Safety and health in mines research advisory board Annual review 2011

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 2011, 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 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 However, FIDESCO is not user-friendly, susceptible to false alarms and is obsolete.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 relatively insensitive to smouldering conveyor belt fires, which are the predominant type.

Previous work tested an electronic nose "Samdetect", a gaseous products of combustion detect, three types of optical, high-sensitivity smoke detectors and an oxides of nitrogen (NOx) sensor. The latter was used alongside the smoke detectors so they could distinguish smoke from diesel fume. The Samdetect 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 above ground and conditions underground has showed that the Samdetect was the most promising detector. The coal mining industry then entered into discussions with the manufacturer of Samdetect – EADS/RST, for it to be usable and certified for underground coalmines.

The manufacturers of the Samdetect (EADS/RST) have taken the commercial decision not to go ahead with development of a commercial model of their instrument to M1 or M2 certification for the present time. Other possibilities for fire detection now need to be discussed and investigated by HSE and the mining industry.

Fire detection is also being investigated for non-coal mines where M1 or M2 certification is not required. Testing was carried out at Cleveland Potash Mine at Boulby to determine the effectiveness of Samdetect in that environment. Further testing is required (although any work by HSL would be carried out as a separate project) in which the Samdetect would be programmed with a diesel exhaust distinguishing neural net in addition to the products of combustion neural net in order to minimise false alarms in the presence of diesel exhaust fume.

The work has been extended to allow HSL to provide support and independent technical advice to HSE on fire detection in mines; and publish the previous work in a peer-reviewed journal.

Early Detection and Fighting of Fires in Belt Conveyors [EDAFFIC]
The EDAFFIC project, which finished in 2011, had the stated aim of "minimising the risk of initiation and spreading of conveyor belt fires, acting on all control points of the fire initiation and propagation process". The primary results of work carried out by UK project partners (Mines Rescue Service Ltd. and UK Coal Plc) were as follows:

An appraisal of the state of the art in fire detection was carried out to identify technologies for the early detection of incipient fires on conveyors. MOS sensors were found to offer low cost and low maintenance overhead but have not been used

extensively in the European mining industry. An experimental evaluation was carried out, with the result that MOS sensors are recommended for possible use in the multi-sensor device that was developed by another project partner.

Merged visual-IR thermal imaging technology was used in conjunction with a bespoke belt conveyor test frame to detect heat from rollers/idlers. The main purpose of this work was to examine the feasibility of merged visual-IR technology as a means of early fire detection on belt conveyors in coal mining. The tests confirmed good detection of heating points which may be sources of fires in belt conveyors. The tests showed that this equipment would be suitable for portable use as well as in a permanent installation.

A test rig was developed to investigate the novel use of chemical agents in spray mist form to combat spontaneous combustion fires. The aim was to extinguish fires without the generation of water gas (hydrogen and carbon monoxide) which are potentially explosive and which can be generated when using pure water sprays. Although pure water was the most effective at extinguishing fires, hydrogen was given off. However, by using either a 100% sodium silicate solution or a 75%:25% mixture of sodium silicate and hydrochloric acid, no hydrogen was detected.

Issues of the exposure of personnel to radiative heat sources and the potential of personal cooling systems were studied. Excessive exposure to heat can inflict heat related illness (hyperthermia), skin burns and burns in the respiratory tract. Detrimental effects are exacerbated by increases in the moisture content of the air, of the clothing ensemble, and by high activity. Recommended maximum air temperatures and radiation levels, consistent with the safety of fire fighters in tunnels, were obtained.

The theoretical requirements of water mist equipment for cooling fire-fighters were studied. A gallery was equipped with temperature and humidity sensors along its length. Gas burners simulated a fire and an air flow was established to simulate mine ventilation. The spray equipment was pressurised and used with three different nozzles, each of which was tested at three pressures. Significant temperature reductions – sufficient to maintain the body temperature of fire-fighters below that at which it becomes stressed or life-threatening – were demonstrated for a substantial period of time and the results allow the correct choice of nozzle type and pressure to be selected for a range of scenarios. Favourable results led to the production of a prototype portable unit capable of providing an effective cooling mist for a period of around one hour.

The Final Report has now been completed and provided to the European Commission for publication. In addition, a guide, “Conveyor Belts in Underground Coal Mines”, was produced and will be made publically available (http://antares.aitemin.es/edaffic/) to aid mining companies in the installation of conveyor belts and in their maintenance, the implementation of new technologies for early detection of fires in conveyor belts, and ventilation management.

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 improved strategies for the prevention of fires and explosions, research into bio-degasification techniques to reduce explosion and spontaneous combustion fire risks is being undertaken. Bacteriological cultures were produced from samples of underground mine material taken from a wide range of locations at 3 UK coal mines; the locations were selected to represent areas exposed to ventilation air over a range of time scales. Laboratory tests showed that a diverse range of methanotrophic bacteria occur naturally in coal mine environments. Methylocystis bacteria were found to be prominent members of the methanotroph communities identified. Moreover, two potentially novel bacterial strains were identified, which appear to be particularly well-adapted to a mine environment. Further trials are currently being undertaken to determine optimum growth conditions and methane absorption rates.

Research into the sampling of incombustible dust content and automated stone dusting control techniques is also being undertaken. In the light of the specification/performance requirements established by existing stone dusting standards and legislation, a variety of basic optical and geo-electrical properties were investigated, to ascertain whether any further improvements in the instrumental approach to the measurement of incombustible dust content was viable.

At the time of submission of the original project proposal, there were no commercially available instruments that could be used in an underground environment to measure the incombustible content of roadway dust. Since that time, two instruments have become available, the “coal dust explosibility meter” (CDEM) developed by MSHA/NIOSH and the Fotopylox developed by EMAG. However, the need for careful sampling and sample preparation remains and these instruments cannot provide the continuous/on-line monitoring of incombustible content or roadway dust required to implement automated/improved systems for stone dusting. Moreover, the research indicates that further alternative instrumental developments are unlikely to improve reliability or to be commercially viable. Consequently, the potential use of optical methods of continuously monitoring airborne dust, combined with mathematical models to determine the distribution of dust concentrations, is now being investigated.

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.

Following on from some Chinese research, the first part of the MRSL studies examined the premise that outburst triggering and development is inextricably linked to electromagnetic emission phenomena acting at a molecular level on the coal substrate. Test apparatus was constructed with the provision to selectively impose either electro-magnetic fields (E-fields) or magnetic fields (B-fields) to examine the induced desorption characteristics of three coal samples - a UK non-outburst prone coal, a Slovenian outburst prone brown coal and a Spanish bituminous coal.

Extensive electronic design studies were undertaken on how to safely generate a high level E-field. E-field tests will commence when the E-field generator is commissioned. Baseline desorption tests were carried out on the three coals and these were followed by tests involving a high intensity magnetic B-field applied to the coal samples. Analysis of the test results undertaken so far is ongoing, but the tentative indication to date is that an externally applied field does stimulate the gas desorption process.

In the associated MRSL research concerned with the detection of electro-magnetic radiation from outbursts, work progressed on designing a laboratory EMR detection and recording arrangement.

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. The research has investigated the types of material suitable for deployment as 'airbags' underground, the inflator design and the possible use of a secondary airbag which would remain inflated for several tens of seconds, rather than just milliseconds. The research has also examined alternative outburst detection options, including direct outburst particle impingement detection, air overpressure condition detection and fast acting methanometry.

Practical airbag initiation trials commenced in two areas of the underground galleries at Mansfield Rescue Station, using an air cannon as a basis for an outburst simulator. Loaded discharge 'product' consisted of 50% dried limestone and random stone with a <50mm mesh size. Tests also included a number of high density wooden blocks, to simulate spalling.

Low Carbon Mine Site Energy Initiatives [Lowcarb].
This project is designed to investigate and to develop modern technologies and techniques that can significantly reduce the coal mining industry's carbon footprint in terms of both CH_4 emissions and CO_2 from operational energy consumption, whilst remaining technically and commercially competitive. UK partners are CSM, MRSL and Nottingham University, with further partners in Poland, Spain and Slovenia.

The underpinning research to date has included reports on the carbon and environmental footprints of underground coal mining, the potential for renewable energy at mine sites and the economic environment, covering the global picture of demand, carbon taxes and credits and specific studies into the financial environment for 'low carbon' initiatives in the UK and Poland . An inventory of EU mine production and methane emissions has been compiled and further wider report on EU and global methane has been produced, including review of the IPCC reporting guidelines.

Work by Polish partners on coal properties from Polish mines has provided detailed results, with a comparative study of Slovenian coal. Methane drainage simulation in Poland is leading to in-mine tests of optimal drainage configurations. Indicators for outburst prediction from software simulation have been specified and tests for methane occurrence with ground penetrating radar are underway in Poland, hopefully to be followed in Spain once industrial action has ceased.

A detailed report on ventilation air methane oxidisation and utilisation around the world by CSM, MRSL and a Spanish partner has supported ongoing study of the catalytic flow reversal reactor (Spain) and a gas turbine option (CSM) as novel technologies to challenge the current developing use of thermal flow reversal reactors with VAM. In this context, tri-generation mechanisms for the effective utilisation of the energy outputs are also being studied. Concentration and use of very dilute methane has been considered, but potential is low with current technology.

Conversion of the power metering system at a UK mine and analysis of SCADA data for profiling loads has been carried out by CSM, providing a detailed understanding of the electrical functions both underground (e.g. shearing, conveying, pumping) and at surface (e.g. fans, hoists). Work on load optimisation to smooth demand peaks is underway, with potential for a product for wider use.

A ventilation improvement initiative at a complex mine in Slovenia has involved installation of up-to-date gas monitoring and air flow sensors, linked to software development.

Construction and early theoretical work for a mine simulator for pumping efficiency research has been carried out at the CSM Test Mine and subsequent simulation work is commencing, with the intention of CSM incorporating actual pumping data from the Slovenian mine. This simulator has potential for a range of subsequent mining research functions.

A report reviewing surface facilities energy efficiency has been produced by MRSL.

The objective of the University of Nottingham (UoN) contribution to LOWCARB is to identify the key factors that need to be considered / evaluated for the development of a compressed air energy storage (CAES) facility utilising a mine shaft.

A series of numerical models (144 in all) has been conducted at UoN using FLAC^{2D} to investigate the effect of some factors on the development of a disused circular mine shaft as a CAES facility. We have begun with a sensitivity study of a generic mine shaft as a CAES facility in which factors shown in the table below have been varied. As this research focuses on the behaviour of the shaft liner and shaft caps under gas pressure, so the surrounding soil and rock field has been simplified to a single type of rock, which is siltstone, rather than a complex mix of soil and different types of rock strata.

Variation		**Different values**
V1: Shaft length for storage		100, 200, 400, 800 m
V2: Compressed air pressure		4, 6, 8 MPa
V3: Shaft cap material and dimension	Thickness: t	0.5, 0.75, 1, 1.25 m
	Width into surrounding rock: w	0.8, 1.2, 1.6, 2 m
	Materials*:	NSC, HSC
V4: NSC concrete liner thickness		0.4, 0.5, 0.6, 0.7, 0.8 m
V5: Grout or no grout behind the shaft liner		Yes , no
V6: Backfill or no backfill above the upper shaft cap		Yes, no
V7: Distance from the upper shaft cap to the ground surface		5, 10, 15, 20, 30 m

*NSC – normal strength concrete with uniaxial compressive strength 35 MPa
HSC – high strength concrete with uniaxial compressive strength 100 MPa
Underlined values – those used in the basic models

Table 1 Selected variations in the sensitivity study

Based on the preliminary numerical modelling, some conclusions can be drawn as following:

- The lower cap is the key area (it suffers the largest displacements) when there is backfill material above the upper cap. However, the upper cap becomes the key area when there is no backfill material above it.
- The deformations of shaft liner and shaft cap is clearly linked to gas pressure.
- When NSC was used for shaft caps in the current sensitivity study, it only remained intact when it's thickness was not less than 1 m or the gas pressure was not bigger than 4 MPa.
- HSC caps worked in all the modelling cases (whatever the shaft length, gas pressure, cap width). Deformations of HSC caps were smaller than those of NSC caps under the same conditions.
- The modelling suggested that cap width (the amount it is keyed into the strata) has a very limited influence on deformations of shaft liner and shaft caps.
- It seems that shaft length has a very limited influence on deformations of the shaft liner and shaft caps, especially when there was no backfill material above the upper cap.

- The distance between the shaft upper cap and ground surface has a significant effect on the deformation of the shaft upper cap. This distance must exceed 5 m, and 10 m worked well in case of deformations of the shaft upper cap and the backfill material above it.

Further research work will attempt to focus on the effect of cyclic loading on the stability of the shaft liner and modelling of the shaft liner's cyclic life expectancy. Additionally the next stage of the research will concentrate on identifying actual abandoned mine shafts in the UK. The researchers will be seeking to identify a site where a shaft exists that has been closed by surface capping alone and underground insets are at a minimum. The search will also concentrate on shafts sunk within the last fifty years in which the liner is concrete. Initial investigations have identified a number of potential candidate sites. The modelling exercises conducted for the generic shaft will then be extended to the shaft environment at the chosen site

Advanced tools for ventilation and methane emissions control (AVENTO)
Project partners: AITEMIN (Spain), DMT (Germany), EMAG (Poland), GIG (Poland), Hunosa (Spain), ROMANIAN MINE SAFETY EXECUTIVE, KHWSA (Poland), University of Nottingham

The main aims of project are:

- Improve ventilation monitoring systems, in order to improve safety and climatic conditions in work areas, with specific attention being given to reviewing the actions taken after severe methane incidents.
- To reduce the annual 200 billion kWh of energy used to ventilate European coal mines by using innovative "Ventilation on Demand" techniques. A more targeted use of ventilation air and cooling, as and when it is required, is to be considered.

UoN contribution:

- The development of a 1D transient mine ventilation code, to allow for the prediction of flow transients that occur after events such as fan stoppage, and the use of bypass ducts and variable air door shutters.
- The development of Computational Fluid Dynamics models of longwall and development workings. Again, the models will be transient and will look at situations such as methane clearance from a heading where the auxiliary ventilation has been deliberately/accidentally switched off.
- Both models will be validated against full-scale data, provided by other project partners.

Study of stability issues associated with Potash and Polyhalite extraction at Cleveland Potash, Boulby Mine.
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.

UoN developed some numerical models of a variety of mining excavation scenarios for working the Polyhalite. This modelling work has been extended to examine alternative working layouts in the Potash bed. The modelling has been based on dimensional data supplied by the mine and the results of laboratory testing, at the University, of rock samples from the strata column surrounding mine workings. Numerical models inevitably include a degree of simplification of mine layout and input data modification to allow them to run. The outcome of this work is, in part, a contribution to the mine's decision making process on how such deposits might be

mined, but also to develop experience with, and confidence in, numerical modelling as a planning tool in real mine situations. The latter will be achieved only from a review of actual closure data from the mine and its comparison with that predicted by the modelling.

Ground control

COmplex Mining EXploitation: optimizing mine design and reducing the impact on the human environment (COMEX)
Project partners: INERIS (France), GAUK, University of Nottingham (UoN), CERTH (Greece), GIG (Poland), GEOCONTROL (Spain), DMT (Germany), UK Coal.

This project will focus on:

- -mine exploitation with over- or under-lying old mine workings and the potential resulting hazards
- -the reduction of the impact of mining exploitation on the human environment in such conditions

For mining in underworked coal seams, (work begun under the PRESIDENCE RFCS Project) a draft methodology was developed to design mine layouts in these cases.

The work under this Project will:

- -apply this methodology to the workings at target mines
- -closely monitor their condition on drivage and face retreat
- -improve the methodology based on the experience gained

The Project will need to develop improved geotechnical numerical modelling techniques to better represent the condition of subsided rock and to couple large scale stress distribution modelling with small scale support system modelling to predict roadway support behaviour in these complex conditions.

The stress and strain caused by deep exploitation may affect old shallow mines. Ground vibration resulting from mining seismic events can be dangerous due to the reactivation of old shallow exploitation. The problem with mining seismicity is worldwide, but in EU it is still occurring in Upper Silesia Coal Basin and in German mines. It can cause discontinuous effects in near surface soils or even land collapses. Moreover, it can trigger slope instabilities in open pits, like in Belchatow lignite mine in Poland where mining seismic events have reached magnitude greater than 4.

To protect in an efficient manner surface building assets, we need to be able to predict the effect of ground movements on their stability. Recent research shows that the transfer mechanism of the strains from the ground to the building is dependent of some complex and non-linear soil-structure interactions. This project will answer the need to evaluate and reduce the vulnerability of buildings subjected to those hazards.

The University of Nottingham is mainly involved with Work Package 3. The objectives of this Work Package are:

- Establish a set of building types which are typical of buildings within coal mining affected areas and which are vulnerable to damage from mining induced subsidence.

- Evaluate the degree of vulnerability of the building types to mining induced subsidence using physical and numerical modelling.

- Develop vulnerability curves for the identified building types which define the level of damage expected based on proximity to mining activities.

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

This project commenced in July 2010. Golder (GAUK) are the co-ordinator and UK Coal (UKCOAL) and the University of Nottingham, (UoN), are partners on the project. Three Polish and one Spanish Partner also 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 solutions.

Instrumentation developments have been undertaken by GAUK and UKCOAL for monitoring soft rock behaviour and the loading and performance of the support systems used to control soft ground. Work concentrated on the development of instrumentation to determine the in-situ length and integrity of rockbolts to locate broken bolts. A TDR, Time Domain Reflectometry, technique was investigated and further investigations were made with respect to the acquisition of consistent results from the RF, Radio Frequency, method within the coal mine environment. It was concluded that for steel bolts and cables both the TDR and RF techniques were limited by ionic conduction effects related to local strata properties. TDR works well when used with 'sentinel' type rockbolts. The use of the ultrasonic technique was reinvestigated but consistent results were limited by the bolt end condition. Considerable effort was dedicated to an Acoustic Vibration technique and its potential as a viable technique for bolt length determination and degree of encapsulation was demonstrated though further development under this project will not be possible due to resource constraints.

Material properties investigations have been undertaken 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 Coal Measures rock obtained from Shotton opencast mine. With soft rocks it is notoriously difficult to obtain conventional samples for laboratory testing. The research has shown that shear box and triaxial test results obtained to date for soil-like samples prepared by breaking and sieving coal can provide reliable strength and stiffness parameters that can be used for numerical modelling of weak strata. Testing 'reconstructed' cored rock samples has also shown that glued planes perpendicular to bedding make no significant difference to UCS determination. Creep testing of intact strata samples has been initiated and increased machine capacity is now being addressed for further creep tests. Weathered samples have been produced under controlled conditions and testing of these has demonstrated a reduction in sample strength.Further testing is ongoing to differentiate between the influences of humidity and temperature and also to more fully understand microstructure changes in rock that occur as a result of weathering.

GAUK and UKCOAL are collating in-situ observation and applying appropriate instrumentation to characterise the behaviour of soft floor and sides under specific geomechanical conditions. Considerable work has been undertaken at Daw Mill for 303's panel where weaker geology and a higher stress field are leading to more challenging support conditions. The importance of manholes and drivage horizon were confirmed. An improved rib monitoring scheme is being developed.

Measurement of support performance and observation of support behaviour are being made both in laboratory test rigs and underground. Laboratory investigations have led to an improved understanding of the effects of rotation on bond failure of long tendons and the potential benefits of the large diameter split cylinder test for low confinement applications. None of the three types of alternative cuttable rockbolt tested have demonstrated improvement on the current GRP bolt in use.

Numerical modelling has commenced; the UoN is involved with development of appropriate time dependant constitutive models for simulation of soft floors and GAUK is modelling stress distributions and stress control options relevant to UKCOAL mining situations. A classic creep model has been set up in FLAC3D with back analysis against laboratory testing and this has supplied reasonable results indicating potential for analysis of coal mine soft floor behaviour when more creep properties of further rock types become available. Numerical model results have shown the significant effect of cutting horizon on rib and floor condition. The effects of variable rib dowelling densities and lengths, broken GRP rockbolts, dinting and breasting off have been simulated and the models' current underestimation of floor heave is being investigated.

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.

MRSL’s focus is on the identification and evaluation of positioning radio technologies to act as navigational aids in underground mines. This aspect of the research is being undertaken in close cooperation with the company EMAG from Poland.

Following laboratory testing, two end-user devices were developed. One is a portable (wearable) and battery powered device to be continuously carried by underground personnel. The second is a ‘beacon’ which, when placed in a fixed and known location, is used as a position reference by the mobile devices. The beacon is easily integrated into existing mine installations via an I/S Ethernet port.

Subsequently, a network comprising 14 beacons in 8 tunnels was installed and evaluated in Holman’s Test mine at Camborne School of Mines, thereby covering a significant portion of the mine. A ‘calibration mode’ in the software enabled the accuracy of the system to be checked by the simultaneous use of optical surveying equipment. The beacons were mounted in waterproof enclosures fitted with sockets for omni-directional antennas.

Earlier in 2012, the Polish partners also carried out trials of similar equipment at their test coal mine Guido and the project went on to develop and test a location/tracking and paging system based on the same technology.

The project finished in June 2012 and the Final Report is now in the process of being prepared.

Mine operations

Improved Extraction Ratios for Deep Coal Mines [IMPREX]
The project objective was 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.

GAUK was the co-ordinator of this Project. Other partners were 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 was completed in June 2011 and the final report has been submitted and accepted by the European Commission

The mining methods examined during the project fell into the following general groups:

- Improved exploitation of thick seam deposits (mainly through modified longwalling methods).
- Enhanced longwalling systems in conventional mining heights.
- Continuous miner based methods..
- Coal augering for remnant pillar extraction.

General constraints and opportunities.
A range of constraints and opportunities were identified for improving extraction ratios in Europe's "deep" mines. The most obvious factor is depth itself. Another is regulation, with apparently more regulatory constraints affecting the German industry than in the UK and Poland. For example, single entry longwalls are ruled out for Germany but potentially permissible in the UK. Another difference between states is longwall practice. Across most of Europe they are worked "skin-to-skin" with gates supported on steel arches. In the UK and Norway (Spitsbergen) pillars are left between panels to allow successful support by rock reinforcement. In the UK and Norway, great improvements in extraction ratio could be achieved if these pillars could be extracted. A final constraint is seam thickness. There are extensive thick seam reserves in Poland, but Germany has none. The UK has one thick seam at Daw Mill.

Thick seam extraction.
UK Coal and Golder examined the possibility of applying the Longwall Top Coal Caving system at Daw Mill. LTCC can extract a thick seam of coal with only a single, medium height longwall. Some 100 LTCC faces currently produce over 200 Mt/yr in China. In 2004, the method was introduced into Australia (Austar). The studies concluded that LTCC has excellent potential for improved extraction of thick seams in Europe and worldwide. No major technical impediments to application at Daw Mill were identified other than the high cost of equipment, the change in culture required and the need for retraining. However a reduced face heading width could not be achieved at Daw Mill with the equipment currently available. Also, steering problems with the large main gate support system, experienced at Austar on the first 3 faces, were cause for concern and to-date Austar has had relatively low production figures. A further potential problem for Daw Mill is that a significant proportion of reserves are in thinner sections, where there would be no benefit. Also, even where 6m plus

sections are present, an LTCC face with a 70% recovery ratio would produce only the same or less coal than 5.5 m conventional faces

.

Enhanced longwalling in conventional mining heights.

The UK's experience of single entry "shortwall" mining led to the development of an innovative longwall geometry by Golder and UKCoal, particularly suited to Daw Mill where 180m pillars are left between longwalls. This would involve placing the longwall tailgate in its current position but the longwall reteat face would span the tailgate and extend into the "finger" pillar, extracting a considerable proportion of the pillar on retreat. Modelling of this concept proved inconclusive due to the difficulties in accurately modelling stress distributions around goaf. It is expected that significantly higher vertical stress would be experienced in the face end area requiring improved rib control. Ventilation modelling concluded that forcing the fresh air along the face from the maingate and using conventional antitropal ventilation would be appropriate. An outline design and costing for a pilot study for Daw Mill colliery was produced. Current AFCs, drives and powered supports would be used. The additional equipment cost for a face at Daw Mill was estimated as £1.3-1.4 m. Examination of the current Daw Mill colliery five year plan indicated that adoption of this geometry would not facilitate any additional longwall faces in the current 300 area of the mine but it would allow an additional longwall in the 400 area realising a further 6.5 MT of reserves.

Continuous miner based methods.

Initial studies identified there was significant potential for partial extraction of subsidence sensitive remnant pillars and mining irregular areas of coal, though the hazards at depth should not be underestimated. Room and pillar mining has been successfully deployed at up to 800m depth in the USA. Firstly, three continuous miner based partial extraction systems were designed, applied across numerous panels and closely monitored at non European coal mines. These comprised a "run out and pocket" yielding pillar retreat system at a very shallow mine in weak strata, a conventional "split and fender" retreat room and pillar extraction system at a relatively shallow mine with moderately massive roof and a partial pillar extraction "yield pillar" retreating system, designed to isolate the working area from the goaf, in a moderate depth (400m) mine with very difficult to cave roof. The conclusions from these practical examples were that, in order to achieve a safe system, site specific design was necessary taking full account of local conditions and using a combination of empirical pillar strength calculations and modelling. Detailed measurements, particularly of pillar stress and rib deformation, were necessary to monitor performance against design expectations. Also, use of appropriate safety monitoring, such as autowarning telltales, coupled with a Target Action Response Plan were necessary. With these precautions, conventional split and fender room and pillar retreat mining could be successfully designed for safe high extraction ratio mining at moderate depth but was unlikely to be practical in the deeper European mines (+500m). Both the "yielding pillar" system, which divorced the working area from the goaf and the "run out and pocket" (or "fir tree") system had potential for application at greater depth. The second approach was to undertake modelling and equipment studies to investigate application of these types of system at up to 1000m depth in European conditions. A trial "run out and pocket" system was designed for a remnant pillar at 800m depth at Daw Mill with 10 – 15 m wide yield pillars and regular, larger barrier pillars. However, the mine decided against implementation at the target site.

Coal augering for remnant pillar extraction.

The general conclusion of the research into augering at depth by Nottingham University was that suitable auger designs exist and are manufactured, they can be made to fit into an underground roadway and the coal can be mined, but

geotechnical considerations will limit production, with 600 – 700 tonnes per week being the maximum. This would limit its application to small underground mining operations or, in a large mine, to help fill a face-gap or supplement longwall output.

Mine Emergency Support Technologies [EMTECH]
This project was intended 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 other UK partner involved was UK Coal. The research addressed all aspects associated with an emergency, from the infrastructure in place at the time of the incident, through to coordinated search and rescue involving mines rescue teams.

The major objectives were to provide a resilient communications 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 project was highly application focused and a number of innovations and prototypes were 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 excellent prospects for successful technology transfer and subsequent take-up of the research outputs by industry. The key innovation aspects were:

- 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, and tenability.
- 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.

The project was completed in 2011 and the Final report approved by the European Commission in May 2012. The published report should be available later this year.

Mine Shafts: Improving security and new tools for the evaluation of risks [MISSTER]
Many abandoned mine shafts are lined by multiple rings of brick. To analyse the stability of these shafts, it is important to simulate realistically the behaviour of the brickwork lining. However, due to lack of literature, the behaviour of brickwork lining is relatively poorly understood. Two issues, time and water effects on the brickwork, are particularly important in this context since the strength of the brickwork could be considerably degraded with time and chemical attack. In order to have a better understanding of the time and water effects and collect realistic parameters of

brickwork, weathering tests have been conducted. The weathering tests involve two sets of experiments:

- Immersion test: to replicate degradation of shaft/fill/capping materials.
- Laboratory test: to evaluate weathering effect on structural parameters of the test materials.

Test samples include cylindrical samples of brick, mortar, and concrete and brickwork beams designed for testing according to BS EN 1052-2.

The immersion tests are divided into four groups:

- Samples in air (base line);
- Samples in potable water;
- Samples in mine water;
- Samples in aggressive acidic solution (to accelerate the weathering process).

At different time periods, the samples will be collected from the immersion tanks and the following laboratory tests will be conducted:

- Mass loss (ML): to indicate the degree of weathering;
- Uni-axial compressive strength test (UCS): to measure E, n, σc (brick, mortar and concrete samples);
- Tri-axial compressive strength test: to measure c, f, Ψ (brick, mortar and concrete samples);
- Scanning electron microscopy, SEM: to study surface degradation (brick, mortar and concrete samples);
- Four point bending tests (FPB tests): to measure the flexural strength (brick walls).

By comparing the results obtained from different phases, the water and time effects on the material can be studied; the degradation of material properties with time and chemical attack can be examined. At the same time, the measured parameters of the material, such as the Mohr-Coulomb constitutive model parameters, will be used in the numerical models in the further analysis.

Physical modelling in the University of Nottingham geotechnical centrifuge will allow for the study of failure mechanisms of shaft linings near the ground surface. The purpose of this task is to study the behaviour of superficial soils and shaft linings post-failure and to determine the effect of discrete weakened zones within the shaft lining on the resulting subsidence. This will ultimately provide valuable data which may provide insight into the location of shaft rupture based on post-failure ground surface profiles. The centrifuge model container has been designed and constructed.

Numerical modelling will be used to evaluate the effect of the deterioration of shafts elements on overall stability. The numerical modelling at this stage aims to obtain the equivalent material properties for the brickwork (a composite material) so that the equivalent properties will be used in the modelling of the brick-lined shaft stability analysis. This stage is necessary since numerical models which replicate individual brick and mortar elements are very computationally expensive and would not be feasible for this analysis.

A flexural strength test of brickwork beams (four-point bending test according to BS EN 1052-2) has been simulated using FLAC3D models. The tests will focus on determination of flexural strength for a plane of failure perpendicular to the bed joints. These models will be updated with the brick and mortar properties obtained by the laboratory tests performed by UoN as part of this WP. The result of the experimental 4-point beam tests will also be used to validate these numerical models.

A parametric study on the effects of brick and mortar properties, different loading values, loading span and loading velocity on the deflection of the brickwork beam has been conducted. The modelling results show that stiffness and tensile strength of brick and mortar influence the flexure strength of the brickwork beam significantly.

In order to provide an international database relative to incidents directly involving mine shafts, the project required partners to collect information on incidents relevant to their country. This was undertaken, with most of the partners documenting their experiences, in terms of past incidents of mining shaft collapses, in order to identify the main types of incidents. Data collection was achieved from archive material and literature sources, together with illustrations and photographs, identifying the best representative cases for each type of incident. Analysis of the selected cases was carried out in order to identify the causes and underlying key factors. A paper covering these aspects of the study was given at the IOM3 conference in London during April 2012.

Most of MRSL's research into geophysical imaging techniques to locate old mine shafts was completed and reported last year. A state-of-the-art review was produced, covering earth resistivity surveying equipment design (20 products from 12 manufacturers), inversion techniques, pattern recognition, power sources and data transmission. The review was later extended to incorporate electromagnetic methods. A number of improvements and recommendations have subsequently been proposed and work is currently centred upon a "plug and play" system for connecting the electrode switches together in the field using less expensive patch cables. A summary report, which will include an assessment of seismic techniques, being undertaken by French partners, is due for completion this year.

Studies undertaken relating to analysis of the critical constitutive elements of shafts, which influence the risks of failure over time has been two fold. Laboratory tests were carried out, in order to evaluate the percentage of voids in three types of aggregates which may be used for shaft infilling /grouting and typical grout mixtures used for stabilisation are being tested as to their durability under conditions which may be expected in an abandoned mine. Secondly, in order to acquire data for physical and numerical modelling, MRSL are researching the durability of different reinforced concretes and additives. A testing methodology has been developed where samples are immersed in an acid solution in order to evaluate deterioration effect with time. Initial results indicate that the compressive strengths of the samples immersed in liquid have reduced by some 2% for water and some 5% for acid water.

Appendix 1 – Members of SHMRAB 2011

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 M Lawton, 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;
Mr K Stanley, National Union of Mineworkers

Others who contributed to SHMRAB meetings during 2011
Dr P Foster, Camborne School of Mines, University of Exeter;
Mr D Bigby, Golder Associates (UK) Ltd:
Mr S C Bennett, Mines Rescue Service Ltd;
Mr N Hill, HSE, Secretary to SHMRAB;

SHMRAB Secretariat
HM Inspectorate of Mines
Foundry House
3 Millsands
Riverside Exchange
Sheffield S3 8NH
UK

Appendix 2 - Contact details for researchers mentioned in this review

- **The Health and Safety Laboratory**
  http://www.hsl.gov.uk
  hslinfo@hsl.gov.uk
- **Golder Associates (UK) Ltd**
  http://www.rmtltd.com
  rmt@rmtltd.com
- **Mines Rescue Service Ltd**
  http://www.mrsl-research.com
  d.gibson@mrsl-research.com
- **University of Nottingham**
  http://www.nottingham.ac.uk/ncg
  geomechanics@nottingham.ac.uk
- **UK Coal Mining Ltd**
  http://www.ukcoal.com
- enquire@ukcoal.co