Safety and health in mines research advisory board Annual review 2009

Introduction

The Safety and Health in Mines Research Advisory Board (SHMRAB) is one of the Health and Safety Executive's (HSE) advisory bodies and is a sub-committee of the Mining Industry Committee (MIC). It is chaired by Her Majesty's Chief Inspector of Mines and has members representing employers and employees in the British mining industry. Current members and others who contributed during 2009, are listed in Members of HMRAB 2009

Contact details for more information on the research houses and individual projects mentioned in this review can be found in Researchers mentioned in this review

Fire and explosion

Mine Fire Detector: Combined High-Sensitivity Smoke and NO_X/CO Sensors

In UK underground coalmines, fire alarms detect fewer fires than mine personnel, particularly during the early combustion stages. As collieries become more automated there are fewer personnel to detect fires and, as drivages become longer, the time for evacuation is increased.

Two types of fire detector are principally used in UK coalmines based on products of combustion FIDESCO and carbon monoxide. However, FIDESCO is not user-friendly, susceptible to false alarms and is obsolete. Carbon monoxide sensors are used to detect spontaneous combustion and more developed fires but are insensitive to smouldering conveyor belt fires, which are the predominant type.

Previous work identified that a sensitive fire detector could be based upon a combination of an optical, high-sensitivity smoke detector (HSSD) and an oxides of nitrogen (NOx) sensor to distinguish smoke from diesel fume. However, the HSSD was fitted with a cyclone to remove coal dust and required a powerful pump to maintain airflow. This complicated its use underground and hinders commercialization. This joint project (HSE, HSL, UK

Coal, Maltby Colliery and TES) was initiated to investigate the performance of proposed alternatives to the cyclone-HSSD:

1. HSSD (Monitair): based on the response of a blue/infrared (IR) sensor, which does not require a pump.
2. HSSD (Stratos): similar to the cyclone-HSSD except it uses a filter to remove coal dust and requires a smaller pump. It can change its sensitivity to match the background dust levels.
3. Samdetect (EADS/RST): uses a neural network to distinguish fire events based upon the outputs of six semiconductor gas sensors. Once trained for use underground it should not need a NOx sensor to distinguish diesel fume.

Testing of the detectors by exposing them to small fires and conditions underground has been completed and the Samdetect has been chosen as the most promising detector. The work has been presented at AUBE'09, the 14th International conference on automatic fire detection in Duisburg, Germany and published in the proceedings. An HSL project report has been completed and distributed.

The project has been extended to allow HSL to provide independent technical advice/input to HMMI and the Joint Industry Working Group (i.e. HSE and the mining industry) on trials to be carried out by the fire detector manufacturer and industry; support knowledge transfer of the high-sensitivity underground fire detector through the JIWG; and to present work at a major international conference and publish the work in a peer-reviewed journal.

Ongoing discussions are taking place with all interested parties (HSE, HSL, UK Coal, Maltby Colliery, TES Bretby, EADS/RST – the manufacturer and their UK agent Schauenburg) about M1 or M2 certification for a commercial model of the Samdetect for use underground. Additionally, the plan for underground trials has been agreed using existing Group 2 (non-mining) certified Samdetect detectors under Manager's Rules in Kellingley, Daw Mill and Maltby collieries. The data obtained will be used to gain experience on its performance and train a more robust neural network to distinguish fire events from safe conditions in any UK colliery.

Early Detection and Fighting of Fires in Belt Conveyors [EDAFFIC]
Research activities within Edaffic will deal with the specific topic of fires in conveyor belts and related ventilation issues. All aspects of conveyor belt fires will be addressed, including fire prevention, early detection, combustion processes, new belt materials and firefighting.

A study of coal spillage from conveyor installations was undertaken, principally by UK and Spanish partners. The study examined the conveyor drives, scrapers and 'multiple' belt cleaning systems to prevent 'carry back', support idlers and the effects of air speed on the generation of airborne dust. Conveyor belt system designs were investigated, covering such issues as material loading and discharge, which also examined simulation models of loading on the belt systems, belt alignment and the use of dust suppression systems. A number of more recent installation developments, to improve belt performance and hence reduce spillage, were also analysed, including impact beds at loading points, skirt boards, wing style tail pulleys and control devices to detect anomalies in belt performance.

The issue of heat strain potential and its avoidance is another area being researched, with a number of avenues being investigated. Consideration has been given to various thermal physiological models appropriate to underground firefighting, including evaluating heat release rates from various fire types, exposure issues to radiative heat sources and limit criteria for thermal radiation. Available mitigation strategies were assessed, focussing mainly on the use of cooling garments followed by initial consideration of the cooling potential of water mist zonal protection schemes. The latter appears of particular value and provides full justification for the further research to be undertaken during the next phase of the project. (Protection of firefighters using water spray-mist techniques).

In another part of the research, an extensive investigation was conducted into advanced discriminating fire detectors and their potential application to conveyor belt installations for the early detection of incipient fires. A self-contained report was compiled evaluating POC (products of combustion), smoke and flame detectors. For each, the principles of operation were investigated, advantages and disadvantages considered and commercial suppliers identified. The report concludes that POC sensors appear to provide the earliest indication of an incipient fire, although smoke detectors may have some role. Metal oxide semiconductor (MOS) sensors offer several advantages over other POC sensors, so will be investigated further. In due course, the intention is to develop a multi-sensor meter for detecting incipient fires.

Minimising risk for and reducing impact of fire and explosion hazards in underground coal mines. MINFIREX
MINFIREX is aimed at minimising the risks of fires and explosions by developing strategies to prevent fires and explosions and developing innovative detection measures and fire fighting methods, especially for hidden fires, as well as developing an innovative active extinguishing system to ensure effective protection against propagation of fires or explosions. UK Coal is a joint partner.

Mine environment

Development of novel technologies for predicting and combating gas outbursts and uncontrolled gas emissions in thick seam coal mining. COGASOUT
The objective of this project is to develop and test novel technologies for the prediction and combating of gas outbursts and uncontrollable gas emissions in coal mines which operate in thick and/or steeply dipping thick seams, primarily in Slovenia and Spain. Imperial College is one of the other partners. MRSL's research has two elements, one applying electromagnetic seam survey methods to determine the influence of stresses imposed by very high pressure entrapped methane and possibly mobilise the gasses, and secondly a study of protective barriers which may be used to protect face workers against sudden emissions.

Low Carbon mine site energy initiatives. LOWCARB
This project is designed to investigate and develop modern technologies and techniques that can significantly reduce the coal mining industry's carbon

footprint in terms of both emissions (CO_2, CH_4) and operational energy consumption (CO_2), whilst remaining technically and commercially competitive. Other UK partners are CSM and Nottingham University.

Occupational Health

Conformity and performance assessment of Breathing Apparatus parts
The Draeger BG4 Closed Circuit Breathing Apparatus (CCBA) has been in use by the UK Mines Rescue Service (MRS) for approximately six years. Before the Draeger BG4 set, the MRS used the SEFA (Selected Elevated Flow Apparatus) CCBA. While the SEFA was in service, a programme was set up to randomly check test the performance of the sets. This was to monitor their ongoing condition, performance and maintenance, and also to ensure that HSL's capability to respond to incidents involving CCBA was maintained. A similar programme had not been set up for the Draeger BG4 so the condition, performance and maintenance during the current period of use were not being monitored. In addition, HSL's ability to provide a quick response to HSE in the event of a BG4 incident was potentially compromised.

As a result of the above and after discussions with HMIM, a project was set up to perform an initial check test on two Draeger BG4 sets with a view to establishing a testing programme similar to that previously used for the SEFA. This would entail periodic examination of sets from all stations of the MRS. As a by-product, this will help to develop HSL's knowledge of the BG4 apparatus and give MRS workers confidence in the kit they are using.

Three tests on a breathing simulator were performed on each of the two Draeger BG4's received at HSL and both sets met the performance requirements of BS EN 145. Both sets showed signs of being well used but were both in reasonable condition and well maintained.

The face seal on both facemasks was slightly deformed in places but this should not affect the performance of the BA providing correct donning procedures are followed and a good fit obtained. Facemask condition should be monitored to ensure timely replacement. The inner masks were slightly distorted at the bottom when viewed through the breathing tube connector most likely as a result of being squashed whilst in storage. Steps should be taken to avoid this and facemasks should be examined before connection of the breathing tubes.

It is recommended that a rolling programme of check testing be set up to randomly check test the performance of the Draeger BG4 CCBA as used by the UK MRS.

Ground control

Development of more innovative support systems for gateroads under the influence of rock stress.
The final report of this Project, completed in 2008, has not yet been accepted by the Commission, so the report is not yet available for circulation.

However, most of the instrumentation and measurement techniques developed under the project are now in everyday use. These include:

- New sonic extensometer system
- New strain gauged rockbolt readout and data logger
- Strain gauged GRP rockbolts for rib stability monitoring
- New rib wire extensometer
- New rib shear monitor
- Borehole video camera system suitable for rockbolt diameter holes
- Software for rib closure data monitoring analysis
- Improved Remote Reading extensometers and software

Evaluation of Tensioned and Non-Tensioned Long tendon Reinforcement Systems in UK Deep Mining Conditions.

The final report from this project, which was submitted in December 2008, has not yet appeared on the HSE website. It included:

- Theoretical aspects of tensioned tendons
- Laboratory and underground testing of tensioned tendons
- Underground monitoring of performance and effects of tensioned long tendons
- Improved modelling of flexible long tendons
- Advice and drafts provided to BS revision committee
- Laboratory testing of alternative rib reinforcement systems
- Suggested revision of DMCIAC cablebolting guidance.

The report strongly recommended that the DMCIAC guidance document on cable bolting should be revised to incorporate the cable bolting practices and systems currently in use, including tensioned systems and the many problems associated with installing some types of these properly. A draft revision was included in the report as a basis for discussion which incorporates provisions to alleviate the potential problems discovered including the captivation/anchorage of tendons during installation which was the basis of a severe accident at Welbeck in 2008. It is not known whether any further progress has been made in the respect.

The Project also part funded RMT's contribution to the Committee on revision of BS7861 Part 2. The revised Standard was published by BSI during the year, came into force on 31 October 2009. It covers flexible long tendons for roof reinforcement (both tensioned and non tensioned) in coal mines.

Increased productivity and safety of European coal mines by advanced techniques, knowledge and planning tools enabling strata control of the face-roadway junction.

This Project, which commenced in July 2007, has now been running for 30 months and is close to completion. Golder RMT and UKCoal are both partners on the Project. The emphasis has been on investigating and finding solutions to the rib control problems being experienced at UK collieries. Early work was involved with identifying the mechanisms associated with the rib fall which occurred in the coalgate of a retreating longwall panel in January 2007 in order to develop strategies to prevent re-occurrence. The work has been regularly reported to a bi-monthly rib working party at the mine, originally chaired by the HSE, which has been very successful at driving ground control standards and practices at the mine.

The Project has been involved with the successful introduction and monitoring of the large diameter roof and rib bolts at the colliery and the adoption of much longer systematic rib reinforcement, which have produced much improved conditions in the latest gate roadways. It has also been involved in spreading the support management and risk assessment techniques developed to other UKCoal collieries through a regular HQ organised Working Party.

Rib control problems are being experienced at several UK coal mines and much of this is associated with the unsatisfactory mechanical properties of current cuttable reinforcement tendons, including the new large diameter type. These are weak in bending and have very low elongation strain to failure. The measurements undertaken during the Project have shown significantly worse performance of cuttable rib reinforcement compared with steel reinforcement and regular cuttable bolt failures. Gates at one mine are now being driven with steel reinforcement on both sides until an improved cuttable tendon is developed.

A series of large full scale load deformation tests on Link-n-lock cribs was completed which resolved anamolies which arose from a previous set of tests undertaken in 2003. The results of all these tests have been incorporated into the latest version of the NIOSH STOP computer program (Support Technology Optimisation Program). Also the Support System Handbook, originally produced in 2003, has been updated to cover the reinforcement and cribbing systems currently in general use in UK mines. Both of these are deliverables under the Project.

The Project has also been involved in developing strategies for support of gates on drivage and retreat where they are oriented in the less favourable direction or the face have been inappropriately handed.

Advanced Drivage and Roadheading Intelligent Systems. ADRIS

This Project also commenced in July 2007 and is approaching completion. Both Golder RMT and MRSL are partners. Golder RMT’s main objective is to develop practical strategies for designing, driving and supporting coal face headings to the necessary dimensions required for modern longwall face equipment. These need, for practical reasons, rectangular roadways which therefore require suitable rockbolt and long tendon support.

Problems associated with face line drivage and support have increased as face headings have become longer, wider and deeper. UK longwall panel widths have increased from typically 250m to 300m with some now at 350m. This leads to longer standing times and consequent support issues. Wider face headings are required due to the larger face equipment being used. Some faces are now being driven as wide as 8.5 to 9.0m.

Golder/RMT's main activities under the Project have been developing and applying FLAC 3D models for recent face line drivages at both UKCoal and other mines and in extensive monitoring of their actual performance on drivage. Various drivage scenarios have been modelled and compared for the more problematic sites and generally it has been found that drivage at a narrow width, followed by heavy supplementary reinforcement and minimal subsequent widening is the preferable method. This is borne out by international experience, particularly in Australia.

Where particularly difficult conditions are encountered then it would be preferable to be able to place the powered supports immediately behind the widening machine, but a practical means of achieving this, using the current drivage equipment, has not yet been implemented (at least during the period of the Project). Unfortunately face line drivage strategies in the UK are often subject to variation at short notice due to operational considerations.

MRSL's research is, as agreed with the Commission, very much a 'blue skies' element, primarily associated with assessing the feasibility of unconventional rock fracture methods within manless, automated excavation schemes, involving the development of a) models of electro-fracture mechanisms, b) a techno-economical understanding of the technology and c) the concept of manless mining in an inertised atmosphere.

As mentioned in last year's report, one method of achieving rock fracture is via a pulsed electrical discharge with a very fast pulse rise-time. This can be achieved using a Marx generator and research was undertaken to investigate techniques of generating a dual discharge using sufficiently compact equipment. Unfortunately, however, the detonation 'discharge' did not occur. The reason for this has been established as an electrical impedance problem; 3 more sets of trials are now planned to further investigate this issue and to demonstrate the technique. In the second, scaled-up trial it is planned to use very small fragments of rock. A small scale test facility is being evaluated, in which tests are to be undertaken in air, in nitrogen and in water.

Key design criteria for a large scale, high voltage, trial were investigated, including high energy, high voltage capacitors and means of providing reliable triggering. A range of general safety and operational control requirements were also identified.

The long term aim of this research is to assess the feasibility of complete automation of the rock fragmentation process in a nitrogen inertised environment. To this end, studies of nitrogen supply and 'sealing' of the work area are being assessed.

Prediction and monitoring of subsidence hazards above coal mines. PRESIDENCE

This project also commenced in July 2007 and is approaching completion. Golder RMT, UKCoal and MRSL are all project partners. Nottingham University were subcontracted to develop numerical modelling to improve surface subsidence prediction techniques taking account of geology. This part of the work was completed with a conclusion that modelling can give much better predictions of maximum subsidence than the SEH where there is unusual geology but the 2D FLAC approach used was not able to predict accurately the shape of the subsidence profile. A database was compiled containing data from nearly 700 subsidence measurements, some of which had been used in developing the SEH with others being more recent and/or from elsewhere worldwide. Analysis of the data has shown the important effect of geology on subsidence and highlighted the need for an alternative approach to the SEH.

Golder RMT's work on this Project concerns sub surface subsidence and disturbance of the strata and is particularly involved in studying the circumstances of water inflows into working mines and in improving our understanding of how to work longwall panels above old worked areas. The latter is relevant to current and planned workings at four UK coal mines.

Historic and case study data on water inflows into working longwall panels due to mining induced permeability were obtained and analysed. Considerable historic data was recovered from the UK Northumberland and Durham coalfields, pre 1980, but re-analysis of this data had not produced very useful results due to uncertainties over the data and the water sources involved.

Three sets of water inflow incidents have occurred in the UK over the last 25 years, and data from these cases - in the Selby coalfield, N W Leicestershire coalfield and Northumberland - have been gathered and analysed. Data from the first 2 sites gave an excellent correlation with a rule that a Disturbance Index equal to the SEH (1966) calculated aggregate tensile strain at the base of the water source should be limited to less than 15-4.44w/h. The Northumberland data is less clear with the w/h ratios outside the boundaries of the data from the other sites. The best indicator obtained from combining all the data is that the above relationship holds where w/h is less than 1 and, above this, the disturbance index should be limited to below 10.5mm/m

Work on the problems associated with mining above previous longwall panels has included obtaining data from historic case studies, examination of recent experiences at a colliery currently working the Deep Soft seam above old Parkgate workings and analysis of potential problems likely to be encountered in the neighbouring mine which is just commencing work in this seam. An initial analysis of stress distributions on development and retreat with the current planned layout at the latter mine was completed using MAP3D.

A FLAC 3D model was developed for analysis of roadway support in the Deep Soft seam. Detailed geotechnical measurements from the first mine working the Deep Soft were made and have allowed back analysis of actual experience using the new 3D model. A particularly important aspect here is how the condition of the strata within the Parkgate subsidence trough is represented in the models and an approach to this has been developed which

can now be applied to improved modelling of the planned gate roadways at the neighbouring mine.

A subcontract was placed with Exeter University to examine alternative modelling packages for application to this type of problem involving large scale caving and stress re-distribution. In particular, Exeter examined the "ELFIN" package. This is a hybrid code which allows the rock mass to fail into non predefined blocks and can go on to follow the behaviour of the blocks during the caving process. The conclusion was that this approach has significant potential but that there is considerable development work required before it could be applied economically to coal mine caving problems particularly in three dimensions. The technique is currently being successfully applied by Golder to hard rock mining block caving design.

MRSL's research has three major components – the monitoring of shaft fill material, in order to provide advanced warning of subsidence and consequential risks, field studies including shaft imaging in low visibility conditions, and the adverse effects of mine water pollutants on shaft fill and shaft lining materials, incorporating methods to neutralise these effects.

The shaft-fill stability (SFS) sensor linked to a custom-designed low-power data logger and a GPRS (i.e. 'cell phone') transmitter was assessed during the year. The purpose of the field trials was to evaluate the shaft-fill sensor, together with the logging and telemetry components, first separately and then combined in an extended trial at several sites.

Preliminary tests of the shaft-fill sensor showed some stiction, with a very slowly moving fill (of the order of 2 mm/hr) resulting in some 'binding' of the components. However, in all cases the sensor became unstuck immediately if small vibrations or air currents were present. It is considered that a production component could be adequately designed, but it is not known how corrosion and biological activity could affect this aspect of the operation. With regard to battery power, the current consumption of the logger, reporting its status once every two days, would be around 400 mAh/year, so a 'twin' set of $LiFeS_2$ cells should last for 15 years, which is their recommended lifetime. An analysis of cellular network coverage in the primary areas where disused shafts are located in the UK suggested that the use of standard antennas would be adequate. Accordingly, the field trial of a high gain antenna is not justified.

Experimental work was undertaken on a test rig built to assess potential incremental improvements to optical imaging techniques in turbid water. Rather than investigating ultrasonic imaging, the trials were designed to assess a range of measures for improving the performance of the current generation of optical shaft imaging devices. Various different lighting regimes were tested, but none of the combinations were able to produce an image that was appreciably better than with the baseline configuration.

Long duration testing continued, to evaluate and quantify the effects of the chemical processes associated with mine water pollutants interacting with a range of mine shaft materials. These materials are representative of shaft fill, shaft lining and shaft capping. These long term immersion tests were supplemented by a series of smaller scale tests, to precisely determine the

evaporation and changes to the solids. All samples have yet to be scientifically analysed.

A further sub-task is targeted at neutralising the adverse effects of mine water pollutants upon shaft fill, shaft lining and shaft capping. To prevent ingress of minewater into a shaft lining (competent and weathered) a number of concrete samples were subjected to additional immersion tests following treatment with readily available water repellent products.

Mine communications

Researching the applications of innovative open wireless technologies. RAINOW

This Project was completed in June 2008 and the final report has now been approved and published by the European Commission. It is available from the EU Bookshop. The new, wireless enhanced, version of the m-Comm Mines Rescue Communications system, which was developed during the Project has been going through ATEX Intrinsic Safety approval for the last 18 months and should be commercially available later this year.

The main objective of this research was to enhance mining operations through the widespread introduction of advanced wireless network technologies, including smart open wireless sensor networks, wireless digital voice communications and wireless position tracking systems. The other UK partner in this project was RMT.

As related in the 2008 SHMRAB report, the principal results were the development of a proof-of-concept underground mine tracking system, using mesh wireless technology, which was tested out at CSM, and evaluation of the potential application of smart wireless sensors using mesh technology for improved mine safety monitoring.

Enhanced miner-information interaction to improve maintenance and safety with augmented reality technologies and new sensors. EMIMSAR

The research will develop, implement and demonstrate “Augmented Reality” devices and applications, enhanced marker systems and real-time location systems that will improve the interaction of mine personnel with computer-stored information and knowledge in several fields of work. The project also involves condition-oriented preventive maintenance, which will be addressed through the development of novel sensors for online monitoring of critical parts of AFC and plough systems.

Initial work was undertaken on the identification and evaluation of suitable positioning technologies to act as navigational aids in underground mines. Techniques considered included those based on underground beacons, dedicated surface transmitters and existing navigational systems. A number of systems have their respective merits, but further assessment is required. It is also possible that a ‘hybrid’ system may be most appropriate, for example combining an inertial navigation system with local beacons.

The project is also intended to create and refine a Knowledge Based Management System suitable for emergency operations. Two case studies

relating to emergency operations in UK mines are in the process of being prepared.

Consideration was given to the format and method of updating mine plans to be used in a planned ‘ proof of concept’ informational and navigational aid. A study of mine surveying methods and graphical data formats was started. It is envisaged that software data-format converters will be straightforward to implement from, for example, raw mine survey data or AutoCAD DXF files, resulting in a simple internal vector graphics format that can be used to draw the map data dynamically using PHP graphics routines.

Mine operations

New mechanisation and automation of longwall and drivage equipment. NEMAEQ

This Project was completed in June 2009. The final report is awaiting approval by the European Commission. Golder RMT's work was focussed on developing improved techniques and tools for designing mechanical cutting drums used in coal mining machinery. This covered roadheaders, with axial and transverse heads, shearers and continuous miners.

Numerical modelling of the cutting process using FLAC 3D made significant progress and successfully reproduced lab cutting tests. However this approach has many limitations and new modelling techniques for rock cutting are required for the future. An improved, user friendly 3D graphic drum design software package was completed and is now available for commercial application. This offers many more features than the old British Coal software which had become obsolete. It can check the balance and efficiency of existing drum designs and be used to design new drum lacing patterns To date there appears little interest in its application within the industry and manufacturers are jealous of retaining control of their drum designs.

Although the Vaisala MMT318 oil contamination monitoring sensor was considered to be adaptable to provide an ATEX M1 or M2 certified water-in-oil sensor (as reported last year), it became clear during 2009, after discussions with Eickhoff GB and Vaisala, that production of these devices was uncertain and, at best, likely to involve long lead times before any direct industry benefits could be realised. Consequently, an alternative sensor with a monitoring and transmission technology that would facilitate a more immediate implementation strategy was investigated. This work was undertaken in close collaboration with Polish project partners and resulted in a prototype water in oil sensor being developed, which is compatible with existing wireless machine monitoring sensor networks. Tests of the prototype sensor, combined with its ultra low power design, indicated that the time required for the practical implementation of a final product, which has been designed specifically to meet mining applications needs, will be greatly reduced.

Maintainability and human reliability techniques were examined by MRSL and then refined and developed to produce an integrated software tool kit. The primary element of this tool kit provides a metric, a maintainability 'score', which allows the industry to:

Compare maintainability across machines with similar functions, and hence aid equipment selection.

Assess the impact of potential design improvements/retro-fit modifications, to improve maintainability and hence improve production performance and reliability.

Assess the physical effort required from maintenance staff. This assessment, combined with a measure of the artisans' perceived 'importance' of doing the task correctly can be employed to provide an indication of human reliability.

Identify the potential for health and safety risks and critical human errors to arise.

The maintainability assessment tool allows virtually any of the mining maintenance tasks typically undertaken across a wide range of production and safety critical items of mining equipment, to be evaluated. Additional software modules allow estimates of risks to be included directly into the maintainability assessment analysis structure and the potential for procedural violations to be assessed. These facilities serve to provide the additional information required by human factors specialists to investigate and reduce the potential for human errors to arise in situations where industry users identify the need for additional specialist assistance in solving reliability problems.

The project finished in June 2009 and the final report is nearing completion.

Advances in Exploration Methods and Applications. ADEMA
In addition to MRSL, other UK partners involved in this project were UK Coal, Heriot Watt University and Seismic Image Processing. The ADEMA project comprised a programme of integrated research seeking to enhance mining exploration and planning capability. The main topics studied were seismic processing, radio imaging, drilling parameter analysis, micro seismic activity and predictive analysis.

Oil industry techniques were adapted to the coal environment. 3D seismic data was reprocessed for inversion and modelling projects and refined for lithology classification schemes. This enabled UK Coal to interpret the Daw Mill impedance volume in terms of dominant roof strata above the main Warwickshire Thick coal seam as either sandstone or mudstone/siltstone. The technique was successful in identifying increased dirt split within the coal seam where splits greater than 1.5 m were present.

Radio imaging methods have been analysed. An extensive appraisal of electromagnetic propagation in coal seams has been completed, prototype transmitting equipment built and the parameters of the coal seam medium measured. Investigation of signal transmission acquisition systems and tomographic reconstruction techniques were used to construct theoretical models. Practical results indicate the restrictions associated with RIM are due to the higher electrical conductivity, limiting transmission in the UK and European coal fields. Any further application in Europe depends on the conductivity of the target seams and the range required. The various electro magnetic modelling systems developed in ADEMA show potential for further research. Some innovations are applicable to underground communications, the development of novel antennas in particular. The results of this project will be used in current European research including RFCS project EMTECH – Mine Emergency Support Technologies – grant agreement RFCR-CT-2008-00003.

Drilling parameters have been defined. They were combined to obtain specific energy and drilling exponent, which can be correlated with mechanical properties of the rock mass. The application of the techniques developed was successful in providing good correlation between the drilling parameters and various characteristics of the in situ rocks. Further development is necessary

for application underground in coal mines where there is a potential gain in association with modern tunnelling machines with on board drill rigs.

A 64 channel, relatively inexpensive flameproof Seismic Observation System (SOS), incorporating new low-frequency geophones has been installed in a Polish coalmine. Evolutionary tomographic algorithms have allowed the construction of velocity images for the surrounding rocks, providing a method for location of seismic hazard zones three dimensionally underground in coal mines. The work provides two key opportunities:

- Using passive tomography for the assessment of potential seismic or rock-burst hazards, and possibly also of use in mines subject to coalface gas outburst events.
- Assessing safety of the underground excavation under dynamic load.

The results may be used in both the planning of mining operations under predicted high seismicity conditions and the rational choice of geotechnical support. Thus helping to ensure continuity of mine production, and importantly, provide a significant enhancement in workplace safety.

The project finished at the end of June 2008 and a final publishable report sent to the Commission was approved in November 2009.

Improving Mining Transport Reliability. MINTOS

The project addresses a range of novel approaches to improving the performance, reliability and environmental aspects of operating transport systems underground in deep, extensive coal mines with complex networks. The use of alternative motive power provisions for transport vehicles is also being investigated, by examining the potential for using alternative fuels, including fuel cells. The study also encompasses transport logistics and the potential merits of using advanced management information and machine diagnostic systems. In addition, the safety and health aspects of machine fires, exhaust emissions and whole body vibration are included.

During the year, tests were undertaken to investigate the feasibility of using water mist and additive technologies to develop a cost effective wet scrubbing system for the eradication of diesel particulate and, possibly, gaseous matter from transport vehicle exhaust systems. Various spray nozzles were assessed, using a selection criterion that the selected nozzle should be adequate for purpose, yet supply a low volume flow rate, such that the water can be carried in a reservoir on an operating machine and give a long period of mist application. The final nozzle selected was the RXT 0060.T1 which delivers a ‘mist’ average droplet size of 60 – 80 micron at a pressure of 8 bar and gave the smallest flow of water over the test period.

The additive solutions were chosen carefully to fulfil four parameters:- Safety to the personnel handling the solutions (COSSH), cost of use, chemical suitability for the removal of particulates from exhaust emissions, and chemical suitability for removal of potentially harmful gases from the exhaust emissions. In addition to water, nine solutions were selected, including 1% and 5% non ionic, anionic and amphoteric surfactants, Copper Chloride Solution, and 1Butyl 3Methylatimidazolium Tetrafluoroborate solution.

The results indicated that a water mist system is capable of reducing particulates generated by diesel engine exhaust emissions. The addition of a small quantity of low cost anionic / non ionic surfactants can further reduce the level of particulates in the emissions. Some difficulties were encountered however in maintaining a spray over a prolonged period due to contamination of the nozzle, implying that nozzle replacement may need to be part of the routine maintenance of the system.

The result of the tests to reduce the gaseous content of the diesel exhaust showed little reduction. This part of the study requires further research in terms of increasing the range of molarities used.

Future studies, during the remainder of the project, are designed to investigate the use of water mist and additive technologies to develop a cost effective wet scrubbing system for the eradication of diesel particulate and gaseous matter from transport vehicle exhaust systems using bio-diesel.

Mine Emergency Support Technologies. EMTECH

The central objective of this project is to ensure that European standards and procedures to be used in the event of a mine incident continue to be at the forefront of world best practice. The research will address all aspects associated with an emergency, from the infrastructure that is in place at the time of the incident, through to coordinated search and rescue involving mines rescue teams.

A review document was compiled examining safety assessment methods for mining communications systems. The document reviews existing methodologies, standards and established good practices in order to identify approaches that would potentially enable the resilience and functional safety of mine communications systems to be evaluated.
There are no formal methodologies employed in the EU mining industry (or in mining industries elsewhere) at the present time that allow the safety and resilience of critical mining communications infrastructure to be quantitatively assessed. Hence, formal assessment methodologies and safety standards that would potentially enable the survivability of mine communications infrastructure to be evaluated were examined with a view to evolving a practical methodology, with generic application potential, that could be used to provide a representative EU overview of the resilience of currently installed systems, together with identifying key areas requiring additional attention.
The principal conclusions of this review are as follows. The allocation of SILs to communication systems and/or discrete elements of the communication systems in line with the requirements of IEC 61508 is achievable and potentially beneficial both to equipment/system suppliers and end users. However, IEC 61508 and the other related functional safety standards do not provide defined methodologies that would enable the survivability and resilience of systems to various disaster scenarios to be fully assessed.

Nevertheless, the pre-existing hazard identification risk management and assessment techniques referred to in the IEC 61508 family of standards will be valuable in terms of meeting the project's objectives.
Securing resilient response from the mine communications infrastructure requires the transmission infrastructure and power supplies to be engineered for automatic network recovery in case of partial network breakdowns or

damage and mains power loss etc. To secure this, the entire network will need to be provided with multiple redundancy features. Hardware redundancy and dynamic packet rerouting are two key approaches here. It will also be necessary to equip critical sub-systems with a standby power source capability.
UK and Spanish partners have examined underground refuge specifications and designs, along with respiratory and thermal criteria. UK Coal developed a prototype fixed infrastructure type refuge, together with evaluating transportable refuge designs.

Mine Shafts: Improving security and new tools for the evaluation of risks. MISSTER
The project aims to develop innovative cost-effective tools to enhance the understanding of hazards that may affect mine shafts and to optimise safety conditions relating to active shaft maintenance and disused shaft treatments. Nottingham University is the other UK partner.

Improved extraction ratios for deep coal mines. IMPREX
This project commenced in June 2008 and has now reached midterm. Golder RMT are the co-ordinator and Nottingham University and UKCoal are partners alongside German and Polish colleagues. The main aim of the Project is to research, identify and develop practical means by which coal recovery ratios in European deep mines can be improved significantly in a safe and efficient manner.

Initial work concentrated on defining the state of the art and world best practice in the various mining methods to be examined. These include room and pillar development, pillar extraction, reduced longwall pillar sizes, remnant pillar extraction through short longwalls and auger mining, increased mining height in thick seams and longwall top, coal caving.

Golder are heavily involved in designing and monitoring the performance of fully mechanised room and pillar operations in India and Indonesia and this work has allowed us to examine the available room and pillar design and operational methods for suitability to safe application in a European environment. In particular, operations at a 400m deep Indian mine with difficult caving has allowed adaptation and application of a partial pillar extraction system based on yield pillars which has good potential for safe application for remnant pillar extraction in Europe. This work is being undertaken in close collaboration with the Indian DGMS.

Development and application of instrumentation suited to monitoring the performance of these operations has been important and it has been found that instruments based on our remote reading extensometer and telltale system, but without the complexity of surface monitoring, are ideal as they allow detailed monitoring from a position well away from the mining operation. Also an ATEX approved “Auto Warning” telltale has been developed and trialled under the project. This provides remote warning of a preset level of roof movement via a flashing LED. It is intended to provide warning of imminent caving to miner operators during pillar extraction operations. These are now being used extensively in India.

Longwall Top Coal Caving (LTCC) is being studied in detail under the Project. Having been developed significantly in China from its original European antecedents, it is now a mining method which has significant potential for highly efficient application in thick seam mining. The first Australian LTCC colliery (Austar) has been very successful and is currently completing its third longwall. This face was recently visited under the Project. It is using a heavy duty set of face equipment supplied by DBT (now Bucyrus). The face height is 3m and is located at the base of the seam, with a further 3 to 3.5m of caved coal being captured by a second AFC located behind the shield supports. The shields are equipped with retractable rear extensions for controlling the flow of caved coal onto the rear AFC. It has been established that the system has significant potential for improving thick seam extraction ratios, whilst limiting face heights and equipment size and work is now underway on studying the feasibility of its application to a UK site.

We have also been modelling a possible longwall face geometry which would incorporate a “centre tailgate” and a blind face end. This could extract some of the longwall side pillar without changing the position of the tailgate with respect to the neighbouring goaf. Similar systems are in use in Poland and in Slovakia. Other work includes testing a suite of Australian long tendon consumables for comparison with the new British Standard. This is ongoing.

The main research area being investigated at the University of Nottingham involves the examination of auger operations in a deep mining environment. The original work programme proposed 2D computer modelling, followed by 3D modelling. Initial modelling involved some FLAC 2D work, but it soon became apparent that the problem was too geometrically complicated to simplify into a 2D analysis and that the compromises in assumptions to allow 2D models to be developed, would greatly influence the results obtained. For this reason, the modelling work has been primarily conducted in FLAC 3D. Despite FLAC 3D analysis being more complicated to set up and the models having significantly longer run times to solve, it is felt that the results produced are much more realistic and enable a comprehensive analysis to take place.

To date, two contrasting examples have been modelled, one shallow surface mine and a second, a deep underground extraction from a typical UK Coal mine roadway. The bulk of the work was concentrated on the second group of models.

Main Results

Shallow Surface Model.

An initial review of the literature on Augering highlighted that a UK opencast contractor owned a coal auger had used had extracted coal using it in the past. The contractor was currently developing a new site where augering was again planned to be used. A model of this site was developed to help ascertain the key parameters affecting the augering process and the stability of the holes. Being a low stress environment, (low overburden and minimal induced stresses) the effect of the extraction process could be understood, without the influence of large externally induced stresses. The site also had the advantage (over underground sites) that an abundance of good quality rock material was available for testing to provide the necessary parameters

for the model. It was also hoped that since the operator would be conducting augering, the model could be verified with actual data from the site, giving some validation of the RMR reduction and modelling.

The model itself represented a 12.4m wide vertical slice through the 50m high wall, with 16 potential (dependant on desired extraction) 0.5m diameter auger holes, 60m long with a 0.3m rib in-between in a 1.0 m high seam.

The results indicated that in the low stress environment that even with small rib widths (0.3m) between holes there was minimal hole closure. Several ribs were also extracted (to simulate a worse case rib failure) and failure of the highwall still did not occur.

Deep Underground Model.

Using the experience gained from the shallow model, a deep underground generic model was developed. It was assumed in this model that augering would take place from a heading driven into a virgin coal seam. The model was developed using a typical UK Coal roadway set up (5.5m x 3.5m roadway), with roof bolting as support. Geological data was readily available and had a very similar lithology column to Thoresby Colliery. The prime purpose of the initial model was to investigate the effect of variation of inter hole rib widths on hole closure and general roadway stability. Inter hole rib pillar widths of 0.5m, 1m, 2m, and 3m were selected, two base mesh models having to be used to produce valid mesh geometries. The models were over 570,000 elements each.

To ensure that the roadway was in a realistic stress state prior to the augering process, the roadway was extracted in 3m stages of advance. The model solved after each extraction and prior to the installation of the support bolting for that extraction stage. The repeating of this extraction process enabled a typical stress profile to be built up around the completed roadway. A 3m extraction was selected, being a compromise from that used practically (1 – 1.5m) to reduce the number (and hence time) of solutions required but still give a realistic stress profile. The stress profile is of particular importance in the sidewall area being the area into which the augering would be undertaken.

Once the roadway was completed, the 1m diameter by 30m deep auger holes were extracted sequentially (an initial roadway pillar being left). The model was solved after each extraction to establish hole closure on that particular hole, and its effect on those previously extracted.

Figures 1 and 2 illustrate the block model cut along the axis of the road way, showing the auger holes in the sidewall and an enlarged section in which holes 6-12 have been extracted.

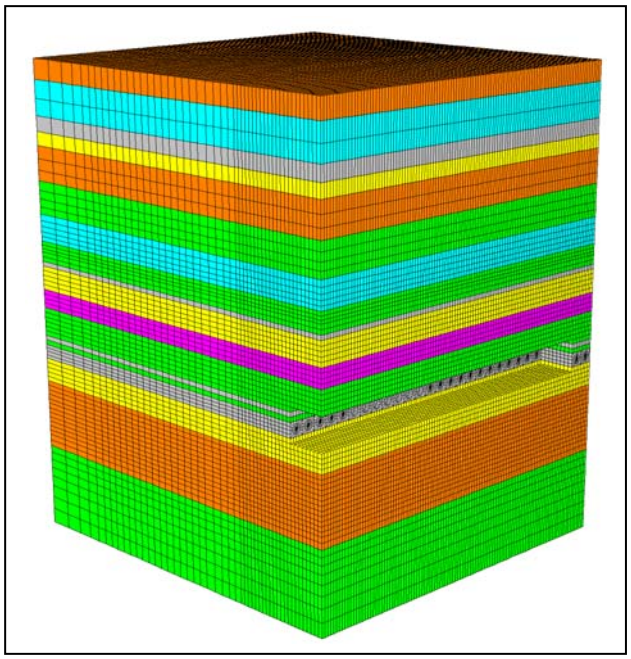

Figure 1: View of the overall deep underground model (cut away along the roadway)

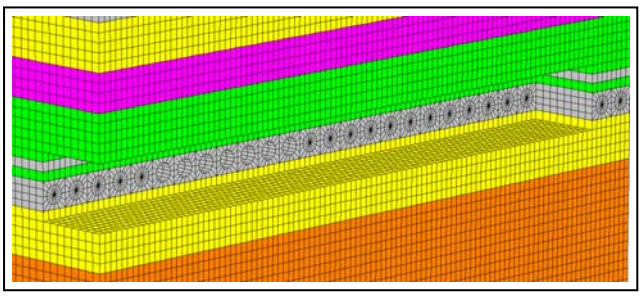

Figure 2: Enlarged view of the auger hole section, Holes 6 -12 have been extracted

Conclusions from initial models.

Shallow Surface Model.

The shallow surface model demonstrates well a low stress environment that is very favourable for auger mining in practice. It provides a useful reference point for the results from the more challenging deep mining stress environments.

Deep Underground Model.

The underground model has shown that an augering type operation is geotechnically feasible in a deep underground mining situation.

All holes showed closure. When initially drilled, this ranged from 19m for 0.5m rib to 9mm for 3m rib. Subsequent mining of holes also created further closure. The subsequent hole closures varied from 18m (and increasing) for 0.5m rib to 0.5mm for 3m rib. The hole closure both during excavation of the hole, and the influences of subsequent holes is critical to auger flight pinch and the increasing of friction and thus torque and power requirements. Furthermore, if auger flights are to be stored in the previous hole (only being retracted when required for the augering of the subsequent hole), then the response to hole closure induced by the augering of subsequent holes (particularly the adjacent) is of paramount concern to prevent these stored flights not being trapped in the hole. Only in the 2m and 3m rib cases is this subsequent closure minimal.

For each hole there is a rapid rise in hole closure reflecting the abutment stress from the roadway extraction after which the closure drops off. The rate of drop off depends on the stability of the adjacent ribs. In the 0.5m rib case where the inter hole ribs are not providing adequate support, there was a continual drop off to the final hole depth. In all the other cases, there is a pronounced reduction from the 5-10m section after which very little change in closure occurred. The reduction in hole closure beyond the 10m hole depth varied from 2mm to 1mm.

This is a significant factor as once through the sidewall abutment stress, hole closure is almost independent of hole depth provided rib stability is maintained. Hole length then becomes dependant on other factors such as hole sloughing, direction control, friction and machine power.

It also indicates that the use of back fill or pneumatic supports for the first 5-10m of the hole may help to stabilize movement and allow for smaller rib width.

Analysis of results to date has indicated several other important issues that require further research

- **Staged Extraction:**
  a. Investigate the closure profile through the stress abutment area. Dependant on the speed of closure, mechanisms such as back reaming the first 10m or so after cutting may help to ensure good hole conditions through the high stress areas.

  b. Investigate the effect of closure on adjacent holes.

- **Depth:** Increase the depth of the model to see the effect on the increasing stress on the four auger rib width's scenario's (0.5m, 1m, 2m, and 3m) run in this initial research.

- **Back fill/ additional support:** Apply support to the high stress areas of the auger hole (by backfill or pneumatic) and investigate the potential for it to help reduce hole closure and hence the width of the inter hole ribs required.

- **Geotechnical parameters and constitutive model:** Perform a rudimentary sensitivity analysis on the geotechnical parameters. Also change the constitutive model to a Hoek-Brown failure criteria and compare the results.

- **Hole Size:** Perform a rudimentary sensitivity analysis on hole size to see if there is a critical diameter above which there are increasing stability problems.

- **Extraction Order:** The current extraction procedure is to extract the holes sequentially (i.e. one after the other). Some benefit to reduce hole closure may be seen by introducing a staged extraction.

Deep Mine Inclined Seam Model

Work is also proceeding on a steep seam underground augering model to see the effect of the highly inclined strata on stability. This work is being conducted in conjunction with a UK auger manufacture and a Spanish mining company which intend to use this technology in one of their underground mines.

Additional work on the IMPREX project

Collection of rock property data

Geotechnical properties, primarily strength and stiffness, of a variety of coal measure rock types have been gathered at the University of Nottingham from its own resources and those of other partners particularly Golder RMT. This significant data resource has been sorted into a database and a format has been developed for its display in a data book “Rock properties and Modelling Parameters for Coal Measure Rocks”. Further testing is currently on-going to increase the data sets for each coal measure rock type. Opencast sites have been identified for coal measure sample collection and permissions have been successfully sought to gain access. It is also expected that additional data will be supplied by partners.

Cleveland Potash

Nottingham University reported last year on the progress it was making in its examination of the performance of the concrete linings of the shafts at Cleveland Potash. The postgraduate involved is now in her final year of studies. The work is largely based on computer numerical modelling , initially in FLAC 2D, but more recently in FLAC 3D. In the last progress report to the company, the following conclusions were drawn:-

1) The models have provided useful comparisons between the four lining types (original cast lining and first, second and (proposed) third restorations).

2) The modelled deformations of the concrete liners in all three restorations were bigger than those of the original cast concrete liner. This was because the replacement liners were concrete blocks with squeezable plywood packs between them which were employed to improve the flexibility of the whole lining systems.

3) The biggest modelled deformation of the concrete liner occurred in the second restoration – double rings of concrete blocks. The ratio of concrete liner’s closure with liner’s inner radius also reaches its peak in the second restoration. These results imply that single ring concrete blocks are a more effective liner.

4) The maximum value of major principal stress in a concrete liner always occurred at the inner surface of each concrete liner threatening the stability of the concrete lining system. The maximum major principal stress in the concrete liners modelled was a hoop stress and increased with the increasing concrete strength, reaching a peak in the second restoration and decreasing in the third restoration.

5) The maximum major principal stresses in the original concrete liner, the first and the second restorations were very close to the strength of the concrete, about 90% of the concrete strength. However, the maximum major principal stress in the newly designed thicker liner (the third restoration) is only 54% of the concrete strength in the modelling. These modelling results illustrate again that the newly designed liner (the third restoration) should perform better than the previous restorations because of the lower maximum major principal stress in the concrete liner.

6) Stress concentration zones were evident along the inner surface of the concrete liner at the end tips of the plywood packers. This demonstrates that the plywood packers improved the flexibility of the concrete lining systems successfully but caused stress concentration zone at its inner surface, thus decreasing the strength of the whole lining system.

7) A possible reason for the original concrete liner's failure may be due to uneven (point) loading on the concrete liner, due to uneven thicknesses of backfill material. The modelling results show that uneven loading could initiate massive tension and shear failure zones in the original concrete liner.The cement backfill grout applied in all the restorations accommodated the high pressures before they affected the concrete liners. This grout layer transferred high ground pressure to the concrete blocks gradually and facilitated the avoidance of potential uneven loading on the concrete liners.

The modeling work continues in 3D with a closer examination of both the lower shaft lining area through the Marl bed where damage has been experienced, but also by building in to the model the shaft inset and the initial excavation leading from it to evaluate the importance of the stability of this area on the lining immediately above.

Usage of light metals underground (a review)

An issue was identified by the HMIM in that there was an apparent discrepancy in the available standards relating to the safe use of light metals in mines. The standard relating to the equipment for use in potentially explosive atmospheres in mines, BS EN 1710:2005+A1:2008, refers to two other standards for guidance on the use of light metals; BS EN 13463-1 for non-electrical equipment, and BS EN 600079-0 for electrical equipment. The normative references given in BS EN 1710:2005+A1:2008 specifically refers to old versions of these two other standards, namely BS EN 13463-1:2001 and BS EN 600079-0:2004. These versions of the standard do indeed show a discrepancy in the maximum permissible concentrations of light metals in mines applications. However, both of these standards have been updated in 2009, and are now consistent (at least with regard to the allowable light metal concentrations in mines). Further attempts will be made to identify why the current levels are as they are.

General interpretation of non-destructive testing (NDT) tests and results

This project is a 2 year call off contract, evaluating the following:

- Failure of NDT to detect faults.
- Unusual NDT results.
- Developments in NDT.

The only work submitted under this budget has been the evaluation of the Intron NDT system recently purchased by Bridon. Bridon hope that this system will become the new “standard” NDT system for UK Coal, replacing the outdated and (mechanically) unreliable Ropescan system.

Bridon have been carrying out field trials (HSL attended in 08-09 financial year) and they now want to test the NDT system using HSL’s reference rope. HSL have been in contact with Bridon but the work has been delayed by the ongoing field trials. It is hoped to carry out a test and complete the evaluation) in March.

Evaluation and interpretation of the failure mechanism of idler rollers on fast moving underground coal conveying
Following a number of incidents, research work was requested that would provide a scientific understanding of the flammable/explosible materials produced during failure of idler rollers. As part of the initial phase of work, scientific analyses were conducted on the Idler roller component materials, (including seals, grease, paint and bearing cage material) to determine the ignition properties of the materials during an idler roller bearing failure.

In addition, tests have been performed on static idler rollers, to determine the practical effect of heating the roller to temperatures seen during bearing failure mode.

Recently the continued use of Flame Resistant (FR) grease over non-FR mineral grease has been questioned within the industry. In order to investigate whether changes to guidance should be made, a number of tests have been performed comparing the propensity of FR and non-FR grease to cause a fire. It has become clear from this work that the continued use of FR grease is essential to minimise the risk of the ignition of coal dust deposits within a mine. In order to assist HMMI in convincing the industry of the continued use of FR grease, HSL (VPS) will produce a video demonstrating the effects of using both types of grease.

Interpretation and explanation of abnormal defects and potential failure mechanisms of mine shaft conveyance suspension equipment
A new method for the assessment of pitting corrosion in mining suspension gear is being proposed. The method is based on assuming the worst case of a pit acting as a crack initiation point and predicting crack growth rates under normal usage. This gives a maximum safe number of loading cycles that a component can undergo before the next inspection. For example, for a link an inspection interval of 80,000 loading cycles would be allowed, assuming the highest level of stress cycling and a pit of 2 mm depth. This value could be significantly increased it if could be shown that the loading was less arduous. Tables for maximum loading cycles between inspections have been produced for links and pins for different loading levels. It is proposed that these tables are used in the assessment of suspension gear at its regular inspections.

Members of SHMRAB 2009

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Mr T Spurry, Group Safety Engineer, UK Coal Mining Ltd;

Mr E Moreland, Chief Executive, Health and Safety Laboratory;
Dr R Stace, School of Civil Engineering, University of Nottingham;
Mr R Young, President, the British Association of Colliery Management;
Mr D Flack, Chairman, the Federation of Independent Mines;
Dr R Quinlan, Medical Director, RPS Business Healthcare Ltd;
Mr J Wood, President, the Union of Democratic Mineworkers;
Mr A Allsop, Union of Democratic Mineworkers;
Mr R Soar, National Association of Colliery Overmen, Deputies and Shotfirers;
Dr P Holmes, British Gypsum Ltd and the Mining Association of the UK;
Mr R A Fenton, Secretary Mining Association of the UK (MAUK)
Mr S Hunter, Cleveland Potash Ltd.
Mr C Daniels, Manager, Hatfield Mine, Powerfuel
Mr M Padley, Health & Safety Manager, Hatfield Mine, Powerfuel;
Mr D Pascoe, Specific Interventions, Policy Group HSE
Mr R G Siddall, Past President of the Institution of Mining Engineers;
Dr B Jones, Chief Executive, Mines Rescue Services Ltd;
Mr P Shorthouse, SES Contracting Ltd;
Mr G Huitson, Maltby Colliery Ltd;

Papers to Mr K Stanley, National Union of Mineworkers

Others who contributed to SHMRAB meetings during 2009
Dr P Foster, Camborne School of Mines;
Mr D Bigby, Golder Associates (UK) Ltd:
Mr S C Bennett, Mines Rescue Service Ltd;
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