# Safety and health in mines research advisory board

## Annual review 2010

## Contents



## Introduction

The Safety and Health in Mines Research Advisory Board (SHMRAB) is one of the Health and Safety Executive's (HSE) advisory bodies. It is chaired by Her Majesty's Inspector of Mines and has members representing employers and employees in the British mining industry. Current members and others who contributed during 2010, are listed in Appendix 1.

Contact details for more information on the research houses and individual projects mentioned in this review can be found in Appendix 2.

# Fire and explosion

## Mine Fire Detector: Combined High-Sensitivity Smoke and NOX/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 However, FIDESCO is not user-friendly, susceptible to false alarms and is obsolete.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 tested an electronic nose “Samdetect”, a gaseous products of combustion detector, three types of optical high-sensitivity smoke detectors and an oxides of nitrogen (NOx) sensor. The latter was used alongside the smoke detectors to enable them to distinguish smoke from diesel fume. The Samdetect, which uses a neural network to distinguish fire events based upon the outputs of six semiconductor gas sensors, should, once trained for use underground, not require a NOx sensor to distinguish smoke from diesel fume. Testing of the detectors by exposing them to small fires above ground and conditions underground showed that the Samdetect was the most promising detector. Following on from this the coal mining industry has entered into discussions with the manufacturer of Samdetect – EADS/RST, into the possibility of making Samdetect usable and certified for underground coalmines.

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

Ongoing discussions are still taking place with all interested parties (HSE, HSL, UK Coal, Maltby Colliery, TES Bretby, EADS/RST and their UK agent Schauenburg) about a commercial model of the Samdetect for use underground. The manufacturers have recently declined for the present time to continue development of the Samdetect to M1 or M2 certification. Other possibilities for fire detection now need to be discussed and investigated by the JIWG.

Fire detection is also required for non-coal mines. Testing was carried out at Cleveland Potash Mine at Boulby, to determine the Samdetect’s effectiveness in mines that do not require hazardous area certification. Other such mines include salt mines. The Samdetect was found to respond rapidly to various types of small underground fires but also to diesel exhaust. It is therefore essential that the Samdetect be programmed with the diesel exhaust neural net in order to minimise false alarms in the presence of diesel exhaust fume, before any further testing is carried out.

## Kellingley Colliery Methane Explosion

On the 10th December 2010 there had been a methane gas explosion at Kellingley Colliery and the only possible ignition source could be as a result of a rock fall within the mine. The three possible scenarios that might cause an ignition are:

1 Rock striking rock

2 Rock striking steel

3 Steel striking steel

HSL tested the following samples: sandstone bedrock from the roof, two steel box sections used as supports and corrugated roofing.

In order to try and recreate a rock fall onto one of the steel supports or corrugated roofing, crude hammers were made from the sample steels and were struck against the sample sandstone with a glancing blow within a methane atmosphere. Although dull sparks and hot smears were evident during the testing, no ignitions were observed. This method gave impact energies of approximately 100 to 150 J.

In order to increase the impact energy, a low speed rubbing machine was used. This allows a sample of sandstone to be forced against a rusty mild steel disc rotating at up to 3000rpm within a methane

environment. Despite increased energies of 250 J and above, no ignitions of methane were observed. However, a methane ignition was produced with steel on steel.

A literature review has also been carried out and from the practical and literary information accumulated to date, the most likely cause of ignition is a sandstone on sandstone impact. However, this is highly dependent on the composition of the given sandstone.

HSL recommends that the roof sandstone be sent for composition analysis to assess it for quartz and pyrite content.

The most likely way an ignition will be demonstrated is through the use of rubbing between a sandstone flywheel and a sandstone brake, rather than steel on rock.

If further work were to be done involving drop weights, it would need to be on rocks of at least 1/2m2 in size and over 5kg in weight.

## Early Detection and Fighting of Fires in Belt Conveyors [EDAFFIC]

Research activities within Edaffic deal with the specific topic of fires in conveyor belts and related ventilation issues. All aspects of conveyor belt fires are addressed, including fire prevention, early detection, combustion processes, new belt materials and firefighting.

A range of metal oxide semiconductor (MOS) sensors was evaluated experimentally. These tests involved monitoring the output of the sensors over time during the early stages of incipient fires involving a range of fuels including diesel fuel, grease, wood, and coal. Tests were also carried out in the presence of potentially interfering gasses not associated with fire, namely FSV exhaust and battery charging fumes.

The tests showed that, by combining the outputs of several sensors, it would be possible to detect the early stages of a fire but not respond to non-fire-related events. Their use was recommended alongside other sensors in the “multi-sensor” device that is being developed by another project partner.

Commercial cameras which combine images obtained in visible light and infrared were tested. Two test sites were chosen, (a) the conveyors in an operational coal preparation plant, (b) a specially designed test rig containing conveyor idlers that could be artificially heated while rotating. It was shown that the infrared part of the image was able to detect over-heating idlers from a considerable distance and that the visible image allowed the hot spots to be identified in relation to their environment. This offers a major benefit over ordinary infrared only cameras.

Tests were carried out using water spray mist with a range of chemical additives to combat spontaneous combustion fires, using a specially built test rig. It was shown that fires could be extinguished rapidly, without the generation of water gas, using very small quantities of fire fighting media.

The use of water mist to cool fire-fighters was investigated experimentally using a range of hollow cone nozzles at a range of water pressures. Heat was generated using a butane burner and the progression of temperature at varying distances from the heat source was monitored. Humidity was also monitored throughout the tests. It was noted that there was a compromise between the amount of temperature reduction and the increase in humidity but one combination of nozzle type and water pressure gave a useful temperature reduction at an acceptable level of humidity. A prototype portable unit has been built.

## Minimising risk for and reducing impact of fire and explosion hazards in underground coal mines [Minfirex

MINFIREX is aimed at developing strategies to prevent fires and explosions by developing innovative detection and fire fighting methods, especially for hidden fires. MINFIREX commenced in July 2010 and the Project partners include Mines Rescue Service Ltd and UKCoal.

As a part of the work aimed at identifying potential improvement strategies for the prevention of fires and explosions, research into biodegasification techniques to reduce explosion and spontaneous combustion fire risks commenced.

Microbiological control techniques represent a radical technology shift in current coal mining. However, the use of microbial degradation and bioconversion mechanisms, and the development of biological processing technologies is more advanced in other industrial sectors.

A state of the art review identified that the candidate microbiological process will involve aerobic microbes (methanotrophs) to oxidise methane to carbon dioxide. The expected reaction rates, residence time and intimacy with desorbing methane are sufficient, in principle, to achieve significant reduction in nett goaf methane emissions. It is also possible to convert methane, albeit more slowly, by means of anaerobic (oxygen-free) microbial processes.

Initial investigations indicate that a collective biofilm comprising aerobic and anaerobic processes may provide an optimum solution. Moreover, the hypothesis that the induced deoxygenation of the coal seam that would arise from this approach may serve to inhibit the initiation of spontaneous combustion is being examined.

Research into the sampling of incombustible dust content and automated stone dusting control techniques also commenced. The strategy being adopted to improve the effectiveness of stone dusting is, firstly, to ensure that a rapid and effective in-situ means is available to test dust incombustible content, and secondly, to ensure that effective, ideally automated, methods are available for stone dusting.

To this end, an examination of a variety of optical and geoelectrical properties of coal and stone dust mixtures is being undertaken. Furthermore, to fully establish the industry's needs and requirements, a detailed examination of current stone dusting practices and legislation has been undertaken.

As part of the process of developing new mitigation systems for hidden fires, laboratory scale fire fighting tests will be carried out on substances currently on the market. To this end, a review of fire fighting additives was undertaken. In addition to identifying current market offering, the review was used to identify any existing experience in the use of additives that are likely to be suitable for use on Class A fires and may prove to be suitable candidates for further testing.

## Detecting Misfires using Electromagnetic Pulses - London Metal Exchange (2009-12)

Blasting is inherently dangerous in underground mining and one of the major issues associated with this is identifying whether a shothole or any part of a shothole has detonated. If this is not the case then a misfire has occurred and if underground this is a reportable incident under RIDDOR. Notwithstanding this misfires are a major safety issue. This research project intends to use Electromagnetic pulses (EMP) which occur as a result of blasting and to use this 'free EMP' which is given out from each shothole and capture the said signals using a specialized antennae and associated instrumentation. This will result in being able to remotely identify every shothole that detonates.

Further to this, we are examining a method of ensuring that each cartridge within a shothole also detonates. This will be undertaken by developing intelligent cartridges which have a 'tell-tale' signature. This is a particular problem in the underground environment where, for example, NG based cartridges are utilised. If for any reason a blasthole suffers from hole shear from an adjacent hole firing, then it is possible that a misplaced cartridge from the hole that has been sheared can find its way into the muckpile. The consequences of this unspent cartridge finding itself into the processing circuit are obvious.

# 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.

In the first area, previous research undertaken worldwide was studied. Research in the field of using electromagnetic radiation (EMR) for detection and prediction of geological anomalies, including outbursts and rockbursts in mining is currently increasing in momentum. It is known that there is a relationship between a build-up of a rock and gas hazard outburst hazard and the appearance of anomalous EMR of rocks. Relatively recent studies in Australia showed that an anomalously high EMR emission was detected one hour prior to a roof-fall, which gave a significant time advantage over the first indications given by the low frequency acoustic emission method.

In other studies, it is claimed that it is possible to use an imposed electromagnetic field to improve gas drainage efficiency of outburst-prone coal seams. MRSL has set up test apparatus to examine the induced desorption characteristics of a UK non-outburst prone coal and a Slovenian outburst prone brown coal.

The barrier protection part of the research is investigating whether adapted motor vehicle 'airbag' technology can be used to develop a system for protecting face workers from material thrown into the face chock track. An underground test area at Mansfield will be used where sensors, inflation devices and air bag materials can be trialled.

## 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 (CO2, CH4) and operational energy consumption (CO2), whilst remaining technically and commercially competitive. Other UK partners are CSM and Nottingham University.

MRSL's initial research is re-examining the feasibility of utilisation technologies for ventilation air methane (VAM). One theme currently being studied in Spain is a catalytic unsteady state reactor, in which gas flow is periodically reversed. The suitability of gas turbines is also being investigated, with several research teams known to have worked on modified gas turbine models to operate with VAM. Another element is a study of how to enrich VAM, by either separating out other gasses, or by blending. In future parts of the project, the potential for removing impurities in VAM will be studied.

A separate part of the research project is a study of energy storage schemes, which is to include the possibility of compressed air storage in mines. This work is being undertaken in close cooperation with Nottingham University.

## Low Carbon Minesite Initiatives (LowCarb) RFCS (2010-2013)

CSM are coordinators of RFCS LOWCARB, which is a three-year research project that started in August 2010, that addresses a range of topic areas linked by the theme of improving energy management and greenhouse gas emissions related to underground coal mining.

Work to date on the project has involved a description of the state of the art of these areas includes a general survey of the energy cost and carbon impact with related economics, potential for renewable energy and energy storage, methane drainage optimisation, technologies for exploiting the energy potential of coal mine methane, intelligent demand management for electrical power, improvement work on ventilation and pumping and the upgrading of surface facilities efficiency.

Research comprised an enhanced review of the early areas of activity, with preparation for detailed work to come. Data has been gathered on coal production trends and a technique for carbon footprint estimation

defined. Aspects of renewable energy with potential at mine sites were explored in some detail and the key economic levers for carbon footprint control identified. A set of definitions and accompanying forms have been prepared for an historical review of methane emissions and methodologies drawn up as the basis for analysis to lead into methane drainage research.

Reverse flow reactor and gas turbine technologies using catalysts were identified and described for further study of energy generation from ventilation air methane. Arrangements were agreed with a mine for the installation of power meters for demand analysis and a scoping review was undertaken for compressed air energy storage using coal mine underground voids.

# Occupational Health

## Evaluation of Alternative Methods for Measuring Diesel Engine Exhaust Emissions

This project is nearing completion and a report will be issued shortly.

The project aimed to demonstrate alternative protocols for measuring diesel engine exhaust emissions (DEEEs) to replace the Bosch meter, which is no longer available.

The Bosch meter provided a simple onsite method for measuring relative amounts of DEEEs on filters for direct monitoring of vehicle exhaust and as a proxy for engine condition. With some further calibration it had also been previously demonstrated that the Bosch meter could also be used to measure elemental carbon on filters from personal sampling.

A set of quartz filters loaded with varying amounts of particulate from diesel engine exhaust have been prepared as a calibration set. Their DEEEs loading has been measured with a number of instruments that rely on similar light absorption/reflection principles as the Bosch meter. These include a colour meter from DR Lange (now Hach-Lange), a Magee Scientific Aethalometer and an office scanner with Adobe photoshop manipulation of the image. Initial results indicate that each of these techniques give an output which follows the same relationship with filter loading as the Bosch meter. This will be confirmed and compared with the elemental carbon contained on the filters determined by a two stage combustion with the Analytik Jena multiEA3100 carbon analyser.

Some filters from a non-coal mine were used to obtain some real samples of vehicle exhaust emissions and general body air to test if the relationships established with the calibration filters hold true for other DEEE sources and environments.

# Ground control

## Testing of Powered Roof Supports

Following a fatal accident to a face worker involving roof supports on Sunday 18/10/09 at Kellingley Colliery, tests were carried out on-site and a number of faults were identified; however, it was agreed that further tests would be carried out subsequently at Joy Mining to confirm these findings and to provide a scenario that would explain the circumstances of the incident. Supports 179 and 180 were examined.

The control system and hydraulic valves were examined and the following was concluded:

1 Failures were identified with the operation of Support 180. These were found to be the result of:

- an electrical fault, which could have led to an intermittent failure of the Power Lower function when operated from the adjacent supports, and
- a hydraulic fault associated with the Power Lower solenoid valve. This fault was observed to lead to:
  - a failure of the Power Lower function when operated from the adjacent supports;
  - failure of the Power Lower function to cease when operated from either:
    - the adjacent supports, or

- manually by direct control of the Power Lower spool valve, or

- spontaneous operation of the Power Lower function as a result of the hydraulic supply pressure becoming available to the support.

2 The electrical fault may have come into existence before or after (i.e., during the dismantling, transport or re-assembly of the system) the incident.

3 The hydraulic fault was the result of erosion of the pressure ball, the valve seat associated with the pressure ball, and the Central Pin of the Power Lower solenoid valve.

4 A similar hydraulic fault was identified with the Power Lower solenoid valve of Support 179.

5 Subjective observations of the operation of Support 179 suggested that, once the hydraulic fault had begun to manifest itself, the magnitude of the fault increased relatively quickly.

6 An additional leakage fault was observed in the Power Lower spool valve for Support 180; however, the nature of this fault was such that it would not have in itself led to the lowering of the support.

7 Support 180 could have either: moved down spontaneously following hydraulic pressure being applied to the support, or failed to stop following it having been commanded to move down by the manual operation of the spool valve by someone beneath the support. The latter could have led to the person operating the spool valve becoming trapped – especially if he were in a confined space.

## Daw Mill Failed Drill String

Following an incident at Daw Mill Mine, where a threaded coupling on a rock drilling drive shank failed resulting in serious injury to an operator, HSL was requested to examine the cause of the failure. The examination incorporated visual examination of the component, fractography, chemical analysis, hardness measurements and metallography.

It was confirmed that the drive shank, which was made from a 3% Cr, 0.5% Mo steel (En 40b), failed at the base of the first turn on the male thread of the coupling by a combination of progressive crack growth by rotating bending fatigue and final overload failure when the stresses on the remaining intact ligament exceeded the fracture stress. Metallographic and hardness examination of the drive shank indicated that although the shank had been carburised to confer good surface wear and fatigue crack initiation resistance, there was a layer of decarburisation at the surface that directly counteracted the benefits of the carburisation.

It was concluded that the combination of the stress concentrating geometry of the coupling joint at the failure location, combined with the decarburisation, resulted in the development of the fatigue crack.

Recommendations were made to ensure adequate furnace atmosphere control during hardening of the tools to minimise loss of surface carbon and the consequent softening effect.

## Further Examination of Failed Drill Rods

Continuing on the theme of fatigue crack induced failure of drill rods, a programme of work was set up to examine a further seven failures in drive shanks and for a commentary on the development of a new design of threaded coupling and use of a new steel type.

Six out of the seven failures occurred at the same location as in the initial investigation, namely at the root of the first turn on the rope thread on the drive shank. One failure occurred at a location along the length of the drive shank that coincided with a reduction in cross-section, but again could be attributed to the development of fatigue cracks at the sharp forged corners of the cross-section. Again decarburisation was found at the surface of most of the failures resulting in a very significant reduction in hardness and resistance to fatigue crack initiation/propagation.

Several additional samples of material were examined. These comprised a new drive shank, two failed torsion test-pieces, one of which had an altered coupling geometry, and two unused extension rods. Several of these were made from a different grade of steel (modified En24) with an additional 2.5%Ni. Decarburisation was still in evidence in many, but not all of these samples, and it did not appear to be exclusive to one grade of steel.

The new design of coupling joint has been developed to significantly reduce the rotating bend loading at the root of the thread. Service trials are underway.

Recommendations arising from this examination reiterate those from the earlier examination regarding the minimising of surface decarburisation during manufacture and processing. They also suggest means of mitigating the effect of decarburisation by a surface treatment either to remove the surface layer or by shot peening the surface to impose compressive residual stresses that would improve the fatigue crack initiation resistance.

## Increased productivity and safety of European coalmines by advanced techniques, knowledge and planning tools enabling strata control of the face-roadway junction [PROSAFECOAL]

This Project was completed in June 2010 and the draft final report has been submitted to the EU for approval. The UK partners were GAUK and UKCoal. Other partners were ARMINES (France), GIG and KWSA (Poland), Geocontrol (Spain) and DMT (Germany). The project was coordinated by RAG (Germany).

The main objectives of the Project were to:

1. Compile, analyse and understand current support design techniques in the participating states.
2. Gather roadway deformation data from gate roads during the coal winning phase.
3. Interpret and compile geotechnical and geometrical data at face ends.
4. Clarify experiences with cable bolting support.
5. Determine the reliability of 2d models of cable bolted rock masses especially at face ends.
6. Documentation of test areas and support technologies applied in thick multi layer seams.
7. Obtain data on stowing material used during coal winning in polish benching operations.

UKCoal and GAUK were mainly involved with objectives 1, 2 and 3. The main thrust of their work was to develop improved primary, secondary and remedial support design for gate roadways and improved risk assessment and support management systems. The work was focused on Daw Mill although other collieries were also studied and have benefitted from the research.

During the Project we tested and field trialled –

- the new 28mm diameter rock bolting system (steel and GRP), successfully used for Daw Mill 32s district,
- the ribguard temporary support system, now used during rib repair operations
- the 10T rib diamond webbing and 20T roof webbing which has been adopted as secondary support ahead of the face at Daw Mill and other mines.
- the use of PU injection as a remedial support system to allow increased telltale action levels.

Whilst the 28mm rockbolting system has been very successful at Daw Mill and allowed 32s gates to be driven with a coal roof, there remains an urgent need for an improved cuttable rib bolt which is stronger in bending than the currently available GRP bolts. This is being pursued under the new Geosoft project.

915mm link-n-lock cribs were tested at various aspect ratios and have now been incorporated into our FLAC3D numerical models of roadway reinforcement alongside the 28mm bolting system. The link-n-lock data were also incorporated into the NIOSH STOP computer program, a tool for assisting with design of cribs and other standing support.

A revision of the Support System Handbook was produced as a Project deliverable. This was necessitated by the many new systems that have been introduced since 2002 and revision of the relevant British Standards.

Golder/RMT's support modelling showed that relatively simple FLAC3D models using translational symmetry can be used to represent complex ground and support interaction in the face end area of reinforced longwall gate roads provided there is adequate model validation using good underground measurement data and the boundary stress conditions are known. Further development of the Warwickshire Thick seam model was

required (underway in Geosoft) but the Thoresby Deep Soft model behaved well. Problems remain with representation of very soft strata often found in the roof and sides (again underway in Geosoft), but good progress was made in preventing premature model termination due to excessive material deformation.

An integrated gate roadway and face end support management system was devised for development and retreat with rectangular rockbolted drivages. This complies with the overall framework agreed by the partners and is suited to tailoring for the specific geotechnical conditions of a site. Application of this approach helped Daw Mill 301s panel to complete retreat safely following the rib fall, 302s panel to retreat its full 2785m, 32s panel to be developed with a coal roof horizon, which has significantly improved and simplified face end support, and 303s gates to be developed in the unfavourable direction, without further falls of ground. The system has been successfully migrated, either completely or partially, to all the other major UK collieries employing rectangular rockbolted roadways.

## Advance Drivage and Roadheading Intelligent Systems [ADRIS]

This project commenced in July 2007 and finished in June 2010. Golder RMT, (GAUK) and Mines Rescue Service Ltd., (MRSL), were UK partners on the project. Three Spanish, two German and one Polish Partner also made up the research consortium. The Project was co-ordinated by AITEMIN (Spain).

The main objective of RMT/GAUK's work was to develop practical strategies for designing, driving and supporting coal face headings to the necessary dimensions required for modern longwall face equipment, (facelines 8.0-8.5m wide up to 4.0m high in high stress and difficult strata conditions). Design evaluations were made based on numerical modelling and practical deployments and addressed drivage options, (twin pass/single pass) and primary and secondary support options.

Work was conducted at sites experiencing quite different ground conditions. The results indicated the drivage and support design methods that are more likely to be successful for different types of anticipated ground conditions. Good drivage rates can be achieved with both single pass and twin pass drivage. The latter can be used to increase drivage rates in poor ground conditions, but this may not necessarily improve roadway deformation levels. The benefits of twin pass with chock installation on the second pass were demonstrated by FLAC 3D modelling, but the system was not deployed in practice for operational reasons.

In principal 8m long Megastrands and 7m long flexible bolts as part of the primary support at the study sites should have helped control roof deformation, but as installed and used in the very difficult ground conditions of the study sites they did not perform adequately. Long tendon support at Daw Mill has now reverted to conventional double bird caged cable bolts. Systematic additional support at other sites was shown to be successful in the instances where it was applied. Secondary support in the form of rockbolts, flexible bolts, polyurethane resin injection, 60 tonne cable bolts and cribs have all proved effectively to reduce roof deformation dependant upon site specific ground conditions. Stabilisation of roof deformation was dependant upon the ground conditions and timing of the installation of the secondary reinforcement.

The principal objective of the MRSL component of the project was to assess the feasibility of using novel rock fragmentation technologies (NRFT) within a manless, automated excavation scheme in coal mining. There were four main goals, namely

*Research Goal 1*: To develop models of electrofracture mechanisms

*Research Goal 2*: To develop a techno-economical understanding of this technology

*Research Goal 3*: To develop a practical proof-of-concept approach, and assess the feasibility of manless mining in an inertised atmosphere, and

*Research Goal 4*: To progress an understanding of the future potential and feasibility of manless coal mining systems.

It is noted that estimates attribute global energy costs associated with rock breakage and grinding to be of the order of 5% of global electrical energy consumption. Therefore enhancing energy efficiency was a further issue and objective of this work.

Generally good progress was made, although there are significant potential safety issues associated with appliation-scale electrofracture schemes, which generically require open discharge of high energy multi kV, multi kA plasma pulses. The work with Golder Associates also highlighted a new field of dynamic fracture mechanic modelling of electrofracture processes, which is proposed as a subject of further research.

## Prediction and Monitoring of Subsidence Hazards above Coal Mines [PRESIDENCE]

This Project was also completed in June 2010 and the final report has just been submitted to the EU. The UK partners on this Project were GAUK, UKCoal and MRSL. Other partners were AITEMIN (Spain), ARMINES (France), EMAG (Poland) and DMT and RAG (Germany). The Project was co-ordinated by Geocontrol of Spain.

The Project objectives were:

- To improve the understanding of the mechanics of mining subsidence regarding the prediction of its occurrence.
- To apply innovative tools in the monitoring of surface subsidence.
- To use the results of the predictions and monitoring of mining subsidence as a tool for a better, safe and accurate land management above closed mines or following active coal mining.

GAUK and UKCoal's work on the Project concentrated on three issues:

- Modelling and prediction of surface subsidence (subcontracted to University of Nottingham).
- Improved understanding of water inflows to longwall workings through subsided ground.
- Improved design of workings within subsided ground (eg. working the Deep Soft above old Parkgate workings)

The main results can be summarised as follows:

- Geology is a major factor in surface subsidence. Empirical predictions are inaccurate where experience is lacking and geology unusual. Geomechanical subsidence modelling can account for geology but requires anisotropic solutions to reproduce subsidence profiles.
- Analysis of UK case studies of water inflows to working longwalls produced a good prediction function based upon the maximum aggregate tensile strain at the base of the potential water source according to the 1966 Subsidence Engineer's Handbook and the panel width to height ratio. Large scale modelling can also be useful. The function was as follows:

  *aggregate strain (mm/m)* > (15-4.44w/h) for 0.3< w/h ≤1

  *aggregate strain (mm/m)* > 10.5 for w/h >1

  The continuous function, aggregate strain (mm/m) > 9.5 + (h/w) is a good approximation to these straight lines for w/h>0.3 and < 4.5.
- Recent experience of locating longwall panels above old workings indicated that previous guidelines were inappropriate for rockbolted gate roadways. New guidelines were developed. A combination of three dimensional boundary element and detailed finite difference roadway models can be used for reinforcement design employing the Hoek Brown GSI to account for rock condition depending upon roadway location within the subsidence trough. This tool will be applied to new workings planned above goafs at several active European collieries. Hybrid models for representing the longwall caving process are promising for future application but are currently constrained to two dimensional simulations.

MRSL's research had 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.

Field trials of the shaft-fill stability (SFS) sensor linked to a custom-designed low-power data logger and a GPRS (i.e. 'cell phone') transmitter were undertaken, to evaluate the shaft-fill sensor, together with the logging and telemetry components, first separately and then combined at several sites.

The summary conclusions, mentioned in last year's report were that the sensor showed some stiction, with a very slowly moving fill, resulting in some 'binding' of the components, but 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, for the current consumption of the logger, reporting its status once every two days, a 'twin' set of LiFeS2 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.

Various different lighting regimes intended to give incremental improvements to optical imaging techniques in turbid water were tested, but none of the combinations were able to produce an image that was appreciably better than with the baseline configuration.

Long term immersion tests indicated degradation to both construction and shaft fill materials from aggressive mine waters, which could reduce the competency of the shaft lining material and reduce the volume of fill in the shaft, so creating a void with the potential for collapse. Even concrete samples treated with available waterproofing solutions showed both water penetration and pitting of the sample surface.

However, the research indicated the potential for using alternative and innovative solutions to cementitious grouting and the use of admixtures, for producing dense, impermeable and durable concrete, along with non steel reinforcement, to prevent degradation and corrosion to permanent shaft caps. A 'flash fill' material suitable for the stabilisation of shaft fill material was engineered from coarse and fine coal mining waste products.

## Geomechanics and Control of Soft Mine Floors and Sides [GEOSOFT]

This project commenced in July 2010. Golder RMT, (GAUK), are the Project Co-ordinator. UK Coal (UKCOAL) and the University of Nottingham, (UoN), are also partners on the project. Three Polish and one Spanish Partner make up the research consortium.

This project is intended to concentrate on the geotechnical problems associated with soft floors and sides in order to improve our understanding of the phenomena and develop enhanced design and construction solutions. This allows continuation of the work on improving rib reinforcement design and application undertaken in the PROSAFECOAL project which finished in June 2010.

Instrumentation developments are planned by GAUK and UKCOAL for monitoring soft rock behaviour and the loading and performance of the support systems used to control the soft ground. Work has begun by concentrating effort on the development of instrumentation to determine the in-situ length and integrity of steel and GRP rockbolts in order to locate broken bolts. A TDR, Time Domain Reflectometry, technique has been investigated for application to steel and GRP bolts.

Results from steel bolts show the technique has potential but further investigative work is needed to more fully define the technique's capability. Results from GRP bolts indicate that the TDR technique can measure the in-situ intact length of a bolt, but this is based on pre-instrumentation of the bolt with two fine copper wires. Work has moved on to an Acoustic Vibration technique and work in 2011 will continue to assess this technique as well as revisit Ultrasonics and the Radio Frequency method. Improvements in instrumentation for roadway deformation measurement are also planned.

Material properties investigations are planned to provide rock property data for use in numerical modelling and to improve our understanding of the behaviour of soft coal measure strata. The UoN is undertaking the majority of the test work with UKCOAL supplying underground rock material to complement opencast Coal Measures rock. Investigation of the problems of sampling very weak strata has started with application of an approach using soils shear box testing of broken material to obtain strength parameters Core testing has started with a suite of tests to investigate the effects of sample 'reconstruction' on rock strength.

Further testing is required for softer rocks to more fully quantify the effect and consequently the potential use of such results. During 2011 testing of intact and broken weak strata will include large scale triaxial soil mechanics type tests on broken coal measures rock in drained and undrained conditions with constant load in some cases for creep property determination. GAUK and UKCOAL will collate in-situ observation and application of appropriate instrumentation to characterise the behaviour of soft floor and sides under specific geomechanical conditions.

Measurement of support performance and observation of support behaviour will be made both in laboratory test rigs and underground in working mines. Laboratory tests by GAUK have initially concentrated on unexpected failure phenomena observed while testing long tendons and its relevance to the testing of consumables for rib and floor reinforcement. A better understanding of the role of rotational failure is being gained alongside the potential advantages of a large diameter split cylinder test to simulate specific conditions such as of low confinement provided by weak coal mine sides.

Numerical modelling is planned to commence in 2011. The UoN will be involved with development of appropriate time dependant constitutive models for simulation of soft floors and GAUK modelling of stress distributions and stress control options relevant to UKCOAL mining situations.

# Mine communications

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

This research is intended to 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.

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 have been prepared.

Initial work was undertaken by MRSL 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 the most cost-effective appears to be an underground wireless mesh network of beacons using the Zigbee technology. Trials of prototype devices were carried out in a disused railway tunnel by MRSL staff.

Consideration was also given to the format and method of updating mine plans to be used in the planned ‘proof of concept’ informational and navigational aid. This included a study of software data-format converters to allow mine survey data to be converted from AutoCad to a suitable format for use in the demonstration device.

Apart from the initial technology assessment and the mine data conversion, MRSL’s work also involves hardware and software for the demonstration device. This work is ongoing, with the project’s mid-term report completed in March 2011.

# Mine operations

## Improved Extraction Ratios for Deep Coal Mines [IMPREX]

This Project is due to be completed in June 2011 and so most research is now complete but the final report has still to be prepared. GAUK are the co-ordinator. Other partners are UKCoal and University of Nottingham (UK), DMT and Clausthal University (Germany), GIG and KHWSA (Poland). This report includes the work undertaken by GAUK, UKCoal and University of Nottingham.

The project objective 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.

UKCoal has been working with GAUK on examining the potential for applying Longwall Top Coal Caving (LTCC) at Daw Mill. No major impediments to application of LTCC were identified other than the high cost of new equipment, the change in culture and the need to retrain personnel. However it was disappointing to find that the size of the equipment, as currently being applied at the first colliery to use the system in Australia, would not enable any reduction in face heading drivage width at Daw Mill, something which was originally envisaged as a major potential advantage. Also the relatively poor production figures and the considerable steering problems with the large and complex main gate support system, experienced on the first 3 faces at the Australian mine, are cause for concern.

UKCoal and GAUK are also examining a possible novel longwall geometry which could be applied at Daw Mill and allow some of the large pillars, currently left between longwalls, to be extracted by the retreating face using a blind tail-end. It proved very difficult to model the stress distribution around the tailgate with this geometry using tools available at the time. It is now believed that large scale FLAC3D modelling would be feasible if the work were to be repeated. Ventilation and climate modelling of this arrangement is still underway (by Clausthal University).

GAUK has been examining a number of methods of extracting remnant pillars at depth, involving various continuous miner configurations. This includes high percentage extraction using split and fender systems, lower percentage extraction employing yielding pillars in a room and pillar geometry and fir tree mining. A special Autowarning Telltale has been developed for use in this type of application and has received ATEX approval. This is intended to provide a highly visible warning of roof deformation with excessive movement triggering a pair of flashing LEDs.

Various non-European mines at shallower depths have been used as case studies in this work and to test the new instrument. It is unlikely that the split and fender system would be applicable to UK mining depths but the other two systems have significant potential for safe application. Studies of the financial viability of such systems have shown it to be highly dependent upon the price of coal, the cost of labour, the availability of infrastructure without additional expenditure and seam thickness.

Nottingham University has been studying the potential application of auger mining in European mines. They have studied available equipment, investigated legislative and environmental aspects and undertaken extensive large scale FLAC3D modelling of both a deep mine site, with a level seam, and a potential steep seam application in Spain. The work to date indicates that augering at depth is feasible provided that sufficient spacing is left between holes to avoid excessive closure. Special measures may also be needed in the yield zone at the side of the roadway. Several remnant blocks of coal have been located at working UK mines with potential for exploitation by augering and studies of the financial viability undertaken. Augering may be a suitable method for remnant coal recovery in thinner seam sections where use of continuous miners would not be feasible.

## New Mechanisation and Automation of Longwall and Drivage Equipment [NEMAEQ]

The project focused on the development of full automatic shearer face equipment. This took into account development of software for the design of cutting tools with a minimum of pick wear and machine down time due to excessive vibrations. Innovative methods of maintenance and planned repair of the machines were also features of the project.

The project finished in June 2009 and MRSL's final research elements were reported last year. The EC Final report was approved last May and should now be in the public domain.

## Improving Mining Transport Reliability [MINTOS]

The project addressed 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 was also investigated, by examining the potential for using alternative fuels. The study also encompassed 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 were included.

During the project, MRSL developed an on-board engine compartment, cab and wheel-arch fire-fighting system, which can be periodically tested and yet still maintain operational capability.

In other research, the feasibility of using 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 was examined. Particulate and gas analysis demonstrated that the introduction of a water mist system resulted in a significant reduction of airborne particulates emitted from the diesel engines.

Furthermore, the test showed that the introduction of low cost, non irritant additives to the water mist scrubbing system could serve to reduce particulate emissions. The result of the tests to reduce the gaseous content of the diesel exhaust showed little reduction.

In the last phase of the project, the impact of selected diesel replacement biofuels on exhaust emission content, and hence the likely health impacts arising from the introduction of these alternative fuels, was studied.

In a series of trials, the particulate and gas analysis demonstrated that the introduction of a water mist system would also result in a reduction of airborne particulates emitted from mine diesel engines, where the fuel is B30 or B50 biodiesel. The results indicated that lower levels of particulate tended to be generated using biodiesel and again demonstrated that the introduction of low cost, non irritant additives to the water mist scrubbing system can further reduce particulate emissions.

The project finished in 2010 and the final report has been supplied to the EC.

## Mine Emergency Support Technologies [EMTECH]

Completion Date: July 2011 Research Coordination: MRSL

The major objectives of this project have been to provide a resilient network infrastructure which meets the dual requirements of operational day-to-day and emergency management needs together with researching and introducing a range of new support technologies for mine evacuation and rescue.

The research consortium involves 3 EU coal operators, 2 mines rescue services and 5 research institutes/manufacturers. The partners have managed collectively to maintain excellent progress and a number of innovations and prototypes have been produced; including resilient networked communications, emergency refuges, evacuation modelling tools, and evacuation support technologies together with knowledge on their application. There are considered to be good prospects for a successful technology transfer process and subsequent take-up of the research outputs by industry.

**Project Key Innovation Objectives:**

- Provision of a ‘safety capable’ underground network infrastructure with adaptive behaviour and high survivability prospects.
- Evacuation modelling and real-time support tools for self-escape routes, escape time prognosis, affected mine areas, environmental conditions, tenability etc.
- Resilient messaging over the entire mine, selected areas or to specific personnel.
- Fit-for-purpose mustering station and refuge designs with secure air supplies and a managed thermal (psychrometric) environment.
- Effective wayfinding and navigation support through dense smoke.

- Advanced emergency location and communication systems with long range strata penetration capabilities.
- Provision of a high resilience rescue team communications infrastructure.

## 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.

In order to provide an international database relative to incidents directly involving mine shafts, the project requires partners to collect information on incidents relevant to their country. This collection includes fundamental parameters that may, in one way or another, have played a role in the instability. MRSL has begun this work in relation to incidents in the UK.

An exercise has also begun comparing different methods of treatment in terms of short and long term stability improvements of shafts including capping, plugging, filling and grouting. This has led to the detailed specification of a programme of experimental work that will investigate the effect of ordinary water and mine water on concrete samples with a range of additives (e.g. plasticisers, corrosion inhibitors, water repellents) and a range of reinforcing materials.

A state-of-the-art review of earth resistivity surveying techniques was carried out, with particular reference to those systems that employ smart addressable electrodes.

In analysing the drawbacks of the current generation of earth resistivity systems with smart addressable electrodes, several benefits were identified that could be provided by a radically different approach. In particular, a system architecture has been specified in which the electrode switches are not hard-wired onto a cabling loom by the equipment manufacturer. Instead, the user connects the electrode switches together in the field using cheap patch cables of a suitable length dictated by the particular survey requirements. In addition, the electrode switches will not have addresses assigned when manufactured, nor will it be necessary for the user to deliberately programme the addresses or specify the sequence of switch addresses to the central controller.

As such the system is described as “plug and play” and offers several major benefits over the state of the art. This analysis will lead into a top-level system design specification which could be used as the basis for a component level hardware design and the design of the associated software.

## Study of shaft stability issues at Cleveland Potash

Sinking of both the mine shafts at Boulby was carried out during the period 1968-1974. The two shafts are approximately 1150m deep and pass through a 10m thick bed of Marl close to the bottom of the shafts. The shaft linings installed at the sinking of the shafts suffered severe damage that resulted from the considerable pressure of the surrounding soft rock and upper strata. The first relining of both shafts through the marl zone took place during 1983-1986, and the shafts were again relined through the same zone during 1997-2001. Now, a third replacement of the liner is required.

A PhD student at the University of Nottingham has been conducting a study of the mechanisms that have affected the stability of the shaft linings during the life of the mine through numerical modelling using the finite difference programs FLAC2D/3D. By modelling the shaft’s restoration history, this project has aimed to explain the various influencing factors that have contributed to the lining failures, and subsequently to predict the long-term deformation behaviour and stress conditions of the newly designed 3rd restoration. The modelling work has been conducted in FLAC 2D and 3D. The results of the numerical modelling suggest three main conclusions.

Firstly, the weak rock Marl may not be the sole reason for the shaft linings’ failure through this stratum. The shaft inset is placed approximately 10 m beneath the Marl stratum and a roadway driven from the shaft has been included in the modelling. The stress redistribution around the shaft caused by the roadway excavation, created an uneven loading regime acting on the circular shaft linings. This uneven loading introduced high shear and tensile stresses which threatened the stability of the circular concrete structures.

Secondly, the interface materials between high strength concrete blocks used in the shaft relinings were shown to improve the flexibility of the lining systems successfully, but, when acting as weak joints between individual blocks, decreased the strength of the whole lining systems.

Thirdly, the results from the modelling suggest that single ring concrete block linings (the design for first and third relinings) are more effective than the double ring used in the second relining.

The research work has included a study of the methodology used to obtain appropriate rock mass input material properties to use in the numerical modelling based on laboratory test data and also includes how input strength values for the concrete blocks, their joint packing materials and various forms of backfill employed during the shaft relining have been chosen and applied.

The student involved in this work has now obtained her PhD and will continue at Nottingham for the next two and a half years as a Research Associate.

## Study of stability issues associated with Polyhalite extraction

A deposit of an evaporate known as Polyhalite has been accessed at Boulby mine some 120m below the currently worked Potash/Rock Salt horizon. So far a short series of roadways have been driven and the mine has instrumented one of these to gain some basic information on rock movement and rockbolt loading at this level.

Nottingham has been asked to develop some numerical modelling of excavations made in the Polyhalite as a contribution to the mine's decision making process on how such a deposit might be mined. The modelling has been based on dimensional data supplied by the mine and the results of laboratory testing of rock samples from the newly developed workings. It is hoped to validate the modelling by reference to instrumentation data as it becomes available.

## Impact Monitoring of Mineral Resources Exploitation (ImpactMin)

ImpactMin (is an EU funded project assessing the potential of remote sensing technologies and Earth observation satellite data to characterise changes top the physical environment. ImpactMin work is being carried out across four different countries and six official demo sites (although the socio-economic strand of the project also includes Cornwall as a study site). These sites are: Russia (Karabash and Mednogorsk), Sweden (Kristineberg), Romania (Roşia Montană) and Bosnia Herzegovina (Vihovići).

CSM are leading on two elements of the project: work packages (WP) 3 and 7. WP 3 focuses on the assessing the socio-economic impacts of mining and gaining a better understanding of how mining affects people's lives. This work has been undertaken through a cross-comparative survey looking at the experiences and perceptions of people across the different sites.

WP 3 has also used interviews across the sites to gain a better understanding of what different stakeholders think about the mining industry and the impact it has on their lives.

WP7, which will be carried out over the following two years, aims to provide environmental data to ground-truth remote sensing studies of the nature and spatial distribution of contamination from mining-related activities in two typical sites in different climatic/vegetative zones in the South Urals; Karabash, Chelyabinskaya district, in the South Taiga zone, and Mednogorsk, Orenburg district, in the Forest-Steppe zone.

## Developing a Safety Maturity Model for UK Coal Operations (2010-11)

The maturity model concept is a recent research innovation within the discipline of safety management and safety culture measurement. These models were developed to allow organisations to understand their own level of safety maturity by assessing the level of compliance with various key elements of safety culture related to both management systems and human/behavioural issues.

They typically rate an organisation on a five-stage scale from a 'basic' site, displaying a 'no care' culture and 'no systems' up to a 'generative' stage where managing risks is a way of life and fully integrated systems are effectively in place. They also assist in identifying what organisations need to focus on to reach the next

level of maturity as sites at different levels are likely to find different types of tools and techniques helpful for moving to the next level.

In 2010, UK Coal plc implemented a new internal safety management system called “The UK Coal Safety Way” which consisted of 12 standards and was rolled out across all their sites. In order to assess initial compliance with the UK Coal Safety Way, a safety maturity model was developed based on the requirements and philosophy of these standards. As well as a means of assessing initial compliance, this model can be used as an ongoing assurance tool for internal and external auditors.

To date the model has been used at the three Deep mines by teams comprising of Managers, Supervisors and the Workforce. Each deep mine has identified where they are on the model and have developed Action Plans comprising of specific accountable actions to allow them to move up to the next level over the forthcoming year.

# Appendix 1 – Members of SHMRAB 2010

Mr J R Leeming, HM Inspector of Mines, (Chairman)

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, Past President, the British Association of Colliery Management;

Dr R Quinlan, Medical Director, RPS Business Healthcare Ltd;

Mr J Wood, President, the 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 2010

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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# Appendix 2 - Contact details for researchers mentioned in this review

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