CHAPTER 4

IGNITION SOURCE FOR THE MOURA EXPLOSION

By
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4.1 Fire or Spontaneous Combustion

4.1.1 Roadways and Cut Throughs

A fire occurred in 24 c/t between No.2 Transformer Road and No.3 Belt Road but was considered to be the result of the explosion. The belt road was inspected by Mr Bayles and Mr Foden prior to the explosion, however, no evidence of a fire was noted.

4.1.2 Goaf Area

Carbon monoxide levels recorded on the continuous monitoring system in the Main Dips Section return airways were low prior to the explosion and there was no evidence of any build up of carbon monoxide due to a spontaneous heating.

4.2 Electrical Apparatus and Cables

4.2.1 Apparatus

A comprehensive examination of all electrical apparatus underground was carried out by Electrical Inspector of Coal Mines Mr A. McMaster with the assistance of Senior Inspector Electrical Testing Mr T.G. Hislop (SIMTARS).

The underground telephone system voltage and currents were tested and found to be within the required values. The high voltage protection system was also found to be satisfactory. An in-situ examination was made of the substation and the fault protection system was later checked at the surface, together with the faces of doors and other fittings. No faults were found. The remote control for the belt conveyor was removed for subsequent intrinsic safety testing at SIMTARS and was found to be operating safely. All electrical enclosures in the section were carefully examined to check on the gap at the flameproof flange and for any signs of any internal ignition within the enclosure. For each enclosure the gap was well below the maximum allowed in the relevant Australian Standard.
The two telephone sets had been incinerated and destroyed by the explosion.

Assumption
no supporting evidence

The lights and fittings at the crib room were found damaged. It is believed that they were damaged by the blast wave of the explosion.

4.2.2 Other Electrical Equipment

A digital watch was recovered and examined at SIMTARS and found to be in operating condition. The interior of a digital watch was recovered during the subsequent cleaning of a shuttle car and also tested at SIMTARS. With a similar watch no ignition occurred in a hydrogen/air atmosphere with either a series spark circuit or a direct short circuit.

Two fully-charged cap lamp batteries were also tested at SIMTARS with the No.3 Break Flash and the German Break Flash apparatus. Two types of tests were done, one with the lamp filament on and the other with a short circuit test across the test apparatus contact points.

The gases used in the tests were methane, propane, ethylene and hydrogen. No ignition occurred even with hydrogen. One cap lamp, considered as a possible ignition source due to a snapped battery cable, was examined carefully for any evidence of arcing during the process of snapping. The bulb filament load is itself non-incendive and tests showed that the battery had retained its charge. Furthermore, no short circuit was detected in any electrical testing of the cable.

The automatic firedamp detector on receipt at SIMTARS was completely discharged. Short circuit tests were carried out on the battery and failed to achieve an ignition in the break flash apparatus, even with hydrogen.

The belt slip controller was also tested at SIMTARS with hydrogen gas without any ignition.

The mine rover reversing light was tested for dimensional measurements at the Workshop of the Drilling Sub-Program and found to be within the tolerances for flameproof construction. Further testing at the Queensland University Experimental Mine at Indooroopilly failed to cause an ignition with propane gas.

4.3 Electro-Static Discharge

4.3.1 Hoses

The hose associated with the trickle stone duster was considered as a source of ignition.

A sample of new air hose from the same manufacturer was tested at SIMTARS. The resistance measurement of the test sample gave a value in the range 10^{11} ohms which was far outside the range of 30 x 10^3 to 10^6 ohms as was required by Australian Standard AS2660.

Rudnick The stone duster was not in use at the time of the accident and the hose was on the floor and may have been coated with a thin film of dust. It was considered that an electrostatic charge would not occur during any air movement caused by the fall in the goaf.

(Golledge/Roberts)

With this type of resistance level, decay time order 1 sec. - sufficiently long to [illegible]
electrostatic charge does not occur, will form in air velocity ≥5 m s⁻¹. [illegible] p 3.3
Water/moisture reduces resistance by 2 orders of [illegible]

4.3.2 Brattice

No details given on measurements.

A sample of the brattice similar to that used underground at the mine was tested at SIMTARS to determine whether the surface resistance value was within acceptable limits. At that time instruments were not available at SIMTARS to measure directly the anti-static properties. The resistance measured was within the acceptable range and it was concluded that an electrostatic charge was unlikely. In the conditions which would have prevailed underground, that is, increased moisture in the atmosphere, it was concluded that any charge would have dissipated more rapidly.

4.3.3 Piezzo Electric Sparking

Although not considered as a potential ignition source during the Moura Inquiry, subsequent investigations overseas have shown that this mechanism of ignition has been the subject of scientific study in a number of mining research facilities.

Experiments conducted under simulated mining conditions have failed to demonstrate that an incendive spark can be produced by piezzo electric sparking.

4.3.4 Other Equipment as Electro Static Discharge Sources

There was no evidence either from mine records or that tendered to the Moura Inquiry that electrostatic sparking had occurred from any other potential source underground at Moura.

4.4 Mechanical Equipment

Mr A. Hepburn, Principal Mechanical Inspector of Coal Mines, accompanied by Mr T. Faber, Mine Mechanical Engineer carried out extensive tests on the mechanical equipment which could have provided an ignition source.

4.4.1 Joy Continuous Miner (JCM-12CM3-BVW)

An underground inspection was first carried out and nothing was found to indicate any problem. The machine was later removed to the mine surface where further examinations were made. A series of tests confirmed no indication of either localised heating or any source of ignition.

4.4.2 Joy Shuttle Cars (15SC/48/MCHPVW, Nos.31 and 30)

Initial inspection of both s/c was carried out underground by Mr M. Bell, Mechanical Inspector of Coal Mines and Mr Faber, as above. Both vehicles were removed to the surface for further examination. Although there was some minor damage, there was no evidence of any mechanical deficiency likely to contribute to sparking or ignition.

It was noted in Mr Hepburn's report that the usual practice was for s/c No.31 to be parked in 26 c/t between the belt road and the supply road, where the power supply cable was anchored.

4.4.3 Main Dips Belt Conveyor

Mr Bell, accompanied by Mr Faber and Mr R. Curran (Photographer) inspected the belt conveyor underground and at a later time on the surface with other professional and technical assistance.

The conveyor was inspected throughout its approximate length of 550m with the exception of the section buried in fly ash between 25 c/t and 24 c/t.

There was no evidence of any heating or sign of frictional sparking.

The grizzly screen off the boot end which has a mass of approximately 0.2 t was displaced some 5m inbye.

The tail end of the conveyor was displaced inbye some 750mm outbye on the right-hand side and some 500mm outbye on the left-hand side, as viewed from behind the drum.

4.4.4 No.9 Mine Rover

Accompanied by Mr T. Faber, Mr Bell and Mr Curran inspected and photographed the mine rover underground. It was observed that the driver's backrest and left-hand passengers backrest were badly damaged and that the foam fillings showed no evidence of fire.

No evidence was found to indicate that the engine was running or that the vehicle was other than parked normally at the time of the explosion.

As stated earlier a rear light and the alternator were examined and tested at SIMTARS and found to be safe and satisfactory.

There was no evidence to suggest that the vehicle had contributed to the explosion.

4.4.5 Miscellaneous Mechanical Equipment

Pneumatic chain saws were examined as part of the mechanical investigations and were found to be in a satisfactory condition. There was no evidence of any malfunction of the surface air compressors nor of any abnormal heating from their operation.

Some of the air hoses in use at Moura were not fire resistant and antistatic, however no evidence was discovered that indicated an explosion initiating from an electro-static spark.

4.5 Aluminium Entonox Cylinder

(Golledge/Roberts)

Parts of the Entonox bottle were retrieved from underground and initially examined on the surface and then removed to Rockhampton for further, more detailed scrutiny and investigation.

The cylinder and regulator assembly were microscopically examined by Dr I. Smith, then Assistant Professor in the Queensland University Department of Mining and Metallurgical Engineering. An examination of the fracture at the neck of the bottle suggested that a bending overload was responsible for the failure. The opinion was given that the level of impact loading required to fracture the brass fitting would be substantially higher than that expected from a fall of about 1.5m on to a coal surface. The only component of the regulator assembly and the bottle which showed the effects of exposure to high temperature was the polymeric handle on the regulator which was charred. The paint on the bottle was relatively unaffected. An examination of the microstructure of the brass fitting showed no sign of exposure to elevated temperature since processing. There were no signs of exposure to high temperature in the alloy from which the bottle was made. Dr Smith concluded that the bottle was damaged by flying debris in the explosion, with no evidence of the bottle having exploded or having been exposed to high temperature for a significant period of time.

Further tests and experiments were carried out at Capricornia Institute of Advanced Education with the assistance of CIG (manufacturers of the Entonox bottle). These tests were carried out to try and assess the possibility that the Entonox valve was broken by being knocked whilst being carried by a miner. The conclusions from the tests and experiments were that the damage to the Entonox bottle assembly was not caused by a miner striking it against a solid item; the damage to the assembly was consistent with a blow from a heavy object, travelling at high speed, which struck the corner of the carrier furthest from the regulator while the Entonox assembly was stationary. In the absence of any other explanation, the damage to the Entonox assembly occurred as a result of the explosion with no evidence that 'rocketing' of the bottle initiated the explosion.

The matter of a possible ignition by the discharge of the contents of the Entonox bottle was considered by Dr A.F. Roberts, at that time Director of the Health and Safety Executive Flame Laboratory at Buxton, UK. Dr Roberts expressed the opinion that the combustion of coal dust by combustion of the O_2/N_2O mixture, assuming it was 100% O_2 would only have filled the cross-section of the c/t for a distance of about 2m. The pressure rise from this combustion, estimated to be about 10 kPa would be insufficient to cause a coal dust explosion.

4.6 Frictional Ignition

Although there is almost an intuitive belief that frictional sparks can ignite methane/air mixtures, laboratory research over 100 years has demonstrated that ignition can only be achieved under conditions which one would not expect with a goaf roof fall.

Mallard, Le Chatelier and Chesneau [8] were unable to ignite firedamp by the sparks obtained by pressing a steel bar on a rotating emery wheel. Edwards [9] and Stirling and Cadman [10] showed that if the wheel was made of sandstone then an ignition of firedamp could occur. However, ignition was not caused by the sparks but by the bright yellow flash which occurred at the point of impact as were shown by Burgess and Wheeler [11]. Subsequent work by Blickensderfer [12], and others up to the time of the Moura explosion and since have confirmed the earlier conclusion of Burgess and Wheeler.

All investigators have found that even for the most incendive rocks tested, it was necessary to hold the specimen against the rotating wheel at a constant force for a number of revolutions before an ignition would occur. In practical terms this meant that one piece of rock was stationary while the other was rubbing against it at a constant velocity over the same rock surface and with a constant force for some distance and for a time period varying from less than one second to many seconds before ignition occurred. The combination of circumstances for a frictional ignition, if they exist must occur very infrequently otherwise explosions from this cause would be relatively common.

It is known from research work currently underway at SIMTARS that even with hydrogen gas ignition by single impact of rock against rock can only be achieved under certain conditions. The combination of gas concentration, specimen orientation and velocity must be within a narrow range for an ignition to occur even with hydrogen. In spite of many repeated attempts it has not been possible to ignite any concentration of methane/air under similar experimental conditions.

In experiments at Buxton to investigate the influence of surface area on the ignition temperature of methane Rae et al [13] showed that a temperature of over 1100°C was needed for a heating source 400m² in area in a 7% methane/air mixture but the temperature had to be increased to 1600°C to ignite an area of 6.25mm.

Sparks from frictional heating of rocks are passive in relation to oxygen in that they do not enter into a chemical reaction. Typical examples of such particles are those from sandstones and other quartzitic type rocks which are themselves oxides. It is known that the temperature of sparks from such rocks is limited by the plasticisation temperature of quartz, that is, about 1200°C. The ignition capacity of these particles depends on the temperature and size of the exposed rock surface and on the particle concentration in the area of contact.

Some other particles such as steel, pyrites, aluminium and magnesium are active in the presence of oxygen in that they are exothermic and therefore provide additional energy and ignition capacity. At the one end of the scale particles of steel burning in air may attain temperatures of 1700°C and particles from aluminium and magnesium alloys 3700°C, as quoted by Rae [14].

Experiments at Experimental Mine Barbara in Poland reported by Lobejko [15] with high speed film showed that an ignition of methane/air from friction experiments with a cutter head against sandstone was caused by the concentration of incandescent particles attached to the rubbing surfaces.

Two hypotheses are examined for the circumstances at Moura No.4 Mine regarding an ignition caused by friction. Firstly it is assumed that ignition occurred through frictional contact between rocks during falling. One rock is assumed to be at an angle on the floor and is hit by another piece of rock which falls afterwards through a total height of approximately 7m. For an ignition to occur in a time of just over 1.2 secs a sufficient area of rock must be heated to over 1000°C or alternatively a sufficient density of rock particle sparks at about 1200°C must be produced to act as an ignition source. The methane concentration in the vicinity must be within the explosive range and must be stationary or at very low velocity.

With fragmentation characteristics during caving it seems unlikely that one fixed and one moving piece of rock could remain in contact whilst falling under the conditions necessary for a frictional ignition to occur.

The second hypothesis assumes that ignition occurs at the point of impact when the falling rock hits a piece of rock already on the floor in the goaf area. In this scenario the temperature conditions from either a heated part of the rock or a cloud of sparks would need to be achieved in something less than 100ms. The inability to achieve this with grinding wheel experiments with methane air mixtures suggests that this scenario is highly improbable.

If the ignition were to be caused by friction between steel and rock, again it is necessary to create a cloud of hot particles of sufficiently and possibly a hot area of rock or metal that would provide an ignition source. At roof elevation the velocity of rock movement is nearly zero and could not be expected to provide either a significant hot spot on the contact surface or a dense cloud of sparks. Were contact to occur during falling the production of sparks is dependent upon maintaining frictional contact.

It is known from grinding wheel experiments that frictional contact between the fixed specimen and the rotating wheel causes fusion of the quartz particles, or the intergranular materials in the rock and it is the hot spot produced by this fused area that acts as the ignition source. In all experiments referred to in the research literature the grinding wheel has rotated for some revolutions in order to cause the fused surface. In reality the same moving rock surface is being contacted repeatedly by the fixed specimen. Such a set of circumstances would be difficult to visualise during a goaf fall in a coal mine.

Nagy and Kawenski [16] examined, amongst other things, the potential of frictional ignition by impact. No ignitions were produced in 533 drop tests with a weight falling onto an inclined specimen, although visible sparks generally were observed at the instant of contact. Material for the falling mass included roof bolts and pieces of sandstone, while the inclined surface was sandstone, a roof bolt and shale. A 7% methane/air mixture was used for these experiments. Pulverised coal dust and sand, or both were sprinkled on the surface in some of the tests.

The scenario that the ignition at Moura was caused by frictional ignition therefore relies on some critical temperature conditions either from a hot spot or sparks as a source of the ignition. Such conditions are difficult to produce under controlled laboratory conditions where critical factors can be optimised. It seems therefore that an ignition due to frictional causes, while remaining possible, must be considered to be highly improbable.

As a result of the Moura No.4 mine explosion records of explosion inquiry reports have been searched and the result of that is appended below in respect of explosions where friction by rock/rock or rock/steel was deemed to have been the ignition source.

The reports emanated from mine explosion investigations in Canada, South Wales and the USA.

Before discussing those earlier records it is necessary to place the matter in context by referring to the Moura No.4 Explosion Inquiry.

The members of that Inquiry considered eleven possible ignition sources but eliminated all except two - namely frictional ignition and the flame safety lamp. The Inquiry report states [1]

(a) "The members of the Inquiry are of the view that frictional ignition from sandstone on sandstone of the type found at Moura is highly unlikely to have been the source of ignition and,

(b) "The evidence of tests undertaken by Mr Poppitt reinforces the view that sandstone striking steel is unlikely to have been the source of ignition."

Mr Poppitt was employed as Geologist-Underground Operations at Moura. Along with two chemists Messrs Lyons and Kelly he conducted tests at the Mining Company's Laboratory at Gladstone. His report of 11 February 1987 describes test work on "Frictional Ignition of Methane with Sandstone Samples from Moura No.4 Mine Main Dips Section". The test work was carried out on 10 February 1987. The sandstone for the test work was obtained from "Roof from 7m fall one pillar inbye fender" at the extraction taking place immediately prior to the time of the explosion.

The aim of the work was to test empirically if any of the samples were capable of igniting methane in air (with varying proportions) under frictional load. The work was conducted with a bench grinder with sandstone wheels (cut from a Moura drillcore). The gas stream of metered methane/air was applied. The dilution factor was unknown but when lit with a match the mix burned readily with a lean blue flame.

Mr Poppitt in his report states the results of the testwork as follows:

Sandstone/Sandstone Contact

Ignition of the methane/air mixture was readily achieved with sandstone/sandstone contact.

Twelve (12) tests were done with sandstone/sandstone, and in each test ignition was rapidly reached.

Mean time for ignition was 2.5 seconds, with a range from 1.5 to 5 seconds.

The mechanism for ignition of methane/air was NOT sparking, as was observed for propane/air mixtures. Rather, the 1-2mm wide point of contact around the edge of the sandstone wheel became heated very quickly, and reached ignition temperature within 1-5 seconds.

Observation within the 1st second showed the contact area on the edge of the wheel to become heated to a bright orange, and within the next second to white heat. At that point, ignition could occur.

<u>Sandstone/Other Materials Contact</u>

No ignition was achieved with steel on sandstone, or pyrites on sandstone.

Both of these materials, although producing showers of dull red sparks, were too soft to heat the sandstone to ignition temperature. The steel butterfly plate, roofbolt washer and roofbolt simply wore away too quickly to produce the heat required.

Whether the results of such testwork with a grinding wheel can be related to a situation of impact resulting from, say, a fall of roof in a goaf, is questionable - to say the least.

During cross-examination at the Inquiry (Transcript Page 876) Mr Poppitt was questioned about "rubbing friction created over large surface areas". He was asked "... but we can't, at this stage - would you agree - discount the possibility of that being the source of ignition in this case."

Mr Poppitt's reply - "No, I don't believe I've discounted it. I think it's highly improbable, but I've just not discounted it".

There are records of coal mine explosions resulting from both rock/rock impact and rock/steel impact in other Countries - notably Canada and Wales.

Canada - In their paper Stirling and Cadman [10] the authors referred to the Bellevue explosions in Alberta in 1910 and 1911 and also made reference to the Maindy Pit in Wales in 1896.

The following facts are taken from the above Institution of Mining Engineers Transactions to briefly describe three Bellevue Explosions:

> *<u>No.1</u> - An explosion of some violence occurred on the morning of Monday October 31, 1910. There were no persons in the mine because it was a holiday. Work belowground had been suspended at midnight on the previous Saturday and no-one had been in the mine since that time. The fan had been stopped for 9 hours - 7.30am to 4.30pm on the Sunday. The mine was explored and a large roof fall discovered. Evidence collected at the time indicated that the fall was the point of origin of the explosion. The Inspector of Mines "boldly" attributed the occurrence to an ignition caused by sparks from the falling roof*

but others "were not inclined to accept the theory on such indirect evidence".

No.2 - Occurred December 9, 1910 - approximately six weeks later. Thirty miners were killed and public inquiry held. The authors stated "There is no doubt that the explosion was caused by an ignition of fire-damp ignited by sparks emitted from the falling roof.

No.3 - After No.2 explosion there was a general strike throughout the district and the Bellevue Mine was not re-opened. In January 1911 another explosion occurred. The exact date is not known as the explosion was not observed at the time of the occurrence.

On January 25, 1911 (prior to this No.3 explosion) an official inspection was made of part of the workings. A new manager was appointed on January 28, and the effects of this explosion were observed a few days later. The fan had not been operating since shortly after the explosion of December 9, 1910 but was operated from January 13 to 25, 1911 in order to prepare for the Government inspection. It was stopped again after the explosion.

That this third explosion had occurred was discovered on January 30. Subsequent investigation revealed that the explosion had originated at a point where a heavy roof fall had occurred. The mine remained untouched for some months due to the strike and the authors made an examination in August 1911.

An experiment was conducted in the mine with a piece of the hard siliceous roof material weighing some 60 or 70 pounds. This rock was dropped into the "shoot" on the floor of which lay some of the fallen roof. As the piece of rock rolled down the shoot a "brilliant display of sparks" was observed.

The roof rock was microscopically examined and found to contain about 50% quartz.

Experiments were conducted in which the rock was attached to a spindle revolving at 200 to 300 rpm. By allowing another piece of the rock to contact the revolving piece" sparks of sufficient intensity could be produced to ignite coal-gas and methane".

The account of the explosions and investigation includes the following:

It is clear, however, that sparks of sufficient intensity can be produced by rubbing together pieces of the roof of No.1 Seam to ignite methane, which has an ignition-temperature - according to Dixon and Coward - of from 556 to 700° Cent., and as other hydrocarbons have been shown to be present, the temperature of ignition will be less, and an explosive mixture will be more readily ignited.

The writers are satisfied, however, that they have established the fact *that sparks can be produced by falls of roof in the No.1 Bellevue Seam sufficient to bring about the ignition of inflammable gas; and as subsequent examinations after each explosion shown that falls did occur, in which large masses of the roof fell, in areas where gas was in all probability present, it seems perfectly clear that the cause of three explosions at Bellevue has been satisfactorily explained.*

South Wales - In his report on the Six Bells Colliery explosion in 1960 H.M. Chief Inspector of Mines and Quarries states as follows:

> *"No one can say with certainty where or by what means the explosion at Six Bells Colliery started. But after careful consideration* *__I think that__:*
>
> (1) *The explosion started as an ignition of fire damp in the roadhead roof ripping of 0.10 intake.*
>
> (3) *The cause of ignition was frictional heat produced by the impact of a piece of quartzitic rock falling for a distance of about six feet from roof exposed by shotfiring, onto a steel girder ....".*

The Report describes the thorough investigation of this disaster. The results of the investigation enabled the discounting of safety lamps, and the electrical and mechanical plant as possible causes of ignition. This meant that the known possible causes remaining for consideration were contraband, shotfiring and frictional sparking.

Evidence enabled the Chief Inspector to rule out contraband and in the case of shotfiring he stated *"I do not think it at all probable"*. His statement that he thought the ignition was caused by the impact of rock on steel resulted from a process of elimination of other known possible causes.

The following is extracted from that part of the above Report which discusses frictional ignition.

> 75. *The S.M.R.E. has also examined the possibility of ignition of firedamp by friction between rock and rock. The results of tests by Burgess and Wheeler were reported on in 1928[3]. Other tests of this kind have been made recently and reported on in S.M.R.E. Annual Report for 1959[4]. The apparatus used consists of a rock 'slider' which is pressed with known force against the periphery of a rotating rock wheel in an explosive atmosphere; the pressure between the surfaces is measured and the time between the application of the load and any ignition of firedamp is taken. Ignition has been obtained with quartzitic rock. The greater the speed of the wheel and the longer the duration of the friction, the more likely it is to occur.*
>
> 76. *From the experiments it is deduced that, to produce an*

incendive condition, a suitable rock would first have to fall a distance sufficient to gain the necessary speed and then slide some distance on another rock; the shorter the fall of the rock, the longer would have to be the slide.

77. *I have carefully examined the available records of ignitions believed to be due either to the impact of rock on rock or of rock on steel; the latter must, in the nature of things, include the possibility that the incendive impact may have been between rocks. The subject is of such importance that I have summarised the records in Appendix III. Four of the explosions referred to occurred in Canada. So far as this country is concerned, six of the seven instances mentioned were in South Wales. Sir Henry Walker, then Chief Inspector of Mines, in his report on the Marine Colliery disaster in 1927 [5], considered that the explosion may have been due to a stone falling on stone. He cited as supporting evidence for this view possible similar incidents which had occurred between 1896 and 1927 at Maindy, Ferndale and Lletty Shenkin Collieries. In more recent years, other incidents have occurred at Cwm Colliery in 1949 [6] and at Lewis Merthyr Colliery in 1956 [7].*

78. *It seems clear that, if quartzitic rock falls and strikes either a steel object or possibly pieces of similar rock with sufficient impact, an incendive condition may result. Hartwell suggested that the impact of the mechanised pick used in the experiments he described would have been about equivalent to that of rock weighing 260lbs. falling for a distance of three and a half feet onto a steel object. He thought that the most probably cause of the explosion was that there was a fall of rock bringing down with it firedamp that had accumulated at the ripping and that one of the larger pieces of rock struck the canopy in such a way as to produce an incendive condition and so cause inflammation of the surrounding atmosphere. Pieces of quartzitic rock, the largest being estimated to weigh about 240 lbs. were, in fact, found on the ground and on the canopy under 0.10 intake ripping (Plate I). Some of it could have fallen a distance of six feet.*

79. *The mechanics of firedamp being brought down from near the roof by falling stone and then mixing with air have been demonstrated with perspex models, made at the Buxton Station of the S.M.R.E., of the roadheads at which the explosions occurred at Lewis Merthyr Colliery and at Sutton Colliery in 1957[8]. I commend to all mining engineers the film which has been made to illustrate these demonstrations.*

80. *The evidence was not completely satisfying, but I incline to the view that firedamp was brought down by a fall of roof and was ignited by frictional heat at the point of impact between a quartzitic stone and the steel girder forming the top of one side of the canopy. I refer later to methods of minimising the*

risks associated with falls of hard rock from a high cavity and from near the face of high rippings.

81. *If a fall of stone of a not uncommon nature for a distance of six feet or so may be dangerous, the question immediately raised is the degree or risk involved in the routine collapse of roof in wastes. There is, however, no recorded experience of ignition of firedamp from this cause in longwall wastes in this country. This may well be because, for ignition to occur, there must be the remote coincidence of a number of conditions including the fall of a certain kind of rock, the right type and strength of impact and the presence at or about the point of impact of a firedamp-air mixture within a relatively narrow range.*

South Wales - An explosion occurred at Lewis Merthyr Colliery in 1956 and a report was prepared by H.M. Divisional Inspector of Mines [18].

The explosion occurred at the centre road on a double unit longwall advancing face and immediately behind the coal face. All machinery in this district was operated by compressed air. No electrical power was installed. The following is extracted from the Divisional Inspector's Report -

III - EVENTS PRIOR TO THE EXPLOSION

On the night of 8/9th November, 1956, an extensive fall of roof occurred in the roadhead of the centre road from the inbye permanent support practically to the face of the roadhead, a length of some 16 feet. One steel arch was left standing between the inbye end of the fall and the coal face. The cavity was the full width of the roadway and exposed the Three Coals seam some 24 feet above. For some time earlier a small fault had been working down the left hand face towards this road. At the time of the fall this fault was less than ten yards from the left hand side of the road. There was no evidence of this fault in the cavity, 'but it was obvious that the thick bed of clift above the seam had changed to become weaker than normal and lacking in it usual cohesion. The fall was cleared and 14-feet steel arches were erected beneath the cavity. These arches were covered with wood lagging which in turn was covered with a "cushion" of rubbish some four feet thick, the top of which would thus be some eight feet from the top of the cavity. The roof and sides of the cavity above this packing were not supported in any way. The production of coal was resumed on Monday, 12th November, 1956.

Work proceeded without untoward incident until the night of 19/20th November, 1956, when a second fall occurred at the roadhead. This was an extension of the earlier fall. The cavity now extended to the coal head and was some 30 feet long and 30 feet high. It had also widened to about 30 feet exposing a slicken-sided slant some ten feet to the left of the fault previously mentioned, which was now crossing *the middle of the centre road. There had been no earlier indication of the presence of this slant. This second fall made coal production impossible and this situation was unchanged on 21st November. By the afternoon shift of this day, the fall had been cleared and the erection of steel arches beneath the cavity was begun. This work was being carried on by the night shift when, at about 3.00 a.m. on 22nd November, four of the six newly erected steel arches were displaced by a stone weighing about three tons which fell from the cavity. The colliery manager, accompanied by the morning shift overman, arrived at the scene at about 5.30 a.m. He decided to erect an "umbrella" of ten-feet arches covered by wood lagging beneath which the gate conveyor could run. These ten-feet arches could be erected without disturbing the 14-feet arches displaced by the fall. The stone which had fallen was broken up by means of a pneumatic pick and the work of erecting the steel arches begun. By this time the men employed on the morning shift had begun to reach the meeting station at the junction of the left hand supply road with the intake airway. A few of these men were brought forward to assist with the work and the remainder told to stay at the meeting station until they received further instructions.*

IV - NARRATIVE OF THE EXPLOSION

By about 7.15am three of the ten-feet arches had been erected. Fourteen persons were variously engaged in the work. Two workmen were standing on a staging, tightening the fishplate bolts, and four others were holding the legs of the arches. The night shift deputy had gone back in the road some 30 yards to a point where a repairer was preparing wood struts for use between the arches. The others were standing, prepared to cover the arches with wood lagging, when a further fall occurred from the cavity. The fall was of some two tons of stone, most of it in one piece. Almost coincident with the fall there was a flame. One of the workmen on the staging stated in evidence that he heard the fall and jumped from the staging. As he jumped he saw the flame. The deputy heard the fall and looked inbye. He stated that fall and flame were simultaneous.

All the persons present were enveloped in flames and suffered severe burns. Two died from their burns at the scene and seven others died later in hospital.

The men at the meeting station noticed a "puff" of wind and a cloud of dust. A collier who had passed into the left hand face returned to say that he had seen flame in the centre road. The work of rescue was quickly organised. The first aid and rescue work will be dealt with in a later section of this report.

V - THE CAUSE OF THE EXPLOSION

The Nature of the Explosion

From all the evidence it was obvious that an explosion of firedamp had occurred in and beneath the cavity. Flame had been projected some 70 yards outbye along the centre road, for about 15 yards along the left hand face and 25 yards along the right hand face. The severe nature of the burn injuries sustained by many of the casualties suggested that flame had persisted for an appreciable time in the vicinity of the cavity. There was no sign of violence and no indication that coal dust had played any part in the explosion.

The Source of the Firedamp

Tests made during the investigation showed an explosive mixture of firedamp and air nine feet down from the top of the cavity; the methane content at the top exceeded 80 per cent. The normal emission of firedamp from the seam, probably augmented by emission from the Three Coals Seam exposed by the fall, would naturally produce these conditions in an unventilated cavity such as this and it can safely be assumed that similar conditions obtained immediately before the explosion, although the presence of inflammable gas in the cavity had not been detected.

Immediately after the fall on 20th November the under-manager and the deputy climbed up on the debris, examined to the top of the cavity and found it clear. At this time the heap of fallen debris was, of course, deflecting at least part of the air current into the cavity. As the fall was cleared the top of the cavity became increasingly inaccessible both to the air current and for examination. No steps were taken to direct an air current to the upper part of it or to enable examinations to be made there. When the fall was finally cleared the cavity was entirely unventilated and could not be examined as no means of access had been provided. About two hours before the explosion, the night shift deputy stood on the tops of the steel arches and tested for gas at the highest point he could reach, but this was about 15 feet above the floor and 18 feet from the top of the cavity.

The Igniting Medium

All possible means of ignition were carefully investigated and considered.

The electric and flame safety lamps which were in the district at the time of the explosion were sent, in the condition in which they were brought out of the mine, for examination and testing at the Safety in Mines Research Establishment. None of the flame lamps exhibited any defect likely to constitute a hazard. All the electric lamps showed signs of heating and in three cases the heat had been so intense that the cable sheathing and the core insulation had been burned away so as to expose the bare conductors. This damage had obviously been caused by the flame of the explosion. Only one of these electric lamps showed signs of damage other than that caused by heat. In this case the headpiece had been broken so as to expose the main and pilot bulbs, both of which were broken. The filament of the pilot bulb was intact and was bright and clean, showing that it had not been heated in air. The whole of the coiled centre portion of the filament of the main bulb was missing, only small portions of the straight part of the filament remaining attached to the filament supports, which had been bent over sideways to an almost horizontal position. The filament supports were nearly touching, but there were no signs of arcing when examined under a microscope. Microscopic examination also showed that the filament ends, where broken, were angular rather than rounded, suggesting breakage and not fusion. The only occurrence at or about the time of the explosion which might have caused this damage was the fall, and investigation revealed that the person using this lamp was standing at least five yards outbye from the point where the stone fell. The damage could easily have been caused in the confusion following the explosion.

On this evidence it was concluded that none of the safety lamps was the igniting medium.

After the explosion, the compressed air hose from a manifold on the centre road to the turbine of the right hand face conveyor was found to be leaking badly from a hole. There was also a slight leak of compressed air from a joint in the two-inch pipe range laid along the floor. These items of equipment were cut out and sent to the Safety in Mines Research Establishment for examination. In both cases the damage was found to be post explosion, and they were dismissed as possible means of ignition.

A compressed air lamp was found lying in the roadside some 30 yards outbye the cavity. This lamp had been used at the face conveyor transfer point during coaling operations, but there was conclusive evidence that it had not been in use since the second fall occurred.

Except for two mining type telephones, electricity was not used in the district. These telephones were found to comply fully with their certification specification and standard of safety when tested at the Safety in Mines Research Establishment. Later evidence disclosed that these telephones had not been in circuit for some days before the explosion.

Nothing was found in the investigation to suggest that the use of any article of contraband was responsible for the explosion.

The only possible source of frictional heating lay in the belt conveyors. There was definite evidence that none of the conveyors had run during the shift.

It will be recalled that the statements of survivors left no doubt that the explosion was coincident with the fall of roof. This led to a careful investigation of the possibility of incendive sparks having been produced by the fall. The stone which fell was estimated to weigh nearly two tons and was composed of hard clift containing ironstone. The only ground of this nature was near the top of the cavity. The stone had therefore fallen fully 20 feet before reaching the arches.

Samples of the stone which fell were sent to the Safety in Mines Research Establishment and were subjected to a variety of tests. These tests did not produce a conclusive result but, after consideration of all the factors involved, including an appreciation of ignitions previously obtained experimentally using similar stones, the opinion was formed that incendive sparks could have been produced by the impact of a piece of the hard clift from the top of the cavity on one of the steel arches about 20 feet below. Although no trace of inflammable gas was found before or after the explosion at the horizon where the stone struck the arches, tests carried out at the Safety in Mines Research Establishment showed that, under certain conditions, an object falling from near the top of a cavity containing a high concentration of methane could bring down enough methane to produce an explosive mixture at the base of the cavity.

Careful consideration of all the available evidence has led me to form the following conclusions:

1. *After the fall had been cleared and while the steel arches were being erected, the upper part of the cavity contained a high concentration of methane.*

2. *The stone falling from near the top of the cavity brought down enough methane to produce an explosive mixture at the horizon of the steel arches.*

3. *The impact of the stone striking the steel arches produced an incendive spark which ignited the explosive mixture, whereupon flame spread to the extent described earlier in this report and persisted until all the methane had been consumed.*

South Wales - There is a number of other reports on explosions which are believed to have resulted from ignition of gas by a roof fall. They include Maindy Colliery 1896; Ferndale Colliery 1907; Lletty Shenkin Colliery 1913, Marine Colliery 1927 and Cwm Colliery 1949. No purpose would be served here in attempting to precis all or any of these. Suffice it to say that there is substantial evidence to support the conclusion in a number of cases that ignition was caused by impact between rocks or between rock and steel. In some cases that evidence has been given by eye witnesses who survived the explosion.

Research in the USA - the Bureau of Mines published in 1960 a report by Nagy and Kawenski [16].

The report describes work carried out on rubbing friction, impact friction, roof bolt broken in tension and on a bolthead pulled through a washer and roof plate. The research was conducted following a mine explosion in 1958.

The following extracts are of interest -

"The explosion, which killed two men, occurred in April 1958. Gas

was ignited during an induced roof fall in a section where electric circuits had been deenergised and face equipment had been removed. The gas had accumulated because ventilation had been disrupted in the area. Miners 50 to 75 feet from the fall reported seeing sparks and a flash of fire in the vicinity of the falling roof just before the explosion. The witnesses stated that during previous falls streaks of fire had been seen, and sparks had been observed when the roof bolts ruptured.

Limited experiments in the laboratory with specimens of mine rock from a Virginia bituminous coal mine indicate that natural gas-air mixtures can be ignited by sparks generated by rubbing friction of sandstone against sandstone, shale against sandstone, sandstone against (roof-bolt) steel, and shale against steel. Such sparks, generated during a roof fall, may have initiated a recent gas explosion in this Virginia mine, although this cannot be stated with certainty.

No ignitions of gas were produced by sparks or heat generated by impact friction between mine rocks or steel, during tension breaks of roof bolts, or by pull tests of roof bolts through their washers and roof plate. However, this negative result of limited experiments does not preclude the possibility of gas being ignited by these conditions.

In limited experiments performed gas was ignited by friction sparks between mine rocks and between mine rocks and roof-bolt steel.

Of the materials studied, incendive frictional sparks were formed at the lowest speed and smallest load with sandstone-sandstone contact. Gas ignitions were produced readily with shale rubbing on a sandstone wheel and less readily with sandstone or shale rubbing on a roof-bolt wheel. The lowest peripheral speed of the rotating wheel for ignition would be equivalent to a free fall of 2.2 feet - a distance readily obtained in the Virginia coal mine. In our tests a 7 percent gas-air mixture was more readily ignited by frictional sparks than an 8 or 9 percent mixture. The incendivity of the sparks increased with the load and the speed of the wheel. Although ignitions occurred within 1 second of the time of contact of the surfaces, more often they occurred in 10 to 30 seconds. The presence of visible sparks cannot be taken as a criterion of incendivity, as visible sparks occurred whether ignition resulted or not.

Ignitions were not obtained by impact friction, by roof bolts broken in tension, or by roof boltheads pulled through a washer on the roof plate. Sparks generally were visible in the drop trials but not in the pull experiments. These tests cannot be considered as conclusive evidence that such sources may not cause ignitions under some circumstances. The energy expended by falling masses of rock and the rate of tensile loads applied on roof bolts during a mine roof fall could far exceed those studied in the laboratory.

Because incendive sparks can be produced so readily and with so little expenditure of energy, it is virtually impossible to eliminate them in *coal mining. Gas ignitions by this source must be prevented by other measures. One of the most effective measures is adequate ventilation to prevent an accumulation of gas."*

Discussion

The preceding paragraph extracted from the Nagy/Kawenski report is most relevant to this project. It must be accepted that ignition from friction cannot be eliminated in the case of the Moura No.4 Mine explosion. It follows then that the atmosphere in which such an ignition might occur must be rendered inert. In many situations it is not practical to deal with an explosive atmosphere by normal ventilation - namely the provision of fresh air. This is clearly the case where spontaneous combustion can occur in a goaf.

In Britain nitrogen is used to reduce the risk of spontaneous combustion in the goaf of longwall faces. The same treatment can be applied to the prevention of ignition by rock/rock and rock/steel impact in a goaf.

In 1986 the New South Wales Mines Rescue Board investigated "The most recent advances of using liquid nitrogen to combat fires and heatings in coal mines". The investigation was conducted in West Germany, France and Britain. The report of that investigation by Messrs Mackenzie-Wood and Enright of the NSW Mines Rescue Service is comprehensive and makes clear recommendations on the matter of inertisation for every mine in NSW. Specifically the report recommends that high-risk mines should install a dedicated pipe range to the commencement of each district of the mine.

The installation of a nitrogen range at underground coal mines in Queensland represents a practical means of reducing risk from frictional ignition as well as from spontaneous combustion in a goaf. Such an installation would also provide an immediately available facility for dealing with an underground mine fire.

There are problems with the supply of liquid nitrogen to Queensland coal mine sites. In the case of the Moura disaster supply was effected from NSW. Evaporators for the use of liquid nitrogen are not available in Queensland. There are therefore logistical problems to be overcome. It would seem that adequate on-site liquid nitrogen storage is essential.

4.7 Flame Safety Lamp from Moura No.4 Mine

Initial Examination

The flame safety lamp from Moura No.4 mine was examined and disassembled at SIMTARS.

As received the lamp was very dirty externally with loose dust or soot inside the lamp. The upper part of the metal bonnet and part of the metal base near the locking ring had been distorted by the lamp either hitting another object, or having been hit by some other object which would have been travelling at considerable velocity. The distorted base had been subject to some heating since the metal had been discoloured.

The outer surface of the glass cylinder and the outer surface of the bonnet had been coated by a film of dust which had 'fused' to the metal or glass. A similar observation was made about the inner surface of the glass and the inner surface of the bonnet.

The glass was not cracked and the top and bottom faces were parallel within the tolerance limits permitted by the manufacturer. There was no evidence of distortion of the glass by heat. The sealing washers at the top and bottom of the glass cylinder were in position and sealing properly against the glass. The lamp was closed properly and locked. There was no lamp oil left in the reservoir.

There were approximately 5gm of soot particles inside the lamp.

The lamp handle had been stretched beyond its normal curved position.

Examination of Gauzes

The inner and outer gauzes showed no sign of physical damage although closer examination subsequently revealed evidence of exposure to heat. There appeared to be clearance between the inner and outer gauzes when they were assembled in the lamp but when the gauzes were checked outside the lamp it was possible to rotate the gauzes to a position where the gauzes were in contact.

Examination of Bonnet

Samples of the particle deposit on both the inner and outer surface of the bonnet were taken and examined by Mr P. Lynch using the electron microscope at the Queensland Institute of Technology. Electron micrographs and comments by Mr. Lynch are contained in a Memorandum to the Chief Engineer.

On cleaning a strip of the outer surface of the bonnet to expose the metal surface a visual examination was made for discolouration of the metal by heat. No discolouration was observed.

Evidence from electron microscopic examination of the particle deposit on both inner and outer surfaces of the safety lamp shows quite clearly that the particles have been subject to heating consistent with a coal dust explosion.

Research into Flame Safety Lamp Prior to Moura Inquiry

Investigations into the behaviour of an identical flame safety lamp showed that some of the conditions observed in the lamp recovered from the Moura No.4 Mine could be reproduced in the laboratory. In particular it was demonstrated that heating of both inner and outer gauzes would occur as a result of incandescent combustion starting within the inner gauze after the flame had extinguished. This heating was measured with calibrated thermocouples and found to be approximately 1000°C. Further experiments showed that the addition of coal dust particles to the methane passing the lamp would result in

I do not believe that particle could fuse without giving some local heating effect around that particle area.

some particles entering the gauze and burning with a flame which could fill the whole volume of the inner gauze with the bonnet on. Under combined methane/coal dust conditions sufficient heat was produced on the inner surface of the lamp glass to cause 'fusing' of hot dust particles to the surface of the glass.

The experiments referred to above where conducted in an explosion chamber with a closed loop, that is an arrangement where the atmosphere is recirculated by the lamp. No external ignitions were achieved with recirculation of the atmosphere and it is believed that this was due to the build up of CO_2 and the simultaneous reduction of O_2 following combustion activity within the lamp. Air velocities were limited by the apparatus to an upper value of 2.7m/s.

A series of tests were carried out to see if it were possible to cause heating of the gauzes from an external explosion flame. When the lamp was placed in a 3m long explosion chamber it was subjected to the effects of heat from a flame generated by the ignition of a range of methane concentrations up to 10% and with methane/coal dust using the equivalent of 1000g/m³ of coal dust. With optimum mixing of the methane and methane/coal dust, very hot flames were produced. In none of the tests was it possible to heat the outer gauze above 350°C (estimated from charring of paper) and no discolouration of either gauze occurred. In the most severe test there was some slight discolouration of the bonnet but none to either gauze. It was not possible during any of the experiments with an external flame to produce a film of particles fused wither to the glass or bonnet of the lamp.

A series of tests with the flame at the height normally used when carrying the lamp in a mine established that the average flame temperature was 820°C with a standard deviation of 14.6°C.

In a further series of tests the outer gauze and inner glass temperatures were measured with different flame heights. With a flame height of 1cm the outer gauze was 62°C and the inner glass 36°C.

Adherence of coal particles on to the surface of the lamp glass was also measured in a series of laboratory experiments. The lamp glass was heated in a muffle oven until the temperature reached 80°C and quickly removed from the oven and placed on its side 2cm below a Bunsen burner flame. A sample of coal dust from Moura No.4 mine was crushed and sieved to provide a size fraction below 75 micrometre particle diameter. A small amount of this dust was allowed to fall through the Bunsen flame, the temperature of which was measured at 1150°C, and to impinge on the glass surface. Particle adherence was measured by the ease with which it could be removed after cooling to normal temperature. Adherence of particles did not occur until the glass temperature was above 600°C.

Experiments were also made to measure the transfer of heat through the glass from the outside surface to the inside. With a Bunsen flame at 1150°C on the external surface of the glass it took 29 seconds to reach 270°C on the inside and 50 seconds to reach 450°C.

Subsequent to the initial investigations some changes were made to compensate for the lowering of oxygen and increasing CO_2 in the closed loop explosion chamber. Oxygen was allowed to enter the system in such a manner as to keep the O_2 level to the value that would exist in a mine with normal air flow past the lamp. Under such conditions it was shown that the lamp without the bonnet could heat sufficiently to cause an external ignition of a methane/coal dust atmosphere.

Research into Flame Safety Lamp Post Moura Inquiry

With the assistance of a NERDDP support grant the investigation of the flame safety lamp continued at SIMTARS.

A section of duct was constructed with an axial flow fan to provide a range of air velocities up to 6m/s. An inner duct was used to provide a gas concentration past the lamp of up to 10%. The temperature of significant parts of the lamp was measured with four thermocouples and a thermal imaging infra-red camera for general temperature measurement. Air velocity was measured with a calibrated anemometer and the methane concentration sampled with a tube near the lamp and analysed with an infra-red analyser. For experiments involving coal/methane/air mixtures a hopper containing a dust was suspended from an adjustable stand positioned alongside the experimental gallery. Dust from the hopper was injected into the inner duct where it was allowed to mix with the methane airstream.

Signals from each monitoring device were connected to a data acquisition board which was connected to a personal computer. Data acquisition is triggered at the computer keyboard, at the start of each experiment. A commercial software package was used for data acquisition and a program written by SIMTARS staff to analyse the data collected.

An opening in the wall of the outer duct opposite the lamp position allowed viewing of the activity with a video camera, or the infra-red camera, or both.

Without the bonnet on the lamp there is a threshold area of methane concentration and air velocity conditions within which an ignition may or may not occur. Below this threshold area no ignition occurs. Above the threshold level ignition occurs in the lamp under velocity and methane conditions which could easily occur in a mine.

Modifications made recently have resulted in a duct of smaller cross-sectional area which permits the air velocity to be varied up to 17m/s. The only other change has been a minor change in the dust injection system.

Experiments with the bonnet in its normal operating position have confirmed research carried out prior to the Moura inquiry. Heating commences within the inner gauze after the flame has extinguished as long as the air velocity is above a minimum value. The temperature increases as long as the airflow and methane concentrations are maintained. With only methane incandescent combustion occurs within the gauze without any visible flame. As heating continues, the top of the gauze, as seen through the holes in the bonnet, changes colour from dull red to near white, while the temperature increases to over 1000°C on the inner gauze. The presence of coal dust results in a flame within the inner gauze which at times is seen to project into the area of the glass. In some experiments the inner surface of the glass has been heated sufficiently to allow some fusion of heated coal particles to the surface, as occurred in the Moura lamp.

At the time of compilation of this report four external ignitions have been achieved with the bonnet of the lamp in its normal position. Two of these were with methane only and the others with methane and coal dust.

It has been shown experimentally that the flame safety lamp, if it were alight at the time of a methane/coal dust cloud formed as the result of a fall, is capable of providing an ignition source for a coal mine explosion.

Conclusion

A review of the evidence presented to the Warden's Inquiry and available for this project does not enable a decision on whether the impact of rock/rock or rock/steel provided the ignition source for the explosion. It is possible that the goaf fall, as was anticipated, occurred before the explosion. If frictional ignition in the goaf is assumed to have initiated the explosion then it has to be recognised that some blast damage could have resulted from the fall prior to the explosion. (no — pressures too low on values given earlier)

It follows that all of the blast damage which occurred cannot be assumed to have resulted from the explosion. This renders the task of investigation even more complex than would have been the case if all blast damage had resulted from the explosion. That task would be difficult enough given the network of roadways and c/t involved.

There are other alternatives which also cannot be ruled out.

no details have been given and no evidence to demonstrate this has been given to the external consultants (word only)

This is totally incorrect