THE EXPLOSION AT MOURA NO. 4 MINE QUEENSLAND

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Results of tests and calculations made in the U.K.

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Circulation

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1) Introduction

While in Queensland, I made certain observations and collected certain samples for further consideration after my return to the U.K. This report summarises the results of further work carried out by staff of the Explosion and Flame Laboratory, HSE, Buxton related to the explosion at Moura No. 4 Mine.

2) A digital watch as a possible source of ignition

Annex 1 consists of a note by Mr D W Widginton on this topic and a translation of a report on work carried out in E. Germany.

3) Frictional ignition characteristics of a sample of rock

During my tour of Moura No. 4 Mine, I collected a sample of rock from a roof fall in the area where roof collapse occurred about the time of the explosion.

This sample of rock was examined by Mr F Powell and his report is at Annex 2. The quartz content of a sample from this rock was examined by XRD and found to be about 69%.

These examinations show that the sample had the characteristics of a rock capable of giving rise to frictional ignitions in appropriate circumstances

4) The strength of the explosion

Although the Inquiry is more likely to be concerned with the causes of the explosion, the strength of the explosion is of interest for other reasons; for instance, the water trough barrier successfully stopped the explosion - it would be useful to have a measure of the explosion strength to add to our knowledge of barrier performance. Four observations were made relevant to the strength of the explosion:

a) the bending of fire extinguisher brackets in the conveyor road,
b) the crushing of an oil drum in CT 24*,
c) the damage to the permanent seals between the intakes and returns,
d) the damage to the ducting between the portal and the exhausting fan.

* CT = cut through

Each of these relates to a relatively simple geometrical situation from which quantitative estimates of different aspects of explosion strength can be made.

In an explosion in a mine, one can distinguish between two distinct types of damage namely that caused by an increase in static pressure and that caused by a high velocity wind or blast. The combustion region of the explosion creates a volume of high pressure gas which ultimately equalises out with the pressure in the rest of the system by pressure waves and a net outflow of gas. Many pressure wave reflections and flow reversals may take place during this process.

For this reason, many types of explosion damage, as observed after an explosion, are difficult to interpret - an object may have been moved by the blast wind several times and in different directions.

The above observations include effects caused by increases in static pressures and effects caused by blast winds.

Strength estimates:

a) the bending of fire extinguisher brackets

Two fire extinguisher brackets were located in the conveyor road, one slightly to the east of CT 27 and one about midway between CT 26 and CT 25.

Each bracket consisted of a 25 mm diameter rod, 1.25 m long projecting from the roof. At the lower end, a horizontal plate provided a support for two fire extinguishers, one either side of the rod.

During the explosion, each rod experienced a similar degree of plastic deformation - an 80 mm length near the roof was undeformed and then bending of the rod had occurred, resulting in a 540 mm displacement of the tip towards the coal face, in each case. This type of damage is caused by aerodynamic drag from a high velocity wind - it can be observed in typhoon or hurricane damage, for example.

A method of calculating the forces required to cause damage of this type has been developed at the Explosion and Flame Laboratory and validated by experiment (see Roberts, A.F. and Pritchard, D.K. "Blast effects from unconfined vapour cloud explosions". J. Occ. Accidents, 3, 231-247 (1982)). The method described has been applied to the above damage by Dr Pritchard, assuming typical strength properties for mild steel. These calculations show that the damage could have been caused by a blast wind with a dynamic pressure of about 0.3 Bar, persisting for several hundred milliseconds.

This dynamic pressure corresponds to an increase in static pressure of about 1 Bar and blast velocities and flame speeds of about 150 m/s.

In making this calculation, it was assumed that the fire extinguishers were not on the bracket when the drag force was being applied. The positions of the extinguishers relative to the brackets suggest that they were displaced by a relatively mild force. There was no damage to the supporting plate indicative of a drag force applied to the extinguishers being transmitted via the supporting plate. The extinguishers from the bracket between CT 26 and CT 25 were displaced to the east whereas the bracket was deformed to the west.

The assumption that the initiating event displaced the extinguishers and the main event deformed the bracket therefore appear reasonable.

b) <u>the crushing of an oil drum in CT 24</u>

A standard 44 gallon oil drum was recorded in CT 24 between Roads 3 and 4 (conveyor and supply roads), in a damaged condition, during the original damage survey of the mine. The drum had been crushed to some extent so that a 'waist' had been formed.

Tests were carried out at the Explosion and Flame Laboratory on similar drums exposed to coal dust explosions in a 1.2 m diameter gallery.

Two drums behaved similarly. With static pressure increases of 0.4 Bar, no damage occurred. With static pressure increases in the range 0.75-0.85 Bar, crushing of the drum occurred and a distinct 'waist' was formed.

This type of damage is caused by an increase in static pressure rather than by the dynamic pressure of the blast. It is therefore concluded that the increase in static pressure at the location of of the drum during the explosion was between 0.4 and 0.8 Bar.

c) <u>damage to the seals between intakes and returns</u>

The high pressure gas from the explosion applied a rapidly increasing static pressure to the permanent seals in the cut-throughs between the intake roadways and the two return roadways. In the region of main interest a standard design of seal was used consisting of a wall of blocks cemented together. Many of these seals failed in the explosion and a 0 to 5 scale of increasing explosion violence can be used to describe the damage that resulted (as recorded in the original damage survey):

0 Undamaged.
1 Seal partially destroyed.
2 Seal destroyed, debris scattered on both sides.
3 Seal destroyed, debris all on return side but only slightly displaced.
4 Seal completely destroyed, debris all on return side, distributed between seal position and far wall of return roadway.
5 Seal completely destroyed, debris all on return side, thrown against far wall of return roadway.

Using this scale, the damage to this type of seal (another type was used in some other cut-throughs which can not be compared in this way) may be summarised as follows:

Seal Location CT	North Return	South Return
21	1	0
22	1	0
23A	-	3
23	4	4
24	5	4
25	4	2
26	2	-
27	1	-

This summary indicates that for both the north and south return roadways, the maximum damage to the seals was associated with the region near CT 23 and 24.

The summary also indicates that the seals into the north return suffered a higher damage category at corresponding cut-throughs than those into the south return. This is not a distance effect as the two sets of seals are approximately equidistant from the conveyor roadway.

One can apply approximate values to the static pressures at which the limiting types of damage occur. Generally speaking, brick or block walls begin to suffer damage at an overpressure of about 0.2 Bar; a well constructed wall may survive this overpressure undamaged while a poorly constructed wall may be destroyed. At an overpressure of 0.3 Bar, tests on a non load bearing brick wall (well constructed) showed that the wall was destroyed and bricks were thrown about 20 m away.

Clearly, one would need detailed studies on the specific form of construction used for the seals to give accurate estimates but, as a guide, one can say that Category 1 behaviour corresponds to a static overpressure of about 0.2 Bar and Category 4/5 behaviour corresponds to a static overpressure of about 0.3 Bar.

d) <u>the damage to the ducting between the portal and the fan</u>

The portal of the mine was approximately 1.6 km from the site of the explosion. The ducting between the portal and the fan consisted of horizontal and vertical steel sheets bolted together to give a curving flow passage with a 90° change in flow direction as the return air emerged from the mine and entered the fan. Flow straighteners were installed on the bend.

The explosion damaged this ducting by blowing out 3 vertical panels on the outside of the curve and distorting the flow straighteners.

This damage is of interest because of its appreciable distance from the site of the explosion; an estimate of the forces acting on the ducting has therefore been made. It must be emphasised that the data used in the estimate are only approximate as the information was gathered by me on a superficial examination; more accurate estimates could be made by going back to the site and making accurate measurements or by referral to the engineering drawings for the ducting.

Each of the displaced vertical panels was approximately 12 feet high by 7 feet wide with a flange along each side. The horizontal flanges, bolted to the roof and floor sections, each had three securing bolts; the vertical flanges, bolted to the adjacent panels, each had twelve securing bolts. The bolts used were thought to be ½ inch diameter (the panels had been removed and the ducting repaired - see Fig. 2). The panels had been blown out of the ducting and also separated from one another.

The forces required to cause this damage depend on the assumed sequence of failure.

If one assumes that a shock wave travelled up the return and caused all the observed failure simultaneously, then each panel would be retained by 18 bolts, in effect (3 top and bottom and half of the contribution from the 24 bolts on the sides because the adjacent panels are also affected). Assuming a strength of 25 tons per sq in for the bolts gives an applied pressure of 1.1 Bar to cause failure in this way.

If, however, one assumes a progressive failure in which the bolts on the horizontal flanges failed first, causing a loss of integrity of the structure and the vertical panels were then displaced causing bending of the bolts in the vertical flanges followed by failure, then each panel would only be retained by 6 bolts for the initial failure. The applied pressure required would then be 0.36 Bar.

A solid object at right angles to the direction of propagation of a shock wave creates a reflected shock wave; the pressure applied to the object is double the pressure of the incident shock wave.

The above estimates therefore imply shock wave pressures of 0.55 Bar and 0.18 Bar respectively.

The previous estimates of explosion pressure suggest that the seals between intake and return were broken down by an applied pressure of up to 0.3 Bar. This failure of the seals would have produced a pressure wave in the return with a peak pressure of 0.3 Bar which would, quite rapidly, have steepened into a shock wave with the same peak pressure. Once established, a shock wave would travel along an 'ideal' tube (straight, no obstructions, no changes in cross section, smooth walls) with the same peak pressure. The shock wave in the return was subjected to changes in direction, obstacles, reflections at junctions etc. (some eyewitness accounts from the post explosion investigation refer to the locus of damage effects 'bouncing' from wall to wall along the return, which would be induced by shock wave reflection). These non-idealities would progressively reduce the pressure rise at the leading shock wave.

The two sets of estimates are consistent if one accepts the 'progressive failure' assumption for the ducting panels. A pressure wave of 0.3 Bar peak pressure would then have produced a shock wave that travelled along the return for 1.6 km and had a peak pressure of 0.18 Bar at the portal.

5) Dust deposition

A characteristic feature of the explosion effects was the deposition of thick layers of dust on protruding fixed objects.

In a typical example, a wedge of dust would have built up on one side of the projecting part of a roof bolt with negligible deposition on the other side.

During my visit to Queensland, some discussion took place on the significance of these deposits - specifically, did they form on the face of the objects towards the approaching blast wave or away from it.

At a major chemical plant explosion in the U.K., observations on soot deposition on lamp posts showed that the deposits were on the side facing the approaching blast wave. Observations of dust deposition in the Buxton explosion gallery show the same thing.

The mechanism is that as a high velocity particle laden gas stream approaches an isolated solid object, the flow divides to pass round the object, However, the solid particles do not follow the streamlines because of their relatively high momentum (relative, that is, to gas molecules). There is a tendency for the solid particles to continue to move in their original direction (a tendency that increases with particle size) so that a proportion of them impact upon the face of the object towards the flow.

In the wake of the object, recirculating flows do bring particles back towards the object but at a lower velocity; these tend to be the smaller particles. On the whole, because they are following the flow direction into the recirculation zone of the wake these tend to be very fine particles. In the low velocity regions of the wake they may sediment out but little deposition on the object occurs.

At a snow fence, for example (an object more common in Buxton than in Queensland!) impacted snow may be seen in a thin deposit on the upstream side of the fence elements but the bulk of the snow falls out to the ground in the wake of the fence.

For roof bolts exposed to a blast wave, the layer of dust would build up on the side towards the approaching blast wave. Sedimentation effects would not be apparent. For objects supported from beneath, the impacted layer would be the same but some sedimentation on horizontal surfaces in the wave of the object might also occur.

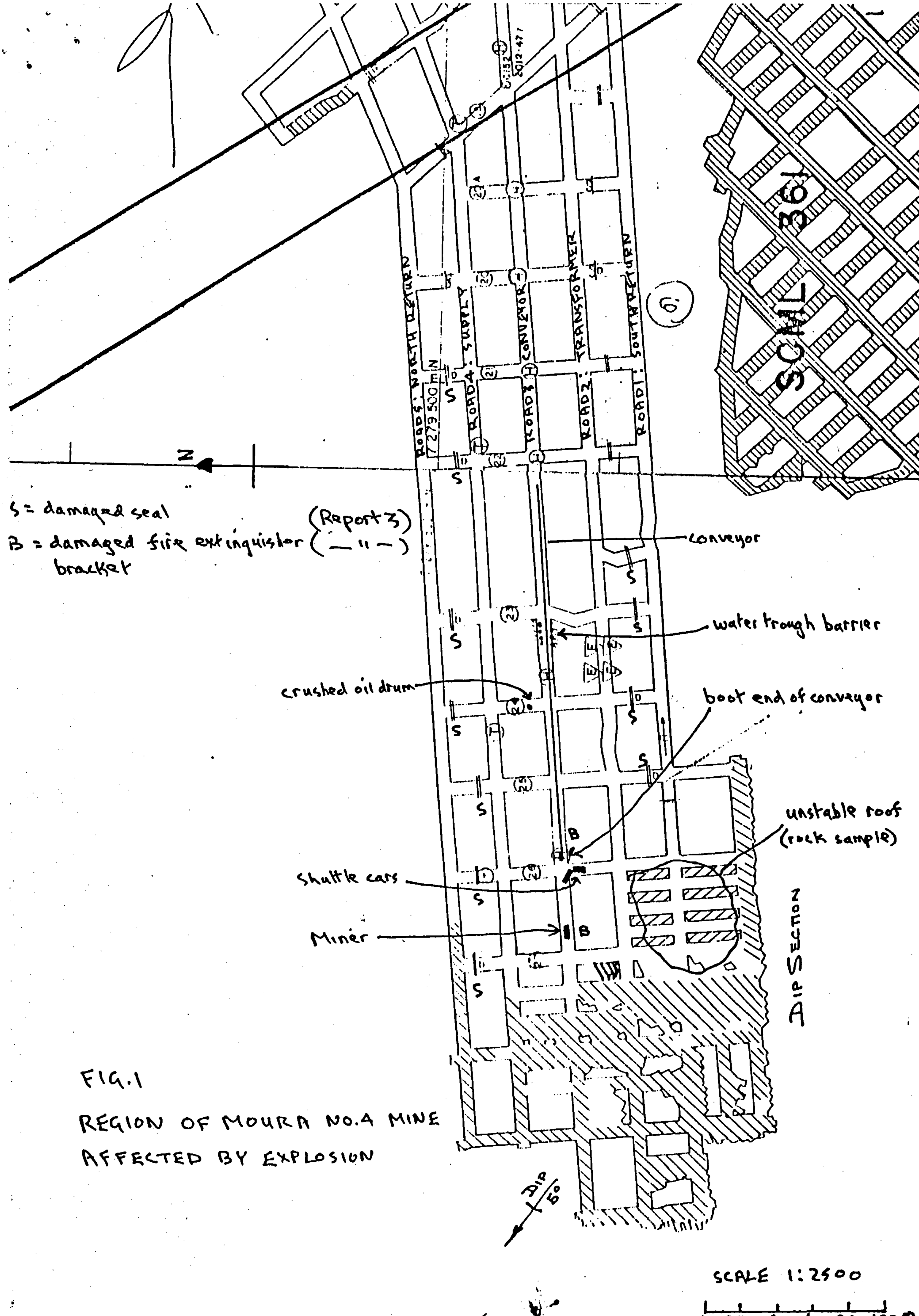
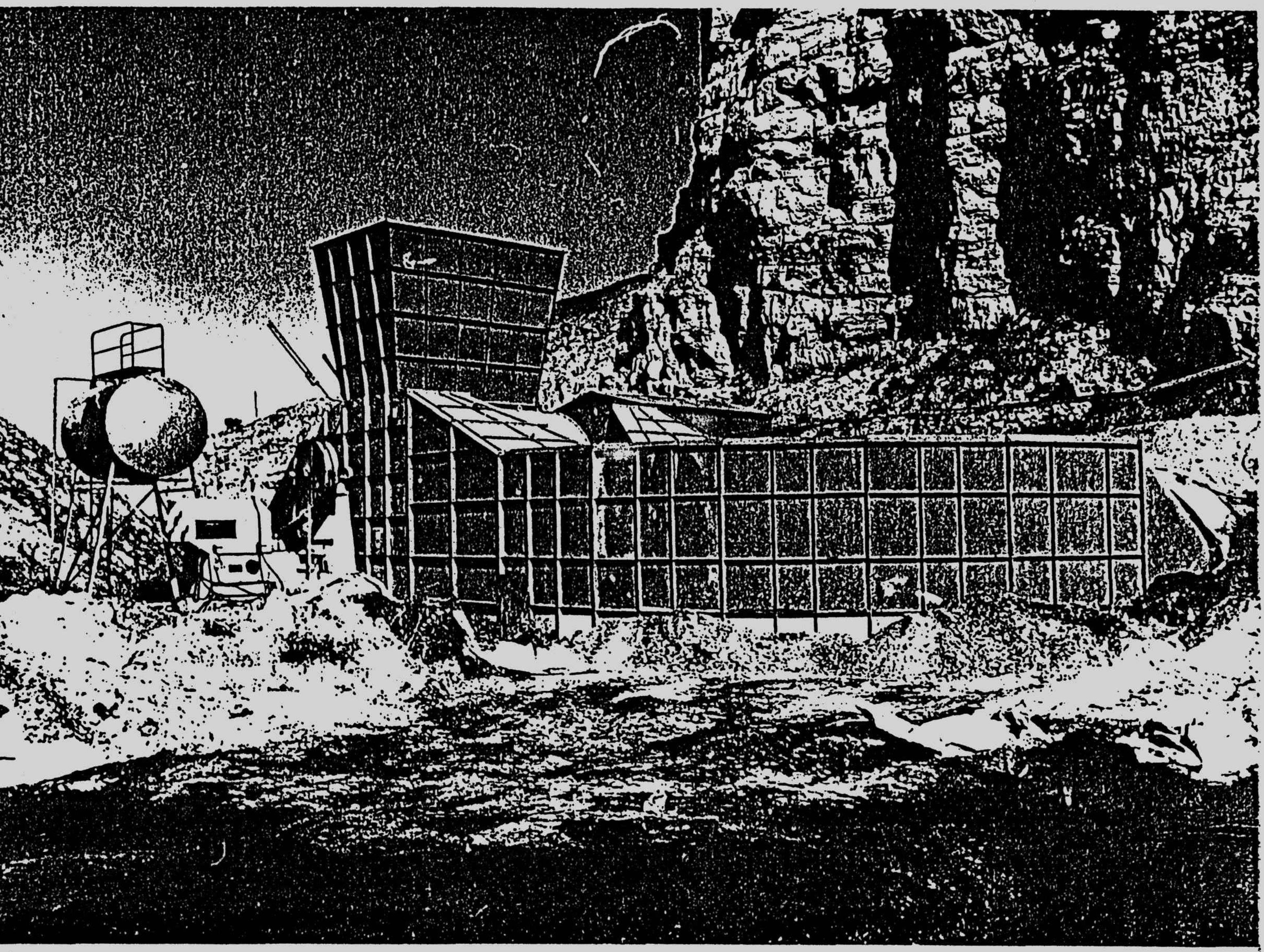


FIG.1

REGION OF MOURA NO.4 MINE AFFECTED BY EXPLOSION



The damaged panels were in this area.

Fig. 2.
The mine portal, ventilation ducting and fan at Moura No. 4 Mine.

BATTERY-POWERED WATCHES AS A POSSIBLE FIREDAMP IGNITION HAZARD

In my view, the hazard of ignition of firedamp from the wearing of currently available types of battery-powered watches is negligible. This opinion is based on the following considerations:

(i) the low voltage and short-circuit currents available from the batteries used,

(ii) the low energy storage possible with the components used, including the coil of the stepper motor used in analogue watches,

(iii) experimental evidence that it is not possible to ignite firedamp by breaking small filament bulbs of the types used in watches, and

(iv) the small internal volume and the "semi sealed" construction used to keep out contamination, which provide an effectively "flameproof enclosure" in the unlikely event that any flammable gas were to penetrate into the watch and be ignited there.

Despite this view, of which HMIMQ is aware, British Coal have chosen to ban the wearing of battery-powered watches underground. Their reasons for so doing is based on a desire to keep control of a situation which could change overnight if e.g. a new type of watch were to be introduced which could no longer be judged as safe.

There is also a problem in that Regulation 64 of the Mines & Quarries Act requires all non-approved electrical apparatus to be switched off if the firedamp level exceeds 1¼%, and strictly speaking battery-powered watches are covered by this Regulation.

ICI in the U.K. carried out ignition tests on battery-powered watches several years ago, and as a result concluded that no restrictions in their use were justified for personnel entering potentially hazardous areas, even for Group IIC. ICI Engineering Codes & Regulations Group C (Electrical) Vol. 1.5 deals with this point; this Code has recently been revised but I understand no change has been made in respect of the wearing of watches. The only reservation raised by A.J. McMillan of Sira Safety Services Ltd., who carried out ICI's original tests when he worked for them, was that none of their tests covered the use of lithium cells in watches, whereas some lithium cells are known to give rise to safety problems. However, these possibly hazardous types are not, as far as I am aware, used in wristwatches.

A translation of an East German paper is attached which deals, among other things, with the possible hazards presented by battery-powered wrist watches. The paper states that the wearing of such watches is regarded as acceptable in coal mines in the German Democratic Republic.

D W Widgington

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Electric wrist-watches in workplaces with an explosion hazard.
(Elektrische Armbanduhren in explosionsgefährdeten Arbeitsstätten).
Sicherheit. 1982, vol. 28, no. 1. pp. 15-16.

Translator: External HSE Transl.no. 10740

HSE Translation 10740

Electric wrist-watches in workplaces with an explosion hazard
Report from the Mining Safety Institute Leipzig

In recent years the Mining Safety Instute in Leipzig, as the Testing Station for explosion-protected electrotechnical apparatus, has been repeatedly questioned about the use of electrotechnical/ electronic equipment which is fitted with its own power source and which is consequently transportable. Such items are to some extent the personal property of the employees and may be taken by them unchecked into hazardous areas.

The questions are aimed at possible hazards which could arise as a result of taking such equipment into workplaces with an explosion hazard.

In this connection it is recognised that, at locations where there is a requirement for safety, employees have to leave even personal means of ignition, such as lighters and matches, outside the hazarded workplace.

Taking account of the equipment listed above the questions have been answered as follows. In general:

- wristwatches with their own power supply,
- pocket calculators with their own power supply,
- radio receivers with their own power supply or
- measuring instruments with their own power supply,etc.

  may represent ignition sources for explosive mixtures and must not be operated in potentially hazardous workplaces without previous testing and positive confirmation by the Testing Station.

Such tests were carried out on request, the applicant having to decide on the basis of TGL 19491, which applies for explosion-protected electrical apparatus, and which has to be taken into account in the design, what precautions of explosion protection he applies. Their effectiveness is confirmed for him by the testing. It is not possible to grant a general approval or even to quote a clear limit because of the great number of types involved, the various kinds of power source used and other causes. The lack of understanding of such a conclusion is perhaps to some extent reduced when one recognises that some gas-air mixtures can be ignited by electrical discharges with an energy of 10 to 20 μJ.

By taking into account various favourable factors a variation from this conclusion can be made for wrist-watches with their own power supply. These factors are:

1. The low values of voltage and short-circuit current of the power sources,
2. The low operating currents and in consequence, no possible non-permissible heating of components,
3. The exclusion of parts producing sparks in normal operation together with low total energies in the components which can act as energy stores, such as the stepping motor of an analogue clock; by this means incendive sparks are ruled out,
4. The high degree of sealing of the case which is in the interest of reliable operation. This sealing not only prevents the ingress of dust and moisture and hence the pollution of any creepage paths, but also prevents the unhindered entry of explosive mixtures,
5. The construction prevents direct access to the power source on the spot and without tools.

This all leads to the conclusion that electronic wrist-watches are adequately safe, without a general demonstration of explosion protection by the Testing Station, to be used without further ado for degrees of explosion hazard EG 3 and EG 4 as defined in TGL 30042.

For workplaces which have been classified as EG 2 it has to be checked how long the employees can actually be in any explosive mixtures that arise as, in contrast to stationary apparatus, they are able to leave the workplace in the event of an explosion hazard. With gases and vapours of Explosion Class/Ease of Ignition Group II C this checking needs to be undertaken particularly critically. With a transiently occurring explosion hazard - related to the watch - even in this case no objections arise.

Where there is doubt the ban on wearing still remains as a precaution. For mines in the DDR with a firedamp hazard, on the basis of the degree of the firedamp hazard, which corresponds roughly to the EG 3 and EG 4 degrees of explosion hazard, the use of electric wrist-watches is regarded as acceptable on safety grounds even in the "firedamp region".

It has to be understood that this general assessment on the basis of the factors quoted is only applicable to wrist-watches and cannot be applied without further consideration to other apparatus.

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Annex 2

Reference..

Dr Roberts

AUSTRALIAN ROCK SAMPLE

The rock sample received was light in colour and did not crumble in the hands. It was, thus, a fairly strong rock and it proved fairly difficult to cut with a hack-saw. When pressed against a workshop grindstone wheel, the sample produced bright yellow heating and the surface of the rock was glazed where the rubbing had taken place.

These simple tests indicated a rock of the type likely to be involved in frictional ignitions i.e. a fairly strong rock with a fairly high quartz content.

This was confirmed by carrying out the grindstone test once more when it proved possible to ignite a bunsen burner (fed with methane) by the hot surface produced on the rock sample. (This is something not easily done, even with Darley Dale sandstone).

pp F POWELL
7 October 1986

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