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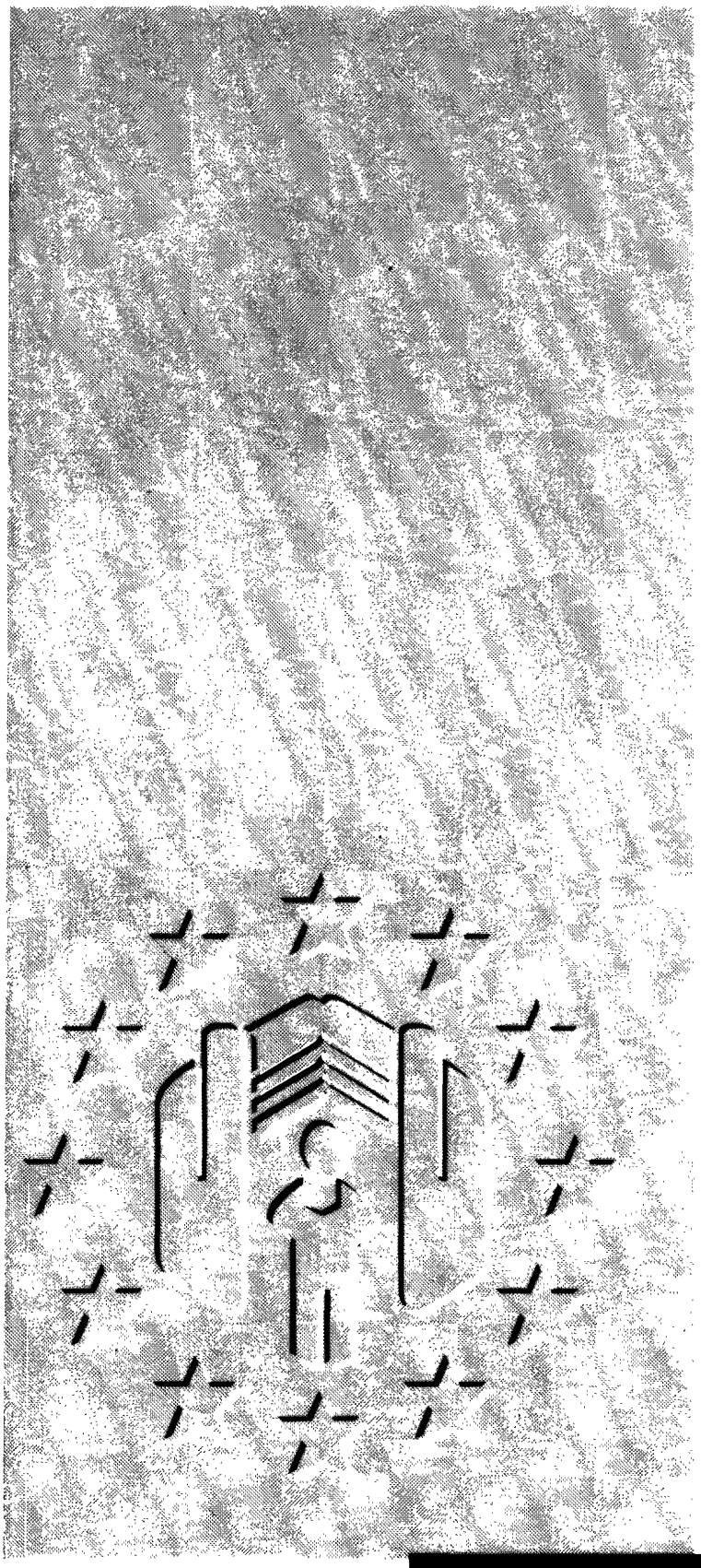

Final report on the second research programme 'Safety in mines'

Health and safety

Report
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Final report
on the second research programme
'Safety in mines'
1982-1988

Health and safety series

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health and safety

Final report on the second research programme 'Safety in mines' 1982-1988

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SAFETY IN MINING

FINAL REPORT

on the second research programme 1982-1988

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1. INTRODUCTION

The aim of this final report is to present a review of the progress made in safety research projects receiving financial aid from the Community under the second 'Safety in Mining' programme (1982-1988).(1)

The report is written in a style and a format appropriate for those producers, workers or government departments who are concerned with promoting the safety strategies and tactics needed for the application of modern mining technologies and who influence the direction of research and technology and the implementation of proved new techniques for the improvement of production, safety and health. It is not written for the research scientist or engineer, for whom the research reports themselves are available.

The report structure is as follows.

- Role of the Commission of the European Communities in promoting safety in coal mines.

- Summary review of the report and conclusions.

- Background to the need for a safety research programme. This comments on changes in mining strategies and technologies, the trend in accidents in the Community mines, the determination of research priorities and the dissemination of the research results.

- A review of each research project. These reviews group the research projects under each of the 11 categories as set out in the Second Programme. A brief commentary is made in the introduction to each section presented.

The role of the Commission of the European Communities

The Commission, in accordance with Article 55 of the ECSC Treaty, promotes and finances technical and economic research relating to production and increased use of coal and steel and to occupational safety and health in the coal and steel industries.

Prior to the establishment by the Commission in 1976 of the first research programme(2) 'Safety in Mines', some financial aid had been granted for mines safety research. This first five-year programme made possible the planning, execution and monitoring of Community and national safety research projects within the framework laid down in the programme.A sum of 7.5

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(1) OJ C 195 of 29 July 1982 (Translator's note: DE text has "January")

(2) OJ C 10 of 14 January 1977

million ECU was approved and the 66 projects selected received financial aid, generally to the extent of 60% of the cost of the project. It also enabled certain research work of common interest to be jointly carried out on a coordinated basis by research establishments in the different countries of the Community.(3)

The second programme 'Safety in Mining' was introduced in 1982, again for a period of five years, but in the event ran until the end of 1988. A sum of 12.5 million ECU was approved to fund 79 projects. A comparison of the project distribution over the different fields for the Second Programme showed that 48% were directed at two fields, namely Fires and Explosions. This was a sizeable increase of 33% over the First Programme and was a measure of the successful work carried out in that programme. Accident prevention projects attracted little attention. Table 3 (Translator's note: DE text refers to "Table 1") shows the distribution over the various fields. The pattern of fields is broadly the same in both programmes.

Other programmes administered by the Directorate-General 'Employment, Industrial Relations and Social Affairs" (DG V) are the Health in Mines(4), Ergonomics(5), Medical(6) and Pollution in the Iron and Steel Industries(7) programmes. Technical and economic research are managed by the Directorate-General for Energy (DG XVII).

The manner in which DG V organises and administers the safety programmes has not changed between the First and Second Programmes. Assessment of project priorities and project progress is carried out by various committees. First there is the Experts' Committee which annually discusses and makes recommendations on the research proposals put forward by each country within the budget fixed by the Commission. Their recommendations go forward to a Committee of Producers and Workers on Industrial Safety and Medicine and from there to a Committee of Government Experts and thence to the Commission for final approval.

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(3) Final Report on the first research programme 'Safety in Mines' 1976-1981 Doc. EUR 10873

(4) 5th Research Programme on Industrial Hygiene in Mines (OJ C 332 of 8 December 1983)

(5) 6th ECSC Programme of Ergonomics Research (OJ C 66 of 14 March 1991)(Translator's note: DE text refers to "19 February")

(6) 5th ECSC Medical Research Programme (OJ C 47 of 19 February 1988)

(7) 5th ECSC Research Programme on 'Technical Control of Nuisances and Pollution at the Place of Work and the Environment of Iron and Steel Works' (OJ C 338 of 31 December 1985)

In June 1988 the First Joint Research Programme on Safety in the ECSC Industries(8) - coal and steel - was imposed on both the coal and steel industries.

Mention should be made of the work of the Safety and Health Commission for the Mining and Other Extractive Industries (SHCMOEI), which produces an annual report with accident statistics and reports on the work of the 12 Working Parties, which examine safety needs, safety legislation, group accidents and carry out investigations into aspects of interest such as training, safety campaigns, etc.. They report to the Safety and Health Commission itself. It was the SCHMOEI which provided the impetus for the projects on 'Training to Improve Accident Prevention'.

(8) OJ C 325 of 29 December 1989

2. SUMMARY AND CONCLUSIONS

This summary is prepared for those who do not have the time to read through the report. It gives the background to changes in the mining industry and the technical changes being made which will have an effect on safety. Brief comments are made on work in each of the research fields. Conclusions are drawn.

2.1 BACKGROUND TO THE SAFETY PROGRAMMES

During the period in which this Second Safety in Mining Research Programme has been running the European coal mining industry has experienced - and still is experiencing at the commencement of 1990 severe and inescapable economic changes which have required it to reduce production and improve costs. This has led the industry to review the production policies and methods of working it followed in the 1970s. Throughout the 1980s, it has therefore been replacing the methods of the 1970s by methods in which production is concentrated on higher-capacity and more efficient underground production units.

These changes have been made possible by

- replacing the plant and equipment with new, more powerful and greater-capacity generations of technical equipment,
- installing such plant with remote control and automation techniques in fully integrated mining systems,
- providing services with facilities and capacities to support these systems,
- installing machine and system monitoring and management information systems for the real-time control and command of the mining systems.

The safety implications of these changes are that

- new hazards are introduced, or are developed, which may or may not modify previously known hazards;
- much smaller, but more highly trained and proficient, interdependent work teams are required, who must be made continually aware of changes and hazards;
- the all-accident frequency rate, which has been progressively reduced through the introduction of this new technology, will continue to show a reduced rate of improvement as full implementation is reached; absence, for whatever cause, and behaviour-related accidents affect safe and effective working;
- as the changes are taking place at a faster rate than those of previous major changes in methods of work there is need to identify early the research required to provide integrated solutions for a safe man/machine/mining environment relationship.

2.1.1 Safety in mines research programmes

The first Safety in Mines Research Programme(9) allocated 7.5 million ECU to 66 projects. The Second Programme allocated 12.5 ECU to 79 projects - an increase in real terms of about 3 million ECU. The First ECSC Joint Programme(10) allocates 26 million ECU for the two industries. Safety-related projects are also to be found in the medium-term health and ergonomics programmes.

The most noticeable points are:

- the distribution of the projects between the research fields, and in particular the high proportion directed at solutions to what may be called 'the potential disaster';
- the increase in projects using new measuring, monitoring and computer analysis techniques to identify hazards at the planning, design and operational stages;
- the very small number of projects dealing with accident prevention.

2.1.2 Dissemination of results

Both programmes refer to the fact that research results are disseminated through the members of the "expert groups", Euro-Abstracts and final reports on the programmes. Over the years, this method has been shown to be reasonably effective in informing all those who require access to this information or who need to assess the research results. Conferences and information days are also organised for interested parties.

2.2 SUMMARY REVIEW OF PROJECT PROGRESS

An arbitrary classification of projects may be based on the following subject areas:

- prevention of potential disasters,
- actual rescue operations,
- safety research on relatively new technical developments which have been made in a variety of technologies,
- research into new investigative methods in order to promote a better understanding of natural phenomena and how these characteristics are affected by methods of working,
- personal accident prevention.

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(9) OJ C 10 of 14 January 1977
(10) OJ C 325 of 29 December 1989

It is clear that the use of measuring instruments, sensors and computer analysis techniques has extended capability to assess safety at both planning and operational stages. It is also clear from a review of projects supported by other European Commission programmes that these too, have safety features in their aims. It should be everyone's concern that there must be coordination and integration of the various disciplines engaged in both research and operations in order to obtain the desired results for both safety and production.

2.2.1 Accident prevention

A Community project was carried out in order to examine the training requirements for improved accident prevention. This was probably the most important project in the programme insofar as it looked at personal accident prevention.

The essential factors established that participation of the operators in an activity, meeting on a regular basis to discuss safety problems with the supervisors, with engineers and management, was a means of improving safety awareness and of reducing accidents and near-miss events. Instruction in problem-solving techniques, in hazard recognition, in leadership was found to be necessary. It was also necessary to establish at the mine a recognised organisational hierarchy wherby information flowed in both directions. The success of this project and consequent developments in Charbonnages de France - in particular the success in reducing the accident rate in the HB Lorraine by 84% - and in Bergbau AG Niederrhein are very encouraging. More attention should be devoted to evaluating and applying the results of this research and its applications. An improvement in accident reporting was examined by one project with a view to improving data on behaviour-related accidents.

Other projects concerned the application of microprocessors in order to improve safety and the testing of overload devices for plough chains.

In view of the new noise legislation one project was devoted to the means of predicting workplace noise. Laboratory studies were carried out in order to establish noise control techniques and develop improved hearing protectors.

2.2.2 Fires

The projects in this programme were extensions of work in the First Programme or of other research work. The projects may be described under the headings of gas and fire detection, testing materials for their fireresistant properties and fire control.

Good work has been done on sensors, especially for gases other than CO and CO_2, such as HCl, which is given off in the thermal decomposition of 'plastic' conveyor belting, electric cable coverings and other 'plastic' materials. Good and reliable sensors and measuring instruments are the essence of a mine air monitoring system. Just as important are the computer programs in the management control system which give a real-time picture of the gases present in the mine ventilation and which can present the information without false alarms. Sensors with the required measuring ranges are commercially available for the various gases.

The development of monitoring systems has progressed and field trials indicate their reliability and acceptability. However, the stage has not yet quite been reached when the fire detection system will identify all heatings and fires. There seems to be a need for an industry-wide survey of experience on the basis of which further research aims could be identified.

2.2.3 Explosions

It has been reported that the average yearly number of explosions causing group accidents had not declined as of 1986, although the number of casualties had been substantially reduced. This is due in no small measure to previous research work and the implementation of the preventive techniques. Whilst explosions due to shotfiring have been almost eliminated, those due to frictional firedamp ignitions have not. It has also been reported that firedamp and dust explosions in single entry roads where there is auxiliary ventilation accounted for 78% of all such explosions. This area therefore still requires particular attention.

The projects are grouped under two main headings and one minor one. In the first group, six projects examined the problems of frictional ignitions and some possible remedies. From these research results and those produced from research elsewhere, systems have been designed which integrate several of the research findings into practical solutions.

The problems of build-up of explosions and the prevention of propagation of explosions have been studied by 11 projects. These have simulated in surface galleries possible circumstances in inclined roadways where methane layers and plugs of methane are present and investigated what effect larger roadway cross-sections have on the design of means of arresting explosions. Excellent work has been done on triggered barriers to the extent that West German mine regulations now specify them for roads where headings or roads are driven by mechanised means. The safety systems required by long drivages must be comprehensive, i.e. they

must cover both the suppression of explosions and the provision of safety havens as well as personal self-rescuers of adequate duration. This latter work on the design of havens for safe means of evacuation of miners was actually recorded under 'Fires' and that for personal self-rescuers under 'Rescue'. It was felt more appropriate to summarise progress under "Explosions".

2.2.4 Rescue

Modern mines are working deeper seams, with higher ambient temperatures, and in which the production areas are extensive and some distance from the shafts. It is essential that rescue teams are not only equipped to work in hot atmospheres but also that the suitability of rescue workers themselves to accommodate to such conditions is tested beforehand.

2.2.5 Monitoring, automation and communication

This is an important subject area and one which is likely to expand. However, care needs to be taken to ensure that the requirements of safety monitoring are fully understood by those designing the central monitoring projects to be found in the Medium-Term Research Programme and other research outwith these safety programmes.

There are eight projects in the field, five in the monitoring field and three in communication. Research on four projects has yet to be completed.

Two of the equipment monitoring projects are concerned with the stopping and starting of booster fans and the switching off of electric power should the methane levels exceed the permissible values.

Communication, direct with personnel, for control of transport equipment, for the selective call of persons working in an isolated area, and for emergency reasons, has become a necessity in mines with modern layouts, and which use automated plant.

2.2.6 Transport

There are only four projects in this field of research, of which one was related specifically to accident prevention. The others were concerned with design improvements. In view of the fact that in 1985 34% of all fatal accidents occurred on transport systems, and that the >56 day accidents had been at stagnation level for 10 years, the lack of research is disappointing.

2.2.7 Electricity

Modern mining systems have greater power requirements. Design of control gear, cables and cable couplers for voltages up to 5000 volts is needed.

The three projects in this field looked at

- the safe use of electricity underground where trolley locomotives are employed,
- a possible lighter design of FLP switchgear based on USBM research, but which turned out to be unsuitable for European standards,
- the limits of safe high-frequency energy transmission in the range 10 to 100 kHz (this work is not completed).

2.2.8 Materials

There were no projects in this field. The testing of materials for fire resistance is to be found under 'Fires'.

2.2.9 Working methods

Two of the three projects were concerned with the preparation of plans. In one case the project examined the prerequisites for the preparation of coloured mine plans, established what was needed and advised early trials in order to gain experience. In the other case the project followed on from work in the previous safety programme which was to develop a computer method of determining whether hazards, such as mine fires and zones of high strata pressures, could be identified. Good progress was reported.

The third project, which still has to be completed, was aimed at the filling of roof cavities on shield-supported faces. This is an important project in view of the number of falls-of-ground accidents on the face. Criteria for good design were established.

2.2.10 Rock and gas outbursts

There were four projects involved in the microseismic monitoring of strata in order to forewarn of possible outbursts. A distinction could be made between what is termed 'normal' and 'outburst' activity. Further development of equipment and underground trials were thought to be necessary. It may be concluded that prediction of gas outbursts is possible with the methods used.

2.2.11 Surface operations

Neither of these projects has been completed. The areas studied were as follows.

- Reduction in the risk of accidents from rockfall and bench failures in opencast mining. A computer program was written to permit the detection of the geometry causing ruptures. Studies have also been made of bolting systems for bench walls in level strata.

- Development of a warning device for surface vehicles which would detect the presence of personnel. Trials of a commercial type were unsatisfactory and a further design has been ordered.

2.3 CONCLUSIONS

All projects have done what they set out to do. Many of them conclude that more research must be done. In view of the rate of introduction of new, proven techniques in a wider range of mining conditions and the curtailment of research facilities and finance in the mining industries of the Community, it would seem imperative that research priorities be urgently reviewed. Such a review should assess the present state of availability, and the success, of proven methods and plant and what benefits would accrue through pursuing certain projects and not others.

In the last 15 years there has been a significant decline in the frequency of serious and >3 day accidents, while over the entire reference period (1958-90) only fatal accidents have shown a clear long-term decline in frequency (see also Table 1).

In order to achieve a further reduction in accident frequency, greater consideration should be given not only to technical but also to organisational aspects and human and behavioural factors. In the USA, for example, research into organisational and behavioural factors associated with mine safety is well advanced.

In view of the fundamental need to "design in" safety from the very beginning of new work, whether it relates to machines or integrated mining systems, it is essential that there be integration of the various Community mining research programmes.

In the mining world press in general, technical papers on safety matters are few. Technical papers describing successful production methods rarely, if at all, report the safety and accident aspects. Improvement is needed. The

methods of communication of research results, as laid down in the first and second programmes, have been poor. An integrated system of communication for all safety, health protection, medical and technical research programmes is urgently required.

3. THE BACKGROUND TO CHANGES IN THE INDUSTRY AND SAFETY

Continuing improvements to productivity, safety and economic performance are essential to the wellbeing of the industry and all those who work in it. This requires that the three resources available - mineral, human and technical - must be integrated in every operation in order to achieve the business objectives and provide an acceptable, safe working environment. When one resource changes so must the others be changed in order to achieve the required aims. The factors influencing change are examined because they have an important bearing on safety.

Changes in mining strategies

During this past decade the European mining industry has, in order to remain competitive, closed some mines and merged others. At these remaining mines production policies have been directed at reducing working costs by concentration of production on a smaller number of working faces. Mines have been able to do this through the introduction of a new generation of costly, high-powered, semi-automatic and automated plant and equipment into the mining systems. Monitoring and control systems have been installed in order to raise the utilisation rate of these mining systems and to maintain a safe working environment.

Technological change

The task of maintaining and improving safety in a mine is never-ending as a result of changes in mining conditions and methods and of the introduction of new technologies. New technologies have improved safety and productivity. Such changes influence the methods, systems and services already existing in the mine. Whilst some of the hazards and risks associated with the adoption of new techniques can be foreseen, others are only manifest when the new methods have been put to use and experience gained in day-to-day operation. But it is not only in new systems that accidents occur. As the accident statistics show, well-established systems in those 'other places' where changes are infrequently made account for some 33% of total underground accidents.

The introduction of shield supports and heavy-duty face equipment, for example, has markedly reduced face accidents, particularly due to falls of ground. Falls-of-ground accidents at the face T-junction do not show a like reduction. Here technology has not provided the solutions. The speedy transfer of this large and heavy equipment between the old and the replacement face introduced handling problems previously not experienced.

The introduction of mechanised cutting and loading into coal winning and mechanised drivages has substantially reduced the number of shots fired and the explosions and accidents due to projected material from the blasting operation. But in machine cutting frictional ignitions occur and the frequency of ignitions due to this cause has been increasing. A policy of providing highly productive, long-life production faces requires long, single entry mechanised drivages, with auxiliary ventilation, which have altogether different safety problems from those encountered in the short drivages of a few years ago. The concentration of output at ever fewer faces has not had a similar effect on accident rates in the transport services.

Changes in management control

These changing and interacting technologies have resulted in the working of a reduced number of faces for the same output. The installation of computer data gathering and analysis techniques which monitor machine health and mine ventilation has provided mine management with a tool which enables it, through an improved and multidisciplinary approach to problem solving on the basis of real-time data, to organise for better machine and system performance and control of the mine ventilation and atmosphere, thereby increasing safety, mine output and machine utilisation time.

It is the duty of those who plan and design the new methods and working procedures to collect data and collate experience, so that they can assess risks both prior to and consequent on later operation. It is also their duty to assess organisational changes needed to monitor and control operations for safety and productivity. Such changes require the active and continuous involvement of all through personal participation in an organised structure. Decisions have to be made more quickly and on the spot in modern mining methods and operators must be trained to identify problems and discuss them in organised meetings with supervisors, engineers and management. As teams of operators on the mining tasks are much reduced, accidents to individuals and absenteeism cause both safety and production problems. The knowledge and skill required to operate modern systems and contribute effectively is increased and requires frequent updating; likewise the task of the supervisory staff is greater and requires more technical and organising competence for the integrated systems being controlled.

Management has a greater task than before to assess the competence, skills and experience, education and training required by all those who have to operate and manage the operation. This training must not be just technical but should provide those participating with the opportunities and abilities to assess, discuss and advise on solutions to problems affecting them and their operation. Much research and exchange of experience is needed on how to improve a person's contribution through participative working and other social programmes. It is clear that there is no one solution and that an integration of several techniques is required. Management's task has changed but the successful implementation of such changes is fully understood by only a few.

Changes in the accident record

An analysis of trends in accident frequency can be used to assess the effectiveness of research. A comprehensive analysis of accident frequency rates(11) in Community coal mines (with the exception of Spain)(12) from 1958 to 1990 shows (see Table 1) that:

- rates for fatal accidents have declined steadily throughout the reference period;

- rates for serious accidents(13) increased until 1975 and have declined significantly since 1976;

- rates for >3 day accidents have declined significantly since 1976 in Germany and the United Kingdom and since 1986 in France(14).

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(11) Accident frequency rate: number of accidents divided by hours worked (in millions)
(12) Spain is not included in this analysis as it became a Member States at a relatively late stage and has only been able to make use of ECSC social research for a short period
(13) Serious accident: >56 day accident
(14) Since the United Kingdom changed its system for collecting accident statistics from 1986, data are no longer directly comparable to those from other Member States. It has thus become impossible to continue with Community-wide accident statistics for underground accidents in mines. From 1986 onwards, assessment is based on individual data from Member States.

TABLE 1

Accident rates per million working hours and output from coal mines in the European Community

	Yeare					
Severity of accident	1958	1970	1971	1976	1985	1989
1. Total accidents (>) days)	-	-	180	155	94,5	
2. 4-20 days	-	-	114	101	56,15	
3. 21-56 days	-	-	51	42	27,30	
4. < 56 days	13,55	15,05	15,09	11,7	10,8	
5. Fatal accidents	0,61	0,43	0,44	0,30	0,26	
(Absolute figures	(770)	(188)	(182)	(170)	(107)	(87)
Output in kg/working/ hour	200	388	398	417	474	603

This trend has been heavily influenced by progress in mechanisation and automation, improved working procedures and training and a change in attitude with regard to danger and the observance of regulations.

ECSC research, together with projects carried out at national level, has played a very important role in reducing accidents.

In 1982 the SHCMOEI initiated a joint project 'Training to reduce accidents'. The principles for participative action determined by the French report have been adopted in the French coal industry. The statistics reported by HB Lorraine since then show a remarkable reduction of 84% in the accident rate per 10^5 shifts. Elsewhere in the world individual companies have introduced like schemes and report accident reductions.

One specific example of the success of ECSC research projects is the sharp decline in the number of group accidents in mining during the last 15 years.

Between 1975 and 1985 there were 13 group accidents, of which nine were caused by firedamp and dust explosions. There were two falls-of-ground accidents.

An analysis of firedamp and dust explosions (the "typical" mining accidents) shows (see Table 2) that the average number of workers killed in each explosion has declined sharply over the last decades, while the average number of explosions per year remained almost constant until 1985. This shows the success of measures to reduce the effects of explosions. Here, too, ECSC research projects have clearly had a significant effect.

TABLE 2

Firedamp and dust explosions in EC coal mines

Period	Explosions (Total)	Fatalities (Total)	Employed below of ground (Average)	Number of fatalities per year per 100.000 employees	Output (Average) in mio t/year	Number of of fatalities per explosion
1958/64 (1)	8	423	325.000	18.4	237	52.9
1965/74 (2)	9	146	311.000	4.7	215	16.2
1975/85	9	71	331.000	1.95	230	7.9
1986 - 31.5.88	-	-	248.000 (3)	-	189 (3)	-

(1) Community statistics for underground coal mining accidents were introduced in 1957.
(2) Including the UNited Kingdom after 1972.
(3) Including Spain and Portugal.

Changes in research priorities

The number of projects supported in the First and Second Safety in Mines Research programmes is set out in the following table, with a breakdown by research field.

TABLE 3

Mines safety research programmes	1	2
Research field	Numbers of Projects	
Accidents and accident information	2	8
Fires	22	20
Explosions	10	18
Rescue	2	9
Monitoring, Automation, Communication	6	8
Transport	nil	4
Electricity	6	3
Metallurgy/Materials	12	nil
Working methods	6	3
Rock outbursts	nil	4
Surface operations	nil	2
Total Projects	66	79
Total Cost (million ECU)	7.5	12.5

There is no doubt but that research work is being carried out on behaviour-related accidents, on absenteeism and other social work problems. Most of this work is to be found in the United States of America and the results are widely disseminated in the USBM Information circulars. The Community Ergonomics Programme contains a few such projects.

It is not the purpose of this review to direct attention to priorities in the Community safety research. That is the task of the experts and the management of the mining industry.

Changes in the dissemination of research results

There has been no change in the policy for disseminating results between the two programmes, nor is any change proposed in the First Joint Research Programme.

The policy statement for the second programme indicates that members of the committees of experts will disseminate results and that a wider dissemination will be made through the Euro-Abstracts published by the Commission. Dissemination of the results of the second programme projects has been poor. Other Community mining and ergonomics programmes organise conferences so that mine management, supervisors and men can hear presentations and discuss them. It can safely be said that in the mining literature safety papers and information are poorly represented.

It must be said that mine management must think SYSTEMS. For this they must coordinate and integrate the input of the various technical professions in the preparation of plans. It seems only logical that where there are research programmes, such as are found in the Community, there should be an integrated approach to the dissemination of the results of safety and production research.

4. SUMMARY REPORTS ON PROJECTS

LIST OF RESEARCH PROJECTS

Abbreviations used:

Federal Republic of Germany:	
Bergbau-Forschung	BF
Deutsche Montan Technologie	DMT
Ruhrkohle AG	RAG
Steinkohlenbergbauverein	StBV
Versuchsgrubengesellschaft	VG
Westfälische-Berggewerksschaftskasse	WBK
Belgium:	
Coordinatiecentrum Reddingswezen	CCR
Institut National des Industries Extractives	INIEX
Kempense Steenkolenmijnen	KS
Poudreries Réunies de Belgique S.A.	PRB
Instituut vor Reddingswezen, Ergonomie en Arbeidshygiëne VZW.	IREA
France:	
Charbonnages de France	CdF
CERCHAR	CERCHAR
Chambre Syndicale des mines de fer	SAMIFER
Houillères du Bassin de Lorraine	HBL
Institut National de l'Environnement Industriel et des Risques	INERIS
United Kingdom:	
British Coal	BC
Institute of Occupational Medicine	IOM
Health and Safety Executive	HSE
Spain:	
Suministros Adaro SA	SUMINISTROS

Research projects are identified by project number and title.

4.01 ACCIDENTS

4.01.1 Accident prevention

072	Training to improve accident prevention	KS
073	Training to improve accident prevention	CdF
074	Training to improve accident prevention	Middlesex Polytechnic
075	Training to improve accident prevention	RAG & WBK
133	Utilisation of accident data to improve safety in the human factors aspects of system design	IOM

4.01.2 Design improvement

079	The application of microprocessors in mine plant monitoring and control systems A specific example - Train arrestors	HSE
093	Overload control for conventional drive systems and pneumatic equipment	WBK

4.01.3 Noise

094	Noise prediction and control	BC

4.02 FIRES

4.02.1 Gas and fire detection

080	Detection of spontaneous combustion underground by the identification of an indicator gas	BC
103	Automatic computer alarm program for the early detection of spontaneous combustion and mine fires	BC
120	Detection of spontaneous combustion using specific indicator gases	BC
111	Development of sensors for CO, total products, of combustion, NO_2, NO_x, CH_4, and total flammable gases in mine atmospheres using solid-state sensors combined with microprocessor techniques	HSE
138	Feasibility of detecting overheating conveyor belts by measuring hydrochloric acid vapours in the air	CERCHAR
139	Use of mass spectrometers in underground fire warning systems	DMT
119	Trials of fire protection devices -2nd continuation	DMT
081	The protection of underground conveyors against fire	BC
140	Testing of equipment for the early detection of fires	DMT
151	A personal lighting and gas monitoring device for miners	SUMINISTROS

4.02.2 Material fire tests

076	Study of the thermal decomposition of polymeric materials used underground in mines	CERCHAR
097	Fire gallery tests on mining equipment made of plastic materials - continuation	DMT
098	Fire gallery tests for non-metallic materials intended for underground use	BC
102	Propagation of fire along electric cables and lines	VG
121	The behaviour in a fire of equipment made of polymeric materials as used underground	CERCHAR
105	Harmonised ignition test rig	CERCHAR
141	Test rig for harmonised fire resistance tests of hydraulic transmission fluids	VG

4.02.3	**Fire control**	
082	Use of new CO measuring equipment and CO fire detectors for improved fire monitoring in belt conveyor roads with large ventilation airflows	WBK
104	Study of pressurised havens	CERCHAR
122	Improvements in stopping construction methods	CdF HBL
4.03	**EXPLOSIONS**	
4.03.1	**Frictional ignitions**	
100	Statistical evaluation of frictional ignitions on longwall faces	BC
106	The use of surface rigs to study frictional ignitions and their suppression	BC
087	Processes for eliminating ignition hazards presented by frictional sparking	DMT(WBK)
108	Adaptation to French mining conditions of Community rules for reduction of the risk of firedamp ignition by picks - Application to the development of shearer drums	CERCHAR
084	The effects of pick design parameters on ignition probability	HSE
088	Water supply for a shearer venturi	BC
4.03.2	**Explosion control**	
124	Study of firedamp and/or dust explosions in particular configurations	CERCHAR
107	The feasibility of using aerodynamic models to study the local build-up of methane gas and risk of frictional ignition in coal mines	IOM
125	The build-up of explosions in large roadway sections	DMT(VG)
083	Investigation of explosions with long build-up distances (>150m) and ways of controlling them	DMT(VG)
085	Partial inertisation with nitrogen as a means of preventing the initiation and propagation of a coal dust explosion	CERCHAR
099	The Belgian system of triggered barriers: technical applications, tests and improvements	PRB
123	Development and testing of mobile explosion barriers in various roadway cross-sections	DMT(VG)
143	Development and testing of new types of suppressant containers to be installed in any position as underground explosion barriers	DMT
144	Barrier protection against explosions	BC
078	Comparison of different methods of sampling neutralised dust in coal mines: statistical studies and conclusions	INIEX

115	Comparison of different methods of sampling neutralised dust in coal mines: statistical studies and conclusions	INIEX
152	Effectiveness of triggered barriers against explosions in auxiliary-ventilated workings	INERIS

4.03.3 Use of explosives

142	The use of bulk-loaded slurry explosives in rock drivages in mines susceptible to firedamp	CERCHAR

4.04 RESCUE

4.04.1 Working times in hot atmospheres

116	Duration of rescue service operations in hot and humid underground workings	BF
117	Duration of rescue service operations in hot and humid underground workings	CCR(IREA)
146	Permissible wearing times for rescue personnel using new self-contained breathing apparatus	IOM

4.04.2 Rescue of trapped miners

110	Improvements in systems for rescue of trapped miners	CdF
130	Method of drilling through fallen ground to supply trapped miners or fight fires	DMT(BF)

4.04.3 Personal rescue equipment

145	Laboratory tests, practical trials and further development of short-term oxygen self-rescuers	DMT(HGRW)
147	Possibilities for the use of portable personal escape apparatus	HBL

4.04.4 Development of portable sensors

109	Measuring system with continuous data transmission for mine rescue brigades	RAG

4.04.5 Test procedures for rescue apparatus

131	Development of testing and assessment procedures for escape apparatus and oxygen self-rescuers	BC

4.05 MONITORING, COMMUNICATION, AUTOMATION AND REMOTE CONTROL

4.05.1 Monitoring plant and equipment

090	Centralised monitoring applied to hazard control in a mine	CERCHAR
129	Time-dependent changes associated with the stopping and restarting of booster fans	BC
128	Safety measures for overhead monorails - communications and control	BF
149	The development of a reliable communication system for recording mine atmosphere and ventilation data and for shutting down electrical apparatus in mechanised drivages and production districts (Parts 1 & 2)	DMT(WBK)
101	Continuation of project 7255-20/063/03 Falls of ground in iron ore mines	SAMIFER

4.05.2 Communication with personnel

126	Radio communication underground, if possible without special waveguides	DMT(VG)
127	Multiplex communication between production districts of a mine	SAMIFER
148	Selective call, alert and surveillance of personnel in isolated situations or with no fixed place of work	CERCHAR

4.06 TRANSPORT

4.06.1 Transport systems

091	High-speed rail-mounted materials transport	BC
092	Inbye materials handling	BC
112	Development and construction of a safer emergency braking system for overhead monorails	DMT(WBK)

4.06.2 Testing of equipment

086	In situ non-destructive testing of steel cord conveyor belts	DMT(VG)

4.07 ELECTRICITY

4.07.1 Study of flameproof enclosures

077	Investigation into the safety of enclosures for electrical apparatus for which wide-area flame traps provide pressure relief experimental study	DMT(WBK)

4.07.2 Safe use of electricity below ground

113	Improved safety in the use of electrical energy in coal mines - Study on limiting the risks resulting from transfers of potential in non-current-carrying metalwork	CERCHAR
136	Establishing the limits of intrinsically safe high-frequency energy transmission	DMT(WBK)

4.08. MATERIALS TECHNOLOGY

No projects

4.09 WORKING METHODS

4.09.1 Falls of ground

114	Safety of the face crew when working under areas of roof fall, particularly on shield-supported faces	DMT(BF)

4.09.2 Hazard identification

095	Requirements for reproducible mine plans in colour - establishing a frame of reference	DMT(BF)
096	Recognition of specific hazards from the mine plan	DMT(BF)

4.10 ROCK AND GAS OUTBURSTS

4.10.1 Prediction of hazards

089	Integrated microseismic monitoring and early warning systems for outbursts of coal and firedamp (PART I)	BC
089	Integrated microseismic monitoring and early warning systems for outbursts of coal and firedamp (PART II)	BC
134	Evaluation of environmental and operational factors in districts liable to ourbursts of coal and firedamp	BC

4.10.2 Study of rock quality

137	Investigations of strata strength in the roof of seams liable to rock outbursts	DMT(BF)

4.11 SURFACE OPERATIONS

4.11.1 Opencast mining

135	Safety of personnel in the vicinity of mobile plant	CERCHAR
150	Prediction and prevention of rockfall in surface mining	CERCHAR

4.01 ACCIDENTS

This field of research attracted little attention in the First Research Programme[1]; only two projects were submitted. One related to the better recording of accidents and the other to investigations and trials of transport equipment. This Second Research Programme supported five projects directed at some ways and means of reducing accidents and three others related to design improvements and noise.

In the Second Programme, the content of this field was based on the assumption that research should be directed to the identification of hazards in existing and new mining methods and equipment, the analysis and presentation of accident data with the aim of developing methods of investigation of accidents, ways of imprving individual attitudes to safety and the harmful effects of noise.

During the period covered by the two safety research programmes the European mining industry has undergone radical changes. Changes in technology and closure of mines have enabled production efficiency to be increased and accidents to be reduced. The technological changes have allowed production to be concentrated on a smaller number of highly productive faces and the numbers of men engaged in face and roadway drivage operations to be reduced. Monitoring and control of operations, of the ventilation and other services have enabled management to control those operations more effectively.

As a result of all these changes the total >3day underground accident frequency rates per million manhours have steadily improved. From a high of 170.6 in 1975 the total accident frequency rate, as reported by the SHCMOEI, has decreased to 94.5 in 1985. However, the rate of improvement slowed down. Particularly noticeable are the fatal and >56 day accident frequency rates, which have stagnated or even deteriorated. The beneficial influence of the strong improvement in face accidents, as a consequence of the introduction on faces of shield, or heavy-duty supports and equipment during the early part of the period, has disappeared as the majority of faces have been equipped.

The accident frequency rate in the category 'falls of victim' shows that although there has been a 20% improvement in the total accident rate for >56 day accidents the rate has deteriorated, whilst that for accidents due to falling objects has not improved.

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(1)OJ C 10 of 14 January 1977

When those accidents are examined which occur in the different locations, as defined by the SHCMOEI, it is seen that, whilst the all-accident frequency rate for the face has decreased by 59%, that for 'other places' has decreased by only 16%.

Behaviour-related accidents have been shown to form a large percentage of all accidents. The figures quoted above bear this out. Early in the programme the SHCMOEI initiated a four-country joint project which was aimed at evaluating what better training methods, aimed at accident prevention, could be introduced. In view of their importance the reports are summarised in more detail than most other research projects. The fundamental concept of 'participation' described in the reports, as practised by regular meetings of operators, supervisors and management in an organisational structure, was endorsed. This concept has been adopted in CdF, HB Lorraine, with significant reductions in accident rates and also in the RAG, Bergbau Niederrhein.

Accident prevention	072, 073, 074, 075, 133
Design improvement	079, 093
Noise	094

4.01 ACCIDENTS

4.01.1 Accident prevention

4.01.1.1 Training to improve accident prevention

Organisations:	KS, Belgium	(7258-01/072/02)
	CdF, France	(7258-01/073/03)
	Middlesex Polytechnic, UK	(7258-01/074/08)
	WBK & RAG, Germany	(7258-01/075/01)

Research objectives

The extension of mechanised methods to the extraction of difficult seams, the concentration of working on fewer, high-capacity, production units and the introduction of automation technology continually influence working methods and conditions in all mining activities. Over the last decade these changes have been very successful in reducing the accident frequency rate and the occurrence of dangerous events. Latterly the rate of improvement has almost stagnated. In fact the serious accident rate has deteriorated.

The SHCMOEI initiated a collaborative study in order to evaluate what better training methods aimed at accident prevention could be introduced. The study group (from France, Germany and the UK) reported in Doc. 5673/1/80 E. The report noted that little systematic evaluation of supervisory training was carried out. Among the recommendations for action was the need for a study into how attitude and behaviour changes could be brought about and how work teams could be given opportunities for the influencing of safety standards and workplace behaviour.

Within this second 'Safety in Mining' programme, four contracts were made, one with each country. The findings of each are reported separately in this review.

Research findings

KS, Belgium (Project - 01/072/02)
The ZOLDER mine was chosen as a suitable site for the practical study. In joint consultation with experts from other countries a training programme aimed at improving accident prevention was set up and agreement reached on the method of evaluation. Changes in methodology were made in the course of the trial. It was concluded that changes in behaviour and the certainty of achieving results are measurable only if measurements are spread over a period longer than the life of this project. A method of evaluating progress is essential in order to further improve behaviour and training. The report recommends that training programmes must relate to practical problems at the mine, that they be organised at each mine, that they be aimed at groups of

workers who work together and that safety must be seen in the context of production levels and targets. As supervisors can influence workers under their charge methods should be developed and tested which enable them to transmit desired behaviour to their teams.

CdF, France (Project - 01/073/03)

The report opens with a description of training programmes on accident prevention in CdF since 1950 and refers to the FAS programme introduced in 1969/70 which was based on ECSC-financed research. Two mines were chosen for the trials; ROZELAY, a mine in HBCM and SAINTE-FONTAINE, a large mine in HBL. ROZELAY works a 10 m seam, at 400 m depth, by 100 m longwall mechanised faces using the soutirage method. SAINTE-FONTAINE mines 2 m seams in flat measures at depths up to 930 m by longwall methods.

There two parts to the report. Part 1 describes the method used to establish a mine accident prevention plan built up from the plans prepared by the different sectors. These plans were prepared through discussion in many on-the-job meetings and with the participation of the mine personnel - the mine manager, engineers, mine officials and mine workers. At these meetings the problems of the individual sectors, attitudes towards risks, the training needs required in the sector were discussed. Thus a dialogue was developed between the different levels in the organisation, and information passed up and down. Good preparatory work and the choice of good team leaders was stressed as very important, especially in the early meetings. An enquiry made in each mine, one year after the introduction of the plan, showed that the participants themselves had the impression that the safety situation had improved. This was confirmed by a reduction in the accident frequency rate. It was considered that the analysed responses of the enquiry complemented on-the-job discussion and broadened participants' knowledge.

Part 2 describes three different training projects. The first consisted of organising a 'safety awareness day' for the entire personnel of the mine in which they were made aware of their collective and individual responsibilities. The second was initiated as a result of pressure which had built up to do something about the handling of equipment. A study group - mine officials and team leaders - considered the training needs and proposed a two-day training programme. Statistics, spanning a 'before and after' period of three years showed a substantial reduction in accident frequency rate. The third described the introduction at ROZELAY of quality circles in which volunteer workmen belonging to the same district or service met regularly, under the guidance of a senior mine official, in order to seek solutions to the problems which concerned them. The report details the problems in setting up these quality circles. Much time and perseverance is required from the members. Support and advice from management is

required, especially in the first few meetings when instruction in assessing the feasibility of solutions, their costs and benefits and in the ordering of their priority. However, the results were encouraging, with a 52% reduction in the frequency rate. The mine manager decided to increase the number of groups.

The report concludes that the participation of employees organised in the manner described does permit knowledge at all levels to be developed and used for the purpose of improving accident prevention.

References: 22

MIDDLESEX POLYTECHNIC, UK (Project - 01/074/08)

The project had to be terminated on account of the national miner's strike and the need to rehabilitate the mines on resumption of work. However, a certain amount of preliminary work had been done to establish a programme aimed at training miners who worked in groups. In order to measure effectiveness of safety training the 'control group' was not given the training given to the 'experimental group'. In all other respects the two groups were subject to the same inquiries from the research investigators and formed on-the-job discussion groups. Four groups were formed, two for each coalface and outbye service chosen for the experiment. Each group member was scheduled to attend five training sessions.

The training content of the programme was designed so as to enable the man to appraise and modify his work habits and to learn self-learning and problem-solving techniques. Any training given was to be related to the man's working place and conditions. The supervisors in the group would attend a further two sessions to assist them in their role as leaders of discussion and of providing feed-back.

Questionnaires were developed to assess the attitudes and behaviour of each individual member and to measure the number of critical incidents of unsafe behaviour or unsafe situations they had observed or been involved in within the last few months. For each incident the respondent was asked a number of questions on what had happened and why. The Critical Incident Survey showed that team workers identified such incidents much more frequently than supervisors. A further technique devised was the Physical Standards Assessment, which involved experienced assessors in reporting their value judgements on the physical entities of the mining operating conditions. The ratings produced would be matched against accident levels in the localities studied. This method was not tested.

As the project was prematurely terminated no conclusions could be drawn about its measured effectiveness. However, the training programme has since been used in a wide range of courses by the Area Training Branch.

References: 9

WBK & RAG, Germany (Project - 01/075/01)

The project was carried out at the MINISTER STEIN mine where two districts were involved - a 'training' district and a 'control' district. Three different evaluation techniques were developed in order to assess the value of training in accident reduction (as in project 01/08/074 for example). These took the form of standard questionnaires in order to determine from the participants their safety attitudes, the analysis of accidents, critical incidents and safety standards in the two districts.

A two-stage training programme was devised. The first part, for the training district miners, key workers and supervisors, consisted of basic training; the second part, for volunteers, provided training in problem-solving techniques for working groups after the style of quality circles. For the first part training took place for five days spread over a period of weeks and was given to 60 men. The course content included self-learning, investigatory and discussion techniques and analysis of practical and potential problems in the workplace. Four working groups, each of eight to ten men with a leader, were set up for coal winning, transport, night shift, and district officials. All four leaders reported to a coordinator. Discussion took place on operational difficulties, unplanned and dangerous events, risky behaviour accidents on the district, the results of critical incident tests and accident statistics. Each group could call on specialist advice available at the mine. In the nine months ending 1985 the groups met some five to eight times for two to three hours at a time. Some 85 problems were discussed, of which 43 were solved and showed a pay-off. Experience showed that the leader must receive instruction in the techniques of leading a discussion, of analysis and of information transfer. It also showed that slow implementation of acceptable solutions reduced the productivity and enthusiasm of the group.

The report concludes that the methods employed for the evaluation of the training programme proved satisfactory.

This shows that the programme needs strengthening in basic training and problem solving instruction, that improvements in leadership training at the first stage are required and that practical, rather than theoretical, ways of handling safety problems are needed to bring about changes in safety attitudes, behaviour and conditions.

The results of the Critical Incident Test suggested that improvement cannot be handled by safety instruction but that the participative approach (problem solving groups) are more effective as specialists can be called on to help find a solution. The project did not result in any special reduction in accidents.

References: 27

4.01.1.2 Utilisation of accident data to improve safety in the human factors aspects of system design

Authors: R.A. GRAVELINS, S. MASON, A.M. RUSHWORTH, G.C. SIMPSON and M.T. SIMS
Organisation: IOM - UK (7258-01/133/08)

Research objectives

Over many years the Annual Reports of HM Chief Inspector of Mines have drawn attention to the role and importance of human behaviour human error - in accidents. Innovations in the mining technologies introduced have been the means of eliminating some accidents but have introduced new ones. The aims of the project are

- to identify from existing records the human factors issues relevant to accident causation;
- to examine the feasibility of improving the present accident reporting and analysis procedures in order to incorporate, as a routine, a wider consideration of human factors;
- to provide a basis on which priority areas for accident prevention programmes concentrating on human factors could be developed.

Research findings

The British Coal accident reporting procedure was examined. This was originally a manual system but it now incorporates computer data base and retrieval systems. The investigation showed the unsuitability of the system for casual users such as Area safety personnel and that it was inadequate for the envisaged purpose.

Following extensive discussions, which also included the approaches to the problem made by other industries, a code list was produced to be used as an adjunct to the existing system. This list identifies behavioural factors which safety personnel feel contribute to accident causation. The list was assessed by colliery safety personnel who applied it, with much success, to a selection of recent accidents.

Training is seen as an important step in accident reduction. An illustrative exercise was carried out in order to indicate how a training course could be assessed to determine its effectiveness in modifying an individual's risk perception.

References 40

4.01.2 Design improvement

4.01.2.1 The application of microprocessors in mine plant monitoring and control systems A specific example - Train arrestors

Authors: UNIVERSITY OF ASTON, A.M. WRAY
Organisation: HSE - UK (7258-05/079/08)

Research objectives

The use of microcomputers in the control of industrial processes and machinery has increased. Their failure could have a direct or indirect safety implication. The realisation of hazards on plant using microprocessor-based systems is essentially governed by the reliability of the software and organisational procedures controlling the maintenance of the program. The aim of the project was to produce software which could be used to control a laboratory-scale automatic device for a manriding train arrestor.

Research findings

The project, which was sub-contracted to the University of Aston, gives a brief overview of the stages in the design of the train arrestor software. Assessment of the software involved a series of check-lists.

The project shows that the design of safety-related software is not straightforward. Its integrity is assessed by the documentation which accompanies the software. It was concluded that the use of computer-based controllers having safety-related applications is likely to encounter problems in meeting the high standards required of the software documentation. Further work is required for the setting of guidelines for the production of software for safetyrelated applications and to enhance the industry's awareness of these guidelines and of the need for strict compliance with them.

The design of the laboratory device was not pursued in view of the software problems.

References : 7

4.01.2.2 Overload control for conventional drive systems and pneumatic equipment

Author: SEELIGER
Organisation: WBK - Germany (7258-06/093/01)

Research objectives

Accidents may occur when winning machines or transport and lifting equipment are insufficiently protected against overload. Broken coal plough chains are an example. The project aims to develop simulation techniques in order to determine what devices can be introduced into machines in order to protect them from overload and to test them under test-bench conditions. The project specifically looks at the Gleithobel F 15. Previous work in this area had been carried out in a research project in 1982.

Research findings

Digital simulation was used to analyse the dynamic movement of the Gleithobel and to demonstrate the effects of load-disconnecting and load-retaining torque limiters. The coal plough was blocked at distances from the tail sprocket drive of 10 m, 125 m and 240 m. Fluctuations in the tractive effort of the chain were seen to be largely dependent on the position of the plough and it was only when the plough was blocked close to the head-end drive that the tensile forces generated were strong enough to bring the relevant torque limiter into operation. At greater distances the elasticity of the chain prevented the torque limit from being exceeded.

The simulation technique demonstrated that 'load-retaining' overload couplings have a more positive effect on the dynamic behaviour of the Gleithobel than do the 'load-disconnecting' types. A further investigation would help to explain the dynamic conditions and the influence of the overload coupling on the gearbox when tension is suddenly reapplied to the chain after a blockage.

4.01.3 Noise

4.01.3.1 Noise prediction and control

Authors: EAHY, MANEYLAWS, BENNET, PICKEN, NORMAN, ROUGHTON, STAINER
Organisation: British Coal - UK (7258-01/094/08)

Research objectives

There is a proven risk to hearing at a number of workplaces in coal mines. Excessive noise interferes with signals and effective communication between workers and there may be a safety risk. A new directive on workplace noise introduces an obligation on the employer to inform the workforce about noise in the working environment which may exceed a recommended level of 85 dB(A) L_{eq}. The aim of the project was to provide a means of predicting workplace noise and to determine the need for noise control measures.

Research findings

There were five parts to the research.

1. Workplace acoustics

Studies were made in mine surface buildings, mine roadways and coalfaces of the total sound received directly from the noise source. The results for surface buildings showed a wide range or results and from these guidelines were produced. In mine roadways, where the sound decays with distance at a steady rate, the effects of roadway shape, size and materials used for support were studied. Further work is required. On the coalface it was observed that dust, loose coal and the goaf are absorbent, whilst the powered supports are reflective and have a scattering and screening effect but with a higher rate of decay. The roadway model can be applied.

2. Noise prediction program

The program NOISEPRED was written and tested in a mechanised mine roadway and a coal preparation plant. this enables designers to calculate and display in colour the total sound pressure level at any point in the place.

3. Noise testing standards

A test standard was developed which incorporates various aspects of two British Testing Standards. This standard is incorporated into the report.

5. Noise control techniques

Laboratory studies were made of possible control measures which might be applied externally to machines and plant where complete enclosure is not possible. Examples are diesel engines, face conveyor deck plates and rope haulage engine houses. Noise reductions were obtained.

5) Hearing protection and communication

Most mining machines generate a noise spectrum in the frequency range 200-1000 Hz. Speech and signal frequencies of 1200-4000 Hz receive a much greater attenuation from conventional hearing protectors than machinery noise. In collaboration with the Institute of Sound and Vibration Research a study was made of the feasibility of applying the technique of Active Noise Cancellation (ANC) to improve the performance and suitability of earmuffs for workers; Sufficient work was done to indicate that a muff design could give the desired attenuation. Further work is necessary to improve communication by attenuation of frequencies above 1500 Hz, and to produce a cost-effective intrinsically safe design.

References: 15

4.02 FIRES

The SHCMOEI does not publish any data on the incidence or causes of underground fires. It does publish accident statistics for the category 'Heatings or Fires'. Over the period 1975 to 1984, in this cause category, the accident frequency rate per million manhours has been very low and has reduced from 0.03 to 0.00. There has been one group accident resulting in seven deaths.

However, it is believed that the incidence of fires has not materially decreased and remains at an unacceptable level. Increased concentration of production has led to the operation of high-tonnage longwall faces and to the need for longer development road drivages, both of which have altered the potential fire risk from that encountered ten years ago. Developments in mechanisation and automation have introduced new materials, diesel-powered free-steered vehicles and greater power needs.

Much research has been done and the results put into practice as the developments matured. The use of nitrogen and anhydrite-type materials has enabled the occurrence of spontaneous combustion fires to be reduced; the introduction of gas sensors and systems for the detection of the products of combustion has enabled incipient fires to be identified. Fires on belt conveyors remain at a high level. The First Programme supported 18 projects in the "Fires" category, which addressed the detection of fires, fire-resistant materials, and belt conveyor fires. The Second Programme supported continuation of some projects; in all there were 19 projects. There are two projects in the ECSC Medium-Term Programme which are concerned with gas detection and data transmission.

Nevertheless, fires are still a potential source of danger, a danger which must be identified in the planning and design stages of an operation and during the actual mining operation itself. Fires originate in spontaneous combustion, frictional heat generated in faults in belt conveyor systems, materials such as hydraulic fluids, electrical breakdowns and ignitions and gas explosions. The hazards stem from noxious fumes given off from materials as well as from the heat and flames and the consequences if the fire becomes uncontrolled.

This section looks at the projects under the following headings:

- Gas detection and monitoring:- development of sensors; identification of indicator gases; surface testing of gas monitoring systems.

- Testing of materials:- study of thermal decomposition of materials; determination of test procedures for materials and equipment.

- Fire control:- trials of gas monitoring and alarm systems for mine air and the early detection of fires; design of pressurised havens for the evacuation of personnel; construction of explosion-proof stoppings.

4.02.1 Gas and fire detection

The proper identification of gases from early combustion and from fires in the incipient stages of their development is essential to their timely control. The occurrence in the mine air samples of gases from diesel exhausts and blasting does complicate analysis, however, and can cause false alarms in the early identification of fires. Research projects in this programme report further development of particular gas sensors and progress in the use of computer techniques which address the problem of false alarms. Surface tests of monitoring systems are reported. Of particular interest in the identification of belt fires is the detection of gases given off from the heating of modern fire-resistant belting; progress has been made.

The reader's attention is drawn to project 7220-AC/837 supported by the ECSC Coal Research programme(2). This project 'Development of infra-red technology for detection of gases in mines' is, amongst other objectives, aimed at the development of instruments for detecting gases. The First Joint Research Programme on Safety in the ECSC Industries (1988) contains a section 'Mine fires and spontaneous combustion'.

Gas detection
080, 103, 120, 111, 138, 139, 119, 081, 140, 151.

4.02.2 Material fire tests

The use of polymeric materials underground is increasing. Projects examined the thermal decomposition of conveyor belting and the covers of electric cables; the possibility of determining standard Community tests for plastic materials (in the event no test conditions could be found which provided identical results) and Community harmonised ignition tests for fluids. Work on identifying the fire hazard of materials should continue.

Material tests 076, 097, 098, 102, 121, 105, 141.

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(2) Directorate-General XVII "Energy", Brussels

4.02.3 Fire control

Four projects were devoted to the underground trials of mine air control systems. A computer-based alarm system - the "Multi-Discriminatory Alarm" - used in conjunction with a tube bundle system for sampling mine air has shown that with a monthly input from management giving changes in mining operations the number of false alarms can be reduced to an acceptable level. With modern mining layouts roadways have become longer - a situation which increases the dangers of evacuation of personnel from their working place. One project studied the design parameters of pressurised survival chambers which would be strategically sited and would provide a haven where men could change their personal self-rescuer or where they could take refuge. Useful data was produced. Attention is drawn to the work on self-rescuers in Section 4 'Rescue'. Another project studied how an explosion-proof stopping could be constructed in eight hours.

Fire control 082, 104, 122

4.02 FIRES

4.02.1 Gas and fire detection

4.02.1.1 Detection of spontaneous combustion underground by identification of an indicator gas

Author: G. GWATKIN
Organisation: British Coal - UK (7258-02/080/08)

Research objectives

To apply recently developed techniques in sampling methods and gas analysis in order to determine whether any product of spontaneous combustion or ratio of products can be identified which is either complementary to, or superior, to carbon monoxide (CO) as an early and unambiguous detector of heatings.

Research findings

The development of concentration techniques and new chromatographic methods of analysis has enabled the separation and quantification of gases previously only possible in mass spectrographic determinations. Five broad categories of compounds were examined:-

1) Compounds found in mine samples and not associated with spontaneous combustion e.g. methane, higher alkanes, hydrogen sulphide. It is unlikely that the development of detectors specific to any one of them will make these substances suitable for control purposes.

2) Sulphur dioxide and hydrogen chloride: although these are found in significant quantities in the combustion of coal in the laboratory, their reactivity is such that they are not found in general body samples by current detection methods.

3) Unsaturated hydrocarbons, benzene and toluene, methylcyclohexane and low molecular weight aldehydes and ketones are produced in spontaneous combustion, in diesel exhaust gases and in shotfiring. It was found that the ratio of these compounds to CO differed according to their source of production. A system of control based upon the ratio of these compounds to one another or to CO may be possible.

4) Oxides of nitrogen are produced in diesel exhaust gases, in shotfiring but not in low temperature coal combustion. They may have a role as differentiators of the source of CO contamination.

5) Carbonyl sulphide was the only compound produced in spontaneous combustion which was not found in diesel exhaust and shotfiring gases. It would be immediately useful as an unambiguous indicator of spontaneous combustion. The level found in general body samples is low.

The feasibility of producing a system for monitoring spontaneous combustion, based on an indicator other than CO, is dependent on the development of a detector, or a range of detectors, specific to low concentrations of the chosen indicators.

4.02.1.2 Automatic computer alarm program for the early detection of spontaneous combustion and mine fires

Author: P.G. SMITH
Organisation: British Coal - UK (7258-02/103/08)

Research objectives

The aim was to design and test a new and improved computer alarm system using the experience gained under project 7255-16/029/08. Underground trials were be carried out using the CO data from the existing tube-bundle system. Further modifications will be made as required when other sensors are introduced.

Research findings

A computer-based alarm system was designed for use with the surfaceinstalled tube bundle system whereby, at 20 min intervals, the concentrations of CO from individual underground districts are obtained. The alarm system was termed the Multi-Discriminating Alarm (MDA). The MDA routines have been applied at 16 mines for long periods of time. It has been successful in establishing a reliable means of detecting spontaneous combustion at an earlier stage than that obtained by normal sampling techniques.

The MDA routine produces mathematically a statistical pattern of the variations in CO concentrations during a typical month, i.e. a month with normal operations and activity and no reported cases of spontaneous combustion. In normal activity, rises in CO occur due to shotfiring, the use of diesel vehicles, barometric variability, etc. These affect the CO peak levels for various periods of time. The system is designed to distinguish unusual patterns or shapes of CO curves and the program incorporates means of detecting both the heatings that produce very slow increases in the levels of CO and those that exhibit rapid rise.

The computer accumulates data at the 'norm' or average level and nine additional threshold levels above in increments of 1 ppm. The timing system determines the length of time by which each threshold level is exceeded. These are statistically processed at the end of the month. Thus the computer predicts alarm times at each threshold level and these provide alarm parameters for the following month.
The number of false alarms found acceptable on a face with multiple increases in CO would be about one false alarm for every two or three months. The automatic setting of alarm parameters at the end of each month provides management with a useful tool. However, the program must be provided with information concerning any changes in mining operations.

As a result of the trials further improvements are foreseen whereby with larger-capacity computers more than the 20 sampling points of the original model can be installed. A dedicated visual display unit is desirable.

References : 2

4.02.1.3 Detection of spontaneous combustion using specific indicator gases

Author: M. COOPER
Organisation: British Coal - UK (7258-02/120/08)

Research objectives

The aim was to supplement carbon monoxide monitoring of the mine atmosphere by using other products of the low temperature oxidation of coal.

Research findings

The first phase consisted in identifying the gases suitable for detection, i.e. those which are evolved in the event of spontaneous combustion but not during normal mining operations.

The following gases were chosen: carbonyl sulphide, acetaldehyde, acetone, ethene and propene.

The second phase was the development of instrumentation which could be used below ground to determine the composition of the atmosphere at a given location. This apparatus consists of a gas chromatograph, normally based in a surface laboratory but such that it can also be taken below ground, which is intrinsically safe (12 V, 0.5 A) and includes sampling and detection systems, a chromatographic column and a microprocessor control unit. Samples obtained during colliery incidents validated the use of these gases as indicators of the progression of a heating.

4.02.1.4 Development of sensors for CO, total products of combustion, NO2, NOx, CH4 and total flammable gases in mine atmospheres using solid-state sensors combined with microprocessor techniques

Authors: B. BOTT, T.A. JONES, G.S. REVELL
Organisation: HSE Sheffield - UK (7258-05/111/08)

Research objectives

The aim of the project was

- to make an overall study of the use of solid-state sensors and other environmental sensors in combination with microprocessors and microcomputers in order to provide a total mine atmosphere monitoring system;
- to improve the selectivity, discrimination and general performance of the sensors;
- to use combinations of sensors to provide unambiguous indications of dangerous occurrences, the system itself deciding whether the combination of signals from different sensors constitutes an indication of a hazard or not.

Research findings

A multi-sensor system was developed. It essentially comprises

- a ZnO single crystal non-selective gas sensor to detect the gases evolved in the early stages of underground heatings;
- a ZnO single crystal sensor operated behind a molecular sieve so that it is primarily a CO detector;
- a PbPc (lead phthalocyanine) sensor to detect NO_2;
- a PbPc sensor with an oxidiser to convert NO to NO_2 for NO_x detection;
- a catalytic flammable gas sensor;
- a catalytic flammable gas sensor operated behind a molecular sieve trap to measure the CH_4 concentration.

The first results obtained were very promising. The work then focused on various physical combinations of zinc oxides.

Field trials showed that the concept of such a system is valid, but also revealed the practical difficulties associated with it and the major problems which would arise if it were to be made into a self-contained, automatic system.

4.02.1.5 Feasibility of detecting overheating of conveyor belts by measuring hydrochloric acid vapours in the air

Author: A. ACCORSI
Organisation: CERCHAR - France (7258-02/138/03)

Research objectives

The aim of the project was to study the feasibility of detecting overheating of conveyor belts by measuring the concentration of hydrochloric acid (HCl) vapours in the mine air with electrochemical cells.

Work carried out in Germany under research contract 7255-10/067/01 showed that a carbon dioxide sensor must be combined with another type of detector in order to detect overheating of conveyor belts. A belt slip test in l'Aumance in 1983 had shown that hydrochloric acid was present in measurable quantities up to 150 m downwind.

Research findings

1) Review of the literature

Two models were found, one of which was developed by an American centre for research into chlorinated polymeric materials to investigate the behaviour of HCl vapours in the course of a fire.

However, these two models can be used only as a general guide, since they assume an even concentration of the vapour in space, whereas acid vapours evolved from conveyor belts remain close to their surface.

2) Hydrochloric acid sensors

Since the analysers used in industry do not seem suitable for mining applications, this problem was specially investigated. Of the sensors studied, the following were selected for full-scale trials: Dräger instantaneous and diffusion tubes, City Technology electrochemical cells and a portable Dräger colorimeter.

3) Full-scale trials

Preliminary trial in the CERCHAR fire gallery:
injection of a quantity of HCl corresponding to 50 ppm; recovery was between one third and half in the vapour phase and often total in the vapour and liquid phases together.

Pit trials at l'Aumance:

a) the electrochemical cells have instantaneous response but "see" 40% at most;
b) with the tubes, one third of the HCl is detected at 120 m.

4) Conclusions

The factors influencing the dispersion of HCl were identified.

Belt slip can be detected by measuring the HCl concentration with electrochemical cells, but only in the vapour phase.

A final suggestion: a system comprising several "triple sensors", the first close to the drivehead and the others downwind, e.g. at 150 or 200 m spacings. These triple sensors could be made up as follows:

- electrochemical cell - pH meter - hygrometer;
- electrochemical cell - hygrometer - particle detector;
- particle detector - NH_4Cl detector - hygrometer;
- particle detector - NH_4Cl detector - electrochemical cell.

4.02.1.6 Use of mass spectrometers in underground fire warning systems

Author: Dr.-Ing. W. HEYN, Dr.rer.nat. K. HOLKE
Organisation: DMT - Germany (7258-02/139/01)

Research objectives

In the early stages of a fire the gases CO, NO and hydrocarbons are given off. These gases are also produced by shotfiring and from diesel engine exhausts. In low concentrations it is not clear what activity has caused these gases to appear. Mass spectrometers can identify simultaneously several such substances and establish their relative concentration. The aim of the project is to establish, in the laboratory and in the Tremonia fire gallery, whether mass spectrometers can identify several components and their relative concentrations simultaneously.

Research findings

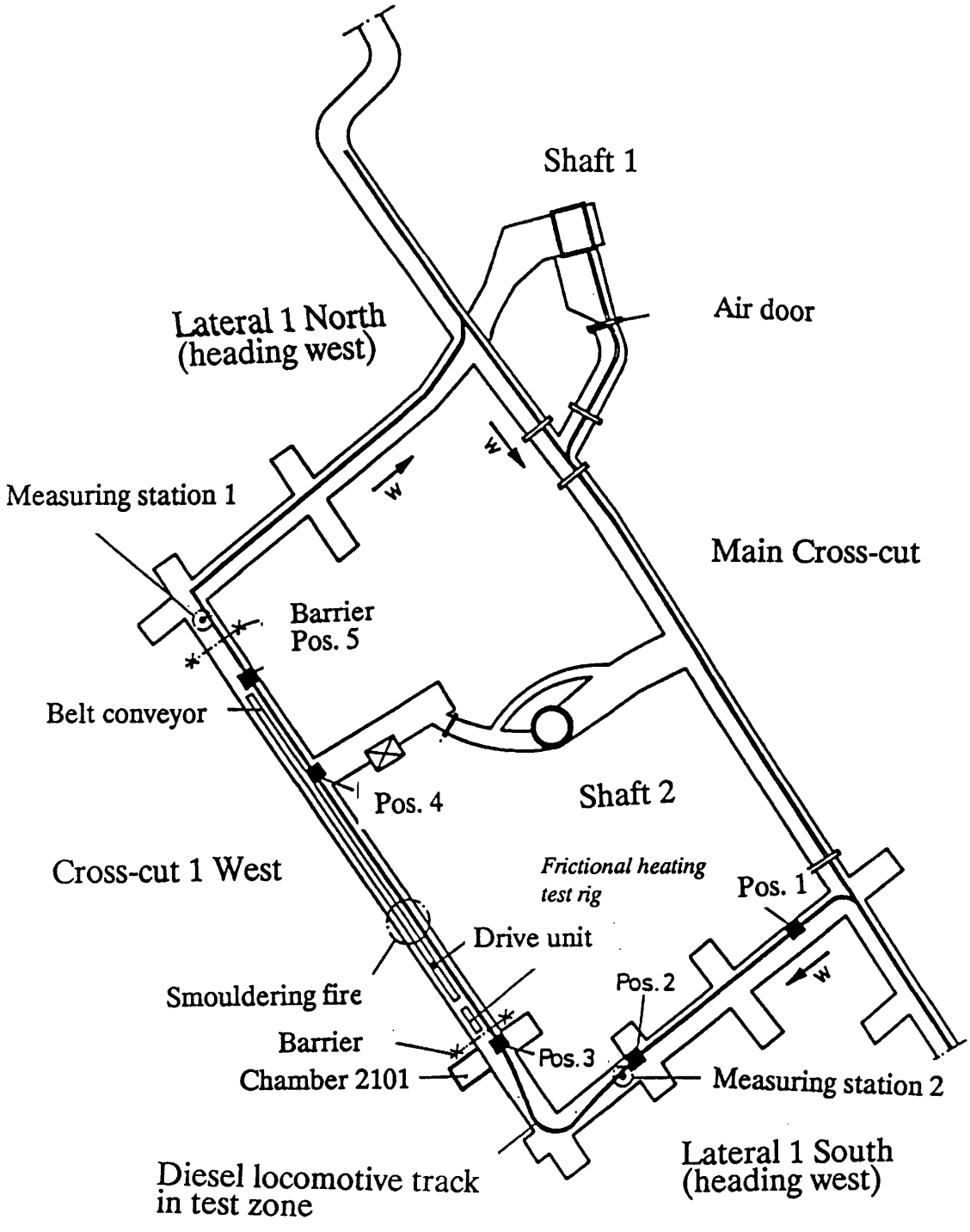
The trials conducted showed that slow combustion of small quantities of coal dust cannot be detected under the test and measurement conditions applied. This is also true of small fires involving 0.5 - 1 kg of fuel. CO and smoke detectors and semi-conductor sensors are far superior to the mass spectrometer for this purpose.

In large experimental fires involving various materials, aromatic hydrocarbons such as benzene were found in addition to CO_2 in the products-of-combustion spectrum. In conveyor belt and foam fires, the spectrometer revealed peaks of as yet unknown origin. These appeared at a late stage in the fire when most of the material present was smouldering; at this stage, the peaks corresponding to the aromatic hydrocarbons were also particularly high.

In mines, this phase of combustion in practice normally occurs in the period between a fire's starting and its becoming fully established, i.e. it precedes the development of a major open fire.

Early detection using gases other than CO, such as benzene, is thus possible, provided the concentration of pyrolysis products is sufficient.

Further work is required on the manner in which such measurements are to be carried out. It has already been established that use of the mass spectrometer below ground on the fourth level of the Tremonia experimental mine has given rise to no problems.



Testing area on Level 2
The drawing shows the positions at which mine locomotives were operated with engines idling

4.02.1.7 Trials of fire protection devices - 2nd continuation

Author: Freiherr von DIEPENBROICK-GRÜTER, Dr.-Ing. W. HEYN
Organisation: DMT - Germany (7258-02/119/01)

Research objectives

The main objective of this project was to investigate the response of different types of sensor to the various phases of combustion involving fluids: smouldering, incandescence, open flame.

One of the aims pursued was to determine the manner in which these sensors were affected by exhaust gases from diesel mine locomotives.

Other aspects concerned
- early detection of a fire in a large airflow;
- the feasibility of using the "LIST" system for monitoring conveyor belt temperature;
- analysis of gases present at trace concentrations by means of a mass spectrometer.

Essentially, it was hoped to establish whether, in addition to CO detection, there were other components of the fire gases or other techniques which would allow early detection of a fire or heating.

Research findings

Conclusions and recommendations with regard to improved early detection of mine fires:
- CO sensors continue to be suitable for the early detection of smouldering coal-dust fires but semi-conductor sensors can also be used.

- Fumes with a low CO content, released e.g. by smouldering fires or by friction due to a belt slipping on a driving drum, can be detected by semi-conductor sensors, but also by optical smoke sensing devices.

- Except for NO_x analysis, detection is not impaired by the operation of low-powered diesel mine locomotives (14 kW/20 CV). Higher-powered diesel vehicles may affect the detectors.

- The use of multi-sensor stations combining a CO sensor with a semi-conductor sensor, an optical smoke detector or an SMPD ionisation smoke detector is recommended as a means of optimising detection of all types of fire.

A combined CO/semi-conductor arrangement is commercially available as the "FIDESCO" system.

- The temperature sensor system "LIST" can be used in certain circumstances to monitor belt conveyors.

4.02.1.8 The protection of underground conveyors against fire

Authors: CROOK, HERBERT, COLEMAN, ANNETTS, LAWSON, WRIGHT
Organisation: British Coal - UK (7258-02/081/08)

Research objectives:

The aim was to develop a control system for the continuous monitoring of mine air samples, from roads where belt conveyors are installed or from single entry roads, which would provide for the instantaneous detection and location of open fires and spontaneous combustion. The system would be designed to use newly developed fire detectors, data transmission systems and management information techniques.

Research findings

The conveyor monitoring system, code-named ARGUS, was developed, tested and installed, for a 12-month trial period, in the surface buildings of a surface to underground drift belt conveyor. The reliability of the sensing head was excellent. The system operated successfully with few modifications. However, it did not pass into commercial use due to incompatibility with the British Standards Specification (BSS) for low and/or high speed telemetry systems.

The microprocessor-controlled sensing head incorporates a Taguchi gas sensor (TGS), an electrochemical cell for CO analysis and a Firant sensor for the detection of thermal noise. Fire gallery tests with a simulated conveyor installation demonstrated that the sensing head with the Firant detector should be sited no more than 30 metres from the source of heat and so give zone protection. Both the TGS and the electrochemical cell could detect early signs of heating and combustion and could be sited along the length of the conveyor controlled.

References

ECSC Report 7255-10/026/08. The field evaluation of detectors for fires and heatings in coal mines. There are eight other references.

4.02.1.9 Testing of equipment for the early detection of fires

Author: H. EICKER, H.J. KARTENBERG
Organisation: DMT - Germany (7258-02/140/01)

Research objectives

The aim of the project was to develop and test intrinsically safe fire measurement and warning devices with semi-conductor sensors in order to enable products of combustion other than carbon monoxide (CO), in particular hydrogen and ethylene, to be reliably detected. A further aim was to test analysis methods and equipment for existing CO differential detectors in conjunction with intrinsically safe microcomputers.

Research findings

1. Development of the PFG GC-1 - an intrinsically safe portable gas chromatograph using synthetic air as the carrier gas, with a TGS 812 metal oxide semi-conductor sensor capable of detecting CO, H_2 and C_2H_4 concentrations in the ppm range.

2. Improvement of this first instrument. The result was the PFG GCM-2 OT, which had no specific carrier gas, this function being fulfilled by the ambient air.

   These two instruments are highly sensitive to hydrogen and ethylene, but ten thousand times less sensitive to methane, and are thus particularly suitable for detection of smouldering fires. The first is appropriate for accurate short-term analysis and the second for long-term monitoring of locations in the mine which are particularly at risk.

   A program for an intrinsically safe pocket calculator was developed for processing of the readings.

3. Development of an intrinsically safe CO differential detector based on metal oxide sensors for monitoring of specific points and belt conveyor roadways. The concept is based on variations over time in the composition of the gases present in the air.
   The detector should be located not more than 50 m from the seat of the fire.

4. Development and testing of the ESCO-PFG 2 system for fire detection in roadways ventilated by an air current of between 35 and 100 m^3/s.
   A first installation consisted of three to eight CO analysers and a microcomputer for signal processing. The method is based on the difference in the CO concentrations at the various analysers (type PFG CO 7).

Spurious alarms should be avoided by the programming of the computer.

However, the PFG CO 7 is custom-built and is thus ill-suited to large-scale use in mines.

This part of the project was intended to make it possible to use an instrument which was commercially available and certified for underground use: the Comytron from Dräger.

An installation comprising the ESCO-PFG 2 and three Comytron 2030i units was tested underground at the Auguste Victoria mine. CO was injected into an air current; the alarm was invariably given within 10 minutes and the site of the incident was immediately known since it lay between two consecutive instruments.

4.02.1.10 A personal lighting and gas monitoring device for miners

Author: L. ADARO DE JOVE

Organisation: SUMINISTROS ADARO SA, - Spain
AITEMIN (Asociación de Investigación Tecnológica de Equipos Mineros)
(7258-02/151/14)

Research objectives

A large proportion of Spanish coal production comes from steeply inclined seams (40% of seams have a dip of over 60°). Safety conditions in these seams, where mechanisation is difficult and various working methods are practised, are worse than in level workings and special safety measures are needed.

The system to which this project relates was intended to provide each miner with a personal warning either of the presence of a dangerous gas or of oxygen deficiency. The requirements to be met were as follows:
- continuous operation without any human intervention;
- ruggedness and lightness to ensure that the system was acceptable to the workforce;
- reliability, to avoid spurious alarms;
- reasonable cost, so that as many miners as possible could be equipped.

Research findings

In view of these requirements, a system combined with the cap lamp was chosen. The equipment receives its power supply from the cap lamp battery and conveys its warnings by flashing of the lamp so that they are perceptible at all times irrespective of the ambient noise and the work being carried out.

The system consists of three modules:
- the battery,
- the gas detection unit,
- the headpiece.

The detection unit is inserted into the cable between the battery and the lamp and is fixed on the worker's chest or at his side. It comprises three sensors for CH_4, O_2 and CO. These three gases are continuously measured and if the concentration for any of them leaves its preset range the cap lamp begins to blink at a frequency which differs depending on the gas concerned.

4.02.2 Material fire tests

4.02.2.1 Study of the thermal decomposition of polymeric materials used underground in mines

Author: M. TURPIN
Organisation: CERCHAR - France (7258-02/076/03)

Research objectives

The use underground of polymeric materials is increasing. They represent an important source of heat; their combustion increases fire intensity and the products of combustion are flammable, toxic and dense smoke and gas.

The aims of the project were
- to carry out a laboratory study of the thermal decomposition of different polymeric materials to investigate the pyrolysis mechanism;
- to carry out full-scale tests to study the behaviour of these materials under the conditions in which they are used.

Research findings

In laboratory tests two types of chloroprene belt, a PVC belt and a urea formaldehyde foam were studied. When heated under controlled conditions, the first sign of an exothermic reaction in the belts occurred around 400°C. At 600°C the reaction became active. Aromatic and hydrochloric (HCl) gases appeared at low temperatures, their volume increasing with temperature. These gases could form the basis of an early warning system for a conveyor belt fire. Decomposition of urea formaldehyde was rapid at 600°C. In low quantities of air HCN and compounds of nitrogen were present.

In the studies on belt slip at the drive head HCl was released before carbon monoxide. The emission of smoke and the rise in temperature around the driving drum were sufficient to provide early warning of belt slip. However, the second of these factors is difficult to measure under practical operating conditions.

In the fire gallery tests, which were intended to investigate fire propagation, burning of the PVC belt (1250) did not extend beyond the 2.3 m directly exposed to the flames of the fire source. The chloroprene (500) belt burned along its entire 15 m length, while the chloroprene (800) belt burned over a length of 6.4 m. The gases given off could cause physiological problems.

Very dense smoke was emitted in the chloroprene and PVC belt fires.

The foam tests consisted in lining the gallery walls with urea formaldehyde foam and then exposing them to fire. After the pyrolysis stage, in which large quantities of gas and smoke were given off, the gases suddenly ignited, causing a general conflagration which completely destroyed the lining. Large quantities of HCN and compounds of nitrogen were given off.

Further tests need to be carried out on expanded plastics before any conclusions can be drawn.

4.02.2.2 Fire gallery tests on mining equipment made of plastic materials (continuation)

Author: W. HEYN
Organisation: DMT - Germany (7258-02/097/01)

Research objectives

This contract is an extension of 7255-10/059/01 'Fire gallery tests for plastic materials', which was carried out in conjunction with British Coal (BC) and the Health and Safety Executive (HSE). The present project, involving the same three partners, sought to establish ventilation speeds, the weight and construction of the wood fire source and temperature measuring techniques.

Research findings

Two series of tests were carried out with different materials; the first with wire grills covered with plastic and the second with hydraulic and compressed-air hoses.

In the first series the grills were placed across the gallery at specified distances from the wood fire. The temperature distribution in the roadway section and at the roadway walls were established and all changes in temperature noted, together with the positions of the measuring points on the grills. The temperature distribution in the VG, BC and HSE galleries could be deduced from the effects of the fire, assessed on a five-point scale ranging from no damage to complete destruction and from numerous temperature measurements.

The second series was based on the first. It was conducted with hydraulic and compressed-air hoses of various compositions in the three galleries.

These experiments yielded very different results for fire propagation along hoses in the VG, BC and HSE fire galleries.

The temperature distributions were similar in the VG and BC galleries, but the mean temperatures for a given position in the gallery were substantially higher in the former.

However, even if the height at which the hoses were hung in the galleries was adjusted to ensure roughly equal temperatures, comparable results were not obtained.

The report recommends that data be compiled on the energy balances in the three galleries, and in particular on the radiant heat emitted by burning materials and the proportion of that heat which is reflected towards the materials under test.

4.02.2.3 Fire gallery tests for non-metallic materials intended for underground use

Author: P.G. SMITH
Organisation: British Coal - UK (7258-02/098/08)

Research objectives

The aim of the project was to establish agreed criteria and test procedures for the fire testing of large items of non-metallic materials in three existing fire galleries: that of British Coal, at their Yorkshire Research Laboratories (YRL), the Buxton gallery of the Health and Safety Executive (HSE) and the German fire gallery at the Tremonia experimental mine. The project set out to obtain three-dimensional temperature data for the fire galleries in order to seek confirmation of the temperature stratification phenomenon and to provide a data bank which would assist theoretical and practical studies. The work described in ECSC Research Project No 7255-10/058/08, which sought to establish conditions under which each of these three fire galleries could produce similar fire regimes, was used as a starting point. Readers are referred to project 7258-02/097/01 in this volume for the description of the VG research.

Research findings

The report gives a comprehensive account of the theoretical consideration that the heat flux from the fire may be characterised by the air/fuel ratio - the R value - of the fire. It discusses the data obtained of heat loss to the tunnel walls, of the tunnel geometry, the temperature profiles along the roadway and the Stanton number effects. Descriptions of the surface YRL and underground HSE fire galleries are given together with the means for providing the heat source, the ventilation, the location of the measuring points along the gallery length, and the temperature and gas measuring and data processing equipment. At each of the six measuring stations thermocouples were arranged horizontally and vertically in the gallery cross-section so as to determine the height at which a particular isotherm traversed the gallery. At each station gas samples were taken.

From the data it is seen that the temperature increases with height downwind and that stratification takes up to 6D (diameters of the tunnel) to develop and stabilise. Test materials were located at each station. Fire damage to PVC-covered grills and hoses was assessed under five criteria from no damage to completely burned. Analysis also showed that repeatable temperature environments could be produced in each gallery, that a 300 kg wood fire was sufficient and that the isothermal approach permits identification of comparable thermal environments.

In conclusion the report states that, with the hoses and the 300 kg fuel load, the degree of damage differed markedly when using the isotherms to determine the best sample position. The nature of the isotherm profiles is such that equivalence between the three galleries cannot be achieved, even when using the same fuel load and horizontal sampling. The construction of each of the galleries is fundamentally different. It is therefore impractical to seek test conditions which would give equivalent results and it is recommended that each laboratory test to its own standards.

References: 19

4.02.2.4 Propagation of fire along electric cables and lines

Author: W. HEYN
Organisation: DMT - Germany (7258-02/102/01)

Research objectives

The main purpose of the project was to check, by means of full-scale fire gallery tests, whether the laboratory and reduced-scale tests prescribed by the German standard (VDE 0472, Part 804) were adequate to assess the fire risk resulting from the use of cables below ground.

A further aim was to compile information on the time for which electric cables and lines could maintain the power supply in the event of a fire, with particular reference to means of communication: telephone and telemetry lines, etc.

Research findings

1) Fire tests on individual cables

The cables may be divided into groups:
- industrial and mining cables: flame propagation beyond 2.5 m;
- silicon and FRNC (flame-retardant non-corrosive) cables: propagation less than 2 m.

2) Fire tests on cable bundles

The bundles always consisted of cables of the same type but of a different construction.

Fire propagation was always more extensive than for single cables:
- industrial and mining cables: over the entire 10 m length;
- silicon cables: 4.7 m;
- FRNC cables: 2.2 m.

3) Comparison with the VDE standard

The laboratory test could not distinguish between cable types.

The semi-technical tests were not carried out in the the furnace specified in the standard, but on cables suspended in the stack of the large fire gallery of the Tremonia experimental mine.

These tests also allowed cables to be classified in two groups, the first comprising industrial and mining cables with flame propagation of 120 cm and over, and the second comprising FRNC and silicon cables with propagation of up to 100 cm.

4) Tests in the underground fire gallery

Even under extreme conditions, FRNC cables propagated flame only over a short distance of about 1 m.

The industrial and mining cables were all completely burnt.

Two final important notes

- The tests showed that flame propagation was decisively influenced by the position of the cables in the section.

- Cables of a different construction or materials may behave in a completely different way.

4.02.2.5 The behaviour in a fire of equipment made of polymeric materials as used underground

Authors: L. MALECHAUX, J. SCHIBER
Organisation: CERCHAR - France (7258-02/121/03)

Research objectives

The underground use of polymeric materials has increased and whilst their safety has improved they also introduce new risks which require investigation. The aim of the project was to study, in the surface fire gallery at CERCHAR, the behaviour of a formophenol foam used as a roadway lining and the metal containers used for transporting it underground, and to make a comparison between two different foams: formophenol and urea-formol.

Research findings

1) Characterisation of the products of pyrolysis and combustion

The potential hazard in terms of the toxicity of the pyrolysis and combustion products is fairly slight, since they contain little nitrogen.

2) Behaviour of resin containers on exposure to fire

Three 30 kg containers of resin were placed close to a 300 kg wood pile.
On exposure to the fire, the containers became distorted, tipped over and lost their stoppers. The resin spilt onto the floor, but did not ignite or propagate the fire.
Large quantities of white smoke were given off, but few toxic substances (freon).

3) Behaviour of roadway lining foam on exposure to fire

700 kg of foam were sprayed over 100 m^2 of roadway wall (over a distance of about 10 m). A 300 kg pile of wood was set on fire beneath the lining. The foam was charred on the surface only, even in the immediate vicinity of the wood pile, and did not propagate the fire. Virtually the only toxic component in the fire gases was CO.

4) Comparison of formophenol and urea-formaldehyde foam

Service properties: after a fire, the formphenol foam is still in place and its properties are unchanged, even when its surface is charred.
Toxicity: the urea-formol foam gives rise to the greater hazard since HCN and nitrogen oxide are produced.

4.02.2.6 Harmonised ignition test rig

Author: G. BLANPAIN
Organisation: CERCHAR - France (7258-02/105/03)

Research objectives

The 6th Report of the SHCMOEI (Doc. 2786/8/80) refers to the 'Continental' and 'British' ignition tests and introduced a harmonised test, for which there was no specification. The report required that this harmonised test would be carried out in parallel with the 'continental' test in order to establish a specification for the consideration and decision of the committee of Experts on Fire-Resistant Fluids . The aim of the project was to carry out tests at CERCHAR in parallel with the British Health and Safety Executive (HSE) and to prepare a specification.

Research findings

Fluids were exchanged between the two research stations. The tests were carried out in accordance with the method described in the Sixth Report on the apparatus built at its Verneuil laboratory. Fluids tested were polyglycols, chlorinated hydrocarbons, phosphate esters, invert emulsions and oil. The test equipment used and the comparative tests are described as conducted at Verneuil, Buxton and Bretby and by the firm CPFT - the apparatus used here was different from that prescribed. The tests on five products were close enough but there were others which only the HSE considered reasonable in spite of the difference which exists between the two test laboratories. An advantage of the harmonised test is that it permits quantification, and hence ranking, of the results.

The report concludes that from the results as obtained from the two laboratories the test rig at Verneuil could be considered as operational. It proposed further trials, including some German tests from the test rig now being erected in that country and that these be examined by the experts group.

4.02.2.7 Test rig for harmonised fire-resistance tests of hydraulic transmission fluids

Author: HEYN
Organisation: VG - Germany (7258-02/141/01)

Research objectives

The hydraulic fluids used below ground must satisfy various hygiene, technical and fire-resistance requirements.

Hitherto, two types of tests have been used in the European Community to determine the fire-resistance properties of such fluids:

- the "Community of Six" and "United Kingdom" spray tests;
- determination of flame propagation in a mixture of coal dust and the fluid under test or on a fluid-soaked wick.

The Community of Six or United Kingdom spray tests, even after modification, do not allow these fluids to be distinguished from mineral oils (which are not permitted) nor can they be used to rank the fluids: they provide only a pass or fail result.

While research was in progress at the VG, the Health and Safety Executive (HSE) developed a new method based on the "quantity of heat released by a stabilised flame". (Note by the author of the summary: the British inventors of the test use the phrase "ease of stabilisation - Eos".)

The aim of this project was to determine which of the tests in use is most suitable for distinguishing between fluids in terms of their ignitability.

Research findings

The new HSE "stabilised flame heat release" test seems to satisfy all the requirements.
Once the acceptance criteria for hydraulic fluids have been determined, it could therefore be adopted as a harmonised test in the various Community countries.

Determination of the persistence of flame on a fluid-soaked wick seems suitable as an additional harmonised test.

4.02.3 Fire control

4.02.3.1 Use of new CO measuring equipment and CO fire detectors for improved fire monitoring in belt conveyor roads with large ventilation airflows

Author: Dr.-Ing. K. NOACK
Organisation: WBK - Germany (7258-02/082/01)

Research objectives

The early detection of CO from heatings and fire in belt roads in which large volumes of air circulate is a vital need for the safety of operations and the workforce; the incidence of fire in such circumstances has not been eliminated or even materially reduced over the last five years. A earlier research project had successfully produced a fire detection system - the ESCO PFG 1 which has been improved to the point where the early detection of fire in roads with airflows of up to 100 m^3/sec is possible.

Research findings

The original system comprised between three and eight CO measuring units and a microcomputer for the collection and analysis of the signals. The development of a new digital data transmission system enabled up to 45 CO units to be connected. The alarm is triggered when the difference in concentrations of CO reaches 1.5 ppm. The analysis method takes account of CO produced by shotfiring, diesel exhaust gases and other sources. Spurious alarms are almost entirely avoided and maintenance periods are monthly. The CO sensors used in the project were the PFG CO 7 metal oxide detectors. A pit trial was carried out at Auguste Victoria in a roadway with 80 m^3/sec airflow. These instruments are not as yet commercially available.

To permit more rapid detection, further tests were carried out on differential fire detectors capable of measuring the signals from the short-term fluctuations in the CO concentration resulting from erratic emission of small amounts of CO in the initial stages of a fire.

The report draws attention to the work being done under research contract 7258-02/119/01 at the Tremonia test station, where instruments sensitive to pyrolysis products have detected fires originating in smouldering combustion and belt slip, and concludes that work should continue on developing and refining signal analysis.

4.02.3.2 Study of pressurised havens

Author: J. FOUBET
Organisation: CERCHAR - France (7258-02/104/03)

Research objectives

Mine evacuation plans provide for locations where personnel may assemble in suitable ventilation prior to evacuation via escape routes. The concentration of workings, which make distances to fresh air points longer, may make it impossible for men to reach the assembly points since they may be overtaken by toxic gases released into the roadways before they reach safety, even though they are equipped with self-rescuers. This project examined the hazards and the requirements for survival chambers where the men can change their apparatus or wait, in safety, for further instructions on rescue arrangements.

Research findings

The report covers five fire gallery experiments which showed that at distances of 100 m from the fire temperatures between 200° C and 600° C could be expected and that these values and the volume of fumes depended on the duration and propagation of the fire and the velocity of the ventilating current. Thus the research was designed to establish the extent to which miners could be protected against toxic fumes and heat and to develop fire-retardant materials for heat insulation and sealing of the chambers to prevent ingress of the hot gases. Two different designs of survival chamber were studied in the surface fire gallery at CERCHAR. The first, illustrated in photographs 1 and 2,

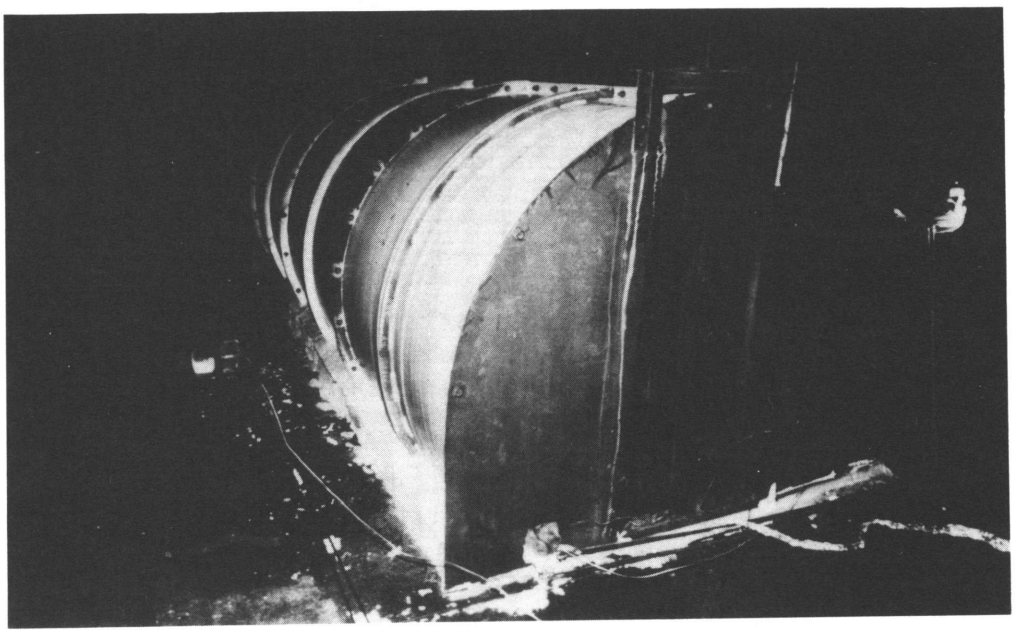


Photo 1 - External view of the 'tube-type' chamber

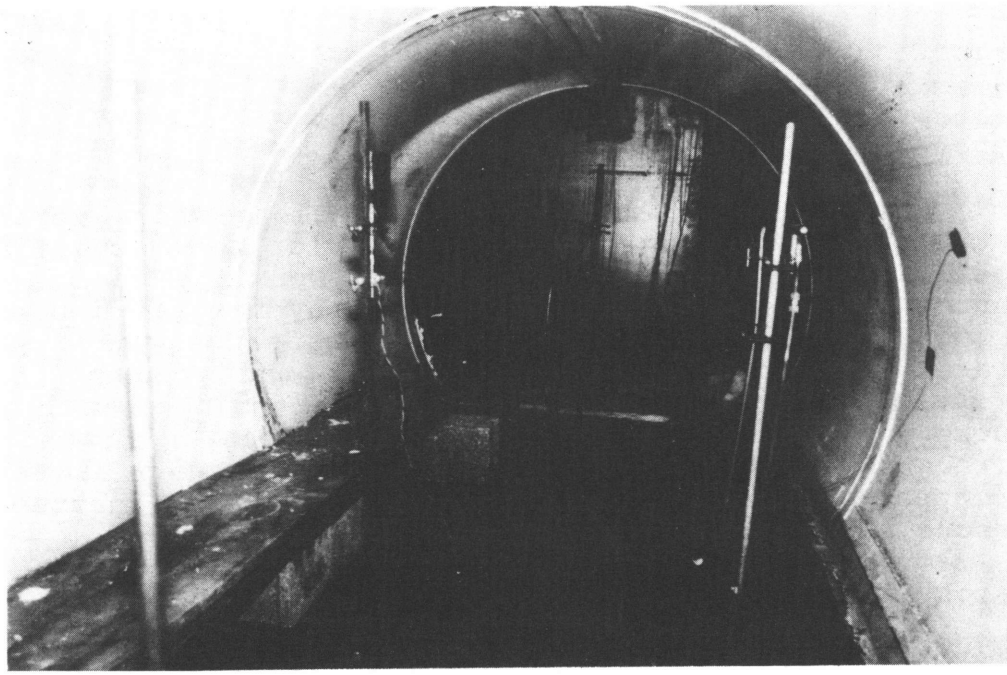


Photo 2 - Internal view of the 'tube-type' chamber

was made of sections forming a 50 m steel tube and installed in the gallery itself; the second was constructed in the side of the gallery to simulate an underground refuge hole.

The first part of the trials sought to

- establish the natural ventilation and the temperature gradient in the gallery cross-section and between the gallery and the survival chamber,
- determine the heat exchange between the hot gases and the interior of the chamber and
- determine the heat resistance of the flexible curtains fixed at the chamber entrance.

Also studied were the cooling of the gases upstream of the chamber, the cooling of the steel tubes and entry curtains by water, the heat insulation of the tubes and the injection of cool air into the chamber.

The performance of the 'tube-type' chamber was studied first. With the burner operating at different power levels the vertical temperature distribution in a cross-section of the gallery was measured upwind and downwind of the chamber. Two distinct layers were measured in the chamber; one of very hot gas between the roof and a point 2.5 m above the floor and a second cooler layer from floor level to 1.7 m above the

floor. Between the two layers a considerable 'thermal jump' of the order of 300 to 400°C were observed. The volume of air to be injected and the time required to purge the chamber of gases before it could be entered was determined. It was also established that an airflow of 300 Nm^3/h was required to raise the inside pressure to 15-20 Pa when the outside temperature was 200° C. With an outside temperature of 100° C the temperature inside the chamber rapidly reached 80° to 85° C. Cooling water applied to the tubes at 2.5 m^3/h and 6 m^3/h reduced this to 60 and 40° C respectively. With an outside temperature of 160° C the inside temperature rose to 65° C, which is well above the human tolerance limit. If the hot air upstream of the chamber is cooled by water sprinklers, between 30° and 50° C reduction could be achieved if the sprinklers were installed at heights between 1.7 m and 3 m. The thermal resistances of various materials for the flexible curtains and air supply ducts were established; the best results were obtained with flexible fabrics based on silicon-coated glass. The position of the air supply ducts in the gallery is a problem, since the air is heated to unacceptably high temperatures by the hot gases.

The performance of the 'wall-type" or 'lateral-type' chamber was then studied. It was 2 m high by 2 m deep and compressed-air purging took five to ten minutes. Again 300 Nm^3/h of compressed air at a pressure of 5-10 Pa was required to maintain stabilised and clean air conditions. The temperature inside the chamber did not exceed 25° to 30° C although the outside temperature was 200° C. A sprinkler was used to cool the curtain; whatever the temperature outside the curtain the inside temperature never exceeded human tolerance. The siting of a spray upstream and at a height of 1.7 m to 3 m, showed that a further temperature reduction could be achieved.

The trials provided significant data which would enable such survival chambers to be designed according to their purpose and their siting in the mine. If the chamber is to be used as a station where miners change self-rescuers or as an assembly point the resistance to ingress of toxic gases is the primary consideration. If it is to act as a refuge until the fire is extinguished then it must afford both thermal and toxic gas protection.

Further studies of cooling systems should be made in order to reduce costs.

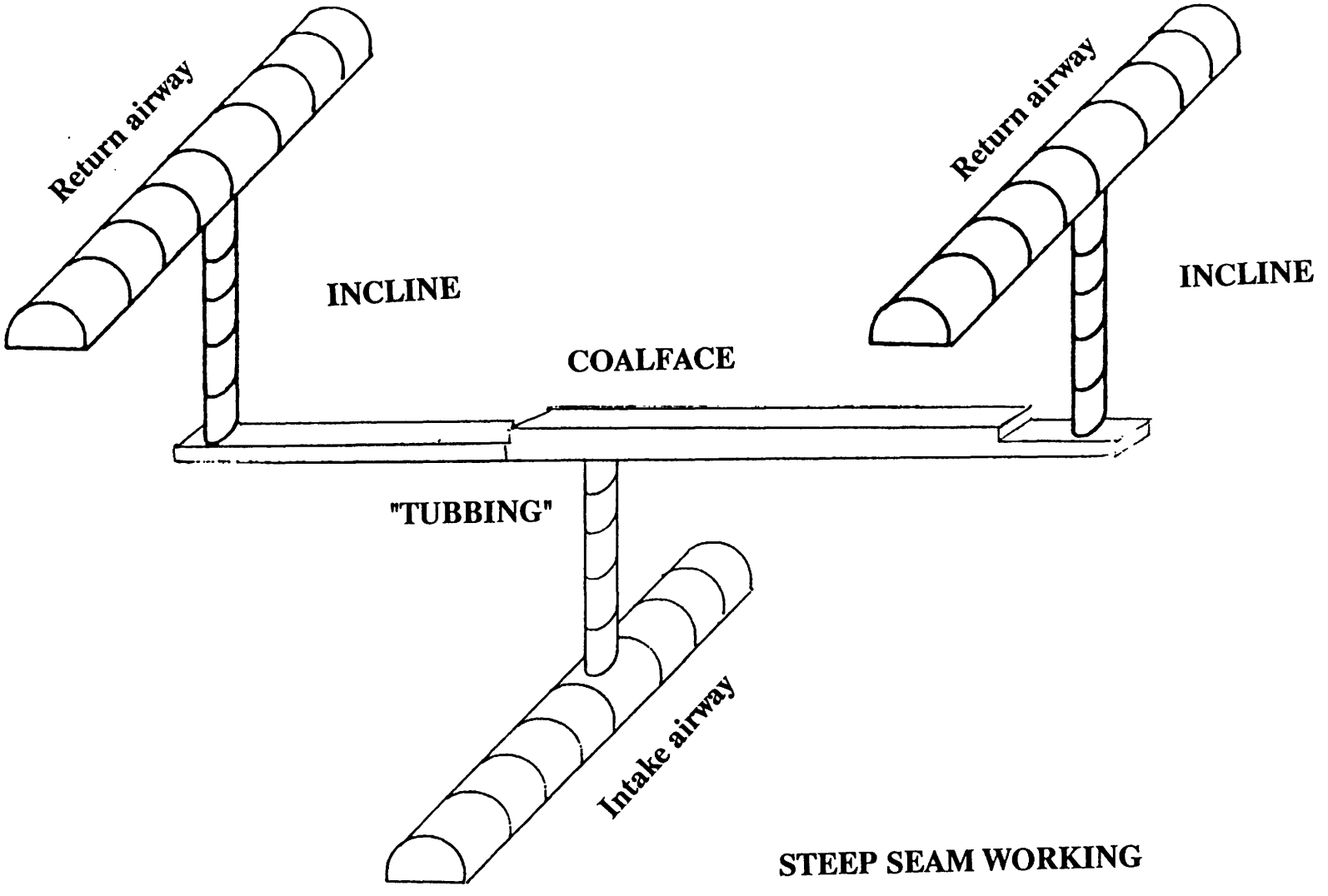
4.02.3.3 Improvements in stopping construction methods

Author: P-M. DUPOND
Organisation: CdF, HBL - France (7258-02/122/03)

Research objectives

In mines where fire is a hazard the construction of explosion-proof stoppings may be necessary to isolate the district affected if the fire cannot be controlled by other means. The operation of construction is not without risk. The aim of this project was to provide means for a stopping to be constructed in less than eight hours for level roadways (<40°) and steeply inclined roadways (>60°).

These latter roads are known as 'tubbings' because they are built up from metal tubbing rings with diameters of 2.20 m for intake airways and 1.70 m for return airways. They give access to the seam and enable the face to be worked to the rise and the waste to be stowed. The gradient of the 'tubbings' varies from 60° to 90°. The illustration (Annex 1) shows one of the two systems used.



STEEP SEAM WORKING

BY SLICES TAKEN TO THE RISE

WITH CAVED GOAF AND ASCENSIONAL VENTILATION

Research findings

Improvements were sought in six areas:

- advance preparation of stopping sites in level roadways;
- preparation and correct preplacement of the necessary materials in the supplies system;
- type of end-wall required - preferably of light, prefabricated construction;
- infill materials - either anhydrite or ready-mixed concrete;
- personnel training;
- nitrogen injection.

Construction of a stopping of lightweight materials, infilling and closure are described in detail. For this type of stopping a team of seven men could complete construction in between six and a half and eight hours in a 15 m^2 roadway.

Where a main 'tubbing' has to be sealed different materials are required. A plug of Mariflex must be placed so as to prevent ingress of concrete into the hopper under the 'tubbing'. Concrete is pumped from a fixed station adjacent to the supplies system. With a team of seven men construction times have varied from four to six and a half hours. Hydraulic stowing of the face was carried out 24 hours after sealing and after 48 hours there was no sign of leakage of the stowing material. A stopping in a secondary 'tubbing' was built in two hours by five men.

The nitrogen injection arrangements are described for situations in which a stopping has to be built and for the more urgent case of an outbreak of open fire.

Training of the rescue teams is based on videos and drills in the surface rescue station. On these occasions, the advantages of this method of seal construction are explained.

4.03 EXPLOSIONS

In the First Programme there were 14 projects which examined the frictional ignition hazard, the development of triggered barriers and other means to prevent the propagation of an explosion and tests on auxiliary fans. This Second Programme comprised 18 projects which continued the research work already started on the means to eliminate frictional ignitions and to prevent the propagation of an explosion no matter where it originated. The projects are grouped in three divisions of like interest.

For the period 1958 to 1985, a statistical survey by the SHCMOEI has shown that the average annual number of explosions has progressively reduced from 1.14 to 0.8. The average number of personnel killed per explosion has been substantially reduced and is now standing at 6.4. The study also showed that nine of the 13 group accidents were caused by firedamp explosions and that seven of these nine explosions were connected with auxiliary ventilation.

Research work, under both this and other research programmes, has identified how frictional ignitions are caused and the combinations of techniques which enable them to be eliminated. Projects in the field have reported that the hazard remains and indeed that in stone work it is increasing. Rigourous adoption of the known remedies should reduce the incidence of frictional ignitions.

Much valuable work has been done on triggered and non-triggered explosion barriers. These systems have demonstrated their effectiveness in limiting or suppressing explosions. The intensive mechanisation of roadway drivage systems for high-output faces and long-run single entry roads called for a rethink on barrier design. The research projects have designed and tested easily erected triggered barriers for such operations. Other projects have investigated the hazardous conditions which might arise in single entry roads, driven on a gradient, in relation to methane layering and the use of nitrogen.

The safety features to be built into the system design of long, mechanised drivages need to be much more comprehensive than the protective systems formerly used in short drivages. The prevention and control measures developed under this field, integrated with remote monitoring of the auxiliary ventilation system and personal rescue protection, together

form a safe control system. The field of research 'Fires' deals with these monitoring systems as well as the development of personal self-rescuers and rescue havens.

Frictional ignitions	100, 106, 087, 108, 084, 088
Explosion control	124, 107, 125, 083, 085, 099, 123, 143, 144, 078, 115, 152
Use of explosives	142

4.03 EXPLOSIONS

4.03.1 Frictional ignitions

4.03.1.1 Statistical evaluation of frictional ignitions on longwall faces

Author: R.A. BURRELL
Organisation: British Coal - UK (7258-03/100/08)

Research objectives

The objective of the investigation was to ascertain if there was any machine, or working method, which carried a greater risk of frictional ignition than any other. Previous research in the first mines safety programme - reports 7255-11/068/08 and 7255-11/068/08 had described the mechanics of frictional ignitions. This second mines safety programme also has two projects which deal with frictional ignitions. This project differs from others in that it sets out to analyse the data collected by British Coal (formerly the NCB) on each reported longwall face frictional ignition and on variables, such as type of machine, drum and cutterpick design, methods of ventilating the cut and etc. as used on that face.

Research findings

The report commented on the earlier work of British Coal and the HSE and summarised the findings:

- the contribution made by worn picks and pick design to the probability of ignition,
- that seams and strata containing pyrites, ironstone and quartzitic rocks are capable of producing incendive temperatures, especially if the ITP (incendive temperature potential) of quartz-bearing rock is greater than 50%,
- the measurement of gas emission in the cutting drum indicates that emission rate is determined by features of drum design and pick lacing patterns,
- that methane concentration in the cutting zone indicates that ignition risk could be correlated with face air velocity and the direction of face ventilation in relation to the direction of cutting.

Data on frictional ignitions has been collected by British Coal since 1965. The graphical representation in the report shows that the ignition risk has continued to rise over the years but that latterly there seems to be a slight improvement. Ignitions are reported for both ranging drum shearers and in-web shearers with the latter machine showing a rate at least twice as high as other machines. Some 20% of ignitions occurred where the drum diameter exceeded the seam section, 69% of these being associated with in-web machines.

Seams less than 1.2 m in thickness accounted for some 50% of all the ignitions.

The data on face airflows showed that most ignitions have occurred on those shearer faces with airflows in the 2 to 3 m/sec velocity band. By far the greater number - 50% - occurred in seams with gas makes of 4-10 m^3/sec.

Whilst there was almost an equal number of ignitions with the machine cutting in either direction to the airflow the worst conditions were cutting against the ventilation with drum leading and cutting with the ventilation with drum trailing. The majority of ignitions took place at floor level. Although Hollow Shaft Ventilators (HSV) had been on the market since around 1970, ignitions have occurred with machines fitted with them. Examination of them after an ignition showed that they could pass little or no air. A few ignitions had occurred where the airflow through the shaft was >100 litres/sec.

An analysis of the seams shows that a small number have been responsible for the greater number of incidents. The report lists 68 seams with a history of unusual emissions of methane and in which 55% of ignitions occurred. Sudden floor emissions had been responsible for the greatest number but ignitions had also been reported in seams with low permeability and seams subject to de-stressing of strata.

The report concludes that the solution to the problem has not been found. Control of the cutting horizon, choice of drum diameter and pick lacing patterns, position of water jets in relation to the cutting pick, monitoring of the airflow through drum ventilation, especially the recently developed extraction drum, are all important design features. It is also clear that whilst the ITP of seams must be examined the possibility of sudden or unusual emission of methane must be considered.

References: 22

4.03.1.2 The use of surface rigs to study frictional ignitions and their suppression

Author: P.G. TREGELLES
Organisation: British Coal - UK (7258-03/106/08)

Research objectives

In the British coal industry frictional ignitions have continued to occur at an average rate of 14 per year despite the reduction in the number of faces in production. Roadway drivage operations have been responsible for 10% of all ignitions. Previous research in this area has been supported by two UK Community projects - see references and by other organisations. Frictional ignitions are a world-wide problem.

The objectives of this project were
1) to verify the experimental method employed on the Mark 1 frictional ignition rig,
2) to examine the ignition prevention performance of commercially available pick-water systems and spray configurations and establish design principles for the future guidance of manufacturers,
3) to study the ignition control characteristics of the Extraction Drum.

Research findings

The Mark 1 rig was designed to reproduce harsh conditions so as to enable pick-water systems to be assessed. The design of the rig is described in the final report. The Mark 2 rig was designed in order to determine the maximum rate at which methane could be introduced into the Extraction Drum without causing an ignition and to demonstrate the ventilation performance of the drum.

The experimental method

The final report describes the method as used on the Mark 1 rig for determining the stability of the experimental conditions, the estimation of ignition probability and particle temperature for which a high speed video technique was used. When cutting without water the analysis revealed that 90% of the ignitions occurred within 300 mm of the pick and 70% within 180 mm. Between 60% and 70% of the ignitions were initiated by hot material lying in the track. The effect of water sprays is to be studied later in view of the fact that many ignitions are caused at floor level. An infra-red technique developed at WBK revealed peak temperatures of 1100° C within a few centimetres behind the pick. A future programme is to use the video to study ignitions occurring when water sprays are in operation. The maximum temperatures of particles causing ignition on the rig fell in the range 1000° to 1200° C.

Investigation of pick-water systems

Manufacturers have produced a number of designs which provide for water to pass from the pick box to a spray or jet positioned close to the pick and behind it. The experimental work compared the relative merits of 22 systems for both radial and forward-attack picks. The experimental parameters provided for a depth of cut of 10 mm, a cutting speed of 117 mm/s, a methane concentration of 7.5% and a water pressure of 7 MPa. The investigation into spray configuration examined spray density and coverage, spray width and length and distance from the leading edge of the spray and the pick tip; nozzle orifice diameter, location and orientation and spray density, pressure and water consumption. Table 12 sets down suggested design parameters for a practical ignition prevention system. The report emphasises the need to maintain the spray system in 100% working order and to inspect regularly the condition of picks and to replace those worn or damaged. A computer program has been written to simplify the task of designing optimum spray configuration.

Investigation of the Extraction Drum

The experimental method is described. For this an extraction drum of 1.37 m diameter was fitted to a fixed arm shearer working on an artificial coalface. Methane was introduced into the cut in order to produce concentrations above 5%. A spark plug igniter provided a source of ignition. Ultra-violet flame detectors determined when the ignition took place. Seven principal variables were examined, airflow and direction of ventilation, blocked sprays and tubes in the drum, roof and floor ignitions, cutting drum trailing and leading. The data collected are discussed. They showed that re-circulation in the drum was higher than expected, which led to more ready homogenisation of the gas mixtures; the extraction drum chosen was too large for the machine on which it was installed and it appeared to under-perform. However, the experiment did show that whereas a methane flow rate of 5 l/s will generate an ignition with no drum ventilation about 15 l/s is required when the extraction drum is used and that flame breakout is restricted and reduces the severity of the ignition should a large volume of methane be introduced into the cutting drum.

The report indicates that for coalface equipment further work is required and that test rigs are needed in order to evaluate new designs of pick and spray configurations.

References: 11

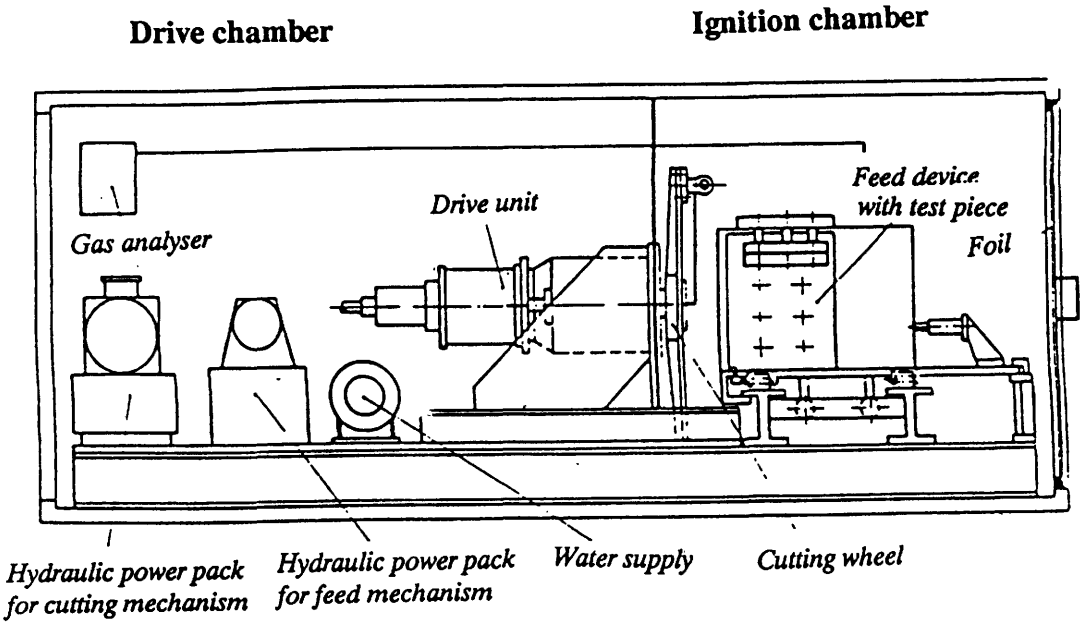
4.03.1.3 Processes for eliminating ignition hazards presented by frictional sparking

Authors: Dipl.-Ing. MARX, Dipl.-Ing. BIEBER
Organisation: DMT(WBK) - Germany (7258-03/087/01)

Research objectives

During the period 1977-1987 there were 43 frictional ignitions caused by shearers and roadheading machines in North Rhine-Westphalia. The aim of this project was to investigate the various types of cutting equipment on a purpose-built test rig at WBK (which has since become part of the DMT) and to determine means of reducing the risk of ignition.

Research findings



The above diagram shows that the cutting of the rock sample takes place in an "ignition chamber" (Abflammraum), which can be filled with a controlled mixture of methane and air. The cutting mechanisms were a two-pick cutting arm and a cutting wheel with up to 24 picks, cutting tests being carried out on a block of very strong, high-quartz sandstone, which thus had a high incendive potential.

Preliminary tests showed that
- no ignition would ensue where the methane content was less than 5% by volume;
- the upper explosive limit of a methane/air mixture depends on the geometry and size of the cutting tools; in roadway drivage using conical tools an upper limit of 9.5% methane was recorded as compared with 7.5% for flat-tipped picks;

- the time factor also plays a part, the time needed for a spark to ignite being shortest with a methane content of 7% by volume.

However, the best preventive systems are of no use if they are turned off because they cause a nuisance, and this is the case if too much water is consumed. Efforts were therefore made to reduce water consumption.

After various tests, this was achieved by controlling the release of water pick by pick: 1.7 l/min per pick at a pressure of 100 bars. Water phasing by drum segment gave less satisfactory results.

All the water jet systems were tested under the same conditions. The requirements for satisfactory spark suppression with a water flow of 1.7 l/m can be achieved by the use of a cone jet built into the body of the pick and with an outlet angle of at least 15°, or preferably 20°.

It is important that the cooling water hits the hottest part of the pick behind the pick point. Blockage of the jet is experienced if the jet diameter is less than 0.7 mm.

The tests showed that the probability of ignition can be reduced with high ventilation quantities, but even with a ventilation speed of 30 m/s ignitions have occurred.

Spraying of a mixture of air and water made it possible to reduce water consumption. Tests on the rig showed that no ignitions occurred with 0.3 l/min of water per pick and an airflow of 0.25 m^3/min. These positive results were confirmed by tests on a roadheader.

4.03.1.4 Adaptation to French mining conditions of the Community rules for reduction of the risk of firedamp ignition by picks - Application to the development of shearer drums

Author: J. SANTAMARIA
Organisation: CERCHAR - France (7258-03/108/03)

Research objectives

In France, whilst there had been no frictional ignitions on the same scale as in the UK and the USA before 1982, there were 13 incidents between 1982 and 1987 - 10 on the face and three in roadways. The aim of the project was to obtain the frictional ignition characteristics of the seams in Lorraine, to develop a new pick and water spray system and to carry out frictional ignition trials in a surface gallery.

Research findings

The study is presented in three parts. The first part reviews the work in the UK and USA and describes the physical examination of some 50 Lorraine seams for their petrographic characteristics and incendive temperature potential. The second part describes the development of new types of cutter picks, the importance of back-face flushing and the importance of ventilation to reduce methane concentrations around shearer drums and roadheader cutting heads. The third part describes the studies carried out at CERCHAR on a surface test rig in order to determine the temperature of the pick track in the rock and the possibilities of extinguishing incipient ignitions.

Seam classification

Some 1000 samples were taken from seams and headings with a heavy make of gas. Analysis of the results provided an index of potential ignition, (IPI), which permitted classification of the seam or mine and changes in IPI; these results are tabulated. It was also noticed that the classification of a given seam varied from a low to a high figure from mine to mine and that "fat" coals had an above-average index. A correlation made between the index as measured and actual ignitions showed that all incidents occurred when the index was higher than two.

Development of new picks and water spray systems

In the difficult conditions of some Lorraine seams - hard stone and high risk of frictional ignitions - the forward-attack pick could no longer, because of the high rate of wear, provide productive and safe conditions when used on shearer machines where the pick speed was more than 3 m/s, the haulage speed more than 6 m/min and the machine power

greater than 600 kW. A conical, self-sharpening, point-attack pick, with a tungsten carbide mushroom tip was developed for use in the difficult conditions. In this design the tungsten carbide tip entirely covered the pick body, thus protecting the steel shank. The initial brazing was too weak but was improved to give a 150 kN breaking-off force. However, the trials at Sainte-Fontaine showed that the pick had a less extensive range of application than the conventional point-attack pick and was cost-effective only in seams with a hardness of 900-1000 bars and where the forward-attack pick was not suitable. Beyond this limit the carbide breaks and the pick ceases to rotate. A statistical analysis showed that the consumption per 1000 tonnes run-of-mine coal was 29% lower than for conventional conical picks. Research will continue into the type of pick suitable for seams with a hardness greater than 1000 bars, which fortunately are rare.

Houillères du Bassin de Lorraine carried out trials on the design of sprays for cutting picks in which the nozzle is fitted into the pick holder behind the pick. The report indicates that drums should be fitted with stainless steel pipes, that the water pressure should be regulated to 20 to 40 bars to give each jet an output of 2 l/min (100 l/min per drum), that the water must be filtered to less than 10 microns in a unit placed in the water supply upstream of the machine. Self-cleaning filters have been used successfully. As far as the ventilation of the cut is concerned, HBL has conducted two trials of the UK developed hollow shaft ventilator and will carry out a trial of the extraction drum following the trials of this in the UK.

For heading machines, tests of the JET-FLOW air/air or air/water jet are scheduled for surface trials. Auxiliary ventilation techniques using forcing and exhaust arrangements, dust extractors and Coanda ducts are currently being tested below ground and conditions for their use are being established. Guidance is given on the placing of these devices around the machine and in the roadway and on the quantity of air they should provide.

The surface test rig

The report gives an account of the test rig and the initial experiments at the surface test site at Verneuil. The purpose of the tests is to determine the role of various parameters - to observe pick track isotherms and the effect of depth of cut, rock properties and worn picks and to assess the design of new picks.

The test rig and instrumentation are described. Using equipment available on site to determine the thermal gradient of the surface cut, trials of three types of pick were made in a block of concrete and in two types of rock conglomerate supplied from HBL. In these experiments no temperature exceeding 700° C was recorded. The results confirmed that the

new pick design gave a lower temperature than the old designs; that increasing the depth of cut (3 mm to 6 mm) caused an increase in temperature ranging from 20° C for the new designs to 150° C for the old. The thermograms showed that the hot surface behind the tool extended some 100 to 300 mm for a width of 20 to 30 mm. The influence of the pyrites in the stone sample could not be quantified.

Trials were carried out in order to determine the amount of air needed to suppress ignitions immediately or prevent their occurrence. The trials showed that for a firedamp make of 10 to 60 l/min the air speed must be between 1 and 4 m/s and that there is a linear relationship between the methane and air quantities which depends on the angle of incidence of the air jet in relation to the source of methane. Further trials are needed.

References: 28

4.03.1.5 The effects of pick design parameters on ignition probability

Authors: POWELL, SLACK
Organisation: HSE - UK (7258-03/084/08)

Research objectives

Previous research has shown that the risk of gas ignition by shearer picks can be reduced by lowering the speed of cutting and by water jets directed on to the hot groove made by the pick. This has operational disadvantages. The project examined the possibility of reducing ignition risk by changing pick shape and material.

Research findings

The rock cutting machine at Buxton was used to compare the ignition risk of various commercially available tungsten carbide picks with water spray nozzles and supply channels as an integral part of the pick, and of picks with material much harder than tungsten carbide. At cutting speeds as used in practice ignition of the 7% methane/air mixture occurred in most of the tests with the tungsten carbide picks. Cutting times for a 50% probability of ignition were used for comparison when the differences in risk were small.

The cutting time for a 50% probability is affected by the shape of the carbide pick tip and by the shape of the pick body near to the tip if the geometry is such that the pick body rubs against the rock. The possibility of using eight safer pick body materials was examined. The only materials which gave times higher than those for steel were those with high copper content, which are expensive.

A polycrystalline diamond material in the form of a thin layer, 0.7 mm, was attached to the rake face of the tungsten carbide. The reduction in pick length was about 0.4 mm after cutting 1000 m at 3.0 m/s.

A tungsten carbide pick gave an ignition after 20 m at 3.0 m/s and the tip was completely worn away after cutting 30 m. No ignition occurred so long as the carbide layer did not rub on the rock.

In a limited number of tests the diamond layer was not damaged by impacts against steps in the rock; damage might occur under less carefully controlled conditions as on boom-type heading machines.

Also in a limited number of tests the rake angle was varied between the recommended values of 14 degrees negative and 2 degrees positive without any signs of damage to the diamond layer.

An integral water spray nozzle in the pick body enables the nozzle to be positioned accurately and give optimum ignition suppression. The cutting distance for a 50% probability of ignition with a water flow of 2 l/min is about three times that for dry conditions. Blockage of the jet may occur if the nozzle is too close to the carbide tip.

4.03.1.6 Water supply for a shearer venturi

Authors: J.A.AGNEW, G. PRATT
Organisation: British Coal - UK (7258-03/088/08)

Research objectives

The original aim of the project was to develop, for a shearer, an on-board compact high-pressure water pump to supply a venturi device for controlling dust and methane concentrations around the drum whilst cutting.

This project was dropped in 1985 since such equipment was by then available commercially.

It was then decided to use the remaining funds to develop a new type of shearer on which coal cutting was assisted by high-pressure water jets.

This system was designated JACC (Jet Assisted Coal Cutting).

Research findings (from work on JACC)

Underground trials were carried out on a shearer equipped with a high-pressure pump (690 bars), which supplied water to the picks in the clearance ring only. The hollow shaft ventilator was supplied with water at normal pressure. Measurements were recorded for variations in the high-pressure water flow and pressures, machine power and speed and dust make. A coal size analysis was made for each trial.

- The haulage force was reduced by water assistance and this permitted the machine to cut faster. Most of the benefit was seen at a pressure of 310 bars.

- The total power consumed by the machine and the pump rose as pressure was increased, but it was demonstrated that the power consumed by the drum was considerably reduced.

- There was a progressive improvement in respirable dust make as water pressure increased, even when water consumption was lower.

Other findings are quoted in the final report, but do not pertain to safety or hygiene.

4.03.2 Explosion Control

4.03.2.1 Study of firedamp and/or dust explosions in particular configurations

Author: J. WINTER
Organisation: CERCHAR - France (7258-03/124/03)

Research objectives

Testing stations have wide experience of the process whereby dust explosions are triggered off by explosions caused by homogenous firedamp/air mixtures at the ends of cul-de-sac workings.

Very different situations, however, may arise in practice.

Two such cases were to be investigated in the project:

1) as a follow-up to an earlier study (7258-03/085/03) already described in this report: oxygen and methane concentration gradients may occur in the vicinity of a flame when, as a fire-fighting measure, nitrogen is injected and ventilation is simultaneously reduced;

2) there may be a methane concentration gradient along the axis of a roadway, e.g. as a result of a ventilation stoppage in a drivage or when a firedamp cloud forms at the face or in a roadway at a faulted zone.

Research findings

When nitrogen is added to a length of methane/air mixture acting as an initiating source (20 m^3) in quantities sufficient to reduce the oxygen concentration to below 14%, dust explosions cannot be propagated.

When initiation is attempted with the same cloud of mixture and with zones inerted with nitrogen but containing 5% methane, the nitrogen concentration has to be increased by 25% to prevent propagation of a dust explosion.

The results of inertisation tests in a 2.5 m^2 gallery are valid for roadways of at least 10 m^2 section.

Tests were carried out with heterogenous firedamp accumulations simulating a moving length of mixture displaced by recovery of a gas-fast heading, a ventilation stoppage in a rise heading or methane roof layers. These experiments highlighted the turbulence resulting from the propagation of reflected pressure waves, which could give rise to violent explosions.

In tests with methane layers at the roof of a gallery, the force of the explosion, given equal valumes, very much depends on the characteristics of the layer. The presence of a "cavity" at some distance from the ignited layer at the end of the gallery may greatly intensify the effects of the ignition.

4.03.2.2 The feasibility of using aerodynamic models to study the local build-up of methane gas and risk of frictional ignition in coal mines

Authors: R.J. AITKEN, J.H. VINCENT, D. MARK, R.A. BOTHAM
Organisation: IOM - UK (7258-03/107/08)

Research objectives

The aim of the project was to examine the feasibility of using small-scale aerodynamic models to investigate the potential accumulation of methane in cavities where it might lead to frictional ignitions and to relate the findings to actual underground situations.

Research findings

The work was exploratory and set out to identify the properties of mine airflow relevant to the problem. These properties were considered to be bulk airflow and the transport of material, i.e. gas and dust, out of regions of partially enclosed, or poorly ventilated flow such as the coal cutting zone of a shearer or headings. Bulk diffusivity of the coal airflow and the characteristic retention time are the quantities most appropriate for the coalface and headings respectively. For the purpose of scaling these properties had to be non-dimensionalised; the Reynolds number was also important.

For the bulk flow along the coalface the experiments were conducted in a 1/10 scale laboratory model, a full-scale surface model and an underground site and for the heading a 1/10 scale model and a surface system were used.

The experiments showed that the feasibility of using small-scale models to investigate ventilation problems was clearly indicated and a set of scaling relationships relevant to the transport of methane and dust were drawn up.

References: 29

4.03.2.3 The build-up of explosions in large roadway sections

Author: J. MICHELIS
Organisation: DMT(VG) - Germany (7258-03/125/01)

Research objectives

With increasing productivity and depth of mining, roadway cross-sections increased by almost 100% in the gates directly serving the face over the period 1962 to 1981 and by 71% in stone drifts.

The present generation of explosion control devices was developed in test galleries with cross-sections of up to 12 m^2 and is reliable only against explosions with a maximum pressure of 5 bars.

It is well known that extrapolation of experimental results in the field of combustion processes is very risky. Results obtained in a 8 m^2 gallery certainly cannot simply be transposed to a 20 m^2 roadway.

The Tremonia underground testing station of the DMT now has a gallery of 19.5 m^2 cross-section 265 m in length. It was decided to use this facility for a project on the effects of explosions of methane, coal or both (i.e. "hybrid" explosions), the following parameters being varied:
- fuel type, quantity and concentration;
- type and strength of initiation;
- dimensions of the initiation chamber.

Research findings

1) In the "ignition zone"

In coal dust explosions, static pressures are inversely proportional to the cross-section, if the quantity of fuel is the same.

In ignitions of firedamp layers in the roof, static pressures are approximately the same, irrespective of cross-section, if the quantity of fuel is the same.

In explosions of firedamp/air mixtures, static pressures for the same quantity of fuel are inversely proportional to the cross-section. Approximately the same propagation speeds were recorded in the ignition zone for the two roadways (8 m^2 and 19.5 m^2). They depended on the type of explosion, but not on the roadway cross-section.

2) In the "combustion zone"

The static pressures and maximum flame lengths resulting from explosions in roadways of different cross-section are not affected by the cross-section when explosions of the same type and with similar energy densities are compared.

3) General conclusion

No major changes in the effects of explosions are to be expected as a function of roadway cross-section.

This conclusion is very important, since it means that all the findings of experiments in smaller cross-sections are applicable to large-section roadways.

4.03.2.4 Investigation of explosions with long build-up distances (>150 m) and ways of controlling them

Author: J. MICHELIS
Organisation: DMT(VG) - Germany (7258-03/083/01)

Research objectives

In earlier work at the Tremonia underground testing station, the distance covered by an explosion flame between the point of ignition and the site of the first explosion barrier could not exceed 150 m because the explosion galleries were not sufficiently long.

They have now been extended to 750 m (8 m^2 section), and it is thus possible to study explosions with long build-up distances (> 150 m), to determine the effect of this distance on the pressure developed and flame speed and to study the performance of explosion barriers in such cases.

Research findings

Over 100 full-scale tests were carried out, comprising preliminary tests without barriers ("Leerversuche" - reference tests) to provide a basis of comparison and tests with different types of barrier ("Löschversuche"- suppression tests). The barriers tested were water trough barriers in a concentrated (types 1, 2 and 3) or distributed (type 4) arrangement. The force of the explosion was also varied by adding different quantities of inert material to the fuel (coal dust) and by using initiation sources of different composition and strength. The pressures developed varied by as much as a factor of ten. The distance covered by the explosions in the suppression tests depended on the siting of the first group of troughs: 90, 200 and 300 m.

In the suppression tests, the flame lengths were progressively reduced in comparison with those observed in the reference tests by a factor of more than two in some cases. If the explosion was allowed to propagate over 200 m, the flames were extinguished before reaching the end of the barrier zone.

4.03.2.5 Partial inertisation with nitrogen as a means of preventing the initiation and propagation of a coal dust explosion

Author: J. WINTER
Organisation: CERCHAR - France (7258-03/085/03)

Research objectives

Nitrogen purging is now widely practised in the European Community as a means of fighting open and deep-seated fires in mines. The atmosphere near the fire may be flammable as a result of the mixture of methane with the products of pyrolysis or combustion and there is a risk of a gas or coal-dust explosion as long as the air reaching the seat of the fire is not sufficiently inerted.

Research findings

Tests were carried out in a 2.5 m^2 gallery 144 m in length to establish whether the existence of a zone of oxygen-depleted atmosphere reduces the likelihood of propagation of a dust explosion initiated by a cloud of firedamp. To this end, the length of the nitrogen-inerted zone, its position in relation to the firedamp cloud and the intensity of the explosion were varied and the limit values of oxygen for suppression of the explosion as far as the end of the gallery were determined.

The results show that the oxygen concentration is not the only criterion; account must also be taken of the length of the inerted zone, which may not be less than a value which depends on the violence of the initiating explosion as the flame otherwise cannot be arrested, even with oxygen levels as low as 5% in the inerted zone.

4.03.2.6 The Belgian system of triggered barriers: technical applications, tests and improvements

Authors: J. ROEGIERS, P. GERARD
Organisation: Poudreries Réunies de Belgique (PRB) - Belgium (7258-03/099/02)

Research objectives

To improve the triggered barrier system so as to make it adaptable to a range of mining conditions, to make it easy to handle, install, and maintain and to provide permanent monitoring of the system.

Research findings to the end of December 1988

This report describes the underground tests at Reumaux and Wendel and the surface gallery tests at Tremonia.

At Reumaux

Tests on the trigerred barrier system - described in an earlier report - were carried out in a drivage using a Roc Miner with a forcing/exhaust duct at the face and with a main ventilation duct of oval shape. The barrier supports were modified to suit the overhead monorail. The eight disperser units of the barrier were grouped in pairs and sited between 15 m and 30 m from the face. An operational fault set off the sensor, which remained armed. This raised certain design issues which could only be resolved by further tests. A second trial was carried out but further operational problems were encountered.

At Wendel

Tests were carried out in a Roc Miner drivage. This installation has two ventilation ducts at the head end, one of which is connected to a Hölter deduster. The barrier comprised 10 disperser units grouped in pairs between 25 m and 45 m and two sensors at 15 m and 46 m from the face. A non-welded enclosure was considered but was thought to be too fragile. No results were reported.

Surface studies were made in gassy conditions of water dispersers of increased capacity (110 l instead of 90 l). There was no burning of the containers.

At Tremonia

Five tests were carried out. All resulted in propagation being halted but with tongues of flame still seen at the end of the barrier zone.

4.03.2.7 Development and testing of mobile explosion barriers in various roadway cross-sections

Author: J. MICHELIS
Organisation: DMT(VG) - Germany (7258-03/123/01)

Research objectives

Since mine roadways are increasingly obstructed by ever bulkier mining equipment, there is often not enough room to instal an explosion barrier or barriers of approved design. This is particularly true of face gates, where congestion because of the presence of mining and transport equipment is compounded by the effects of strata pressure.

A second problem arises in connection with mechanised drivages: because of their high advance rates, the explosion barriers have to be moved forward frequently to keep up with the heading face. The only suitable designs in such cases are mobile barriers, which must be of a type approved by the mines inspectorate, but there is often not enough space to instal them.

The aim of the project was to develop fixed or mobile explosion barriers for use in the above circumstances. The work was carried out in an underground gallery of 19.5 m» finished cross-section at the Tremonia experimental mine (Versuchsgrube Tremonia - VG).

Research findings

Various arrangements were tested in this gallery, which in some of the tests was obstructed to a degree comparable with that found in a drivage. The barriers investigated were mobile barriers incorporated either in the services pantechnicon in a roadheader drivage or in the power train serving a production face. They sometimes included fixed troughs placed at suitable locations to supplement the mobile arrangement.

The first phase of obstructed-roadway trials generally investigates the dispersion achieved with no machinery or other obstruction in the roadway.

It was thus found that at dynamic pressures of less than 20 kPa (200 mbar) water was generally dispersed over only a small part of the roadway cross-section.

Second phase: suppression tests

The first finding was that at pressures of less than 20 kPa only "active" or triggered barriers were always effective. Passive barriers were effective at higher pressure provided they contained at least 200 l of suppressant per m» roadway

cross-section (as opposed 80 l for triggered barriers). The tests also established the maximum permissible distances between the troughs and the roadway sides.

Further tests were carried out to compare concentrated and distributed barriers on the one hand and special designs on the other.
Troughs placed at the roof to supplement special designs proved very effective against weak firedamp explosions.

The third phase was carried out with the gallery obstructed by equipment such as a conveyor belt and special auxiliary ventilation arrangements allowing clearance for rail-mounted or monorail vehicles.
The tests showed that an adequate quantity of water must reach all the free areas around the equipment so that they do not act as preferential channels for flame propagation.
The clearance between items of equipment must be adequate to enable the suppressant agent to penetrate these spaces. It was also found that the obstructions themselves could improve the dispersal of the water, but only if the explosion pressure was sufficiently high.

Whether a mobile barrier is used (six troughs per hanger) or a combination of fixed and mobile barriers, satisfactory performance is achieved only with pressures in excess of 20 kPa.

General conclusions

It proved possible to design compact trough arrangements for fixed or mobile barriers which arrest explosions generating pressures in excess of 20 kPa (200 mbar).

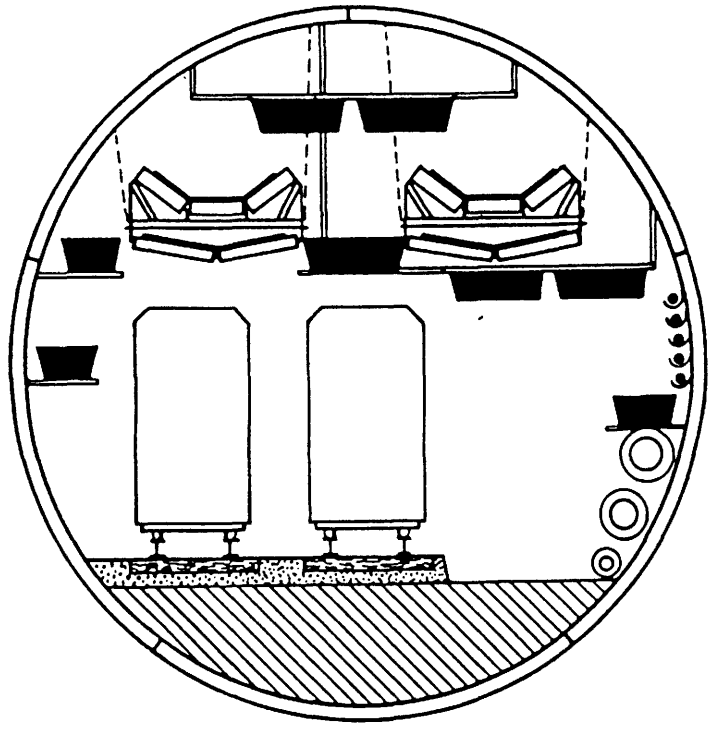
If explosions with a dynamic pressure of less than 20 kPa are to be feared, only active (or triggered) barriers will be effective against this risk.

4.03.2.8 Development and testing of new types of suppressant containers to be installed in any position as underground explosion barriers

Author: Dr.-Ing. J. MICHELIS,
Dipl.-Phys. B. MARGENBURG
Organisation: DMT(VG) - Germany (7258-03/143/01)

Research objectives

With increasing mechanisation, many difficulties are encountered in installing water barriers in mine roadways. These arise partly from the dimensions of the troughs themselves and partly from the limited space available for them because of the roadway configuration. Other factors to be borne in mind are the need to suspend the troughs horizontally, maintenance problems, difficulties arising from high temperatures (evaporation) and mechanical effects liable to cause their destruction.



Water barrier in roadway with two rail tracks and belt conveyors

For all these reasons there was an increasing need to develop water troughs which were not subject to all these disadvantages but were at least equally effective.

Such troughs would have to satisfy the following requirements:
- operation independent of the position of the troughs in the roadway cross-section;
- prevention of evaporation;
- sufficient ruggedness to prevent damage during transport and installation;
- sufficiently rapid release of the suppressant in the event of an explosion to ensure extinction of the flame.

Research findings

1) Troughs for passive barriers

The first tests were carried out with troughs made of a proven PVC. A round container was made from a steel frame and two shell halves, but it was not destroyed by blast pressures of less than 50 kPa. Improvements were made, but without attaining a satisfactory result.

Tests with polystyrene troughs were no more successful.

A completely different approach was then adopted: the development of a steel container with hinged flaps. Water dispersal is then achieved by mechanically activated opening of the four-part side walls. The resulting water distribution is comparable with that obtained using a conventional water trough.
This system is to be further developed, and an application has been submitted for an extension of the project.

2 Triggered-barrier containers

The containers used hitherto are ordinary troughs, with a detonator which shatters them when the barrier is triggered. Since their destruction does not depend on the strength of the explosion, the material of which they are made is not as important as in passive barriers.

In the course of the project, a container was developed which
- is mechanically stable;
- ensures optimum water distribution;
- is maintenance-free;
- can be suspended by chain or rope (as desired);
- is compact;
- reduces the risk of projected fragments (without impairing performance);
- can be mass-produced cheaply;
- can be used in concentrated or distributed barriers.

4.03.2.9 Barrier Protection against explosions

Author: R.T. PYE
Organisation: British Coal - UK (7258-03/144/08)

Research objectives

Existing barriers already developed in West Germany and Belgium have shown that their dimensions and designs are such that, in roadways, they can readily be installed and provide protection at reduced cost. Modern mining methods with rapidly advancing faces and high speed low-profile roadway drivages require the use of an effective barrier against explosions to be installed and provide continuous protection. There has been much research and development in the Community in the development of passive and triggered barriers. It is essential that the barrier is fully integrated into the mining system. This must be studied in order to select the appropriate design of barrier for the particular circumstances.

The project consisted of five parts:
- the introduction of the passive water trough;
- the modification of the suspension system;
- the integration of triggered barriers and subsequent redesign;
- the testing of a novel triggered barrier;
- the consideration of the Belgian triggered barrier.

Research findings

The project was very successful in intorducing a new, effective method of explosion control to British mines. It showed that higher safety levels may be achieved at lower cost.

The whole concept of explosion protection has now moved into the idea of an integrated system using triggered and passive methods.

The authors conclude by expressing their appreciation of the international collaboration from which the project benefited, and thank in particular Dr Michelis (Germany), Dr Goffart (Belgium), Dr Lunn (Buxton) and Mr Bottom (H.M. Principal Inspector of Mines), all four of whom are members of the SHCMOEI Working Party on Flammable Dusts.

4.03.2.10 Comparison of different methods of sampling neutralised dust in coal mines: statistical studies and conclusions

Author: J. BRACKE
Organisation: INIEX - Belgium (7258-03/078/02)

Research objectives

The method of taking and analysing mine road dust samples in order to determine the ratio of inert dust (the neutralisation ratio) varies between countries. The aim of the project was to compare different methods of sampling and analysing roadway dusts. See also project 7258-03/115/02 in this section.

Research findings

The report describes how the samples were collected in two mines. Three sampling zones were established. A pattern of sampling was adopted in which samples were collected at right angles, parallel and diagonal to the centre line of the road. The averages of the neutralisation ratio were calculated. Standard deviations and errors were also calculated.

It was concluded that more reliable results were obtained by sampling at right angles to the centre line than parallel to it. Diagonal sampling gave reliable values from a smaller number of samples. It appears that neutralisation ratios are not homogeneous across a sampling zone. Extensive sampling must still be carried out to devise a method giving reliable results.

Research project 7258-03/115/02 in this section had similar aims.

4.03.2.11 Comparison of different methods of sampling neutralised dust in coal mines: statistical studies and conclusions

Author: J. BRACKE
Organisation: INIEX - Belgium (7258-03/115/02)

Research objectives

The aims are the same as those for contract 7258-03/078/02. The method of taking dust samples was laid down by the Director-General of Mines in April 1982 and is very labour-intensive. The aim is to devise a more reliable and more economical method of sampling.

Research findings

Three sets of samples were taken in three Campine collieries. The individual analyses and statistic processing of the results yielded the following conclusions.

1) In any one zone, the quality of stone-dusting can vary widely, even at places in very close proximity.

2) Samples with a high proportion by weight of fine dust generally contain most inert material.

3) Especially when the overall standard of stone-dusting is poor, there are often "channels" parallel to the centre line of the roadway, in which the percentage of stone dust is significantly lower, and which could therefore allow a dust explosion to propagate over long distances.

4) The neutralisation ratios calculated along lines at an oblique angle to the centre line of the roadway (i.e. along diagonal lines) are those most representative of the mean stone-dust concentration in the zone, both on the roadway sides and on the floor.

5) Deterioration of the standard of neutralisation over time is slow, at least in the roadway in which this phenomenon was observed.

4.03.2.12 Effectiveness of triggered barriers against explosions in auxiliary-ventilated workings

Authors: C. PROUST, J. POSTIC
Organisation: INERIS - France (7258-03/152/03)

Research objectives

To investigate the performance of a category of triggered water barriers (the Belgian triggered system) in suppressing explosions in coal mines.

At present, it is envisaged that the Belgian barrier will be used mainly in blind ends, e.g. in drivages.

It was proposed to study changes in its effectiveness as a function of increasing distance between the head end and the barrier, since this distance is variable and may affect barrier performance.

Research findings

Experiments were conducted in a 10 m^2 test gallery 145 m in length.

Among the findings are the following:

- there is little change in the time elapsing between ignition of the gas mixture and activation of the barrier when the distance between the head end and the triggering device is increased from 45 m to 75 m;

- the movement of gas preceding the flame front (the blast wave) may dilute the cloud of droplets and thus reduce the effectiveness of the barrier;

- the amount of water required to arrest propagation of the flame varies according to the distance between the head end and the first disperser.

If the line of dispersers is long enough, increasing the distance between the head end and the barrier does not seem to impair barrier efficiency as long as the flame speed in the zone where the barrier is installed does not exceed 100 m/s.

4.03.3 Use of explosives

4.03.3.1 The use of bulk-loaded slurry explosives in rock drivages in mines susceptible to firedamp

Author: J. FOUBET
Organisation: CERCHAR - France (7258-03/142/03)

Research objectives

To carry out a feasibility study analysing the requirements for safe loading of slurry explosives by pumping in stone drivages in coal mines.

Research findings

The pertinent regulations require three conditions to be met simultaneously for explosives to be loaded by pumping in stone work.

One of these conditions results from the presence of a detonator at the bottom of the hole during loading: the loading hose must satisfy certain requirements to preclude transmission of the detonation in the event of premature firing of the blasting cap.

One way of preventing propagation in the loading hose is to ensure that its diameter is less than the critical diameter for detonation of the explosive. But this solution is not suitable for mines, since the hose diameter would then be too small.

A device has been developed to arrest detonation between the shothole and the stock of explosive. The concept is based on the "channel effect": if a small empty space is created in the charge or between the charge and the confining medium, the explosion gases may travel through this space and desensitise the explosive by compression, thus arresting the detonation.

It is still to be established whether such devices are effective for very sensitive explosives.

4.04 RESCUE

Whereas the First Research Programme contained only one research project in this field the Second Programme contains nine. The subjects covered range from self-rescuers and breathing apparatus to improving the rescue of trapped and injured personnel. There was joint research on three of the nine projects reviewed. The reviews of projects with like aims are grouped under five headings.

The Medium-Term Programme contains two projects of interest, one on directional drilling and the other on the development of infra-red technology for the detection of mine gases.

Working times in hot atmospheres	116, 117, 146
Rescue of trapped miners	110, 130
Personal rescue equipment	145, 147
Development of portable sensors	109
Test procedures for rescue apparatus	131

4.04. RESCUE

4.04.1 Working time in hot atmospheres

4.04.1.1 Duration of rescue service operations in hot and humid underground workings

Author: M. FUNKEMEYER
Organisation: BF - Germany (7258-04/116/01)

Research objectives

This is a Belgian/German joint project. The Belgian contract number is 7258-04/117/02.

There are different rules in the countries of the EC regarding working times for mine rescue teams in hot and humid atmospheres.

The aim of this project was to establish the climatic limits for rescue workers when wearing fire-retardant garments by means of exercises carried out in the Essen and Hasselt central rescue stations. The results will be presented in the form of tables showing the permissible duration of deployment as a function of the climatic factors.

Research findings

Nine exercise sequences were carried out to study the effect of wearing fire-retardant garments.

The results show that:
- physiological stress increases as the climatic conditions become more severe;
- in climatic conditions which are not too arduous, the increase in the values of physiological variables is much greater when such garments are worn than with light clothing;
- even in the WD index* range 22-30° C, deployment time has to be limited, whereas such restrictions do not become necessary until the index reaches 30° C when light clothing is worn.

Further exercise sessions were conducted with cooling jackets, which appreciably reduce the stress imposed on the rescue workers.

Exercises were also performed with cooling jackets worn under fire-retardant garments.

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*WD index = wet-dry index = 0.85 t_{wb} + 0.15 t_{db}
when t_{wb} = wet-bulb temperature
and t_{db} = dry-bulb temperature

Tables have been drawn up showing maximum deployment times for various conditions of temperature and clothing, over a range extending as far as a dry-bulb temperature of 55° C.

Three such tables are annexed to this summary.

Measurement with the Assmann aspirated psychrometer

Difference between dry-bulb and wet-bulb temperature (degrees)

Dry-bulb temp. °C	0	1	2	3	4	5	6	7	8	9	10
22	80 90										
23	75 90	80 90									
24	70 90	75 90	80 90	85 90							
25	65 90	70 90	75 90	80 90	85 90						
26	60 90	60 90	65 90	70 90	80 90	85 90					
27	55 90	55 90	60 90	65 90	70 90	75 90	85 90				
28	50 80	55 85	55 90	60 90	65 90	70 90	75 90	80 90			
29	45 75	50 80	50 85	55 90	60 90	65 90	70 90	75 90	80 90	85 90	
30	45 65	45 70	50 80	50 85	55 90	60 90	65 90	70 90	75 90	80 90	85 90
31	40 60	40 65	45 70	50 75	50 85	55 90	60 90	65 90	65 90	75 90	80 90
32	35 55	40 60	40 65	45 70	45 75	50 80	55 90	60 90	60 90	65 90	70 90
33	35 50	35 55	40 60	40 65	45 70	45 75	50 80	55 90	55 90	60 90	65 90
34	35 45	35 50	35 55	40 60	40 65	45 70	45 75	50 80	55 85	55 90	60 90
35	30 45	30 45	35 50	35 55	40 60	40 60	45 65	45 70	50 80	50 85	55 90
36	30 40	30 45	30 45	35 50	35 55	40 55	40 60	45 65	45 70	50 75	50 85
37	25 35	30 40	30 45	30 45	35 50	35 50	40 55	40 60	40 65	45 70	50 75
38	25 35	25 35	30 40	30 40	30 45	35 50	35 50	35 55	40 60	40 65	45 70
39	25 30	25 35	25 35	30 40	30 40	30 45	35 50	35 50	35 55	40 60	40 65
40	25 30	25 30	25 35	25 35	30 40	30 40	30 45	35 45	35 50	35 55	40 60
41	20 30	25 30	25 30	25 35	25 35	30 40	30 40	30 45	30 45	35 50	35 55
42	20 25	20 30	25 30	25 30	25 35	25 35	25 40	30 40	30 45	30 45	35 50
43	20 25	20 25	20 30	20 30	25 30	25 35	25 35	25 35	30 40	30 40	30 45
44	20 25	20 25	20 25	20 25	20 30	25 30	25 35	25 35	25 35	30 40	30 40
45	20 20	20 25	20 25	20 25	20 25	20 30	25 30	25 30	25 35	25 35	30 40
46	15 20	20 20	20 25	20 25	20 25	20 25	20 30	25 30	25 30	25 35	25 35
47	15 20	15 20	15 20	20 20	20 25	20 25	20 25	20 30	25 30	25 30	25 35
48			15 20	15 20	20 20	20 25	20 25	20 25	20 30	25 30	25 30
49				15 20	15 20	20 20	20 25	20 25	20 25	20 25	20 30
50					15 20	15 20	20 20	20 25	20 25	20 25	20 25
51						15 20	15 20	20 20	20 25	20 25	20 25
52							15 20	15 20	20 20	20 25	20 25
53									15 20	15 20	20 20
54										15 20	15 20
55											15 20

Deployment time 90 minutes

Deployment only in consultation with incident control

H GRW E	Deployment table for fire-retardant garments with and without cooling jacket - Deployment time in minutes	2/89

Meadurement with the Assmann aspirated psychrometer

Difference between dry-bulb and wet-bulb temperature (degrees)

Dry-bulb temp. °C

	0	1	2	3	4	5	6	7	8	9	10
30	95 *										
31	65 *	90 *									
32	55 60	60 *	85 *								
33	50 60	55 60	60 *	80 *	115 *						
34	45 60	45 60	50 60	60 *	75 *	105 *					
35	40 55	40 60	45 60	50 60	55 60	70 *	100 *				
36	35 45	40 55	40 60	45 60	50 60	55 60	65 *	95 *			
37	30 40	35 45	35 50	40 60	45 50	50 60	55 60	60 *	90 *		
38	30 35	30 40	35 45	35 50	40 55	45 60	50 60	55 60	60 *	80 *	
39	25 30	25 35	30 40	35 45	35 50	40 55	45 60	50 60	55 60	60 *	75 *
40	25 30	25 30	25 35	30 40	30 45	35 50	40 55	45 60	45 60	50 60	60 *
41	20 25	20 25	25 30	25 35	30 40	30 45	35 50	40 55	40 60	45 60	50 60
42	20 20	20 25	20 25	25 30	25 35	30 35	30 40	35 45	40 55	40 60	45 60
43	15 20	20 20	20 25	20 25	25 30	25 35	30 35	30 40	35 45	35 50	40 60
44	15 15	15 20	20 20	20 25	20 25	25 30	25 30	30 35	30 40	35 45	35 50
45	15 15	15 15	15 20	20 20	20 25	20 25	25 30	25 30	25 35	30 40	35 45
46	15 15	15 15	15 15	15 20	15 20	20 20	20 25	20 30	25 30	25 35	30 40
47	10 10	10 15	15 15	15 15	15 20	15 20	20 20	20 25	20 25	25 30	25 35
48			10 15	15 15	15 15	15 15	15 20	20 20	20 25	20 25	25 30
49				10 15	15 15	15 15	15 15	15 20	20 20	20 25	20 25
50					10 10	15 15	15 15	15 15	15 20	20 20	20 25
51						10 10	15 15	15 15	15 15	15 20	20 20
52							10 10	15 15	15 15	15 15	15 20
53									10 15	15 15	15 15
54										10 15	15 15
55											10 15

Deployment time 120 min.
* without cooling jacket

Deployment only in consultation with ~~incident control~~

H GRW E	Deployment table for light clothing with and without cooling jacket Deployment time in minutes	2/89

Measurement with the Assmann aspirated psychrometer

Difference between dry-bulb and wet-bulb temperature (degrees)

Dry-bulb temp. °C	0	1	2	3	4	5	6	7	8	9	10
30	95						Deployment time 120 minutes				
31	65	90									
32	55	60	85								
33	50	55	60	80	115						
34	45	45	50	60	75	105					
35	40	40	45	50	55	70	100				
36	35	40	40	45	50	55	65	95			
37	30	35	35	40	45	50	55	60	90		
38	30	30	35	35	40	45	50	55	60	80	
39	25	25	30	35	35	40	45	50	55	60	75
40	25	25	25	30	30	35	40	45	45	50	60
41	20	20	25	25	30	30	35	40	40	45	50
42	20	20	20	25	25	30	30	35	40	40	45
43	15	20	20	20	25	25	30	30	35	35	40
44	15	15	20	20	20	25	25	30	30	35	35
45	15	15	15	20	20	20	25	25	25	30	35
46	15	15	15	15	15	20	20	20	25	25	30
47	10	10	15	15	15	15	20	20	20	25	25
48			10	15	15	15	15	20	20	20	25
49				10	15	15	15	15	20	20	20
50					10	15	15	15	15	20	20
51	Deployment only in consultation with incident control					10	15	15	15	15	20
52							10	15	15	15	15
53									10	15	15
54										10	15
55											10

H GRW E	Deployment table for light clothing Deployment time in minutes	2/89

4.04.1.2 Duration of rescue service operations in hot and humid underground workings

Author: J. CARDINAELS
Organisation: CCR(I.R.E.A) - Belgium (7258-04/117/02)

Research objectives

To determine the maximum deployment time during rescue service operations in underground workings with hot and humid atmospheres.

The findings are summarised in the form of a table giving the working time for five climatic conditions and five types of clothing.

Research findings

The exercises were performed by fit rescue workers at the training facility of the Campine coalfield's central rescue station.

Five conditions with respect to the workers' clothing were studied (in addition to wearing of the Dräger breathing apparatus BG 174): shorts (297 exercises), working clothes (263), fire-retardant garments (204), cooling jacket (204) and fire-retardant garments and cooling jacket (165).

The tests were carried out with two types of cooling jacket from two German suppliers: Dräger and Vorndamme.

All the usable results for individual exercises (of which there are 1133) are set out in a large number of tables in the final report, and in the summary table reproduced below.

Maximum deployment time (in minutes)
for rescue operations below ground
in hot and humid atmospheres

Effective temperature	30	32	34	36	38
Clothing					
shorts	90	70	50	40	20
cooling jacket	80	70	60	40	30
working clothes	50	40	30	30	20
fire-retardant garment	40	40	30	30	20
fire-retardant garment + cooling jacket	50	40	40	40	30

4.04.1.3 Permissible wearing times for rescue personnel using a new self-contained breathing apparatus

Authors: R.J. GRAVELING, G.G. MILLER
Organisation: IOM - UK (7258-04/146/08)

Research objectives

The aim of the research was to produce new tables of permissible working times in elevated environmental temperatures for use with the new Selected Elevated Flow Apparatus, (SEFA).

Research findings

The first part of the work was to carry out experiments in order to determine the times for which a sample of mines-rescue men could work in a range of climatic conditions without exceeding physiological safety criteria. These experiments covered both heavy and light workload exposures. Following an analysis of the data British Coal decided not to pursue the light load option. A comparison of the 97.5 percentile working time with the maximum safe working periods permitted for the Proto apparatus indicated that the times permitted for the Proto were longer than the 97.5 percentile times at higher temperatures. As a result British Coal Mines Rescue and Medical Services, in consultation with the Mines and Quarries Inspectorate and the IOM, decided to adopt working times which combined the two sets of data. A chart of permissible working times for the SEFA apparatus is included in the report.

As an additional safeguard it was recommended that the procedures used for assessing potential recruits during initial training be reviewed in order to try and identify, and exclude, those who appeared to be particularly unsuited to work in hot conditions. This would exclude from the Rescue Service those who were particularly intolerant of work in the heat and would permit the time to be extended for which others could safely be allowed to work.

References: 22

Permitted work times for the SEFA apparatus in elevated temperatures (Fahrenheit)

DRY BULB

WET BULB	70	75	80	85	90	95	100	105	110	115	120
70	*	*	*	*	*	*	*	119	111	104	97
72.5	-	*	*	*	*	112	105	98	92	86	81
75	-	*	114	106	99	93	87	82	76	71	67
77.5	-	-	94	88	82	77	72	68	63	59	55
80	-	-	78	73	68	64	60	56	52	49	46
82.5	-	-	-	60	57	53	50	46	43	41	38
85	-	-	-	50	47	44	41	38	36	34	32
87.5	-	-	-	-	39	36	34	32	30	29	28
90	-	-	-	-	32	31	30	28	27	26	25
92.5	-	-	-	-	-	27	26	25	24	24	22
95	-	-	-	-	-	24	23	22	22	21	20
97.5	-	-	-	-	-	-	22	20	19	19	-
100	-	-	-	-	-	-	19	-	-	-	-

**120 minutes or more*
Flow rate is determined by permitted time, i.e. low flow
when time exceeds 60 minutes.

4.04.2 Rescue of trapped miners

4.04.2.1 Improvements in systems for rescue of trapped miners

Authors: F. DOUAY, E. FRANCHE
Organisation: CdF - France (7258-04/110/03)

Research objectives

Systems and equipment for the location of trapped miners and their rescue by means of a large-diameter borehole have been developed in previous studies. The aim of this project was to further improve these systems by reducing delays and increasing the chance of survival. There were three objectives:-

- drilling of a 96 mm pilot hole,
- trial of an auto-guidance system for a vertical hole, and
- development, by a firm of constructors, of a hole reamer.

Research findings

A hole of total length 108 m and diameter HQ (96 mm) was drilled in a coal seam with a deviation of only 3 m from target using drill string stabilisers.

The auto-guidance system for a vertical hole was successfully tested. However, minor problems could arise when the expanding reamer was passed along the hole because of the slightly "saw-toothed" profile of the hole walls.

It has taken two years for the constructors to produce the prototype reamer, which is illustrated in the attached diagram.

It consists of three reaming stages (348, 480 and 610 mm), each consisting of two disc cutters, each of which is mounted on the end of an arm which can be retracted into the reamer body. These arms are operated by the pressure of water injected through the drill string.

The full-scale trial was promising, since it demonstrated that the hydraulics performed well in opening the arms and maintaining them in the open position during the reaming process.

Backreaming performance with this prototype was of interest since instantaneous advance was nearly three times that achieved with conventional reaming under thrust.

Cutter geometry will have to be improved.

It is also essential to flush the recesses housing the cutters to avoid the accumulation of material, which would prevent the reamer from closing correctly.

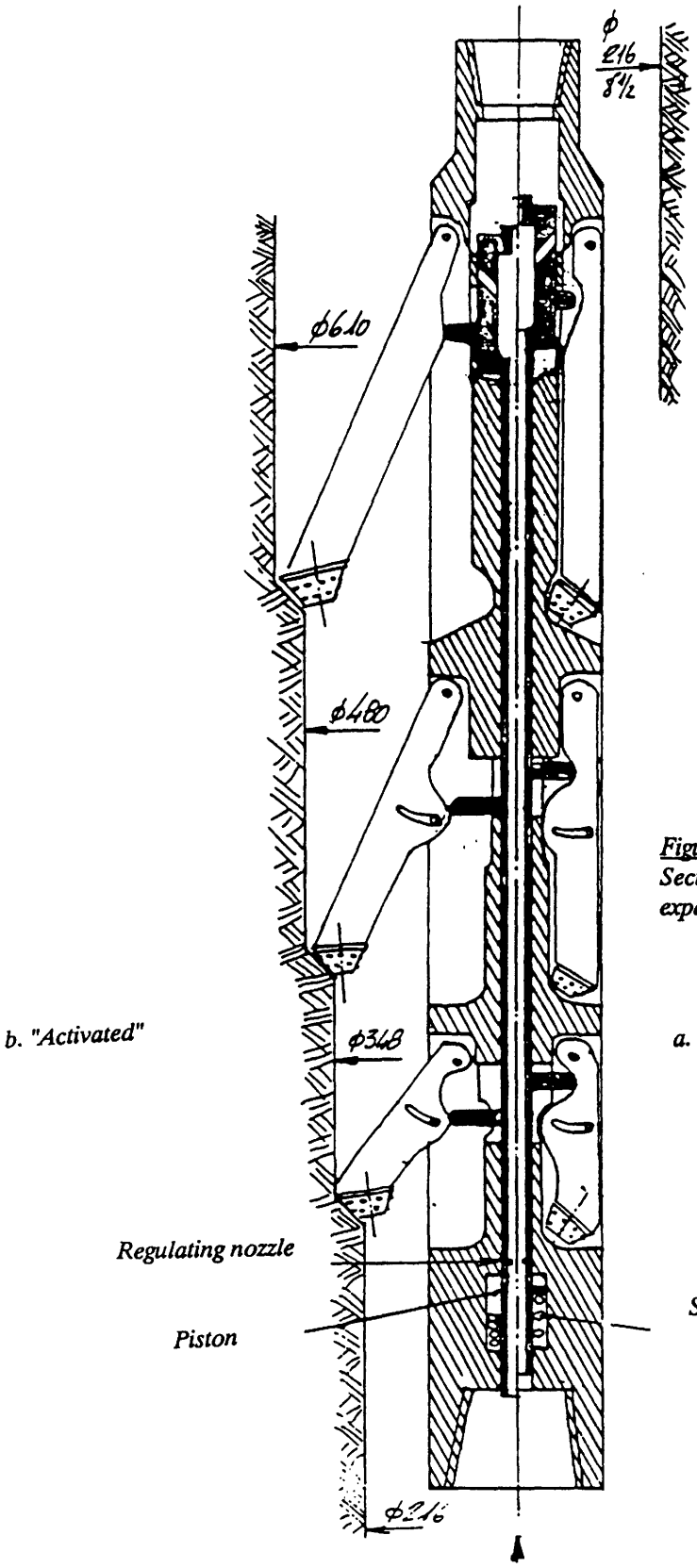


Figure 4
Section through the SMFI expanding reamer

4.04.2.2 Method of drilling through fallen ground to supply trapped miners or fight fires

Project leaders: Dipl.-Ing. FUNKEMEYER,
Dipl.-Ing. WALLUSSEK
Author: Dipl.-Ing VORHOFF
Organisation: DMT(BF) - Germany (7258-04/130/01)

Research objectives

To design a rotary drilling machine capable of drilling through all kinds of fallen ground without the drill head becoming fast and of keeping the hole open.

A major difficulty - apart from the drilling operation as such lies in the fact that trapped miners usually do not have the tools required to remove the drill bit once a breakthrough is achieved.

Research findings

Following a survey of the market, a Klemm double-head drilling system was selected. This equipment makes it possible to drill through loose ground and to install a casing in a single operation.

In the course of trials carried out in ground which included a caved area of old workings, holes of up to 83 m were drilled at penetration rates of 50-70 cm/min.

Although a number of problems have still to be solved, these trials demonstrated that the objective could be attained.

4.04.3 Personal rescue equipment

4.04.3.1 Laboratory tests, practical trials and further development of short-term oxygen self-rescuers

Author: Dr.-Ing. G. LANGER
Organisation: DMT(HGRW) - Germany (7258-04/145/01)

Research objectives

- To continue the development of an oxygen self-rescuer of short duration (15-30 minutes in the current state of the art) with which miners could be permanently equipped and which would enable them to escape from their place of work (especially if auxiliary-ventilated) to a place where long-duration oxygen self-rescuers are stored.

- To determine by experiment the following characteristics of existing devices: respiratory characteristics, tolerability, duration under different conditions.

- To determine whether, in the event of a sudden drop in the oxygen concentration (e.g. as a result of an outburst), the miner can don the device quickly enough and whether it can provide sufficient oxygen flow as soon as it begins to function.

- To improve existing prototypes with a view to their use in mines so that they can be mass-produced.

- To develop apparatus of longer duration capable of being worn by miners at all times and enabling them to reach uncontaminated air without any need to change escape sets.

Research findings

Eleven oxygen escape sets from five manufacturers in four countries (Russia, France, the United States and Germany) were tested both in the laboratory on a lung simulator and in man-wearing trials on exercise courses above and below ground.

The project established that there are now a number of oxygen self-rescuers of short duration (15-30 minutes) which can be permanently worn and which enable miners to reach a place where longer-duration apparatus is stored.

There is also an escape set combination, i.e. the Fenzy Biocell/Biocell Plus combination, which allows an extension cartridge to be fitted quickly to the short-duration device, providing a total escape time of 90 minutes.

An objective which remains to be attained as quickly as possible is to provide miners with a permanently worn oxygen self-rescuer of 60 minutes' duration, which would make it unnecessary to change apparatus in most mines.

4.04.3.2 Possibilities for the use of portable personal escape apparatus

Project leader: LARREUR
Authors: G. SCHNEIDER, P.M. DUPOND
Organisation: HBL - France (7258-03/147/03)

Research objectives

To develop a self-contained light escape set which could be worn at all times and which would enable workers either to withdraw directly to a nearby fresh air circuit or to reach a pressurised survival chamber where replacement sets or extension cartridges of 90 minutes' duration are held in readiness.

Research findings

The novel aspect of the work is the development of a snap-on device allowing an extension cartridge to be fitted to the breathing bag of the apparatus, so that the cartridge can be easily replaced without changing masks.

In the course of laboratory and smoke chamber tests and pit trials, an apparatus was developed which has the following characteristics:
- 30-minute duration at a flow rate of 30 l/min;
- weight about 2 kg and good wearability;
- maximum temperature of the inhaled air 50° C.

The escape set selected following these trials was the Fenzy Biocell 1.

An extensive training programme was carried out before the apparatus was introduced in the Lorraine area. 7160 escape sets are in service and 2630 extension cartridges.

4.04.4 Development of portable sensors

4.04.4.1 Measuring system with continuous data transmission for mine rescue brigades

Author: H.P. CLASSEN
Organisation: RAG - Germany (7258-04/109/01)

Research objectives

During a rescue operation, measurements are essential to assess the (gas and climate) risks to which the brigadesmen are exposed. Measurement by the rescue workers themselves has a number of drawbacks:

- reading and/or transmission errors;
- non-continuous measurement;
- loss of time and hence operational capability;
- need to deploy reinforcements in the event of increased risk.

It was therefore proposed to develop compact, portable, intrinsically safe instrumentation for continuous measurement and transmission of a wide range of data: air temperature and humidity, CO, CO_2, CH_4, H_2, NO_x and O_2.

Research findings

It proved impossible to include CO_2 and NO_x among the parameters measured.
For CO and CH_4, two measuring ranges were needed, i.e. two instruments in one, with more powerful batteries. This led to an increase in weight and the instrument is not genuinely portable.

The instrument finally developed was non-portable and provided continuous mesurement of temperature and humidity, CO, CH_4, H_2 and O_2, with continuous transmission to a microprocessor-controlled analysis unit.

Ruhrkohle A.G. intends to pursue the development of a multi-purpose portable unit providing two CH_4 and CO measuring ranges, with greatly reduced power requirements and hence weight.

4.04.5 Test procedures for rescue apparatus

4.04.5.1 Development of testing and assessment procedures for escape apparatus and oxygen self-rescuers

Author: Dr D.M. SMITH
Organisation: British Coal - UK (7258-04/131/08)

Research objectives

1) Study of the respiratory performance characteristics of a representative number of mines rescue men at different exercise patterns which simulate actual escape conditions.

2) Measurement under controlled laboratory conditions on a treadmill and mechanical ladder of physiological data associated with the breathing characteristics of a cross-section of mines rescue men at different exercise rates corresponding to those established in the above study.

3) Determination of critical performance criteria of different types of escape apparatus by carrying out man-wearing trials at the predetermined exercise patterns.

4) Comparison of the data obtained from the above man-wearing trials with that obtained from lung simulator tests at corresponding breathing volumes.

Research findings

The project centred on the production of a microprocessor system to control the treadmill and acquire the data.

A very wide range of respiratory characteristics was found in a small group of rescue workers.

This wide spread of characteristics must be borne in mind when selecting a given apparatus for a particular escape scenario.

The author emphasises the interaction between Community research and the work of the CEN, in particular TC 79.

4.05 MONITORING, COMMUNICATION, AUTOMATION AND REMOTE CONTROL

Semi-automation and remote operation of many plant and equipment processes is well established. Automation processes in some operations have been proved; the techniques will be extended. By such means operators have been moved out of direct control and have become supervisors of operations. Such equipment has removed the man from certain operations in which there was a higher risk of injury. Whilst engineers do their best to design a safe and efficient system they cannot visualise all the circumstances and variations encountered in operation. The knowledge gained by operators as they pursue their daily task is essential information for future modifications in the system. The establishment of a participative communication network between operator, engineer, supervisors and management is crucial to early correction and modifications to both plant and work procedures.

The development of automation has been accompanied by the introduction of sensors to collect data on machine and system operation. The data so collected is transmitted to the surface for storage, analysis and use for management information and control purposes. On the basis of this information decisions are made which affect the safe operation of the mining system. It goes without saying that all components must be reliable and safe in operation in order to ensure system integrity. As much of the technology comes from sources outside mining there is need to prove its safety in mining conditions within the standards laid down.

Because of the concentration of production, the merging of mines into larger units and the reduction of operating staff through automation and monitoring, it is essential to be able to communicate directly with personnel, no matter where they are, and to contact them speedily in case of emergency.

Whilst the First Programme supported six projects in this field three of them would be classed in the research field 'Fire' of this Second Programme. This programme contains eight projects, which have been classified in two sections.

Monitoring plant and equipment	090, 129, 128, 149, 101
Communication with personnel	126, 127, 148

4.05 MONITORING, COMMUNICATION, AUTOMATION AND REMOTE CONTROL

4.05.1 Monitoring plant and equipment

4.05.1.1 Centralised monitoring applied to hazard control in a mine

Authors: BOUTONNAT, DAVROU, ROSE, TAUZIEDE, ACCORSI, LEDRU
Organisation: CERCHAR - France (7258-05/090/03)

Research objectives

There were three objectives:

1) the monitoring of high voltage (HV) electrical networks; a condition of the project was that the data transmission should be by means of the HV cable itself and that it should be possible to transmit data from parts of the system which had been swtiched off;

2) the monitoring of the ventilation by the use of an increased capacity CGA system;

3) the checking of the location of personnel underground in order to know where they are and whether, in case of fire, they have assembled at muster stations.

Research findings

1) The studies were terminated when it was realised that the objectives could not be attained at reasonable cost.

2) The report gives details of the testing of commercially available sensors and of newly developed ones for CO, CO_2, O_2 and for an anemometer. For CO the City Technology cell was chosen and a sensor developed for the CGA. No choice was made for O_2. For fires three parameters were considered temperature, noxious gases and particulates given off by combustion. The tests showed that a multi-sensor is the solution and the BECON, made by Anglo-American, is being tested underground. The integrated management system was designed to give real-time analysis and presentation of data for alarms and storage.

3) Trials were made of the commercially available personnel location radio system which is carried by a person and activates a signal detector when that person passes fixed points. The disadvantages of the system are that it is expensive and is not certified for use underground.

References: 11

4.05.1.2 Time-dependent changes associated with the stopping and restarting of booster fans

Authors: Mr I. LONGSON, Dr TUCK, Mr S.J. BUNDRED
Organisation: Nottingham University
British Coal contract - UK (7258-05/129/08)

Research objectives

Concentration of mining and increased coal production require major increases in airflow rates and hence fan ratings. Stopping and restarting of a booster fan can thus lead to large changes in ventilation pressures and quantities, and hence also in gas concentrations, in a section of the network and can have an appreciable influence on the safety of the workforce.

The aims of the project were
- to observe and measure the time-dependent effects produced on the whole ventilation system when a fan is stopped or restarted;
- to analyse these effects and develop a supporting theory for fan stopping and restarting;
- to incorporate this theory in a computer simulation for predicting the effects of fan stops and restarts and to test this simulation against reality;
- to assess the effect of stopping or restarting a booster fan on safety below ground;
- to find appropriate means of measuring transient flows (since the instruments in routine use in mines are not suitable).

Research findings

A mathematical model of the phenomena associated with stopping or restarting of a booster fan was produced.

Stopping or restarting produces not only a changing total airflow, but also its redistribution between the various branches. It seems likely that these calculations could be performed by numerical methods (but not with a simple analytical model).

Events associated with stopping or restarting of fans in complex arrangements are not comparable with those occurring in simple circuits.

No risk directly associated with fan stops or restarts was found, but a fairly long period elapses before the pressures and flows return to their initial values.

When a booster fan stops, there is a major rapid reduction in the air quantity and hence a deterioration in conditions, to a degree which depends on the magnitude of the flow reduction, the duration of the fan stoppage and the influence of the pressure changes on gas emission.

When the fan is restarted there is a temporary increase in the gas emission rate and this is the greatest risk associated with booster fan stoppages.

A mathematical gas storage/release model linked to the ventilation model would be required to provide an overall picture of the situation resulting from changes in fan operation.

This subject could be considered in subsequent work.

4.05.1.3 Safety measures for overhead monorails - communications and control

Author: W. RÄTZ
Organisation: BF - Germany (7258-05/128/01)

Research objectives

Overhead monorail systems are being extended throughout mines and it is clear that a data communication system and a means of communication between the vehicles and central control for the exchange of messages is required for their safe and effective operation.

Existing radio systems are not satisfactory for extensive monorail roadway networks.
A different approach was therefore adopted to transmission of electromagnetic waves over distances of up to several kilometres: the use of "leaky feeder" cables or guides installed for the purpose.

This solution has three main drawbacks:
- the transceiver on the vehicle must be close to the waveguide at all times and this inhibits freedom of movement;
- it is usually possible to communicate only along a main line, and branching is expensive;
- the waveguides are incident-prone.

The aim of the project was to lay the foundations for a method of communication not yet used in underground coal mines: freely propagated radio communication using "repeaters", i.e. transceiver units receiving and transmitting at different frequencies and enabling information to be transmitted between mobile sets.

Research findings

The work was carried out partly at the Tremonia experimental mine and opened up the possibility of transmitting electromagnetic waves at 1.27 GHz. Horizontal wave polarisation proved slightly superior to the other polarisation modes. This was also true at a frequency of 10 GHz, at which there is less attenuation than at 1.27 GHz (but the cost of a repeater for 10 GHz is much higher than for the selected frequency of 1.27 GHz).

Tests at junctions, curves and changes in roadway cross-section yielded important data for the planning of a system.

The optimum repeater spacing was determined for specimen cases.

Two repeaters were produced on the basis of these data and tested below ground. The results confirmed the research findings.

4.05.1.4 The development of a reliable communications system for recording mine atmosphere and ventilation data and for shutting down electrical apparatus in mechanised drivages and production districts - parts 1 & 2

Author: Dr KARTENBERG
Organisation: DMT(WBK) - Germany (7258-05/149/01)

Research objectives

In underground workings subject to particular hazards, such as
- those where compliance with the 1% methane limit cannot be guaranteed,
- those at risk from "plugs" of gas resulting from sudden emission or rock bursts,
- auxiliary-ventilated drivages, etc

German mining regulations require instruments to be provided which permit continuous monitoring of a number of gas concentration and ventilation parameters, transmission of these data to the mine control room and automatic cut-off of power if certain values are exceeded.

The purpose of the project was to develop a communications system suitable for most situations arising, which would remain operational and safe even after certain parts of the electrical system had tripped out and which already complied with anticipated future requirements for reliability of shutdown.

Research findings

A concept was worked out for a communications system to allow ventilation data to be analysed and power to be cut off from electrical machinery in mechanised drivages or on production faces.

Its three components are:
- a bus system for the recording measurement data;
- a bus system for operating the contactors;
- a unit for monitoring and controlling these two systems.

A program and a prototype central unit were developed, so that trials could be conducted on the essential components of the system.

Emphasis was placed on high system availability and on fault detection and location. As a safety measure, the non-intrinsically-safe circuits would be made dead if part of the installation were to fail or a signalling line were to be broken.

4.05.1.5 Continuation of project 7255-20/063/03: Falls of ground in iron ore mines

Authors: J. CHOISEL, O. LEONET
Organisation: SAMIFER - France (7258-05/101/03)

Research objectives

The risk of falls of ground in ironstone mines is a major hazard. Sensors cannot always be installed safely in zones where the percentage extraction is high. Certain mining methods also cause surface subsidence, which may endanger the public. Under a previous contract the automatic alarm systems SYALEB and CENSYALEB were designed.

Research findings

Ground deformation sensors were developed and installed on the surface above the zones to be mined and abandoned workings.

The following programme was implemented:

- development of new ground deformation sensors;
- preparation of new computer programs for the new parameters measured;
- installation of fall-of-ground detectors above areas being mined;
- monitoring of inhabited zones located above abandoned underground workings.

4.05.2 Communication with personnel

4.05.2.1 Radio communication underground, if possible without special waveguides

Author: Dr D. FISCHER
Organisation: DMT(VG) - Germany (7258-05/126/01)

Research objectives

Mine radio communications offer many advantages: increased production and productivity and above all improved working conditions and the elimination of certain causes of accidents.

The first task was to acquire an improved knowledge of the behaviour of electromagnetic waves in a mining environment: the same frequency may give good results in certain roadways and much poorer results in others.

It is known from experience that there is (two-way) interaction between electromagnetic fields and their environment. It is also known that very long waves (wavelengths in excess of 30 km) are virtually insensitive to the environment; on the other hand, their low frequency allows good transmission only of very narrow wave beams and their only application in mines would be for personnel location.
Ultra-short waves (< 1 m), are suitable for the transmission of speech communication and for the large volumes of numerical data transmitted by e.g. monitoring instruments.

The main purpose of this project, which followed up previous work by the Tremonia experimental mine, was to achieve a better understanding of speech communication and to enhance the reliability of safety data transmission. This was to be done in close collaboration with the former Bergbau-Forschung in Essen (the two establishments now belong to the "Deutsche Montan Technologie" - DMT).

Research findings

The authors themselves say it is difficult to summarise the findings since they relate to a very large number of factors which affect wave transmission in the mine: roadway cross-section and geometry, support type and materials, equipment in the roadway: transport plant, cables, pipe ranges, properties of the adjacent strata, roadway layout and even the mine climate.

It was, however, clearly established that rectilinear wave transmission differs greatly from transmission in curves, junctions etc.

When transmission is in a straight line, signal attenuation can be expressed in dB/100 m and the final research report shows this value as a function of frequency for each of five straight lengths of roadway at Tremonia. The roadway cross-section does not seem to be of primary importance.

In the low-frequency region, curves do not seem to have a marked effect and attenuation is of the same order of magnitude as in a straight line.

At frequencies above 350 MHz, attenuation is increased by curves as compared with straight-line transmission. Above 6 GHz no transmission is possible in curves.

Main results

1) The frequency range below about 40 MHz is suitable for transmission of speech and measurement data without the use of waveguides. However, the bandwidth is smaller and attenuation not as low as in the GHz range.

2) Preference should be given to the latter since it suffers less attenuation and offers a wider range of wavelengths.
Arrangements must be made in any case to enable the waves to negotiate curves, points where the roadway becomes narrower and junctions, e.g. by means of leaky feeders or repeaters. The DMT Institut für Prozeßleitsysteme und elektrische Anlagen in Essen has developed such a repeater for 1.27 GHz. It was also tested at Tremonia and proved satisfactory.

4.05.2.2 Multiplex communication between production districts of a mine

Author: O. LEONET
Organisation: SAMIFER - France (7258-05/127/03)

Research objectives

A previous contract (7255-16/065/03) had shown that a radio link could be established without waveguides between the workers in a production district.

It became clear that a system linking all production districts and a base station could improve working conditions and speed up rescue operations in the event of incidents or accidents.

This was the purpose of the new project.

Research findings

The necessary devices were developed to permit radio/hard wire links between
- the men working in a production unit and the other production units;
- all the men in the mine and a base station.

To this end, a transmission system was assembled and installed using the existing radio and telephone links in the mine. The system remains in voice broadcast receiving mode, and the portable sets can communicate even if they are not in the same district.

4.05.2.3 Selective call, alert and surveillance of personnel in isolated situations or with no fixed place of work

Authors: CERCHAR : M. NOEL, P. VILLENEUVE de JANTI, J. DELATTRE
U.E. PROVENCE : M. DEJEAN, J. COURRET, P. TAVERNIER, J. SZWED
U.S. Techniques : B. FISCHER

Organisation: CERCHAR - France (7258-05/148/03)

Research objectives

To develop various systems and facilities for selective call, alert and surveillance in order to improve the safety of isolated or roving personnel in various parts of the mine.

Research findings

A two-way direct link between the surface and a continuous miner in a working area
was established to permit call and speech communication with the machine operator. An installation has been operational in the Provence Group since May 1990.

For downcast and upcast shafts,
new call and speech communication equipment associated with the remote control of the cage was designed and constructed.

A long-distance radio-telephone system
for underground roadways was developed. The links depend on a network of waveguide cables. A design study on a selective call and alarm system for roadways showed that it was feasible to produce mobile, portable and vehicle-mounted sets.

An alarm device
incorporated into the underground telephone system was successfully tested.

A surface paging system
for safety staff was installed in the Provence Group.

The new equipment designed for selective call and alarm functions is integrated or associated with other telecommunications systems and thus makes use of their transmission media.

The facilities offered by the equipment designed will help improve the safety of isolated or itinerant personnel and the efficiency of the underground services.

4.06 TRANSPORT

In view of the adverse accident trend in mine transport and material handling operations this underground activity was made a specific field of reserch in the second programme. The first programme contained only one project, which investigated accident reduction in locomotive and rope haulage transport systems. The second programme provided for research into the evaluation and testing of all safety aspects of transport systems for materials and manriding and the problems of transporting heavy equipment. There are only four projects in this field.

As a result of the policy of concentrating production on high-production longwall faces and high-speed mechanised drivages, new demands were placed on systems for transport of men and materials. Transport systems are now required to handle and move high tonnages of bulky and heavy equipment during the installation and termination phases, as well as the increased amount of daily supplies required during normal operation because of the higher rates of face or drivage advance. Inbye district transport systems can be appraised and redesigned when a unit reaches the end of its life and its replacement is installed. This is not the case for permanent or outbye transport systems, which can only take full advantage of new technology or systems when a production area is exhausted.

Accidents in transport arise from malfunction of equipment, the use of unsuitable or poorly maintained equipment, inadequate controls and supervision and from risks taken by the operators, known as behaviour-related accidents. In 1985, 36 fatal accidents, or 33.6% of all underground fatalities, occurred in transport and this statistic was the highest for all causes reported in the SHCMOEI annual report for that year. The fatal accident rate per million manhours in transport has stagnated at around 0.09 since 1975.

The statistics indicate that transport accounts for a high proportion of fatal accidents (61%) and >56 day accidents (61%) taking place in 'other places'. Furthermore there has been a deterioration in the fatal rate for 'other places' since 1980. These statistics seem to substantiate the comments in the previous paragraph. It is a matter of concern that there should be only four projects in this field.

Transport systems	091, 092, 112
Testing of equipment	086

4.06 TRANSPORT

4.06.1 Transport systems

4.06.1.1 High-speed rail-mounted materials transport

Author: I.G. RODFORD.
Organisation: British Coal - UK (7258-06/091/08)

Research objectives
To test and appraise newly developed equipment for performance and safety.

Research findings
The project covered six areas of work.

Locomotive adhesion on the rail track

Using mine locomotives on a surface track, trials were carried out to determine the limiting coefficients of track adhesion for safe braking levels as hitherto defined, to check whether existing data was correct and to provide design guidelines. It was concluded that design guidelines should not be changed but that data should be obtained from tests underground.

Rack locomotives

Further designs of rack locomotives with outputs up to 123 kW have been tested and entered service underground. In surface trials, satisfactory results were obtained on a 1 in 8 gradient with speeds up to 30 km/h and unbraked trailing payloads up to 32 t, and also in the adhesion mode on a 1 in 15 gradient with an unbraked trailing load. The existing design criteria to prevent excessive levitation during braking were proved sound.

Vehicle braking

Eight designs of manriding and materials supply vehicles were surface tested for performance and safety. Design modifications had to be made on some of the equipment, and operating restrictions described, in order to solve the problems encountered.

Vehicle design

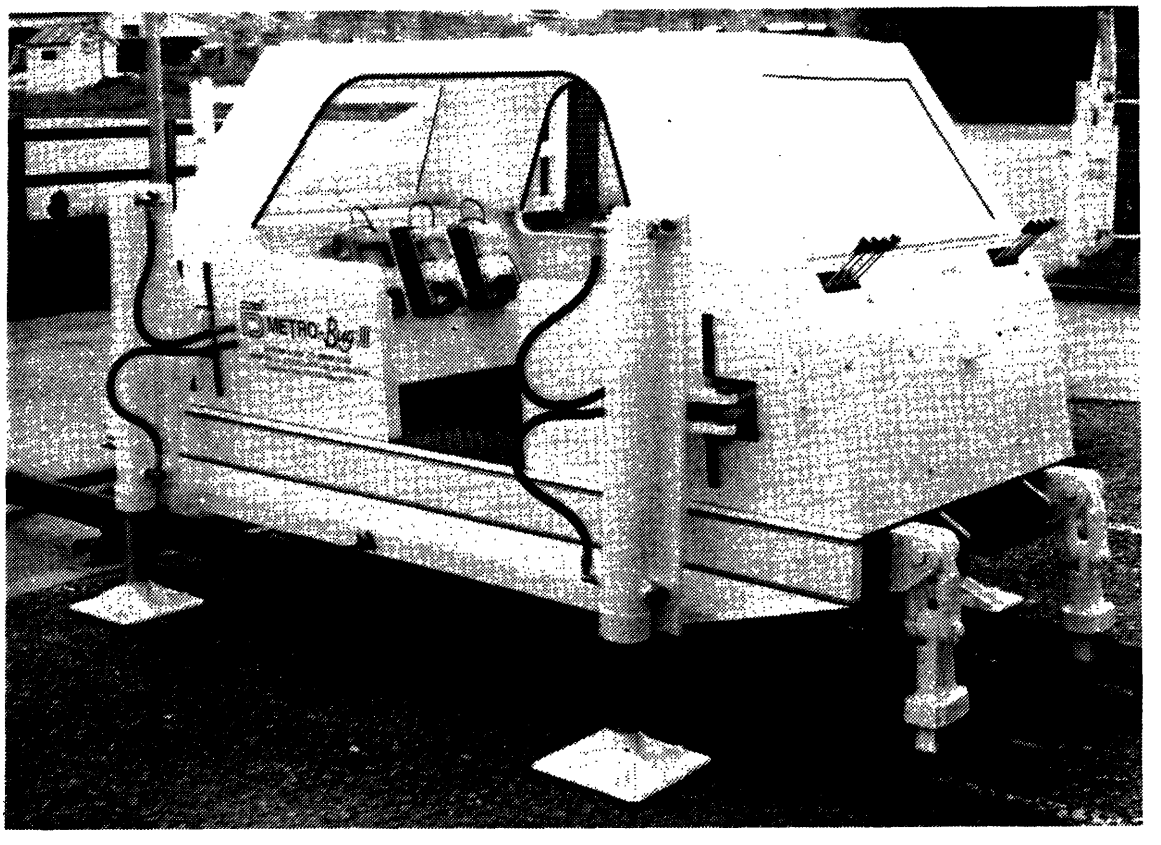
There are no British Standard or British Coal specifications covering materials supply vehicles. Draft "Notes of Guidance" for manufacturers and users were prepared. Alternative bogie designs were investigated in order to provide the suspension required to operate at speed on uneven track. Alternative materials and construction of rubber tyres for rail vehicles were investigated and prototype surface tested. No operational problems were found.

Track design

The benefits of a high standard of track design and maintenance were demonstrated at Lea Hall Colliery where speed increases from 9 to 25 km/h were achieved. Investigations were started to identify the geotechnical and other factors which influence track stability and cyclic load bearing capability. More work is required.

Track monitoring and maintenance

The 'Metrobug', which was initially a track monitoring vehicle, was modified.



Metrobug track monitoring and alignement vehicle

References: 12

4.06.1.2 Inbye materials handling

Author: J. FIRSTBROOK
Organisation: British Coal - UK (7258-06/092/08)

Research objectives

1) To reduce haulage and transport accidents associated with the handling of heavy loads at the inbye end of the gate roadway.

2) To increase the speed and efficiency of materials handling, without impairing safety standards.

3) To reduce manpower engaged on materials handling.

Research findings

The project work did not succeed in meeting most of its objectives. A programme of trials was prepared and specifications agreed with certain Areas to carry out trials on seven different types of materials handling equipment but the closure of mines, the non-availability of capital and a lack of interest were reasons advanced for the lack of progress.

Two projects were implemented. The first used a Becorit (GB) Ltd. monorail system in a face gate road for material supplies and the installation and withdrawal of face equipment. The second utilised a Gullick Dobson free steered vehicle (FSV) for supplies and dinting of the floor in a development heading (this unit is fitted with a bucket and can be used to transport debris from the dinting of a road where there is no conveyor).

The monorail trial exposed the strenuous and difficult manual effort required to advance the overhead 3 m rail section in an arched roadway. Three possible solutions were offered but none were developed further. No indications of manpower savings or reduction in accidents were reported.

The FSV worked for two years on a gradient of 1 in 5 and on a round trip of 3000 m. The reliability of the machine was poor. A second machine, from the same manufacturer, was put on trial at another mine for materials supply to four headings on a gradient of 1 in 10 and a round trip of 2000 m. This machine showed many mechanical advantages over the first one in that it had a limited slip differential, a 135 kW engine instead of 80 kW as in the first model, and better soundproofing. Manpower savings or accident reductions were not reported.

The appendix contains statements on the advantages, disadvantages and limitations of materials systems in operation and specifications for mobile underground cranes.

4.06.1.3 Development and construction of a safer emergency braking system for overhead monorails

Authors: BOLZ, HACKENBERG
Organisation: DMT(WBK) - Germany (7258-06/112/01)

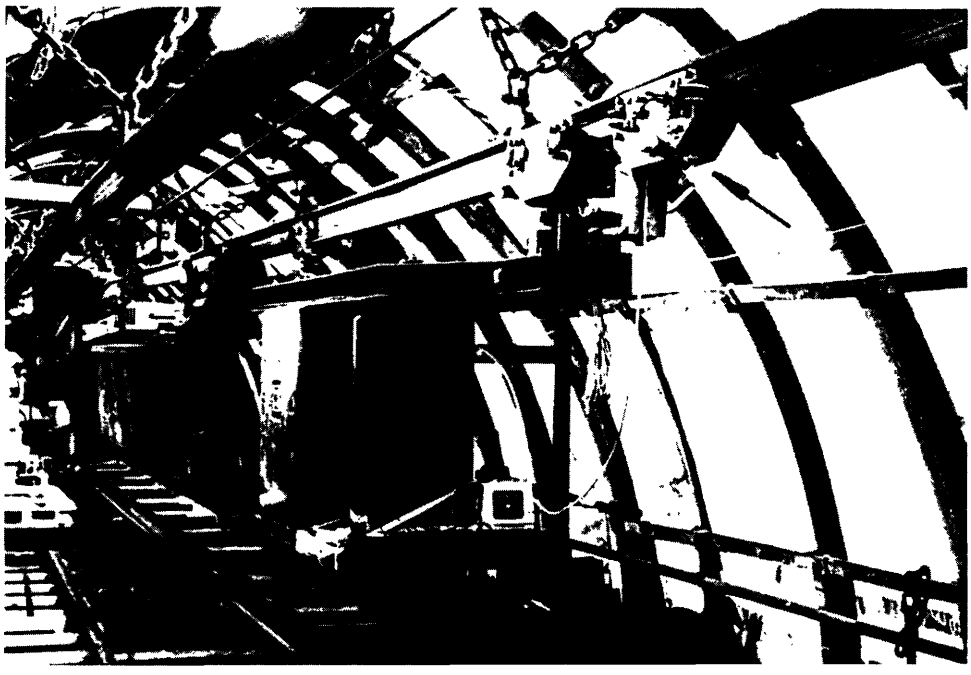
Research objectives

A study in 1981 surveyed the safety problems of overhead monorails which had become apparent through operational experience. Weaknesses in the 10-year-old designs were analysed. The study concluded that brake trolleys should be used on overhead monorails. The aim of the research was to

- establish specifications for new designs of brake trolley in relation to available elements which need to be improved,
- develop sensors for the control of safe emergency braking systems in relation to the gradient to be negotiated and the total load, and
- improve payloads through the use of a brake trolley with a variable braking force.

Research findings

The requirements for a braking trolley with a higher level of safety were worked out from an analysis of the weaknesses, accidents and damage caused. Note was also taken of the recent trend towards using overhead monorails for the transport of heavier loads. An essential problem was the wide gap between the maximum total load on the train and the lowest total load which has to be controlled by the braking system. There are two cases: installations with a wide range of loads working on steep gradients and which require emergency braking, and installations in level roadways, where damage must be minimised. Fig. 2 of Annex 8b to the final report shows the instrumented brake trolley on a steep incline.



Instrumented trolley with acceleration-compensated inclinometer (arrowed) on trial runs with an original monorail train on the test installation

At the moment there are no commercial designs of brake trolley with variable braking force, although attempts have been made to provide them. Tests carried out in the laboratory and in the field have now led to the development of sensors which will provide a brake trolley with a variable braking force.

If a normal dual brake trolley is equipped with load and inclination sensors then it is possible to use either one of the trolleys, or both in combination. On steep gradients, a greater payload would be possible than with the normal dual brake trolley. The scope for increasing payloads in a particular installation equipped with load and inclinometer sensors and controlled braking may be simulated by means of a computer program. The maximum increase in payload when a variable braking force was used in these trials was 39% on a gradient of 35 gon.

References: 17

4.06.2 Testing of equipment

4.06.2.1 In situ non-destructive testing of steel cord conveyor belts

Author: Dipl.-Ing. SLONINA
Organisation: DMT(VG) - Germany (7258-06/086/01)

Research objectives

Steel cord belts are being installed underground for the transport of run-of-mine coal, stone and personnel. Corrosion and breakage of the steel wires is a problem. The purpose of the project was to find a non-destructive method of testing the steel wires in order to check and assess their condition, strength and reliability.

Research findings

Physical methods of assessing damage due to corrosion and breaks were examined.

Ultrasonic and eddy-current methods are unsuitable.

X-ray photographs of the stationary belt provide excellent results; the damage can be seen down to the smallest detail. However, because of the time and expense involved the system can be used only at specific points, e.g. at belt joints or places where damage is known to exist.

Continuous X-ray photography produces pictures of poor quality and evaluation is time-consuming. The method could be contemplated only in conjunction with automatic photograph analysis.

Good results were achieved with a transmitter-receiver measuring system and a magnetic inductive method. This approach makes it possible to detect the smallest defects, which are to be regarded as critical for belt strength.

Possible areas of further development are defect size determination and precise location, recording and storing of large volumes of data and automation. However, firedamp-proof versions of all the instrumentation are still to be produced.

4.07 ELECTRICITY

Under this title projects for research should be directed towards improving the safety of operation of electrical plant and equipment, electrical networks and control systems, through design and testing; the safe use of accumulators and the development of cableless systems of power supply and the hazard of static electricity which the use of synthetic materials may introduce.

The production policies now being pursued throughout the mining industry require higher-powered machinery and plant for the face and roadway drivages than were available in the previous decade. Technological developments continue to be made and applied in order to meet these demands. Higher working voltages up to 5000 volts have been introduced on longwall equipment. There will always be some need to study and research changes in the operational safety of this equipment.

The accidents due to electric shock are not recorded as such. They are small in number but nevertheless they still occur. More of them occur in 'other places' than in other locations.

In the first safety programme five projects examined the reliability of electrical networks and carried out developments for the design of circuit breakers for high-speed shutdown. In this, the Second Programme, there are three projects, one of which studied the safe use of electricity underground where trolley locomotives are used; this is a continuation of a project in the First Programme. The other two projects are concerned firstly with an investigation of the developments in the USA in flameproof enclosure design, which were aimed at producing lighter switchgear, and secondly with investigating the design of test equipment in order to carry out ignition tests which may arise from the use of high-frequency transmissions.

The attention of the reader is drawn to several projects described in the ECSC coal research annual report 1988 concerned with the testing, development, monitoring and control of switchgear, with the safety of the electrical supply and plant and the development of the leaky-feeder radio control system for mobile plant.

Study of flameproof enclosures	077
Safe use of electricity below ground	113, 136

4.07 ELECTRICITY

4.07.1 Study of flameproof enclosures

4.07.1.1 Investigation into the safety of enclosures for electrical apparatus for which wide-area flame traps provide pressure relief - experimental study

Author: D. EISFELD
Organisation: DMT(WBK) - Germany (7258-07/077/01)

Research objectives

In mines where firedamp is an explosion hazard electrical equipment capable of causing ignition during normal operation must be provided with flameproof enclosures. Such enclosures are heavy, bulky and expensive to manufacture. The aim of this project was to test a pressure relief module from the USA to determine whether it conforms to European equipment standards.

Research findings

The US Bureau of Mines provided a prototype to test. This unit has protective shutter and a 13 mm thick porous metal plate which acts as a flame trap. In one of the two models patented the plate is protected from excessive heat exposure by extra layers of wire mesh inside the unit.

The tests were carried out in two explosion testing chambers, 10 and 20 times the volume of the enclosure tested.

Evidence of burning up to 15 minutes after an explosion was recorded in the larger chamber, although a fresh supply of combustible gases had to enter by the shutter through which the inert explosion gases had just escaped. If the protective shutter is dispensed with, a wailing noise results and the enclosure behaves like an organ pipe, producing a noise of 163 dB, while the components are subjected to accelerations of up to 640 g!

Although the flames are contained within the enclosure they may develop into an unacceptable risk. If a malfunction occurs within the enclosure, it may well be opened soon afterwards. If methane is present in the vicinity at an explosive concentration, an ignition may occur.

However, this risk, which is due to a design fault, is of secondary importance compared with another hazard which has been known since the time of Beyling (1906): the porous plate is mounted in a rigid metal frame and is irreversibly deformed when it expands on exposure to heat. On cooling, it is split and the safety of the enclosure is impaired.

4.07.2 Safe use of electricity below ground

4.07.2.1 Improved safety in the use of electrical energy in coal mines
Study on limiting the risks resulting from transfers of potential in non-current-carrying metalwork

Author: DAVROU
Organisation: CERCHAR - France (7258-07/113/03)

Research objectives

A previous research project 7255-14/032/03 had established experimentally that differences of potential exist in the non-current-carrying metalwork found in mine roadways, gate-end boxes, motors, which themselves are earthed at various points in the mine and which are linked by protection circuits. These differences may be due to the normal working of an overhead trolley system where the return circuit is the rail track or to insulation faults in high-voltage electrical systems. Differences of potential can also be found in roads where there are no electric cables. Ventilation ducts, conveyors and steel supports are also part of the metalwork. The potential could be such as to give rise to sparking and it was shown that the energy is sufficient to ignite a suitable mixture of methane. The aim of this project was to develop models to study these phenomena and to determine theoretically what could be done to reduce or limit potential transfer, to conduct underground trials in order to verify the solution proposed and to provide a technique which could be used by the electrical staff to check the performance of equipment.

Research results

Underground tests at two French mines showed that it was possible to ignite a methane/air mixture; that the potential at a point in the metalwork could reach 30 volts; that the impedance of an insulated circuit conductor and the metalwork is between 0.75 and 2.3 mH/km; that although the resistance of the metalwork is low, < 1 ohm, it could be raised to tens of thousands of ohms.

As a result of the trials the French Mines Administration have imposed certain rules for a trolley locomotive system:

- the maximum potential difference between two points in the return circuit must be restricted to 10 volts;
- for a trolley system entering a working section of the mine the cross-sectional area of certain insulated conductors must be limited to 1.5 mm^2;

- all electric systems without exception must be provided with a means by which they are tripped out without unnecessary delay as soon as the first insulation fault occurs.

A computer program has been written for calculation of the electrical characteristics of protective circuits. When this program is applied to French mining conditions the results confirm those of the previous report and indicate that the best protection is provided by conductors forming a mechanical and electrical sheath surrounding the current-carrying conductors and that for maximum safety there must be a connection between the metalwork and the protective circuits at intervals of not more than 2000 m.

References: 7

4.07.2.2 Establishing the limits of intrinsically safe high-frequency energy transmission

Author: Dipl.-Ing. R. HAUKE
Organisation: DMT(WBK) - Germany (7258-07/136/01)

Research objectives

Previous work (project 6205/14/1/006) on electrical apparatus safe for use in methane atmospheres carried out by the BVS with a view to determining ignition threshold values for low- and high-frequency circuits had shown that electrical installations could be supplied with more power using high-frequency intrinsically safe circuits.

The main aim of this project was to investigate the possibility of using high frequencies in mine districts susceptible to firedamp.

Little is known of the maximum values of the various parameters (voltage, intensity, power) for frequencies in excess of 50 Hz, as opposed to DC or industrial AC circuits.

Research findings

In the selected frequency range (up to 100 kHz), curves were obtained for the ignition threshold values for methane, ethylene and hydrogen, as a basis for the development and testing of intrinsically safe apparatus operating in this range. These curves apply to circuits whose source has an internal resistance of 50 ohms. Such circuits allow fairly high power values: up to 40 W at frequencies between 50 and 100 kHz.

The upper limit for DC can be taken as 12 V/2 A. For remote data transmission or remote control, where the limit for DC is 60 mA at 40 V, high-frequency technology will permit values several times as high.

Choosing the test gas is a difficult problem, since the different gases react in very different ways to the high-frequency components of a signal.

The gas normally used (air with 52% vol. H_2) is unsuitable in this case. Ethylene seems a better choice, and it has been established that in all cases it afforded a factor of safety of at least 1.5 in relation to methane.

The conductors also had to be chosen with care. After many tests, 50 W coaxial cables certified for underground use were produced.

The results obtained make it possible to develop and test intrinsically safe electrical apparatus in the range up to 100 kHz.

4.08 MATERIALS TECHNOLOGY

This field of research was based on the assumption that the new equipment becoming available, which would be operating at higher powers and under greater stress, would need to make use of the suitable new materials being offered by suppliers. There would be a need to develop test and analytical techniques which would reveal the hazards and risks of failure of machines and plant.

No projects were submitted.

4.09 WORKING METHODS

This field of research, as set out in the Second Programme contents, is wide-ranging in its scope. It comprehends the application and use of both well-established and new methods and the problems of safety which they already embrace or which they introduce. It is aimed principally at the safety aspects of coal winning and roadway drivage systems, mining plans, problems of interaction in the planning of mining layouts, seams hitherto considered unworkable and also the machinery and equipment used in the methods adopted. The first programme supported five projects, the second three.

The projects concern the production of working plans in colour, the recognition of hazards from the mine plans and the safety of the face crew when working in fall areas on shield-supported faces.

Recognition of hazards at the planning stage through the use of computer techniques enables expert knowledge from many sources to be collected and used in the assessment of proposals. With the retirement of experienced mining engineers a fund of important knowledge could be lost unless steps are taken to collect and assemble it. This is knowledge which younger engineers with fewer years of experience do not have. The reader's attention is drawn to the ECSC Medium-Term Programme, in which there are nine projects aimed at providing computer programmes to identify hazards and information which could have a significant effect on safety and production.

From an examination of the accident statistics in the SHCMOEI annual reports it is seen that, in the cause-of-accidents category "Falls of ground and rocks", the frequency rate in headings and "other places" has only fallen by about 50% whereas the rate on the face has fallen by 70% due to the introduction of shield-type supports. Whilst there has been a reduction of total falls-of-ground accidents at the face it must be noted that accidents resulting in prolonged absence from work - >56 days - are increasing.

One type of face operation which has become more difficult with the installation of shield supports is that of roof cavity filling. The summary of the annual report of this project describes research work to facilitate this particular task and make it safer.

The Second Programme provided for research into safety problems at face T-junctions. The frequency rate for roof-

fall and machinery accidents in roads, including T-junctions, has shown little improvement. The reader should note that only the Ergonomics and Coal Research programmes support research work in these areas.

Falls of ground 114
Hazard identification 095, 096

4.09 WORKING METHODS
4.09.1 Falls of ground

4.09.1.1 Safety of the face crew when working under areas of roof fall, particularly on shield-supported faces

Author: A. RICHTER
Organisation: DMT(BF) - Germany (7258-09/114/01)

Research objectives

The advancing of shield supports below roof fall cavities involves a serious risk to workers. The serious accident rate for this operation is 18 times the average rate for work on the face. This indicates that advancing supports below roof falls from the travelling way is not the best solution.

The project had two aims:
- to determine the major factors affecting the frequency of roof falls;
- to identify ways of preventing such falls.

Research findings

1) Factors affecting roof falls

- Cohesion of the roof and its geological structure; more and bigger falls occur in the vicinity of faults.
- Increased strata pressure (>80 MN/m^2).
- Caving of the goaf. Stowing is preferable.
- The roof must be supported to within a very short distance of the faceline: 30 cm at most.
- Extendible hydraulic cantilevers are the most effective way of preventing roof falls.

2) Methods of preventing and controlling roof falls

- Bolting and grouting are more effective than consolidation with instantaneously setting construction materials or mesh lagging.
- A study was nonetheless made of the combination of mesh with metal forepoling bars, and this equipment was improved.
- Consolidation of a failed roof is effective and provides a good standard of protection against falling of stones.
- Methods of negotiating a fall include bolting and grouting with synthetic resins. An "injection bolt" was even developed which effectively combines the two methods.
- Important aspects of resin grouting are: the time of injection, adhesive properties and proportioning of components; polyurethane resins are suitable for roof falls, whereas silicate resins are used to stabilise spawling coal on the face; correct quantities are

important and injection must be properly timed in relation to face advance.

Light modular drilling equipment was developed, which could be moved along on the face conveyor and controlled from the travelling way.

A cementitious foam developed in the United Kingdom was tested and improved for use in filling fall cavities.

Roof control measures were summarised in a "catalogue" indicating the action to be taken in a range of situations which may arise in the course of mining operations.

4.09.2 Hazard identification

4.09.2.1 Requirements for reproducible mine plans in colour - establishing a frame of reference

Authors: J. LEONHARDT, D. MORGENSTERN, U. RIECKS
Organisation: DMT(BF) - Germany (7258-01/095/01)

Research objectives

The project was directed towards producing mine plans which are in colour, easily readable and which would meet the needs of higher operating performances and enhanced safety. The conventional black and white presentations are often unsatisfactory, especially where circumstances require later additions to an existing plan. Investigations by means of case studies and discussions with experts showed that the requirements were highly complex, divergent and often conflicting.

Research findings

The outcome of this work was the definition of a schematic mine plan which also defined the technical demands required from the plan drawing equipment. A world-wide survey of the suppliers offering specialised equipment was carried out and the results analysed.

Eight plans of different underground mining areas were produced by offset printing making use of available illustrative means, and were assessed by mine surveyors and other experts. One section of the plans was chosen for practical testing of 21 methods of colour reprography in order to ascertain the practical limitations. An economic assessment was made to determine the expected cost as a function of the number of copies produced. Fast and relatively inexpensive colour copiers are available for DIN A3 sizes, but not for DIN A1. Whilst screen printing is more economical than offset printing up to 40 copies, it still requires craftsmanship to produce.

The report concludes that the prerequisites for producing coloured mine plans to specifications are known and that the findings should be put into practice as soon as possible in order to gain experience and optimise the techniques.

However, real optimisation depends on developing new approaches and consideration must certainly be given to techniques borrowed from data processing.

4.09.2.2 Recognition of specific hazards from the mine plan

Authors: P. GRIESENBROCK., J. LEONHARDT, U. RIECKS, H. SCHMIDT
Organisation: DMT(BF) - Germany (7258-10/096/01)

Research findings

This project follows on from 7255-21/052/01 'Hazard recognition on the basis of mine plans'. Known hazards such as fire from old workings and zones of high strata pressure do cause operational problems but there are other dangers, not immediately recognised, such as outbursts, water inrushes, the complex relationship of the rock beds and rock pressures which change through working. It is necessary to set objectives for their investigation. The aim of the study was to find new methods and processes which would help in the recognition of hazards at an early stage in the planning process and which would avoid human error through lack of knowledge. Mine plans do not as yet adequately reflect the geometric changes which occur during extraction. It was considered that computer programs would help in recognition of hazards and appropriate countermeasures.

Over the past 100 years a great number of mining plans have been produced for mine workings, for identification of strata characteristics, quality and pressures and for fault and fracture planes. German mining regulations require that mine plans be made, not only of areas already worked and geological conditions, but also of fire and other hazards and areas requiring protection.

Research findings

As a result of the research project a computer program has been produced to allow the mine surveyor to input all the data from plans, together with the data on fire risks and high strata pressures. The program is an interactive one, permitting a dialogue with the surveyor. The recording, in digital form, of all fracture planes and other geological data is an essential requirement.

To this end, an envelope around the target zone is considered.

A program for the digital system has been developed and tested. It has two functions:
- to generate an envelope around the target area;
- to establish whether known or potential hazards affect this envelope.

This allows very early recognition, excluding the risk of human error inherent in all "manual" evaluation of mine plans, although recording and digitalisation of actual cases is very time-consuming.

The work has provided a solid basis for better recognition of fire and strata pressure hazards.

4.10 ROCK AND GAS OUTBURSTS

This is a new research activity in the mines safety programmes. The programme content envisaged projects concerned with the prediction and possible prevention of strata movements leading to rapid evolution of gas or the projection of fine coal into the workings. Two such outbursts have been responsible for group accidents in which 24 men were killed or injured. It may also be hoped that the measurement and monitoring techniques developed could be of use in ensuring safety of operation at the greater working depths now being reached.

The Second Programme includes three projects concerned with microseismic techniques, one of which examines the radon gas phenomenon. Microseismic monitoring has shown that abnormal microseismic activity, which is a precursor to outbursts in a South Wales mine (Cynheidre), can be recognised by comparing the measurements of events of the 'normal' and 'abnormal' microseismic activity.

The single project investigating roof strata strength reported that it was possible to determine, from a combination of the physical characteristics of the rocks, whether it was possible for the seam to withstand mining pressures. The work continues.

Prediction of hazards	089(1), 089(2), 134
Study of rock quality	137

4.10 ROCK AND GAS OUTBURSTS

4.10.1 Prediction of hazards

4.10.1.1 Integrated microseismic monitoring and early warning systems for outbursts of coal and firedamp

Part I
Authors: N. RIGBY, J. WARDLE, I. MAXTED, P. BOLT
Organisation: University of Cardiff

Part II
Authors: Dr P. STYLES, S.J. EMSLEY
Organisation: University of Swansea
British Coal contract - UK (7258-05/089/08)

Research objectives

To investigate the possibility of using microseismic techniques to achieve a better understanding and if possible solution of the outburst problems in a deep anthracite mine in Wales.

To obtain a better knowledge of the effect of the distribution and redistribution of stresses on the outburst mechanism.

To establish criteria - based on experience gained by monitoring microseismic activity in outburst conditions - allowing a warning to be given as soon as such conditions arise.

Research findings (Part I)

1) Development of a multi-channel system for frequency-modulated transmission to the surface of data from in-seam geophone arrays.

2) Study of the data so obtained with a view to
   - correlating seismic activity with mining operations;
   - detecting, by both qualitative and quantitative means, the occurrence of anomalous activity.

3) The relationship between mining and microseismic activity for purposes of distinguishing between anomalous, but mining-induced activity and non-mining-induced activity proved very complex.

4) Recordings during an outburst showed that precursive activity occurred up to three hours prior to onset of the outburst.

5) Software was developed in PASCAL utilising the attenuation characteristics found by the Bretby in-seam seismics team for the generation of source spectra from those perceived at each geophone. This in turn made it possible to produce a measure of relative energy and finally to identify areas of abnormally high (or low) energy release.

Research findings (Part II)

A network of seismic monitoring stations was installed to record seismic activity below ground at Cynheidre Colliery in South Wales.

Five vertical component seismometers were deployed in a 6 km by 6 km array, making it possible to detect, identify and locate microseismic activity associated with mining activity.

More importantly, a completely new type of seismic activity was recognised which was shown to be associated with the microfracturing of the coal and the emission of methane during periods of abnormal face conditions.

This type of "outburst" activity is rarely seen when face conditions are normal but can rise to levels in excess of 100 events per hour immediately prior to an outburst.

4.10.1.2 Evaluation of environmental and operational factors in districts liable to outbursts of coal and firedamp

Authors: Dr P. STYLES (U.C. Swansea), T. JOWITT
Organisation: British Coal - UK (7258-10/134/08)

Research objectives

To investigate and evaluate the relationship between mining parameters (e.g. shift index, strata activity) and microseismicity.

To evaluate these results and differentiate them from microseismic activity associated with outbursts in order to provide a method of predicting outbursts.

This research follows on from the second part of a previous project on the same subject (7258-05/089/08).

Research findings

A continuous recording system with immediate microprocessor analysis was set up to monitor the activity levels of each of the channels and alert the mine control room.

There is a clear difference between "normal" and "outburst" activity.

The system proved its worth in a serious incident on 19 February 1986, when 8 500 m^3 of methane were released in a controlled manner.

The main benefit of the research lies in the development of this system.

The "real time/on line" combination enabled early warning to be given of this incident, which otherwise might have been a disaster, and also of 14 other cases in 1987 and 1988. The alarm is given seven to ten days before the activity peaks.

4.10.02 Study of rock quality

4.10.2.1 Investigations of strata strength in the roof of seams liable to rock outbursts

Author: K. HEES
Organisation: DMT(BF) - Germany (7258-10/137/01)

Research objectives

The strata adjacent to rockburst-prone seams are known to consist often of hard rocks, generally sandstone.

This observation underlies the aim of this study: to identify, analyse and quantify the strength characteristics of roof strata of various compositions in very deep workings and to show how these strata react to the increased pressures resulting from mining of the seam.

Research findings

Strata conditions in rockburst-prone zones were quantified by means of fracture plane parameters. These zones often contain fairly thin formations and there are few fracture planes.

This information is not sufficient to assess the risk of rockbursts: it is necessary to know whether there is a thick bed of hard rock in the vicinity. The properties of such a bed are: resistance to fracture, elastic deformability and the (deformation-dependent) ratio of elastic to plastic energy.

The final report lists the various tests and methods for determining these parameters. In combination, they permit fairly precise quantification of the types of rock relevant to rockbursts.

Cartographic methods were used to represent "competent" formations, i.e. formations with rockburst characteristics similar to sandstone.

4.11 SURFACE OPERATIONS

This field of research did not appear in the First Programme. The Second Programme provided for projects in all the surface activities of both deep mine and opencast operations. There are two projects and the summaries have been made from the last annual reports.

The first project, which concerned the safety of operators working near vehicles, is of interest to both deep mine and opencast operators. The second project examines the causes of rockfall and bench failure in opencast mines and makes proposals for better control of the rock face.

Opencast mining 135, 150

4.11 SURFACE OPERATIONS

4.11.1 Opencast mining

4.11.1.1 Safety personnel in the vicinity of mobile plant

Author: J. FOUBET
Organisation: CERCHAR - France (7258-11/135/03)

Research objectives

Following various accidents or dangerous occurrences, it was decided to take action to improve the safety of persons on foot or in light vehicles in the vicinity of mobile plant in the opencast workings of the HBCM.

Research findings

Several systems were considered and assessed. Two were selected as possible means of detecting men at a distance:
- radio waves;
- magnetic fields.

The first was quickly abandoned since it was far too expensive.

The second was discussed with a manufacturer; the system in question is based on emission of a modulated magnetic field.

However, the cost of equipping the production sites concerned (Unité d'Exploitation du Gard) proved excessive and it was decided to terminate the project at the end of 1988.

4.11.1.2 Prediction and prevention of rockfall in surface mining

Author: D. HANTZ
Organisation: CERCHAR - France (7258-11/150/03)

Research objectives

The aim of the project is to determine the factors influencing bench stability and rockfall in opencast mines.

Research findings

Improvement of methods of detecting instability by the development of purpose-designed software. The first package was for automated detection of geometry which might give rise to slope and bench failures, while another permitted a probabilistic approach to unstable rock masses.

Study of calculation methods for bench reinforcement with untensioned rock anchors and rockbolts.

Software for calculating the forces exerted by passive elements (BOULON), using the maximum work method, has been developed as part of a calculation of two-dimensional stability.

FIRST JOINT Research PROGRAMME ON SAFETY IN THE ECSC INDUSTRIES (*)

The following text outlines the essentials of the research proposals, section by section.

The economic forces on the industry have engaged the mining industries management in a re-assessment of the manner in which they must deploy and organise the capital and human assets available to them in order to maintain a viable industry. In essence this means improving the utilisation, reliability and capability of men and machines, management and systems in the mining conditions experienced and foreseen.

Mining techniques and equipment have been seen to produce satisfactory returns in good mining conditions; these same techniques have been adapted to difficult conditions, formerly considered unsuitable for mechanised techniques, and have demonstrated their capability to improve productivity and safety in such conditions.

Emphasis is now very firmly on providing mining systems to reduce costs of the investigatory, preliminary, installation and termination work necessary to establish a production unit and of the costs of operating. The safety of the operation and of the workforce has to be considered for each phase. There is no room for accidents to either men or systems.

The result of these strategy changes will be to increase the panel length of the unit, the daily output per face, the daily face and roadway advance. There will be increased demands on the supporting services, in ventilation, dust control, power requirements, transport of men, material and mineral. The adequacy of roof control at the face, the face-end, and in the roadway and its integration into a safe operating system must be developed.

Management control will depend more and more on sensors and management information systems but it is not expected that such systems will replace human observations of operations, of hazards and risks. Indeed it is not possible that system engineers will ever envisage the wide range of factors which contribute to the short system delays and the thousands of minor accidents which befall the workforce. In the modern methods employing automated control techniques and in the existing service systems education, training and licence to operate and supervise will form an essential part of a persons qualifications.

(*) OJ C 325 of 29 December 1989

Accidents, Data on Accidents, - Human factors in Safety

In the Joint Programme this field of work is included in section "General Requirements". Hazard identification and safety assessments of existing and new techniques; the under standing of human error and organisation on the causes of accidents; participation of mineworkers in identifying safety problems, education and training methods. The results of the Community project 'Training to Improve Accident Prevention' are particularly relevant. Opinion was divided on the need for techniques of analysis for accidents, (the loss control systems in other coal mining and other industries could well be studied for their suitability).

1 Fires and Underground Combustion

The risk of fires and spontaneous combustion is ever present. In the 2nd programme some 19 projects were devoted to the various aspects of these problems. Progress was made in the development of sensors for the early detection of fire and in the development of monitoring systems. Further knowledge was also gained in the fire risk associated with synthetic materials. It is considered that further work on the development of fire proof and fire resistant apparatus - belt conveyors, diesel tyres, and fire extinguishing methods - is no longer justified.

2 Explosions

It is considered necessary to continue work on the elimination of ignition hazards caused by sparking and frictional ignitions; on further work on explosion arresting barriers for in-seam roads and places where there is a congestion of plant and equipment. The points in 3, 4, 5, could be embraced in one devoted to the initiation and extent of explosions. In view of higher face outputs research is needed on the effectiveness of methane drainage systems and on the methane problems at the face-end. Work on stone dust and monitoring methods is questioned.

3 Rescue Arrangements

The perfecting of rescue apparatus and communicating systems should be pursued. Points 5 and 6 should be continued.

4 Monitoring, Telemetry, Data Presentation, Remote Control, Automation and Communication

Development is required of systems of monitoring and control of auxiliary ventilation; of the means of communication; of means to protect miners against dangerous situations and of improving the safety of the systems themselves.

5 Transport

This theme is of the greatest importance; attention must be given to the improvement of the systems and to capability in handling heavy equipment.

6 Electricity and Energy

Themes considered essential are the protection for batteries in gassy zones; the materials used in the construction of cables. Points 3 and 4 should be retained.

7 Materials Technology

The themes must be retained but the need for some subjects must be questioned.

8 Winning Methods

Roof control, especially at the face-end and in drivages, is of major importance. Reduction of noise and vibration require at lot more attention; cooling of the ventilation must be continued. Improved safety in man transport systems is necessary.

9 Rock bursts, associated phenomena and instantaneous gas outburst

This theme must be retained. Research is needed into the methods of measurement, of prediction and of the means of prevention.

10 Surface

The views vary from supporting projects for the opencast operations to total elimination of the section. The strategy, in view of the limited funds, needs debate.

One further comment by all deserves mention, and it is one with which the writer is in total agreement; namely that the dissemination of the research results has been poor.

European Communities — Commission

EUR 14842 — Final report on the second research programme 'Safety in mines'

T. L. Carr, J. Mayne

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The Commission of the European Communities allocated a total of ECU 12.5 million, distributed over at least five years beginning in 1982, for the second research programme on 'Safety in mines'.

Seventy-nine research projects received financial assistance.

The aim of this summary report is to set out the results of the work carried out and give details of solutions found.

The programme was divided into 11 sections: human factors and safety, fires and underground combustion, explosions, rescue, monitoring, telemetry, automation and communication, transport and handling, electricity, materials technology, working methods, rock outbursts and instantaneous gas outbursts, surface operation.

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