CHAPTER 1

BACKGROUND TO PROJECT

By
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1.1 Introduction

1.1.1 Overview of the Moura No.4 Underground Coal Mine Explosion

An underground mine explosion occurred at Moura No.4 Mine in Central Queensland on 16 July 1986. Twelve miners were killed. They had been employed on the extraction of pillars in the Main Dips Section of the mine. Their bodies were recovered on 23 July 1986 after an extensive recovery operation.

The Warden's Inquiry pursuant to section 74 of the Queensland Coal Mining Act was conducted in Rockhampton from 9 to 27 February 1987.

The Inquiry found that a roof fall had occurred in the Main Dips Section goaf and that the resulting wind blast blew a mixture of methane, air and coal dust into the working area. The Inquiry also found that:

. An explosive atmosphere developed in the working area and in particular around the deputy's flame safety lamp.

. An ignition occurred creating a violent explosion which caused extensive damage throughout the section.

The Warden's Inquiry Report on the Accident on 16 July 1986 considered a number of potential ignition sources but discounted all the sources of ignition considered except for two, namely frictional ignition and the flame safety lamp. The Inquiry Report [1] [1] states -

"The members of the Inquiry <u>are of the view</u> that frictional ignition from sandstone on sandstone of the type found at Moura is highly unlikely to have been the source of ignition."

The Inquiry Report further states -

"Considering all the evidence and the expert opinions presented, the members of the Inquiry <u>have formed the view</u> that the most likely source of ignition was the flame safety lamp."

"The Inquiry considered that the flame safety lamp, although properly assembled, was the most likely source of ignition".

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[1] [ ] Numbers in parenthesis refer to references in Appendix L.

1.1.2 Background to New Research

A coal mine explosion is capable of producing lethal injuries to a large number of persons underground at the time of the explosion, causing widespread damage to equipment and ventilation stoppings within the mine, and damage to mechanical devices and building structures in proximity to the mine entrance. A major mine disaster is also responsible for long term emotional problems for any survivors, the families and friends of the deceased, members of the mines rescue brigade, other mine personnel (including management) and members of the mining community. The loss of coal production can usually be measured in millions of dollars, particularly when the mine is subsequently closed. There are also long term related costs.

The progression of an explosion in a mine is far more complex than an explosion in an open area on the surface due to the presence of many factors which are peculiar to mining. Methane gas which is much easier to ignite than coal dust may be present. Concentrations of fine coal dust occur on the roof, walls and floor of mine roadways as a consequence of mechanised mining operations and such dust is more explosive than coarser dusts which were produced in the days of hand mining. Changes of cross-sectional area of the mine roadway may result in an acceleration or deceleration of the explosion. Levels of stone dusting may be insufficient in all roadways to prevent propagation of an explosion.

Oxygen, an ignition source, and a source of fuel must be present simultaneously for an explosion to initiate. Methane is usually present in mines but the quantity of ventilation is normally adequate to ensure that its concentration is well below the lower explosive limit. With the precautions taken in coal mines nowadays, some combination of unusual circumstances must occur prior to a mine explosion. In a mine with multiple roadways (as was the case at Moura), the problem of determining the site of the ignition source and the progress of the explosion along the roadways is one of great complexity. Such a task requires an input from persons in a wide range of disciplines including:

. Mining, Mechanical and Electrical Engineers.

. Mines Rescue Personnel.

. Mines Inspectors.

. Union Inspectors/Representatives.

. Mine Management.

. Chemists.

. Scientists of various disciplines.

- Physicists.
- Geologists.
- Metallurgists.
- Pathologists.
- Police.
- Various experts in blast analysis, methane emissions, etc.

Investigation of Explosions

In Queensland the responsibility for the investigation of an explosion at a coal mine rests with the coal mine inspectorate of the Department of Resource Industries, under the Coal Mining Act 1925-1981. However, under the Public Safety Preservation Act an emergency situation can be declared by a Commissioned Officer of the Queensland Police. Under this Act an emergency situation includes any explosion or fire or escape of gas, any accident involving a vehicle or any other accident that causes or may cause a danger of death, injury or distress to any person or loss of or damage to property.

For the Moura investigation, technical and scientific support was provided by mine management, mine inspectorate, staff at the Safety in Mines Testing and Research Station (SIMTARS), the Department of Health and the University of Queensland Department of Mining & Metallurgical Engineering. Other experts from Australia and overseas also provided valuable assistance. During this investigation the scope of the scientific and other investigations was under the direction of the Chief Inspector of Coal Mines.

Coal mine explosions have occurred far less frequently in Australia than in overseas countries. Scientific investigation of methane and coal dust explosions has resulted in better understanding of the mechanism of explosions and means to avoid explosions.

With greater concentration of underground production on longwall faces, there should be less likelihood of an explosion because of improvements in ventilation, strata control and environmental monitoring systems. The development and operation of longwall underground coal mines still requires multiple roadways as does room and pillar systems of mining. There is always a risk that an explosion could occur due to the explosive properties of both methane and coal dust, and potential sources of ignition such as electrical equipment and friction.

Because coal mine explosions are nowadays relatively infrequent events in major coal producing countries, there are few experts with depth of experience in the investigation of such explosions. If the present trend continues, and explosions become less frequent in the future, finding the necessary expertise to investigate an explosion will become increasingly difficult. Australia does not have a history of decades of mine explosion research, as does the U.S. with its Bureau of Mines, the U.K. with the Health and Safety Laboratories at Buxton, or Poland with the Experimental Mine Barbara.

Research.

In those Countries there is a long history of safety research leading to improved safety in coal mining operations and the removal of hazards which might result in explosions. Whilst that work continues overseas in establishments such as the British Coal Corporations Headquarters at Bretby, there is concern that experts in pure explosion research are becoming rare. This highlights the need for developing experts and facilities for this work in Queensland.

1988 Report on Evidence

In September 1988 a report by Drs Leivesley and Romaniuk which reviewed evidence from the Moura explosion was presented to the Chief Inspector of Coal Mines.

The 1988 Report was initiated when training material was being collected for industry safety programs by Dr Leivesley. One photograph of the Moura explosion effects showed a diesel-engined vehicle known as a Mine Rover. The vehicle front seats showed apparent evidence of occupancy during the explosion and there were apparent directional indicators of the flame and blast pressure waves on the seats.

Detailed examination of the photograph showed then that the apparent outline of the head of one of the victims had been burnt into the driver's seat back. The front passenger seat showed signs of being occupied during the explosion and a rear seat showed what appeared to be a flash shadow of another occupant.

Dr Leivesley and Dr Romaniuk (an oral pathologist who had attended the Moura post-mortems) prepared a formal report to the Chief Inspector of Coal Mines after detailed work was undertaken on the post mortem evidence, photographic evidence of blast, and the mine disaster plan.

The initial hypothesis for the review was that the source of the explosion was in an area of the mine forward and to the right of the mine rover. A study of the photographic evidence revealed that a flash had travelled outbye from the goaf area toward the vehicle and from the right hand side (when looking inbye from the vehicle). The preliminary work undertaken in the report concentrated on establishing which forensic facts supported this hypothesis. Other hypotheses of source of blast in relation to the post impact positions of the 12 victims were also explored.

The recommendations in the report were that overseas experts be involved in further investigation, that industry be involved, and that examination of the explosion be conducted until there was conclusive evidence of the cause of the explosion. There was concern that there could be false assumptions on safety within the industry following the conclusion that the flame safety lamp was the most probable cause.

The report concluded with the statement that the work had been limited and a much more detailed study was required.

Action Taken Following the 1988 Report

Discussions within the then Department of Mines (now Department of Resource Industries) including SIMTARS resulted in a submission to State Cabinet in August 1989. The then Minister for Mines in this submission recommended that funds be allocated for further investigation into the Moura No.4 Underground Mine explosion. In particular the funds were to enable investigation into the use of forensic evidence in the interpretation and understanding of coal mine explosions generally.

The Cabinet Budget Committee on 4 September 1989 decided as follows:

"That the further investigations in aspects of coal mine explosions proceed as outlined in the Submission" (See above).

The Submission provided for the co-operation of the Department of Resource Industries, Department of Health, Police Department and co-ordination by SIMTARS utilising the assistance of various outside expert consultants.

1.1.3 Aims and Objectives

The aim of the investigation is to analyse the Moura No.4 explosion to identify whether the results of forensic pathology, blast analysis, computer modelling and other factors can be used to assist in the establishment of location of ignition source and the development of a coal mine explosion.

The objectives include:

. To determine the extent to which forensic pathology supported by computer modelling can assist the conventional techniques in explosion investigations by providing evidence on blast direction, magnitude of blast pressure, flame temperature, body movement and the like.

. To identify from the forensic pathology evidence relating to the Moura Mine explosion whether there are indications of the direction of the blast and information on the causation of the explosion.

. To identify any additional characteristics of the blast at Moura which provide information on the pattern of the blast and the causation of the blast.

. To identify whether the structuring of all future scientific investigations and inquiries following mine disasters needs to be reconsidered.

. To identify what new information on cause of blast has been generated by the research.

. To identify the implications of all the findings for the protection of life in underground coal mines.

Basic Research Areas

Forensic Pathology - it was necessary to achieve a full analysis of the Moura Mine explosion victims. It was also necessary to obtain all the indications of blast and causation that can be provided by the post mortem evidence.

Blast - there was a need to understand the blast pattern in the case of the Moura Mine explosion and therefore to determine what additional characteristics of blast have to be considered.

Investigation Processes - from this project it may be possible to structure all future investigations and inquiries into coal mine explosions.

Causal Analysis - new information on the source of ignition resulting in the Moura Mine explosion. There could be implications for general safety in underground coal mining.

1.2 Research Program

1.2.1 Structure of Project Team and Review Committee

(a) Project Team

Under the overall general management of Mr P. Dent, Director, SIMTARS a research team was formed in September 1989 consisting of:

. Dr P. Golledge, Project Manager, M.Sc, Ph.D, (Mining) University of Wales, Manager Research and Technical Services, SIMTARS.

. Dr S. Leivesley, a research consultant in the field of emergency planning and major incidents, Ph.D, Social Policy & Administration (London).

. Dr K. Romaniuk, a consultant in oral pathology who was present at the post mortem examinations of the casualties of the explosion at Moura Mine, Ph.D, R.F.D., BDS(NZ) MDS (Otago), Dr.med.dent (Munster), Ph.D., FRACDS.

. Dr A. Green, Manager Research, Londonderry (NSW) Occupational Safety Centre; Ph.D, (Edin) C.Chem, Consultant in Fire and Explosion Phenomena.

. Mr I. Roberts, a Chartered Engineer (Mining) and a consultant in coal mining. Former Chief Inspector of Coal Mines, Queensland with extensive experience in the coal mining industry as mine manager and director of coal mining companies.

Provision was made for consultation with Australian and overseas experts and research organisations as necessary.

(b) **Review Committee**

The Committee under the chairmanship of Mr P. Dent consisted of the above team members and

. Mr J. Torlach, Program Manager, Mine Safety and Technology.
. Mr B. Lyne, Chief Inspector of Coal Mines.
. Mr R. Bancroft, Senior Inspector of Coal Mines.

All of the Queensland Department of Resource Industries

. Mr J. Sleeman, Queensland Coal Association.
. Mr G. Duncan, Occupational Health & Safety Officer, Queensland Coal Association.
. Mr M. Best, District Union Inspector, Queensland Colliery Employees' Union.
Researchers . Mr W. Allison, District Union Inspector, Queensland Colliery Employees' Union.

1.2.2 Timetable and Progress of Research Project

The timetable of the Research Project was designed to allow for work in Australia and with international experts overseas. Weekly research meetings were held throughout the project period (October 1989-June 1990) and monthly review meetings were attended by the Review Committee to receive reports on progress and to contribute to the research program.

Preliminary work in September/October developed two scale models. The scale models of the Main Dips Workings and the workings in the vicinity of the 26 X-cut are shown in Appendix J. Early work concentrated on the review of all literature, reports, photographs and other material that was available on the Moura Mine explosion. Searches of various departmental sources identified a collection of information much of which had not been part of the formal presentation of evidence to the Warden's Inquiry. Case history material was prepared on the 12 victims and documented with assistance of reports and verbal interviews with overseas experts.

A network of Australian and overseas contacts was prepared through the multidisciplinary team contacts and the assistance of the Review Committee. In Australia a specialist from police forensic laboratories in Victoria was consulted. Overseas countries provided a variety of experts representing a core representation of international research on blast and forensic methodology. The countries involved included the United States, United Kingdom, New Zealand, Federal Republic of Germany and Norway. A full summary of the experts involved is supplied in Appendix K.

The Queensland Police Department nominated two officers to work on the project and these officers reviewed internal departmental information on the Incident and prepared material for recommendations to the Police Commissioner on forensic investigation methods for future incidents. The Department of Resource Industries provided assistance in reviewing all information on the project and Inspectors were involved in discussions on the evidence and on the development of further research questions for the team.

Dr Green provided a research link between SIMTARS and Londonderry and commuted to Queensland for various working party/review committee meetings. Dr Green developed with the assistance of Londonderry resources the methodology for computer modelling to test some of the dynamics of the explosion at Moura.

Londonderry also provided further modelling for the testing of the timing of various effects of the explosion. This modelling consisted of a 1:54 scale model with gas experiments which were photographed.

Various hypotheses of the ignition of the explosion were explored by the research team with the help of the physical models. The forensic details on the victims and the equipment underground were used to gain information on the progress of the explosion. Hypothesis testing was a continuous process.

The research team travelled overseas for consultations for three weeks and used portable scale' models to undertake further analytical work with overseas experts. These consultations provided further details on the explosion and forensic evidence and allowed specific hypothesis to be accepted for further consideration and negated other hypotheses which had previously been considered.

Early in the program conclusions on the need for detailed scientific investigations became obvious and work was undertaken on possible recommendations to solve this problem. It was recognised as a joint problem between police, health, and mining departments within State Government and the project provided a basis for representatives to consult and work together on the solutions.

The report was prepared by all researchers with the assistance of the overseas experts detailed in Appendix K.

1.3 Project Structure

The project structure provided for input to the Review Committee from all sections of the coal mining industry. The Committee assisted with the task of interpreting the applications of the findings for industry and relevant safety procedures.

The Review Committee, chaired by the Director of SIMTARS, Peter Dent held monthly meetings with the researchers and participated in all phases of the research. Contributions by the Committee members assisted the core research team with interpretations of the mining conditions at Moura, contacts with relevant persons who had underground experience at Moura, contacts with overseas experts who were to be consulted and expert advice on circumstances of the Moura explosion.

Police Liaison

Two officers with the Queensland Police Department were designated as liaison officers under direction of Superintendent D. Buckly (Operations). Inspector N. Sprenger and Sergeant J. Hopgood provided the police research component for the report.

Australian and Overseas Researchers

For the six months of the Research Program extensive consultation was undertaken with Australian and overseas experts.

Review Consultant Research Project

Professor D. Rowlands, University of Queensland, Department of Mining and Metallurgy reviewed the final report and considered the overall findings independently of the project team.

1.3.1 Methods for Study

The explosion research within the current project was planned in three phases. The first phase was designed to meet the objectives listed above and to be completed by end June 1990.

The work program for Phase 1 is summarised below:

- Undertake a preliminary study over a period of 6 months and at the completion prepare a written report for consideration by Cabinet.
- Orient the research after literature searches and consultation with Australian researchers, mining engineers and overseas experts by means of group discussions and overseas travel as appropriate.
- Seek assistance from specialists including police forensic experts and various scientists particularly where information is not publicly available.

- Develop processes for the modelling stage and allow scientific hypotheses to be formulated.

- Carry out literature searches.

- Undertake further forensic work.

The Phase 1 written report is prepared for submission to the Minister for Resource Industries. The results were intended to indicate any requirement to proceed to further work.

Continuing research could involve a second phase to establish modelling with international assistance for the development of enhanced protection against explosions in underground coal mines and to undertake continued research into forensic science. The work program for this phase would involve construction of small scale models, involvement in large scale modelling in international facilities and developing evidence from forensic science on explosion effects.

1.3.2 Visit to US Bureau of Mines

Drs Golledge and Leivesley and Mr B. Lyne visited the Pittsburgh Research Centre of the U.S. Bureau of Mines at Bruceton on 15 and 16 March 1990. Information on the Moura explosion was presented to the following staff of the Bureau of Mines:

Dr N. Greninger	Chemical Engineer (Fires & Explosions)
Dr W. Courtney	Supervisory Research Chemist
Dr M. Hertzberg	Research Chemist
Dr J. Edwards	Research Physicist
Mr K. Cashdollar	Research Physicist
Mr A. Furno	Supervisory Physical Scientist (Retired)
Mrs L. Snyder	Physicist
Dr Cohen	Physicist

All the above staff have worked at the Bureau of Mines for periods of 10 years or more in many aspects of explosion research both at the laboratory level and in full-scale explosion testing at the Bruceton experimental mine and at the Lake Lynn Laboratory (explosion gallery).

There was general agreement that the ventilation circuit at Moura Mine was very complex and would result in a coal dust explosion the path of which might not be possible to determine. The message was reinforced that the pressure, flame and velocity of coal dust explosions fluctuate widely even in straight explosion galleries with as uniform as practicable dust loading and using a well mixed methane source and an electric ignition source.

At Moura Mine with an ignition source in the area of the shuttle cars or in the goaf it was these experts' opinion that the path of the explosion could not be determined by any known method due to the complexity of mine roadways and the presence of many intersections.

The research work of the Bureau was brought to our attention where it has been demonstrated and is known from coal mine explosions that mild explosions can cause considerable damage if material, equipment or construction work are in its path. Weak explosions are considered to develop an overpressure of about 30 kPa, moderate explosions from 70 to 105 kPa and strong explosions usually in excess of 300 kPa.

On being shown and allowed to examine the flame safety lamp involved in the Moura explosion there was much discussion about the possibility of the lamp being the ignition source compared with an ignition in the goaf. No research into the behaviour of the flame safety lamp has been carried out in the U.S. for several decades. There was general agreement that the effects of heating observed in the lamp were the result of activity within it rather than that of an external flame. With thermal activity over a period of some seconds (about 10) it was recognised that the external gauge temperature might be sufficient to ignite an external atmosphere, particularly if coal dust of appropriate size range were present simultaneously with methane gas.

As to rocks acting as a frictional ignition source it was agreed that this might be possible in a mine situation although very difficult and costly to simulate in the laboratory.

The SIMTARS group was then joined by Mr C. Stephan of the Mine Safety and Health Administration who is the Senior Mining Engineer responsible for providing technical support in the areas of explosion flames and forces. He expressed the view that frictional ignition had not been given as a source of ignition over the past 15 years or so when better methods of investigation had been used to establish the most probable cause. It appears that frictional ignition was given as the cause of a number of explosions on previous occasions when no other explanation had been found.

The simultaneous occurrence of incendive sparking and a methane concentration within the right range is thought to have a very low probability.

Mr Stephan stated that MSHA would not carry out any detailed metallurgical examination of the gauges in any flame safety lamp recovered after a coal mine explosion if the lamp performed in accordance with approval testing procedures.

On 16 March 1990 in the company of Mr K. Cashdollar a visit was made to the Lake Lynn Laboratory of the U.S. Bureau of Mines. A video presentation of mine explosion was given followed by a tour of the explosion gallery.

Experimental work is still confined to a single entry configuration with testing of concrete block stoppings in adjacent c/ts. The data acquisition and computer system, a Micro VAX II operating under VMS, is configured with 68 data acquisition channels to handle data from the single entry configuration. To extend the data acquisition system to cover a room and pillar configuration would necessitate doubling of both data acquisition and computing capacity.

Current full scale explosion research involves the testing of concrete block stoppings against the overpressure developed in a methane explosion. Concrete block stoppings, mortared and of interleaved double thickness blocks supported at the sides and top with steel channel bolted to the roof, floor and ribs and with a central reinforcing column have been tested successfully against a methane explosion with an overpressure of approximately 315 kPa without failure of the stopping. Further experiments are designed to investigate the explosion strengths of different types of block stoppings.

Laboratory demonstrations of a dust deposition meter, incombustible dust monitor, remote methanometer, research on spontaneous combustion and developments in ventilation of longwall to reduce respirable dust concentrations were witnessed.

Research carried out at the Bureau of Mines indicates that failure of block stoppings is likely to occur at about 105 kPa if the stopping is anchored securely into the roof, floor and falls. Without such anchoring failure will occur at lower overpressures.

Implies research been done?

There was some discussion about the possibility of an ignition produced by a piezzo electric source due to distortion of the quartz crystals by various forces. No research has shown this to be a cause under realistic mining conditions.

1.3.3 Visit to Research and Laboratory Services Division, Buxton, United Kingdom

Dr Golledge and Mr B. Lyne visited the Explosion and Flame Laboratory (EFL) of the Health and Safety Executive and presented information on the Moura explosion to the following:

Dr B. Thomson	Director
Mr P. Williams	Deputy Chief Inspector of Mines, Bootle, Lancs.
Dr J. Barton	Deputy Director
Dr G. Lunn	Fire and Explosion Research
Dr D. Pritchard	Incident Investigation
Mr F. Powell	Retired (Formerly Frictional Ignitions)
Mr R. Brookes	Retired (Formerly Explosion Investigations).

The Buxton staff were very experienced; Messrs Powell and Brookes having spent a working lifetime at Buxton and the remaining staff have at least 10 years experience in this area of research.

The Moura lamp was the source of an interesting discussion. EFL are testing a similar model flame safety lamp in a closed circuit chamber at air velocities up to 15 m/s. To date they have not achieved 'fusing' of dust particles to the glass of the lamp which occurred during the Moura explosion and which has been simulated at SIMTARS. This may be due to intrinsic properties of the dust rather than differences in laboratory techniques. Both EFL and SIMTARS have achieved repeatability of results at their respective laboratories and indeed some degree of reproducibility. EFL has observed the same incandescent burning within the inner gauze and transition to the space between the two gauges at the top and ignition of the external flammable atmosphere without the bonnet on.

There was general agreement that activity in the Moura lamp occurred prior to its movement to its final location behind the offside front wheel of the shuttle car. There was no support for the suggestion that the heating in the lamp was externally caused. It was believed that the lamp and deputy were separated before the lamp reached its final location. Buxton has achieved a flame external to the lamp with the bonnet in place under conditions of high dust concentration. At the time however the tests were being conducted with an external atmosphere which was not explosive. To date the experiment has not been repeated.

[illegible]

Pure coal dust [illegible]

It is reasonable to say that an ignition by the flame safety lamp might be possible if the surrounding atmosphere has a methane concentration above the lower explosive limit and a dense coal dust cloud is present.

Information will be exchanged between SIMTARS and Buxton about existing and future research into the behaviour of the flame safety lamp.

Dr Golledge had the opportunity to inspect the experimental apparatus used at Buxton over a number of years to investigate frictional ignition of methane. According to Mr Powell, who was responsible for most of the experimental work of a number of years, no ignition has been achieved in the laboratory with rock/rock contact in methane atmospheres, other than by means of a grinding wheel.

They have [illegible] tried

The consensus of opinion was that frictional ignition might occur in a falling goaf, although this has been a rare occurrence but it may not be possible to simulate the combination of circumstances in the laboratory.

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With regard to the possibility of a piezzo electric ignition source Powell stated that some research had been carried out on a number of sandstone samples under simulated vertical stress conditions. No incendive spark was produced. During these experiments there was no attempt to simulate a high horizontal stress which characterises many underground coal mines in Australia.

1.3.4 Visit to Experimental Mine Tremonia, Federal Republic of Germany

Dr Golledge and Mr B. Lyne visited the Experimental Mine Tremonia in FRG which has recently become part of the newly formed German Mining Technology group Deutche Montan Technology (DMT) which includes the former Steinkohlenbergbauverein (STBV), Westfalische Berggewerkschaftskasse (WBK) and Versuchsgrubengesellschaft mbH (Tremonia) organisations. Information on the Moura Mine explosion was presented to:

Dr Ing J. Michelis	(Head of Dept of Explosion & Shotfiring)
Mr G. Muller	Physicist
Mr B. Margenburg	Physicist.

and various technical matters were discussed with DMT.

Dr Michelis is a mining engineer who has been involved in explosion research for more than two decades and during this time has carried out a number of post explosion investigations. He still holds a very strong view that the overpressure developed during the Moura Mine explosion has been overestimated in work done in Australia. Tremonia Mine is well instrumented, and according to UK experts, probably the best in the world. Results have been obtained from over 4,000 explosions. The damage to the victims at Moura (photographic and other evidence) are not consistent with the high overpressures of 300 kPa or more suggested by work done in Australia. Dr Michelis has suggested that the maximum overpressure at Moura was probably less than 100 kPa. Experience at Tremonia indicates that at 300 kPa there is massive damage to equipment on a much greater scale than occurred at Moura.

At Tremonia Mine methane and coal dust explosions are usually initiated near the inbye end of the 1,000m long explosion gallery where the cross sectional area is $20m^2$, of the same order as the roadways in Australian coal mines. Explosion proof doors, designed for an overpressure of 300 kPa, and installed in massive concrete bulkheads are used to isolate the explosion from other parts of the experimental mine. The normal dust loading is $300g/m^3$ which ensures that the minimum dust concentration of $125g/m^3$ is achieved during a coal mine explosion when approximately 50% of the dust does not take part. Particle size of the 23% volatile dust is in the size range 22 to 80 micrometres with 90% less than 50 micrometre diameter.

From experiments carried out at Tremonia it would appear that a person standing about 100m from the ignition of an explosion would have about 3 sec in which to react before the arrival of the flame. The sound of the explosion resembles a strong wind rather than the sharp crack of an ignition following explosion by detonation. Microphones in the gallery linked to recorders, together with video cameras and high speed photography have precisely recorded the progress of an explosion to the point of observation. Even from an initiation at the inbye end of the gallery an explosion (methane or coal dust) develops relatively slowly and becomes stronger as it moves outbye.

Experiments also showed that with an explosive wave having a maximum dynamic pressure of approximately 30 kPa, a person could move with a maximum velocity of about 6m/s and could travel some 7m in a time of 3s. The human body can only tolerate a relatively low dynamic pressure but can tolerate overpressures as high as 500 kPa.

The dust deposited on the Moura conveyor rollers was not typical of a German coal dust explosion. This might suggest complex air movement with high dust concentration following rather than at the time the pressure wave and flame were passing.

The explosion at Stolzenbach lignite mine in 1988 was investigated by Dr Michelis. Although the flame from the explosion reached the portal of the mine none of the victims underground were severely burned.

Measurement of oxygen concentration following an explosion at Tremonia has been as high as 5% by volume after a methane or coal dust explosion. The staff at Tremonia and other mines rescue staff regularly enter the explosion gallery immediately after an explosion to restore ventilation, collect samples and any repair work as necessary. Levels of carbon monoxide have been recorded as high as 10% but often do not exceed 1% after a mild explosion.

Movement of bodies was also studied at Tremonia Mine by Dr Michelis and staff and the results of this work were documented in a thesis submitted to the Technical University of Aachen in 1979. A dummy was used of the same mass, surface area and volume as an average miner fitted with a safety helmet, cap lamp and self rescuer. What is quite apparent from studies of movement of the dummy during an explosion is the rotation of the body from the axial plane of the explosion gallery. The dummy in some experiments rotated about the vertical axis and ended up nearly 45° from the centreline of the drift.

Discussion

In most experiments in explosion galleries explosions are ignited at a position that will provide the strongest explosion as soon as possible. This position is at the inbye face end of the explosion gallery. Nagy and Mitchell [3] reported on work carried out at the Bureau of Mines prior to 1963 during which a 15m length of 9.5% concentration of methane was ignited at increasing distances from the face. When ignition occurred at the face the maximum overpressure developed was 175 kPa but when the ignition distance was increased to 14m the maximum pressure developed was reduced to 7 kPa. The confining effect of the face of the drift greatly assists the process of pressure development.

For the Moura Mine explosion two hypotheses have been advanced to explain the ignition source. One is that a frictional spark occurred in the goaf as a consequence of some movement or falling of the roof. In an area some 60m by 50m by 7m high there may have been little confining due to the open nature of the goaf. If this were the case the explosion may have had great difficulty in reaching any reasonable overpressure by the time the pressure wave reached any roadway. There is a large volume to absorb any expansion caused by combustion of the methane or coal dust.

If the ignition occurred in the belt roadway between the continuous miner and the shuttle car the start of the explosion could also have been relatively slow but may have been assisted by the presence of those items of equipment.

Expert opinions from the three countries visited, without exception, acknowledge that it is very difficult if not impossible to forecast the path or paths which the explosion took. The presence of so many 4 way junctions and the unpredictability of the behaviour of explosions when passing along such junctions present a task of major magnitude in attempting to model any explosion, or indeed in trying to decide in which direction the explosion passed through the Moura mine roadways.

If the German experience is recognised and accepted, then the assumptions that the overpressure exceeded 300 kPa and that there was a near detonation velocity in No.4 Supply Road between c/t Nos.22 and 23 (Hereafter this location is referred to as the "taj mahal" so called because of the extensive roof fall which had occurred long before the date of the explosion.) are incorrect. Even for relatively weak explosions the experimental explosion galleries ensure that components which are required to remain in place are heavily braced or anchored to ensure that they are not moved out of position by the force of the explosion. Relatively low dynamic pressures can move steel supports which are not securely anchored. Damage to other metallic objects at Moura was not consistent with a strong explosion but representative of a weak to moderate explosion.

Moura [illegible] = 5.