems are also found to be the best systems to address the risk used by sectors of the coal mining industry.

#### COL 814 Process guidelines for the integrated design and planning of underground coal mining processes to ensure safe, healthy and effective mining operations

Underground coal mine planning and design involves the compilation and integration of all relevant geological, geotechnical, mining, engineering and economic data into a single document to define

#### The planning and design process



and describe the exploitation strategy for a particular coal deposit within acknowledged and identified legal, financial, technical and regulatory requirements and constraints.

Guidelines for the effective integration of all disciplines and activities involved in the overall mine planning and design process have therefore been developed. The guidelines describe a methodology which provides a structured and systematic approach to each element of the mining process and present planning and design procedures for the following underground coal mining process elements: mining method selection; mine access/exit systems; underground layouts and scheduling; underground equipment; underground support services; and surface services and infrastructure

#### COL 815 Develop international links for co-operative research in coal mining with special emphasis on interaction with international experts for developing industry guidelines for the design of pillars in coal mines

Coal pillar design is a complex subject that has received attention from researchers the world over for several decades. This project therefore afforded the opportunity for scientific discussion and exchange of ideas that could result in the identification of future research needs and enhance the general level of research execution in South Africa.

The bulk of the technical issues that were discussed are already in the public domain and as such accessible through literature searches. However, the possibility to incorporate highwall design results into underground production bord and pillar design methodology would probably not have arisen had it not been for attendance at the workshop held as part of this project.

#### COL 816 Specifications for a portable counting seismometer

Previous SIMRAC work has shown that seismic activity is the most reliable indicator of impending major goafing in shallow coal mines. The feasibility of a small, independent device monitoring local seismicity to extract similar information to that recorded by a temporary network of seismometers was therefore investigated. Seismic signals from a uni-axial geophone mounted on a roof-bolt stub were continuously logged onto a local hard disk, while a small, intrinsically safe geophone network simultaneously recorded local seismicity generated by stooping operations in section 17 of Brandspruit 2 shaft.

Analysis of the uni-axial record revealed that a simple triggering algorithm could successfully discriminate between mining noises and signatures of fracturing, and produce similar seismic activity data to that recorded by a network of five tri-axial geophones. This result provides the theoretical basis for development of a small portable device that warns of seismic activity increases greater than some pre-defined levels. Current technology levels are advanced enough to embed the analysis algorithms into a small micro-processor.



*Projects conducted generic to all mining operations covered tuberculosis control, methane detection, and development of a "making safe" system and a smart rockbolt.*

**\*GEN 524** A randomized controlled study of the effectiveness of annual and six-monthly screening with Mass Miniature Radiography (MMR) for the active case-finding of cardiopulmonary tuberculosis patients

**T**uberculosis is the infectious disease responsible for the most deaths on mines. Tuberculosis control programmes that exceed the national guidelines are present on most mines but the epidemic, now confounded by the HIV/AIDS virus, continues.

This project therefore aims to determine the effectiveness of six-monthly screening by MMR compared to annual screening in terms of the annual detection of cardiopulmonary tuberculosis; the relative contributions of different case-finding methods to the total and type-specific detection rates; the severity of disease in newly identified cases; and the frequency of permanent disability on completion of treatment.

A study population of 22 634 workers was selected and active screening for the two-year intervention has been completed, together with follow-up of all annual X-rays and sputum results. All data regarding the X-rays, sputum results, disease severity, disability and method of detection have been collected and entered into the relevant databases.

**GEN 705** Ranging open path remote methane detection/monitoring device

**P**revious research established that the method of underground open path, remote flammable gas measurement, in its existing form, did not comply with 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, an average percentage of gas concentration per metre.

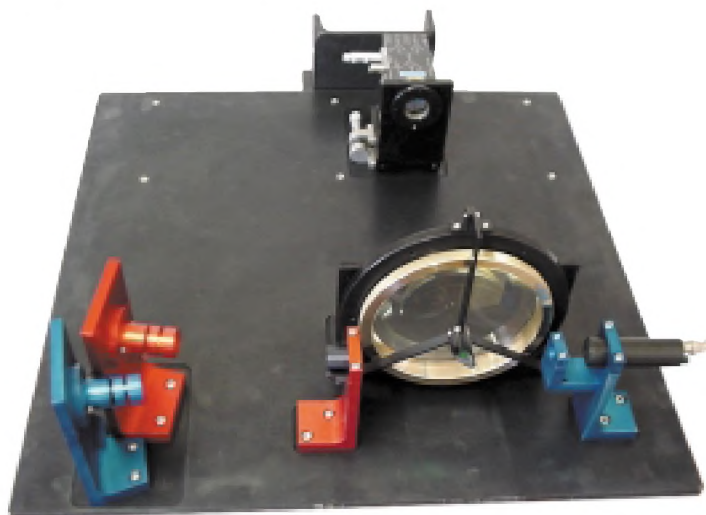
It was proposed that a time Ranging Open Path Remote Sensing (ROPRES) device should be developed. This technology enables the distribution of flammable gas concentration along the open path to be determined, thus ensuring that the safety regulation requirements for routine methane monitoring and early 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.

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 therefore undertaken to

determine the expected backscattered radiation from the dust of a typical mining atmosphere, and the results of this were used to specify system requirements.

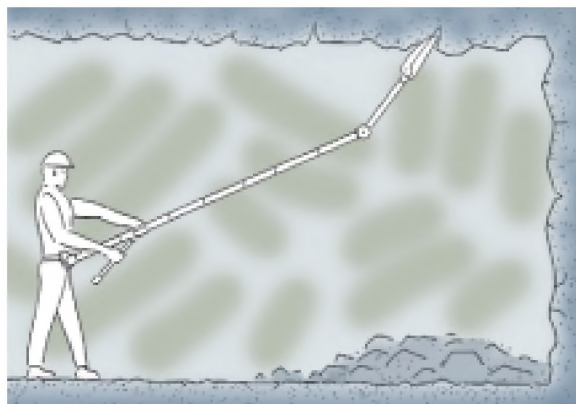
The study demonstrates that due to the substantial amount of airborne dust in the mine atmosphere and due to the advent of a new convolution-based DIAL technique, a proposed system fit for underground application (1-2 m spatial resolution) is feasible. The hardware and processing software has subsequently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



*Experimental configuration and test tunnel for laboratory testing of the DIAL system.*

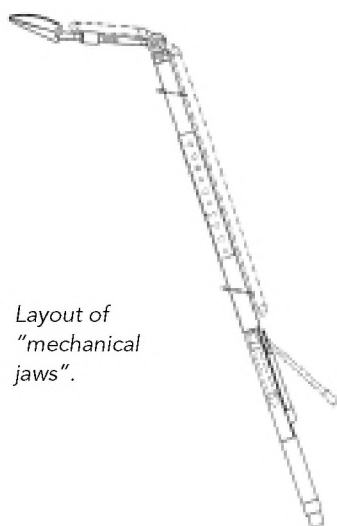
**\*GEN 801** Investigate a possible system for "making safe"

**"M**aking safe" is one of the most stressful and dangerous activities an underground miner can undertake. The operator is often unable to work at a safe distance and is sometimes forced to work directly underneath unstable rock when attempting to "make safe". The equipment currently used is archaic and there is a need to devise a simple system to enable operators to stabilise the rock effectively and efficiently from a safe distance before



*"Mechanical jaws" in operation.*





Layout of  
"mechanical  
jaws".

work begins in the area. Furthermore, current methods are physically demanding on the operator, which can lead to poor concentration, improper completion of tasks and accidents.

Following a literature and international survey of existing systems and field visits to different mines, different concepts for "making safe" were generated and evaluated against system specifications. The concepts selected as promising for further development are a "lightweight pinch-bar" where the bar is manufactured from composite materials, and "mechanical jaws" which comprise a hand-held and

operated mechanical system, and which make use of hydraulic pressure activated jaws to pry rocks loose.

#### \*GEN 810 Development of a smart rockbolt

Support, which is adequate on installation, may be insufficient when loading conditions change. A smart rockbolt was therefore proposed that, when stressed underground, undergoes a microstructural transformation, with its properties changing from non magnetic to magnetic depending on the degree of plastic deformation. This property can be monitored using a portable magnetic instrument to determine a change in loading conditions, and to warn of a possible overload condition.

Two octagonal ingots of smartbolt material were successfully rotary forged down to a section size of 140 mm square. Rolling to wire rod (20 mm in diameter) was successfully carried out and a 100 % yield was obtained. The forged billets were soaked at 1200 °C, put through the roughing mill and finally through the 12-stand bar mill. The rod material was annealed and water quenched (heat-treated) and then taken for rockbolt manufacture and calibration of individual bolts. Samples taken from the material from both ingots were fully characterised in the laboratory. Important aspects in developing smart materials are that the incubation strain is reduced as much as possible and that the microstructural transformation rate is high, thus enabling effective monitoring.

Results from the characterisation programme show that the smartbolt alloy has a good combination of high strength and ductility; this is important in order to resist extreme conditions of high tensile and shear stress, much as a conventional roof bolt.

A portable ultrasonic (USM 25 DAC) monitoring device was used to measure the longitudinal velocity during the calibration trials. The results show a good correlation between the longitudinal ultrasonic velocity and strain.

Smartbolts of dimensions 0,9 m by 16 mm and 1,5 m by 20 mm are currently being installed in a gold and platinum mine respectively for monitoring.



Top: Rotary forging of smartbolt ingot. Bottom: Batches of smartbolt wire rod (20 mm in diameter).



*In the Occupational Health area, the priority areas included tuberculosis; the impact of airborne pollutants including respirable dust, diesel fumes and manganese dust; emergency care; hearing impairment; heat tolerance; substance abuse; and environmental ergonomics. An important focus area was technology transfer with a highlight being the publication of an occupational health handbook.*

## **HEALTH 612** Handbook on Occupational Health Practice in the South African Mining Industry

**R**esearch and other information regarding occupational hazards and health effects in the mining industry are of varying quality and are available from a variety of sources. This project was therefore initiated to assemble a knowledge base that would provide practical tools to prevent occupational illness and disability.



A single authoritative manual on the identification, assessment and control of hazards and related diseases in the

mining industry and incorporating best practice guidelines has been produced to serve as a practical guide, an audit tool, a planning tool, a referral document to other information sources, a vehicle for technology transfer and an education tool.

## **HEALTH 701** Strategies for reducing the burden of TB infection and disease in South African gold miners: the role of preventive therapy. Phase 1

**C**ompared to many other infectious conditions, the dynamics of TB infection and disease are well understood and quantified. Two of the key aspects are first that a latent stage of TB infection, without any manifestations of disease, can exist for many years, and, secondly, that following infection the lifetime risk of TB disease is low in the absence of predisposing factors (estimated at about 10 % for healthy individuals).

Pre-existing models were used and estimates of the important constants governing TB transmission were

adapted to provide the framework for a model of TB infection and disease in gold miners, and the impact of interventions including isoniazid preventive therapy (IPT). The model suggested that TB transmission among miners is more intense than occurs in equivalent general populations, or non-silica exposed miners. Because of the high transmission rates, an unusually high proportion of miners are latently infected with TB. HIV infection greatly increases the risk of progression to TB disease following TB infection. In the context of high TB transmission rates and a high percentage of miners latently infected with TB infection, the impact of the HIV epidemic has been profound.

The upward TB incidence trends of the last decade can be reversed by a number of different possible interventions, or combinations of interventions. These include treatment of latent TB with IPT. Two main alternative strategies were considered, namely the mass untargeted therapy given during a brief period, and employment-long IPT targeted to individuals known to be at high risk of TB.

## **\*HEALTH 702** A prospective study to assess the incidence of and work-related risk factors in the development of musculoskeletal disorders in the South African mining industry

**G**iven the narrow and confined working conditions in South African mines, musculoskeletal disorders pose a serious, potential health hazard to South African mine workers. A prospective study to assess the incidence of and work-related risk factors in the development of such musculoskeletal disorders is therefore underway with the ultimate objective of presenting recommendations based on sound ergonomic principles to alleviate them.



*Awkward body postures that can lead to work-related musculoskeletal disorders.*



Data has been gathered at medical centres of gold, platinum and coal mines and used to establish a database of high risk occupations. The analysis of selected mining tasks to identify work-related factors in the development has yielded possible ergonomic interventions to reduce the prevalence of work-related musculoskeletal disorders.

## **\*HEALTH 703** The occurrence of Hand Arm Vibration Syndrome in South African gold mines and identification of the potential effects of Whole Body Vibration

**H**and Arm Vibration Syndrome (HAVS) is caused by regular exposure to vibrating hand tools. The condition was first reported in 1911 in mineworkers and it has been described in the mining industry of many countries. As HAVS affects the hands, the performance of daily activities, including work, becomes difficult. In South Africa no cases of HAVS have been reported despite the use of rock drills in the mining industry for nearly a century. Previous research reported high levels of vibration from rock drills used in the South African mining industry, raising the suspicion that although HAVS may be occurring, it is not being recognised.

In order to determine the prevalence and severity of HAVS in gold miners, a cross-sectional study of randomly selected mineworkers was conducted. The results were based on 296 mineworkers comprising 156 subjects with occupational exposure to vibration and 140 controls with no occupational exposure. A prevalence of HAVS of 15 % was found in the subjects. Eight per cent had neurological and vascular symptoms, 5 % had neurological, and 2 % had vascular symptoms. Five per cent of controls had signs and symptoms that mimic HAVS.

These findings indicated that HAVS occurs in South African gold miners, but the prevalence and severity is low. HAVS is associated with operating rock drills.

A consistent and strong association exists between vehicle operation and low back pain (LBP). Drivers are exposed to whole body vibration (WBV), but it is not known if WBV per se causes LBP. LBP is common in the general population and confounders such as posture and manual work complicate studies. It is recommended that long term, prospective, intervention studies be conducted and that capacity be developed to measure and monitor WBV.



Project leader Busi Nyantumbu with Mary Ross at a feedback session on HEALTH 703.

## **HEALTH 704** Evaluation of newly available real-time dust monitoring and gravimetric sampling instruments for personal exposure assessment for use in South African mines

**R**ecent research has shown that the use of direct reading light scattering instruments for the assessment of the hazards posed by dusts in mining and various industrial operations is not reliable due to the inherent sensitivity to particulate matter other than dust (diesel soot and water droplets for example). This raised doubt on the validity of measurements and on the conclusions that may be drawn in using the data collected by the means presently available.

Therefore, this project aims to identify an improved or alternative instrument that will be able to measure occupational exposure more accurately and more reliably. Laboratory evaluations of the test instruments have been completed and underground evaluations are in progress on gold, platinum and diamond mines.

## **\*\*HEALTH 705** Provisional assessment of the impact of adding sputum screening to existing active case finding methods for tuberculosis in a gold mining workforce

**A** cross-sectional study was conducted amongst gold miners in the Free State to identify appropriate screening methods in active case detection of TB, to determine the point prevalence of active TB and to identify risk factors for TB prevalence and incidence. Additional objectives were to investigate incidence of TB following intensive screening and to determine the optimum interval between screening.

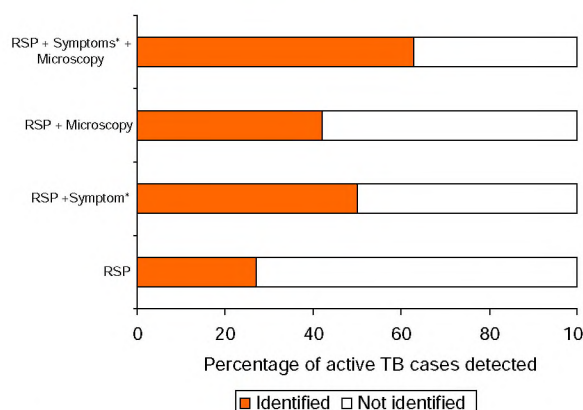
A total of 1 978 individuals participated in the study, 580 (29 %) of whom were HIV-infected. Some 48 cases of active TB were diagnosed. Investigation of the screening methods confirmed that the use of a single screening method for the detection of TB is insufficient. Of the four screening methods evaluated, sputum culture was the most sensitive (70 %). The radiological screening programme (RSP), the current standard of active case detection, had a sensitivity of 27 %. The proportion of TB cases detected with sputum microscopy (25 %), compared with RSP, was similar. Symptom screening (sensitivity 29 %) for TB appeared to give a higher yield than sputum microscopy.

The prevalence of active TB was 2,5 % and did not vary significantly by HIV status, or silicosis grade. TB incidence was 2,4/100 py (person-years); higher for HIV-positive than HIV-negative miners (5,4 and 1,2/100 py respectively). The estimated duration of active disease was 0,61 years in HIV-infected individuals and 1,79 years in HIV-uninfected individuals. HIV infection and silicosis are strong risk factors for incident but not prevalent (active) TB, reflecting more rapid progression of TB in the HIV-infected host with major implications for case-finding and TB transmission.

It is recommended that all persons with either: a new abnormality on the chest radiograph; or any of the three symptoms of cough, night sweats and fever; are identified for further investigation for TB. HIV-negative individuals are likely to be important sources of TB transmission despite low incidence, because of their



long duration of infectivity. TB control strategies in high HIV prevalence areas should not underestimate the importance of HIV-negative TB.



\* any of cough, weight loss or night sweats (symptom combination)

*The sensitivity of combined screening methods in the detection of all cases of pulmonary TB.*

**HEALTH 711** Two phase longitudinal or prospective study of the nervous system effects of occupational environmental manganese exposure on mineworkers or processing plant workers at two manganese mines in the Northern Cape Province

**O**ccupational exposure to airborne manganese dust has been shown to produce adverse effects on the central nervous system. Concerns have also been expressed about very low level environmental exposures to manganese resulting in revisions of both occupational and environmental recommended exposure limits.

A study was therefore conducted amongst manganese mine employees in four underground mines with surface processing plants, one surface sinter plant and two residential/office locations.

Univariate analysis showed, by comparison with both exposed smelter workers and unexposed referents, that the study group was comparable to both these groups. There was no association between blood manganese levels and dust exposure levels, and no obvious clinical abnormalities consistent with clinical manganism were detected.

Multivariate analyses showed that no outcome was associated with any measure of exposure including blood manganese. The absence of nervous system effects indicates that there is unlikely to be a subclinical neurotoxicity problem at exposure levels near the ACGIH TLV in these manganese miners, despite some underestimation of exposures. Results are consistent with the smelter study which found no convincing effects at exposure levels on average four times higher, ranging as high as  $5\text{mg}/\text{m}^3$  for certain groups.

It is recommended, therefore, that there is no need for screening programmes for early effects of manganese neurotoxicity. There is a need for occupational hygiene surveillance to be rationalized and to be geared to prevention by easily yielding information that could be integrated with medical surveillance programmes.

**\*HEALTH 801** Analysis of emergency care provided for injured miners in South African mines

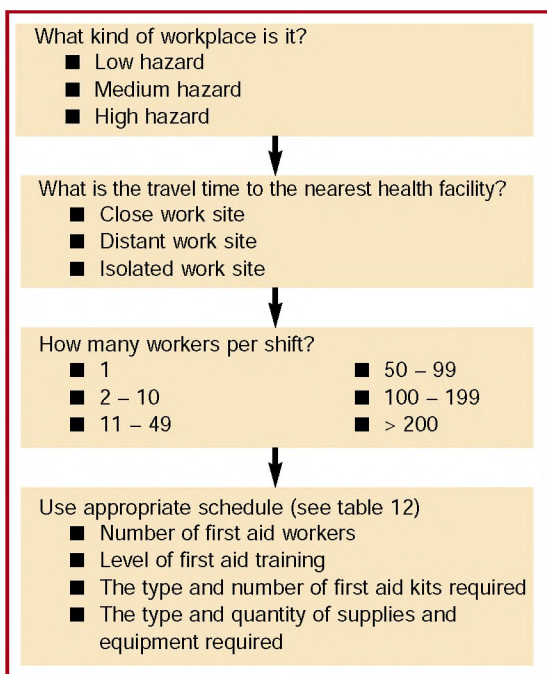
**A** literature review of emergency medical and trauma care services identifies time as the most critical factor affecting the outcome of severely injured patients. The primary aim of this project was therefore to assess and make recommendations on the provision of a comprehensive emergency medical service in the South African mining industry to ensure that all the required systems are in place to deliver a skilled emergency response to all incidents.

A detailed review of the emergency medical care services in the mining industry in Canada, Australia and the United States showed the provision of emergency care to be an integral part of occupational health and safety services. There is a shift from providing prescriptive standards to a process of risk assessment and the provision of services that are pertinent to each mining operation. There is also an increasing emphasis on the monitoring and evaluation of services through a process of self-evaluation, the use of positive performance indicators and auditing. The use of inspections and review by authorities remains important in ensuring compliance with legislation.

An audit of the emergency care services provided in the South African mining industry showed that the emergency services available on the mines vary enormously from highly sophisticated outsourced services to almost no service at all. Overall, there is a sense that emergency services are less than optimal and that delay in injured miners receiving appropriate care is

| <b>MINE-INJURY REPORT FORM</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                |                            |                   |
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*Procedure for determining appropriate level of first aid facilities. Alberta, Canada.*

contributing to fatalities and severe injuries. Areas of particular concern are the adequacy of first aid training of miners, the adequacy of the ambulances used by some mining operations and the fact that few occupational health staff have any trauma training at all. Other concerns relate to coordination and management of emergency medical care and the general lack of adequate monitoring and evaluation of the system.

This work has resulted in a number of recommendations being made for the provision of emergency care in the mining industry and highlighted the need for further research in this area.

## **\*HEALTH 802** Feasibility of using oto-acoustic emission methods for screening early hearing impairment in South African mineworkers

**N**oise-induced hearing loss (NIHL) costs the South African mining industry hundreds of millions of Rands each year for compensation claims, and for re-training and rehabilitation programmes to

deal with the consequences of noise exposure. It also impacts on productivity and safety by impeding communication and, most importantly, on workers' health and safety and their ability to earn a living.

This project investigated the possible use of oto-acoustic emission (OAE) testing for the pre-symptomatic diagnosis of inner ear damage and identification of individuals who are particularly susceptible to NIHL, to better enable preventive interventions.

Distortion product oto-acoustic emission (DPOAE) and transient-evoked (TEOAE) tests (screening and diagnostic procedures for both types) were performed on an experimental group of 106 mineworkers with an average exposure period of 11,6 years, and a normative group of 17 novices with no history of occupational exposure.

The findings indicated the need to implement more effective preventive measures, since the prevalence of irreversible cochlear damage among mineworkers with symptomatically normal hearing appears to be considerable. Use of DPOAE methods for routine medical surveillance would be most beneficial if relevant normative data were available to better evaluate screening results and, thus, ensure appropriate interventions. Consideration should be given to developing a local normative database of OAE and audiometric test results for non-exposed individuals of various ages, corresponding with others having had various levels and durations of exposure to noise.

## **\*HEALTH 803** Guidelines and material for the technology transfer of X-ray reading skills

**A**ugmentation of proficiency in Radiological Occupation Lung Disease Surveillance (ROLDs) is essential to the implementation of forthcoming regulations concerned with this matter in terms of the Mine Health and Safety Act. Self directed, interactive distance learning materials for health practitioners have therefore been developed in the form of a CD-Rom based interactive program with visual and audio components including a simulation of ROLDs.

Although mainly concerned with radiology of gold and coal miners, the program will be further developed to include asbestos related diseases. The product is available to health practitioners and is highly recommended for current surveillance readers in the industry as a means of earning ROLDs CPD points and for newcomers to the field.

## **\*\*HEALTH 804** Identification of health hazards in mineral processing plants relating to chronic exposure to multiple chemicals

**P**revious research focusing on health hazards associated with heavy metals in 15 types of mineral processing plants highlighted the fact 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



About 30 mine medical officials attended a training symposium held as part of HEALTH 803 in an endeavour to improve x-ray reading skills for medical personnel in the mining industry. Ray Glynn-Thomas can be seen above with attentive students at the training symposium.



# OCCUPATIONAL HEALTH

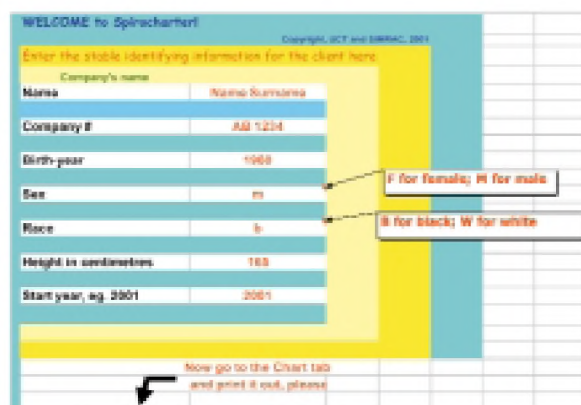
the presence of sulphur dioxide together with calcium oxide. The plant surveys conducted in this research played an important role in observing these issues, and the methodologies that were developed provided an essential framework for making occupational health risk assessment and management in mineral processing plants more complete, relevant and useful.

It has therefore been proposed that the approaches used in this research be used and expanded to cover all chemical hazards associated with routine operations in mineral processing plants. At the same time, the extension of the project will be used to test the previous study on heavy metals, and to reaffirm the conclusions and recommendations in the industries.

An interactive CD has been produced with information on 17 mineral processing plants, as well as for 13 generic processes or activities that are applicable to most of the plants.

## **\*HEALTH 805** Develop percentile charts : semi-quantitative tracking of lung functions

Previous research made far-reaching recommendations pertinent to the practice of spirometric surveillance in South African mines. It was recommended that the optimally valid reference equations it identified be used and be operationally implemented and this project was therefore the first step towards achieving better spirometric practice in the mining industry.



The SpiroCharter identity screen.

The principal aim was the development of percentile charts for semi-quantitative tracking of lung functions over time. It was intended to optimise medical surveillance by graphing successive spirometric measurements. Optimisation would take place in two ways: maximal use of existing historical lung function data for a particular worker, and early identification of lung function loss by examination of the graphical trajectory over time. Three innovative computer-based products were developed for use in small, medium and large mines. SpiroCharter was developed for small mines for hardcopy use, although generated by computer. The other products are computer-based: SpiroTracker for medium mines was developed in Microsoft Excel, and SpiroAccess for large mines is under development in Microsoft Access.

## **\*\*HEALTH 806** Best practices in preventing adverse effects of noise and vibration

Since vibration of the air produces noise, vibration and noise are related, both of which are acknowledged as producing adverse health effects in the mining industry. Although knowledge of these physical hazards and their effects has been greatly increased through past research, exposure to noise and vibration has not significantly abated in the industry. There is therefore a need to consolidate what is known, research what needs to be developed and implement best practices to prevent the adverse health effects of noise and vibration in the mining industry.

## **\*HEALTH 808** Develop technology transfer programme to enhance clinical performance in TB management

Previous research reviewed the autopsy findings and medical records of miners who died in 1999, and demonstrated that significant problems exist regarding the diagnosis of pulmonary tuberculosis (TB) in these men. Clinicians failed to diagnose TB in 44 % of cases coming to autopsy, incorrectly ascribed TB as the cause of death in 29 %, and only correctly ascribed TB as the cause of death in 27 % of cases. The omission of accurate, appropriate and timeous clinical history, examination and diagnostic tests was identified as a major contributing factor to delayed, mis- and missed diagnosis.

The purpose of this project was to identify, produce and distribute appropriate material to facilitate implementation of best practice with regard to TB in the mining industry. A number of innovative methods and technologies to meet the needs of the end-users were developed and a review of the literature identified process based performance review, undertaken by clinicians' themselves, to be one of the most effective ways of developing successful practice habits. Process based performance review involves the identification of clinically important actions that ought to have been carried out in a particular condition, followed by a periodic review of whether these actions have actually been carried out.

The process of performance based process review as developed by this project is sustainable and participation is incentive driven through the mechanism of continuing professional development points, which are a legal requirement for ongoing registration with the Health Professions Council of South Africa.

The products (a manual in paper format and a CD version of the performance review process, four posters and a bookmark) were piloted with doctors from the gold, coal and platinum industries and from small and large medical centres.

## **\*\*HEALTH 809** A review of occupational health services in small and medium other mines and the development of the best model for provision of occupational health services in small and medium sized other mines in South Africa

Due to their limited turnover, small to medium mines in South Africa are in many cases not



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complying with legislative demands – a situation that is not unique to South Africa. In particular, many small to medium mines are not complying with the provisions of the Mine Health and Safety Act of 1996, which requires mine managers to provide medical surveillance to miners on a continuous basis and to provide occupational services in their mines.

This project set out to identify a suitable model for and to provide recommendations on the provision of comprehensive occupational services in the small and medium mining industries. Following a literature review, a protocol for interviewing was developed for the review of the current status of occupational health services in this sector in South Africa. Informal discussions were held with two clay mines, and a pilot study with a dolomite mine was completed.

### \*HEALTH 817 A pilot study to assess the heat tolerance of female miners

It is generally believed that, under conditions of high ambient temperature, thermoregulation in women is 'less efficient' than in men. Furthermore, individual characteristics of males and females can have a significant influence on the responses to physical work at high environmental thermal loads.

The heat tolerance of a group of 27 female mineworkers and a group of 17 male mineworkers, who acted as controls, was therefore assessed by means of Heat Tolerance Screening (HTS).

The results highlighted the importance of individual anthropometric characteristics in the response to heat stress. Factors such as body mass, BMI, body surface area and body surface area to mass ratio played an important role in the outcome of heat tolerance screening procedures. Physical work capacity (aerobic capacity) was also a key factor

in determining individual heat tolerance.

In terms of existing recommendations and standards, all employees who work under "conditions conducive to heat stroke" should be screened for gross or permanent heat intolerance by means of the HTS procedure. Based on the findings of the present study, there is no fundamental reason

why such a requirement should not be extended to female mineworkers destined to work under similar conditions.

Within the context of recruiting a labour force to undertake physically demanding work in hot environments, gender matching is irrelevant and concessions for gender or any other physical or physiological feature are therefore entirely inappropriate.

In view of their smaller physical work capacity and physical strength, female mineworkers may experience undue physiological strain when performing "strenuous" tasks while working underground. Since no information is currently available on this, it is recommended that this aspect be investigated.

As a second phase, the body temperature responses of a group of female mineworkers using the standard block-stepping routine were compared with their corresponding responses while using stationary bicycle ergometers during the HTS. From the results obtained, it is recommended that the block stepping routine remains part of the HTS and that bicycle ergometers be used only in exceptional cases.

### HEALTH 824 Determine potential carcinogenic effects on underground coal miners exposed to diesel fumes

Research findings indicate that diesel particulate matter (DPM), which absorbs chemical substances, is a critical exhaust emission pollutant to which miners are exposed. The chronic effect of long-term exposure to diesel exhausts is thought to be tumourgenesis, due mainly to the polycyclic aromatic hydrocarbons (PAHs) which absorb onto the DPM. Benzo-a-pyrene (BaP) is one of the most carcinogenic of the PAHs and is regarded as a marker of potential mutagenicity. 1-hydropyrene has been found in urine of non-mining workers exposed to BaP and this indicator of PAH provides a practical approach to exposure assessment.

A cross-sectional study was undertaken to determine whether there was any difference in PAH levels between workers exposed to diesel exhaust fumes and those not exposed but living and working on a coal mine. Despite its limitations, the pilot study indicated that there was no statistical difference in the exposure to PAHs between the two groups and there was no association between smoking and 1-hydropyrene level in the urine. However, since smoking is a well established cause of cancer, every effort should be made to educate workers on the potential combined risk of smoking and diesel exposure.

Level of exposure is related to characteristics of the machine, mine and man. Two workers who had 1-hydropyrene levels greater than the accepted limit for industrial exposure were diesel bus drivers where the exhaust outlets were in close proximity and who were not wearing any protective respiratory apparatus.





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