

QUEENSLAND DEPARTMENT OF MINES
TESTING AND RESEARCH STATION
REDBANK

REPORT OF INVESTIGATIONS
OF FLAME SAFETY LAMP

P. Gollidge

P. Gollidge
Chief Engineer
Department of Mines
Director
Testing & Research Station

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CONCLUSIONS

An analysis of all the investigations carried out at the Testing and Research Station, metallurgical examinations made by the Department of Mining and Metallurgical Engineering of the University of Queensland and electron microscopic studies at the Queensland Institute of Technology suggest that an intense explosion occurred in the flame safety lamp which was recovered after the Moura explosion.

The intensity of the explosion in the lamp was sufficient to heat the gauzes in the lamp to a temperature of approximately 900 C. During the course of investigations it was demonstrated that the average temperature of the outer gauze for an explosion was not less than the value shown below:

251 C	methane/coal dust explosion
472	methane explosion

A temperature of 900 C needs to be maintained for a very short time to cause an ignition of any of the explosions referred to above. This time period is of the order of fractions of seconds or less.

The deposition pattern of dust particles fused to the inner and outer surfaces of the lamp glass and bonnet indicates that the lamp would need to be at the ignition point of the explosion.

It is suggested that a fall of ground in the goaf caused a methane/coal dust atmosphere which at the position of the flame safety lamp was above the lower explosive limit for such atmosphere. Methane and coal dust entered the lamp which was alight prior to the explosion and caused an intense explosion inside the lamp. This explosion occurred over a sufficient period of time to cause heating of both inner and outer gauzes to approximately 900 C. The atmosphere surrounding the lamp was still explosive and the lamp gauzes provided the ignition source for an external explosion in the mine roadways.

IV

It is likely that there was a potentially explosive cloud of airborne dust with methane between the coal face and the lamp at the time of ignition. Under such conditions an explosion would have proceeded rapidly towards the goaf and along the edge of the goaf area wherever there was a potentially explosive mixture of methane and coal dust. Outbye of the lamp the explosion could have started as a methane/coal dust explosion and as it moved outbye changed to a coal dust explosion the progress of which was ultimately arrested by the barrier.

V

SUMMARY :

This is a report of a fairly comprehensive investigation into the behaviour of a flame safety lamp in various methane/coal dust atmospheres which might occur under some circumstances in an underground coal mine.

The investigation was carried out by staff of the Testing and Research Station at Redbank. During various phases of the investigation all the staff at the Station were involved. Specialised assistance was also provided by staff and equipment at the Department of Mining and Metallurgical Engineering of the University of Queensland and the Queensland Institute of Technology.

The following table shows significant temperatures relating to the flame safety lamp and methane or coal dust explosions.

SIGNIFICANT TEMPERATURES

Temperature C	Comment
2 200	Coal Dust Explosion in Lab (USBM Tests)
2 000	Estimated Temperature in Flame Lamp Tests
1 000- 900	Moura Gauzes Heated to this Temperature Achieved During Tests in Explosion Chamber
960	Maximum Inner Seam Temperature Recorded
820	Flame Temperature of Safety Lamp
628	Max Temp Inner Gauze Seam Methane app 5%
570	Methane Re ignited by Hot Gauze Bench Test
472	Methane Explosion by Heated Gauze in Chamber
434	Max Temp Inner Gauze Top Methane at app 5%
251	Ignition Temp Methane/Coal Dust Cloud
130	Max Temp Outer Gauze Top Normal Air
105	Max Temp Inner Glass 4cm Flame Height

VI

INTRODUCTION

The flame safety lamp has been in use in underground coal mines since its invention in 1815. Designed as a safe means of providing illumination in a firedamp atmosphere it has also found use as a reliable means of detecting the presence of methane in mine atmospheres.

Although coal mine explosions have been attributed to the flame safety lamp these have usually occurred when it has been subsequently demonstrated that an essential part of the lamp was damaged, faulty or had inadvertently been omitted during assembly of the lamp.

Some observations made during the examination of the flame safety lamp from Moura No. 4 mine suggested that a detailed examination of the behaviour of the flame safety lamp should be carried out.

This report is divided into the following sections.

- I - Examination and dismantling of lamp.
- II - Explosion Chamber Tests
- III - Flame Lamp Tests
- IV - Miscellaneous Tests
- V - Instrument Calibration
- VI - Analysis of Results
- VII - Appendices

SECTION 1

EXAMINATION AND DISMANTLING OF LAMP

Initial Examination

The flame safety lamp from Moura No. 4 mine was examined and disassembled on 1986 at Redbank Station in the presence of

P. Golledge	Director
T.G. Hislop	Senior Inspector Electrical Testing
A.G. Evans	Senior Inspector of Coal Mines, Ipswich
S. Bell	Senior Chemist

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 some 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 was approximately 5 gm 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 showed some 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.

Associate Professor I. Smith of the Department of Mining and Metallurgical Engineering of the University of Queensland was requested to metallurgically examine both gauzes from the lamp and to compare them with a set of unused gauzes. He was asked to investigate temperature effects which are included in the Uniquist report in Appendix 2.

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 in Appendix 3.

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

Discussion

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. Hertzberg et al (1) in a U.S. Bureau of Mines publication shows a series of electron micrographs of coal particles after an explosion in a closed chamber. The characteristic blowhole appearance of the particles is similar to those obtained during our investigations. Lightman and Street (2) have shown that particles heated above 1300 C were highly devolatilized.

Note: Names and numbers in parenthesis () refer to references at end of this report

SECTION II

EXPLOSION CHAMBER TESTING

Test 1 - Construct and Check Performance of Small Scale Explosion Chamber.

Investigators:	W. Urbanik	Mining Engineer
	V. Osborne	Mining Engineer (Part of Time)
	J. Brough	Testing Officer
	P. Gollidge	Director (Supervisor)

Test Method 1

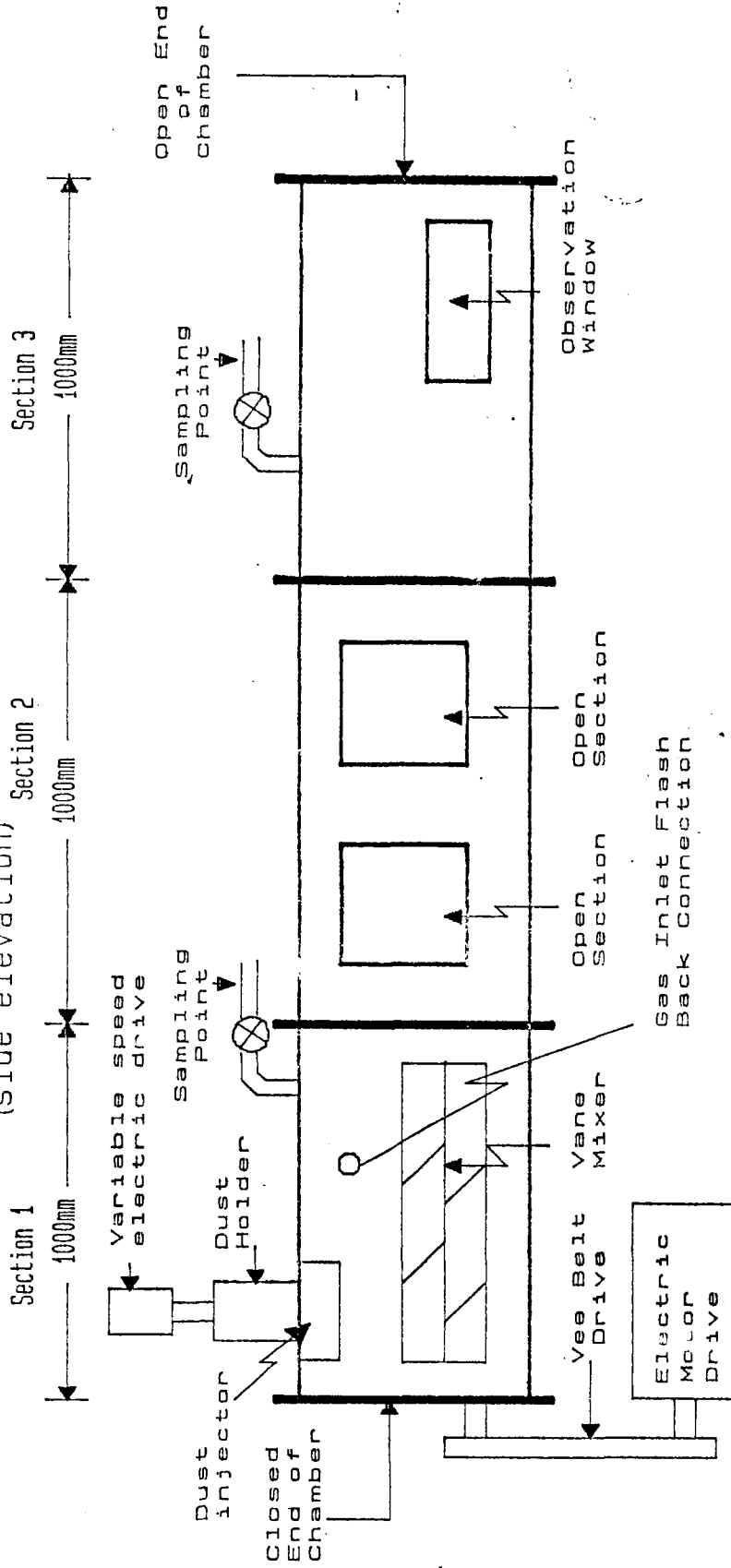
A small scale explosion chamber was constructed in the Station Workshop. The chamber consists of three 1 metres long section, each of cross sectional area 400mm by 400mm. The Sections have flanges at each end which permit joining and interchanging of sections as required. The general layout of the explosion chamber is shown in Fig 2.1. Initial experiments were carried out with Section 1 on its own without either the vane mixer or the dust injector. During this series of experiments gas was introduced by means of balloons which were inflated from a storage gas bottle via a calibrated flow meter. The balloon was burst by means of an electric heating element in contact with the lower surface of the balloon. Another electric heating element in the top of the chamber was used to ignite the gas mixture. Propane gas was used for the initial series of experiments. Dust was placed on the upper surface of the balloon and dispersed into the air when the balloon burst.

Modifications were made to the first Section with the fabrication by the Workshop at the Station of two 1 metre long vanes fastened to the floor of the chamber and running freely in sealed bearings at the ends. An external electric motor powered the vanes through two vee belts which rotated the vanes in the same direction. A dust injector was also added to the roof of the chamber which was designed in such a way as to disperse the dust in a radial direction above the vanes when the mixer was turned on. A variable speed motor allowed the time time and quantity of dust injected to be varied at will. The combined vane mixer and dust injector proved to be an efficient way of maintaining a dust cloud in the first Section and of mixing coal dust, methane and air in varying proportions as required.

Fig 2.1

LAYOUT OF EXPLOSION CHAMBER

(side elevation)



2.3

Section 2 of the chamber contains two open sections on each side of the metal duct. Depending on the type of test, these open sections were covered with aluminium foil, translucent plastic or transparent plastic film as required. The edges of the plastic film were sealed with masking or other sealing tape as required.

Section 3 contains a polycarbonate observation window which allows progress of the flame to be monitored with the aid of the video camera.

To retain the gas, dust and air while mixing takes place a plastic or aluminium foil membrane is attached to the appropriate section flange as required by the test.

Gas is introduced in Section 1 through a flash back preventer attached to the gas inlet in the wall of the duct.

For later experiments the explosion chamber was further modified as shown in Fig 2.2. A length of flexible duct was added to the chamber and the atmosphere within the chamber circulated by means of an electrically powered axial flow fan. During such experiments the safety lamp was placed in Section 2 opposite an open section in the wall of the duct. Thermocouple probes were attached to various parts of the lamp and the electrical connecting wires brought out through the opening and connected to the appropriate instrument. The opening was sealed with transparent plastic to permit observation of the flame and the gauze by means of the video camera. The telephoto lens of the video camera was focussed prior to each test on the flame of the lamp. The lamp position was varied between vertical and 45 degrees. The bonnet of the lamp was removed for some tests to allow direct observation of the gauze. The air velocity was controlled by a butterfly valve and varied between 0 and the maximum permitted by the equipment of 2.9 m/s.

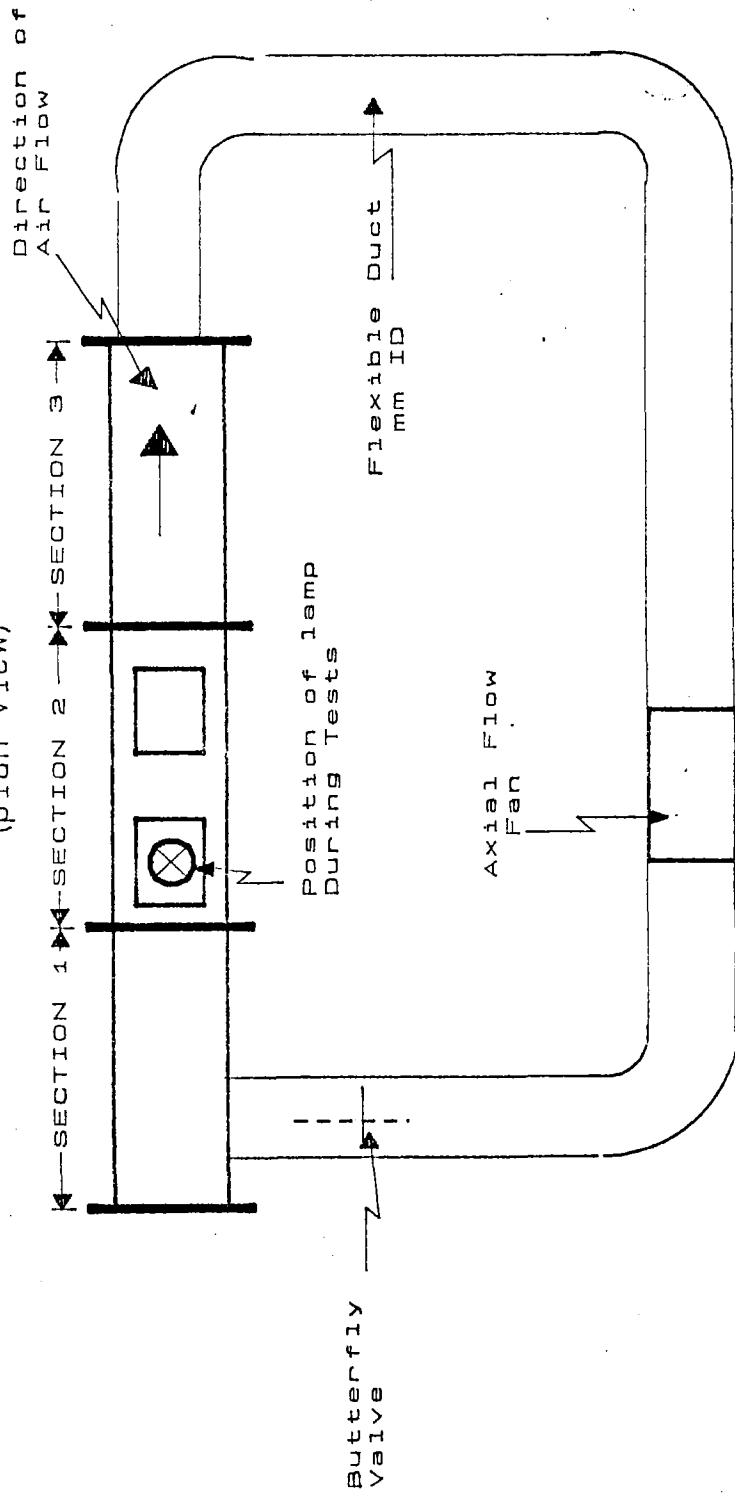
Coal from Moura No 4 mine was used in all coal dust explosion tests. The coal was crushed and sieved to produce a size fraction less than 75 micron diameter. Some experiments were also carried out with the size fraction below 39 micron diameter and below 20 micron diameter. It was considered that the smallest size fraction may more faithfully represent the 'float dust' produced by conveying and other operations in the mine.

Fraction analysed was sized at 250μ

Dust raised by fall not "float dust"

Fig 2.2

EXPLOSION CHAMBER WITH CIRCULATING FAN
(plan view)



2.5

To test the behaviour of the chamber some 6l explosion of propane or propane and coal dust were made between 26 November and 10 December, 1986. During these tests propane concentrations varied between 2 and 8% with coal dust concentrations between 50 and 700 gm per cubic metre.

The strength of the explosion was crudely estimated by the noise produced by the explosion and the observed length of the flame. With propane only the strength of the explosion was observed to be low at the lower explosive limit, to increase as the propane concentration increased and to decrease above the most explosive concentration. A very strong explosion occurred with a coal dust concentration of 50 gm per cubic metre and 4.2% propane concentration.

2.6

Particle Deposition During Coal Dust Explosions

Test Method

A number of objects were placed in No 3 section of the explosion chamber where they were exposed to a flame front estimated to be moving at a velocity between 20 and 40 m/s.

Dust concentrations were increased up a maximum of 1000g/m³. Additional dust was placed on longitudinal and transverse shelves to add to the airborne dust load. Methane and propane concentrations were varied up to the concentration known to produce the strongest explosion.

Test Results

It was observed in all cases that there was always a preferential deposition of dust on the surface of the object. Dust build up was always greatest on the surface of the object facing the explosion with little or no dust on the leeward side. With very heavy dust concentrations the pattern observed produced a sharp edge facing the explosion.

In our tests it was not possible to produce any deposit of dust which was uniform around the surface rim nor was it possible to 'fuse' dust to the surface of either the glass or bonnet of the lamp.

*Residual
heat ??*

Safety Lamp Explosion Tests

Test Method 1

The safety lamp with bonnet was instrumented with thermocouples each of which was connected to a FDUKE thermocouple and a YEW multichannel recorder. The lamp was placed approximately 0.5m away from the diaphragm end of the explosion chamber. Several tests were carried out with a number of methane/coal dust concentrations.

Each test was also recorded by a video camera focussed in close up on the flame of the lamp.

In another test a piece of tissue paper was placed on top of the inner and outer gauze of the assembled lamp and the lamp placed in the explosion chamber and exposed to the intensity of a methane/coal dust explosion.

Test Results

The lamp was exposed to an intense flame estimated to be 2000 C for a time of approximately 1 second as measured by analysis of the video tape during playback in slow motion.

The temperature measured by the thermocoupled probes was 100 C or less perhaps due to the relatively slow response of the probes compared with the rapid temperature rise during a methane/coal dust explosion.

During the tissue paper test the paper on the surface of the outer gauze was slightly charred estimated to be 350 C or less. There was no evidence of any change in the colour of either the inner or the outer gauze.

In one test there was some discolouration of the bonnet after exposure to the flame but no obvious discolouration of either gauze.

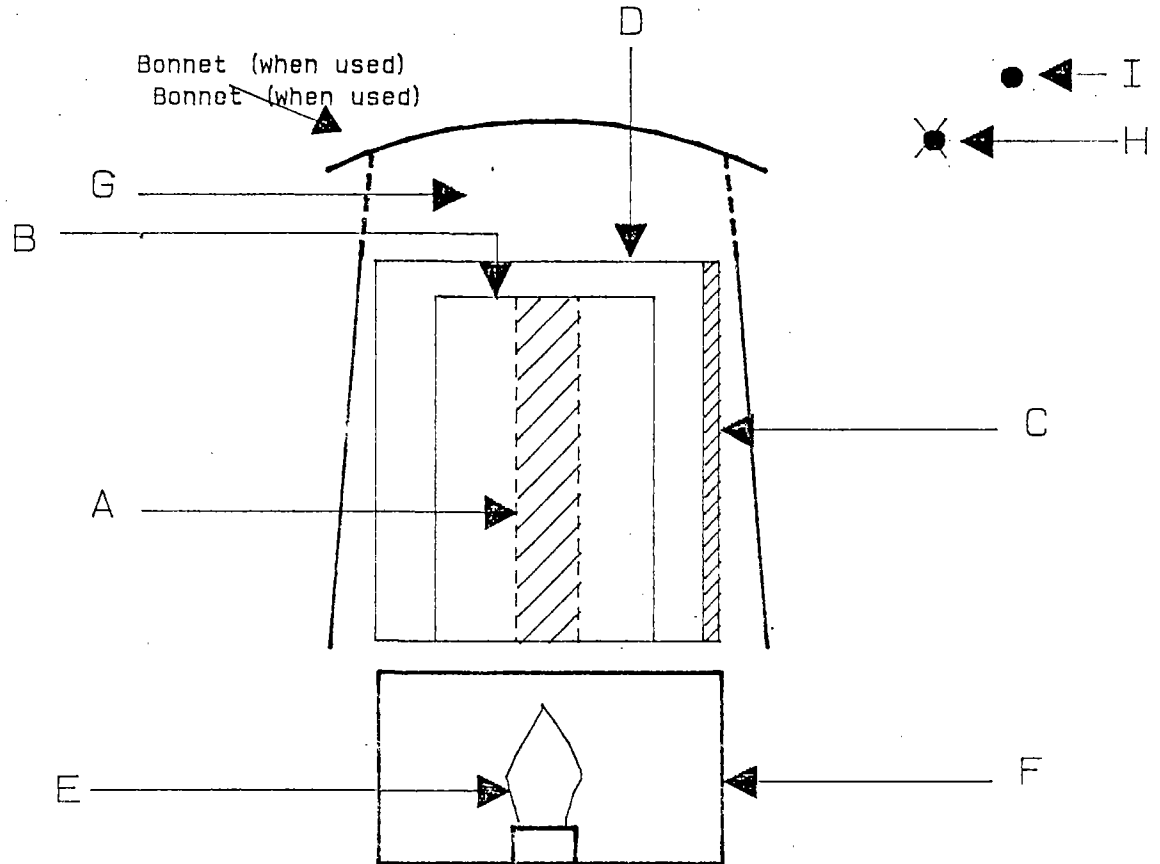
It was not possible to produce a 'fused' particle dust film on either the inner or outer surfaces of the safety lamp.

Test Method 2

The flame safety lamp was instrumented with thermocouple probes and placed in Section 2 of the chamber with the duct connected so that there was complete circulation of the air current past the lamp. The lamp was sealed into the duct and methane injected into the lamp and the concentration of methane gradually raised to the point of extinction of the lamp flame. The temperature at various critical points in the lamp was monitored while the gas concentration was increasing. The temperatures shown in Table 2.2 below represent 90% of the maximum value recorded on the graph a sample of which is shown in Fig 2.3.

*Single pass
flame.
Evidence of
flame in two
directions, at
least in
location of
lamp.*

MONITORING FLAME SAFETY LAMP
IN EXPLOSION CHAMBER



Positions Monitored.

- | | | | |
|---|------------------|---|----------------------------|
| A | Inner gauze seam | F | Inside edge lamp glass |
| B | Inner gauze top | G | Space above outer gauze |
| C | Outer gauze seam | H | Duct air temp. |
| D | Outer gauze top | I | Ambient temp. outside duct |
| E | Flame | | |

Table 2.2

Temperature Measurements in Parts of Lamp
(methane only)

CH ₄ %	Air Vel m/s	Temperature C and Duration of Heat (secs)			
		Inner Seam Gauze	Inner Gauze Top	Outer Seam Gauze	Outer Gauze Top
5.4	0	628 C(9s)	434 C(47s)	86 C(110s)	184 C(80s)
5.4	1	435 C(326s)	391 C(486s)	70 C(146s)	116 C(240s)
5.4	1	406 C(36s)	356 C(39s)	52 C(125s)	94 C(9s)

Table 2.3

Temperature Measurements in Parts of Lamp
(propane and coal dust)

C ₃ H ₈ %	Air Vel m/s	Temperature C and Duration of Heat (secs)			
		Inner Seam Gauze	Inner Gauze Top	Outer Seam Gauze	Outer Gauze Top
1.5 250g dust	1.4 20% < 22 micron 80% < 75 micron	960 C(65s)	616 C(42s)	364 C(50s)	200 C(35s)
1.5 100g dust	0.2 100% < 22 micron	304 C(17s)	212 C(30s)	76 C(95s)	120 C(180s)
6.0 250g dust	2.6 100% < 75 micron	232 C(143s)	214 C(205s)	60 c(165s)	63 C(120s)

Flame Effects on Objects

Test Method

Sections of the chamber were covered with polyethylene sheet to observe the passage of the flame during a gas or gas/coal dust explosion. Small pieces of thin cardboard and balsa wood were also placed in the centre of the flame. Pieces of polypropylene rope were also suspended with the end of the rope at the centre of the flame.

Test Results

The flame estimated to be at a temperature of 2000 C was of insufficient duration to cause more than slight charring to the thin strips of balsa or the pieces of cardboard. There was some evidence of fusing of the individual fibres in the polypropylene rope but it was necessary to expose the rope to three explosions before the stiffness was similar to that observed in samples from the Moura No. 4 mine.

The polythene covering on the chamber shrunk on exposure to flame but was used usually for 3 explosions before it was necessary to replace it.

Discussion

It was possible to produce methane or propane coal dust explosions over a broad range. Intense flames were observed during these explosions the temperature of which was estimated to be 2000 C. Baker et al(3) quote a temperature of 1960 C for a methane explosion and 1980 C for a propane explosion. Hetzberg et al measured the maximum temperature of a coal dust explosion as 2127 C.

There are many factors which influence the initiation and propagation of a coal dust explosion. An additional degree of complexity is introduced when the explosion is the result of methane as well as coal dust. It is not possible to accurately scale all these factors. Indeed there is now evidence that the progress of an explosion in a large explosion gallery is significantly different from that of a small gallery.

It is believed that the temperatures achieved in the explosion chamber testing at the Station would be not less than those experienced during the actual explosion at Moura. It is probable that the duration of flame would have been longer at the mine.

Thermocouple Positions - Tests J - 12

Channel	Position	Colour
A	Inner Gause Seam	Blk
B	Top of Inner Gause	Red
C	Outer Gause Seam	Green
D	Outer Gause Top	Blue
	1000°C - 1.00000	
E	Lamp Flame	Dark
F	Side of Glass	Dark
G	Temp of Duct	Light
H	Ambient Temp Outside Duct	Light

4 cm/m
0.08850 °C
0.1227 °C
0.05299 °C
0.1078 °C

87/01/23
11:22
4 cm/m
0.08874 °C
0.1231 °C
0.05323 °C
0.1084 °C

87/01/23
11:23
4 cm/m
0.05133 °C
0.04861 °C
0.04878 °C
0.04260 °C

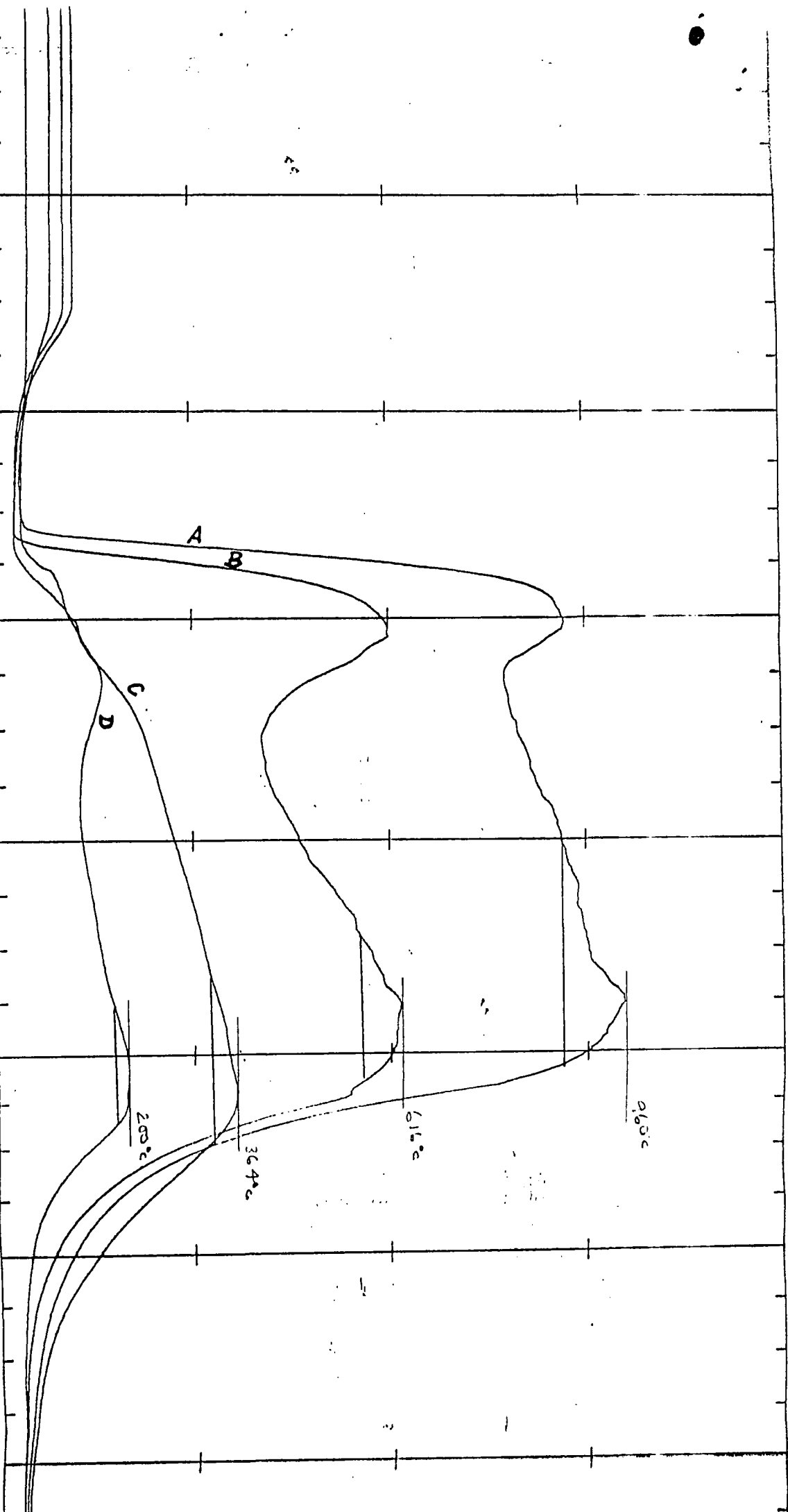
87/01/23
11:24
4 cm/m
0.8670 °C
0.5924 °C
0.1203 °C
0.1156 °C

87/01/23
11:25
4 cm/m
0.8618 °C
0.4628 °C
0.2715 °C
0.1313 °C

87/01/23
11:26
4 cm/m
0.8878 °C
0.8020 °C
0.3531 °C
0.1968 °C

87/01/23
11:27
4 cm/m
0.1127 °C
0.08413 °C
0.1522 °C
0.04894 °C

87/01/23
11:28
4 cm/m



SECTION III

FLAME LAMP TESTS

Test 1 Measure Lamp Flame Temperature in Normal Air

Investigators	K.Harris	Instrument Technician
	W.Urbanik	Mining Engineer
	V.Osborne	Mining Engineer
	P.Golledge	Director(Supervisor)

Test Method 1

A thermocouple was placed at a position in the flame of the lamp to record the maximum temperature of the flame. The flame height was adjusted to that normally used in a mine other than when being used to measure the methane concentration. The thermocouple was connected to a FLUKE thermocouple module which in turn was connected to a FLUKE meter calibrated to give a digital temperature reading. Temperature readings taken at 10 second intervals gave an average temperature of 820 C with a standard deviation of 14.6 C.

Test Results

The test results are given in Table 3.1 below:

Table 3.1

Safety Lamp Flame Temperature Measurements

Time (Sec)	Temp (C)
10 sec	794
20 ..	819
30 ..	820
40 ..	824
50 ..	820
60 ..	830
70 ..	833
80 ..	829
90 ..	830
100 ..	838
110 ..	795
120 ..	801
130 ..	820
140 ..	841
150 ..	836
160 ..	829
170 ..	828
180 ..	812
190 ..	799
200 ..	812
210 ..	834

3.2

The flame lamp was instrumented with thermocouples to monitor the outside gauze temperature and lamp glass temperature with the lamp flame height varied between 0.25 and 4 cm. With the bonnet on the lamp and the lamp in the vertical position the results shown in Table 3.2 below were obtained:

Table 3.2

Safety Lamp Gauze and Glass Temperature
(ambient temp 30 - 34 C, normal atmosphere)
(air vel 2.2 m/s)

Flame Height cm	Temperature (C) of	
	Outer Gauze	Glass Inside
0.25	36	31
0.5	47	33
1.0	62	36
1.5	88	43
2.0	90	48
2.5	115	88
3.0	130	95
3.5	105	85
4.0	130	105

Time?

3.3

Test 2 Re-ignition of Methane by Heated Gauze

Investigators	K.Harris	Instrument Technician
	W.Urbanik	Mining Engineer
	V.Ösborne	Mining Engineer
	J.Brough	Testing Officer
	P.Golledge	Director (Supervisor)

Test Method 2

The inner and outer gauzes were placed on a tripod as in Fig 3.1 and heated from below by means of a methane bunsen burner flame. When the gauzes reached approximately 650 C the methane gas supply to the burner was turned off and on again. This caused the flame in the bunsen burner to go out. The flame was then re-ignited by the heat in the gauzes. Temperatures were monitored by means of thermocouples placed at suitable points and connected to the recorders by the module units. All thermocouples, modules and recorders had been calibrated.

*See
lamp tests
Platt.*

After the first three experiments of this type the thermocouple on the flame of the bunsen burner (green) was change to the inside top of the inner gauze.

Test Results

The first three experiments show evidence of the flame passing through the gauzes. In each experiment re-ignition occurred regularly and the point of final cut off of gas is noted by a sharp fall off in flame temperature.

In the fourth experiment, where the thermocouple was attached to the inner gauze, as shown in Fig 3.2 and connected to the recorder. Re ignition occurred initially from a hot spot on the surface of the inner gauze. When heating of the inner gauze was continued the outer gauze rose in temperature and at one stage there was a fall in the temperature of the inner gauze. Then the outer gauze became the source of re-ignition. A typical graph obtained from these tests is shown in Fig 3.3.

Fig 3.1
MONITORING LAMP GAUZE TEMPERATURE
(OUTER GAUZE)

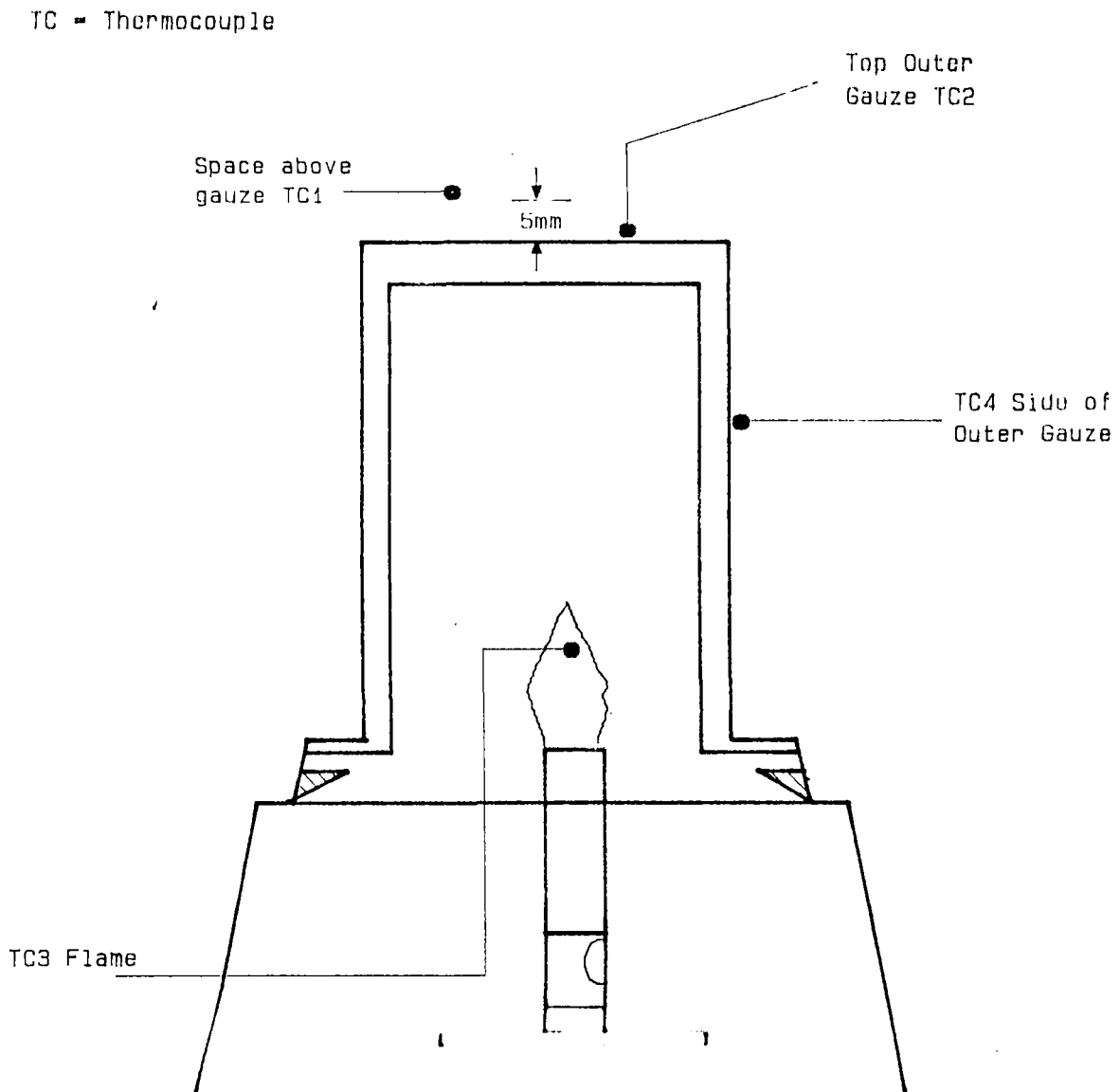
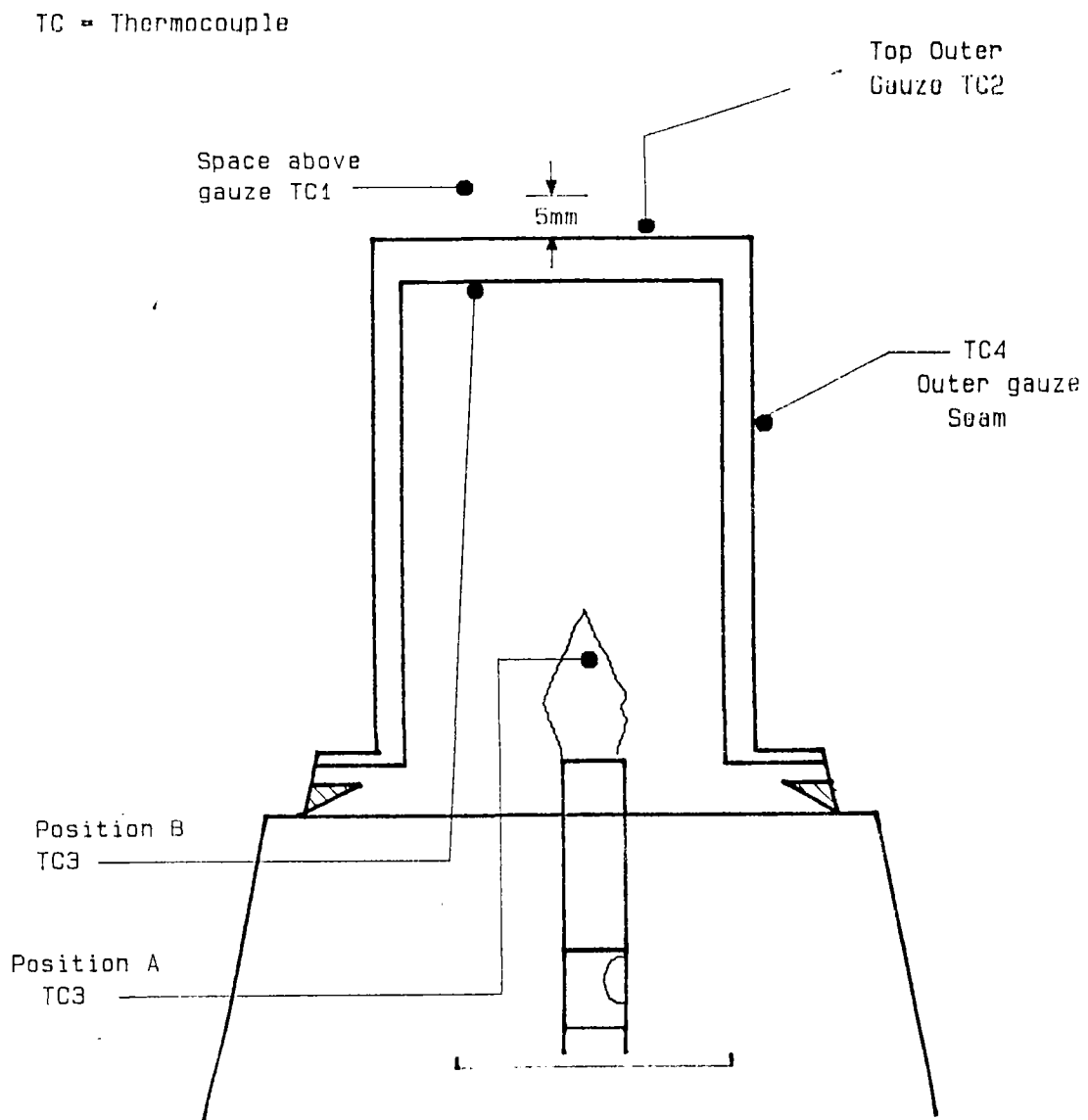


Fig 3.2
MONITORING LAMP GAUZE TEMPERATURE
(INNER GAUZE)



Test 3 Determine Temperature at Which Flame Passes through Heated Lamp Gauze.

Investigators - V. Urbanik Mining Engineer
- V. Osborne Mining Engineer
- K. Harris Instrument Technician
- J. Brough Testing Officer
- P. Golledge Director (Supervisor)

Test Method 3

The inner and outer gauze were heated in a Carbolite Muffle Oven, to a set temperature. The gauzes were then quickly removed and placed on a tripod stand under which was a bunsen burner. Thermocouples, pre-set into position monitored the temperature of the gauzes and the surrounding air. The burner was supplied with methane gas and lighted. As the temperature of the gauzes rose due to the burner flame a point was reached where the flame passed through both gauzes to the outside atmosphere. This point was noted on the graphs.

The tests were set up as shown previously in Fig 3.1 The four thermocouples were placed as shown and connected to the recorder in the order shown.

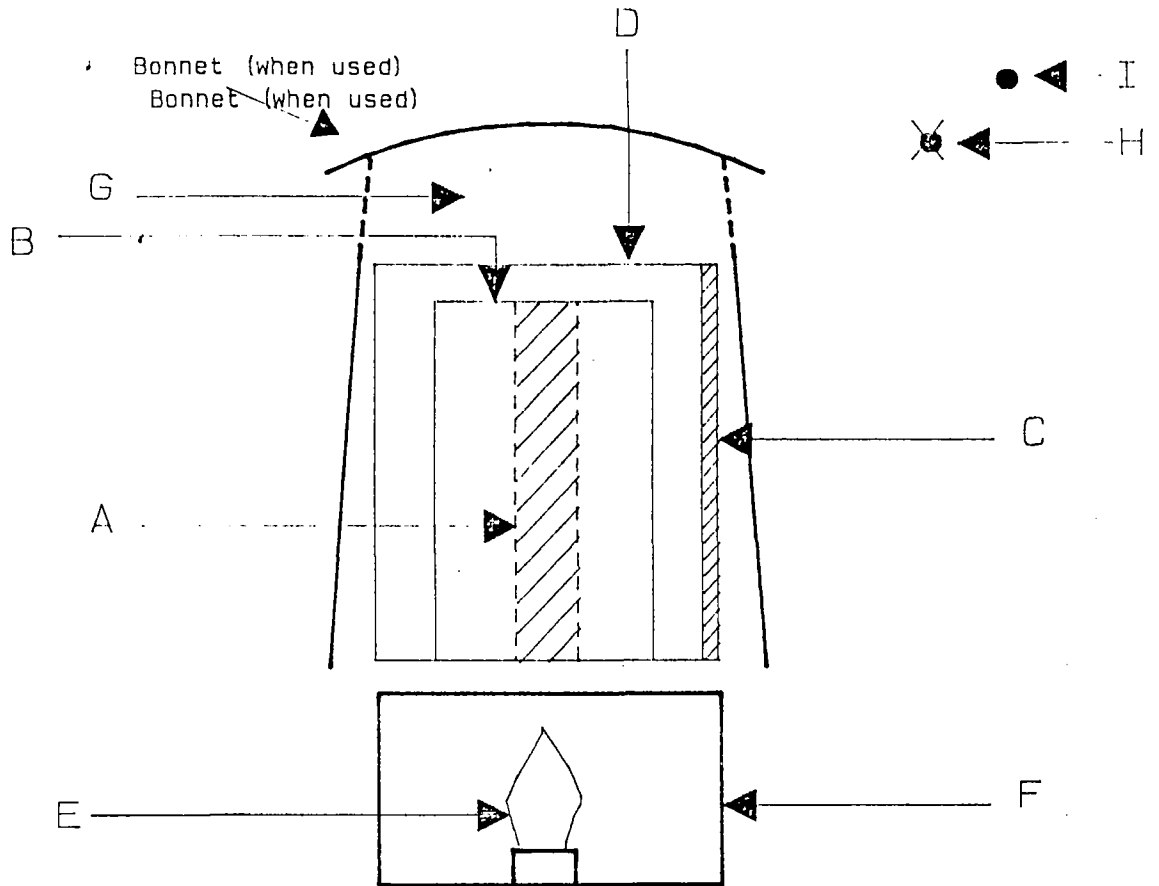
The thermocouples were connected to the recorder via four previously calibrated Fluke 80TK thermocouple modules.

Test Results

The test results are in the form of graphs produced on a YEW 3655 Analysing Recorder. The graphs show that at about 500-600 C the flame passed through the gauzes to the outside atmosphere. An example of the graphical output obtained is shown in Fig 3.4.

Fig 3.5

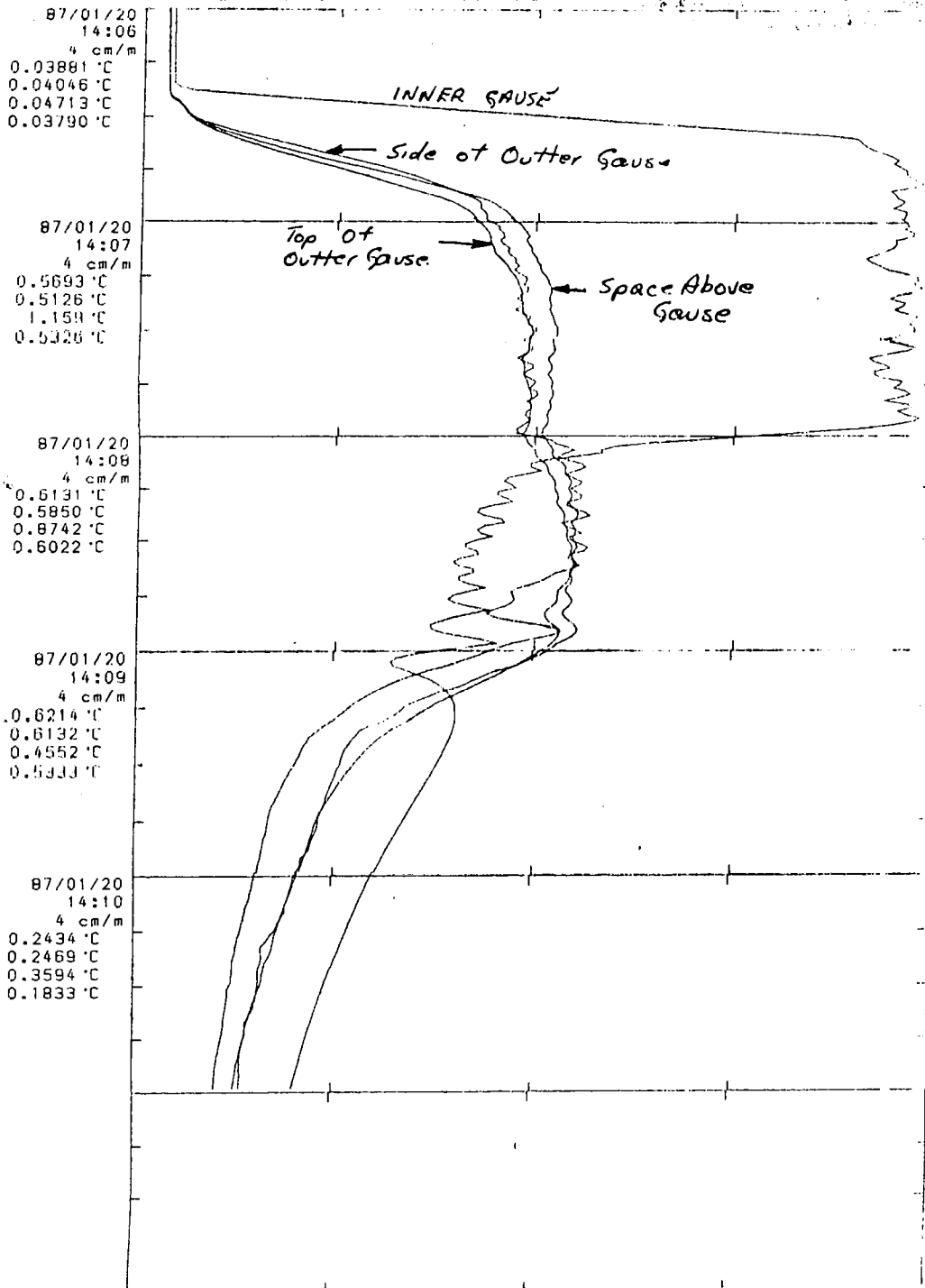
MONITORING FLAME SAFETY LAMP
IN EXPLOSION CHAMBER



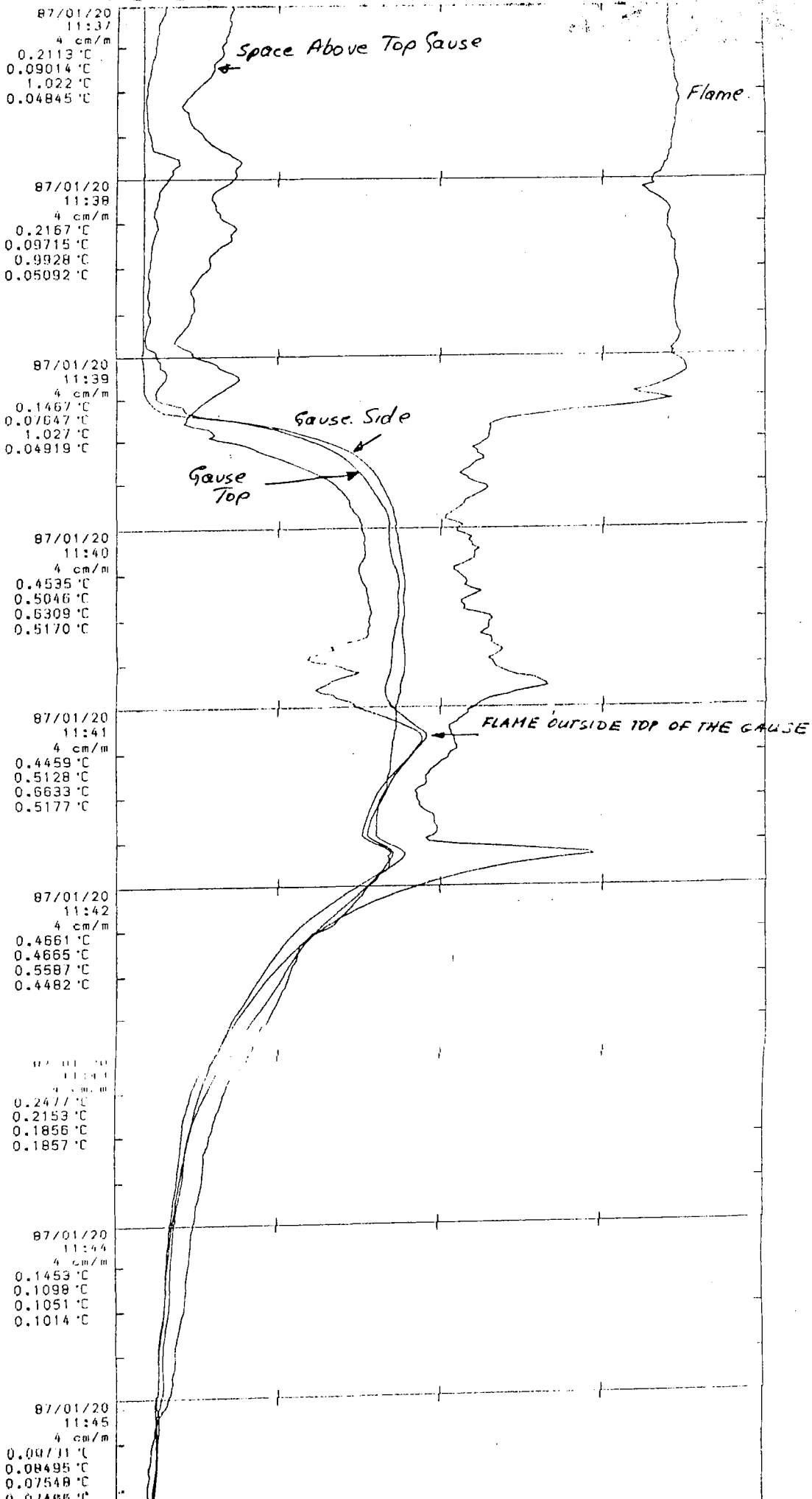
Positions Monitored.

- | | | | |
|---|------------------|---|----------------------------|
| A | Inner gauze seam | F | Inside edge lamp glass |
| B | Inner gauze top | G | Space above outer gauze |
| C | Outer gauze seam | H | Duct air temp. |
| D | Outer gauze top | I | Ambient temp. outside duct |
| E | Flame | | |

FLAME SAFETY LAMP TESTS



FLAME SAFETY LAMP TEST VERTICAL POSITION



4.1

MISCELLANEOUS TESTS

Investigators	K.Harris	Instrument Technician
	C.Rowan	Laboratory Technician
	P.Golledge	Director(Supervisor)

Test 1 Determine Effect of Heat on Gauze Colour

Tests were conducted on:
Stainless Steel Gauze
Stainless Steel Strip
Miners Safety Lamp Gauze

Equipment Used

Carbolite LMF Muffle oven.
Analogue Devices digital Temp Meter.
Fluke 80TK TC Module & 8024B D.M.M.
Kaye K140-4 Ice Point Reference.
Promac Calibrator.

Equipment specifications and the method of calibration are detailed in Section V of this report.

Test Samples

Three types of test samples were used

Sample A Stainless Steel Gauze
Sample Size 50mm x 100mm
Wire Size
Gauze Size

Sample B Stainless Steel Strip
5mm x 100mm x 1mm

Sample C Safety Lamp Gauze
Sample Size 35mm x 110mm
Wire Size 0.32 mm
Gauze Size 0.530mm

Each Sample was cleaned in a light solution of HNO₃ and allowed to air dry before being placed in the oven.

4.2

Test Methods

The temperature measuring equipment was calibrated as outlined in Section V.

A triangular support was placed in the Carbolite Muffle to support the test pieces clear of oven floor as in Fig 4.1.

The thermocouple probes for the two temperature meters used were placed under the support and spaced apart so that their contact point with the gauze was equidistant from each end of the sample.

When the strip of stainless steel was placed in the oven it was put on the support so that it would be touching, or as close as possible to the thermocouple tips.

A small bucket of water was kept close to the oven so that when the samples were removed from the oven they could be quickly quenched.

It was determined that the samples should be heated in 50 C steps beginning with 100 C.

The oven controller was advanced in small increments to avoid overshooting the desired temperature. As the oven approached the desired temperature the controller was backed off and the temperature maintained with + 1 C of the reading by opening and closing the furnace door in small amounts. When the temperature rose more than 1 C above the desired value the door would be opened until it fell 1 C below the desired value.

The sample was then quickly placed in the oven on the triangular stand so that the thermocouples touched or were as near to the sample as possible.

Each sample was held in the oven at the desired temperature for 2 minutes. After this time it was quickly removed and quenched in a small container of cool water which was placed next to the oven.

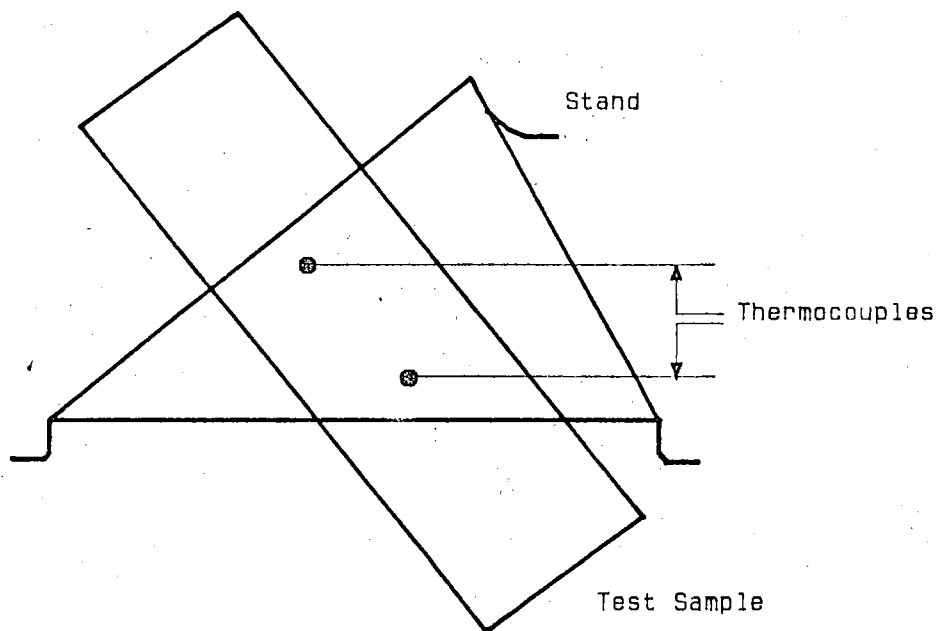
The sample was then allowed to air dry then it was labelled with an identification letter and the temperature at which it was removed from the oven.

This procedure was repeated for each sample type.

Revised?

Fig. 4.1

POSITION OF THERMOCOUPLE ON GAUZE TEST STRIP



RESULTS

A table of the samples with corrected temperature reading is supplied in Table 4.1 below.

Table 4.1

Gauze Samples and Temperatures

Sample	80TK/AD2051		Actual Temp (C)
A	402	401	400
B	451	449	449
C	497	491	492
D	555	546	548
E	605	595	596
F	660	650	650
G	705	696	696
H	760	751	750
I	808	800	800
J	828	821	822
K	861	850	850
L	905	896	896
M	955	950	950
N	1007	997	998
O	1001	991	991
P	1003	994	994
Q	1055	1050	1050
R	1106	1104	1104
S	1153	1150	1150
T	1193	1212	1210

4.5

Test 2 Measure Adherence of Coal Particles on Glass of Flame Safety Lamp With Bunsen Burner Flame.

Investigators - C. Rowan Laboratory Technician
 - K. Harris Instrument Technician
 - J. Brough Testing Officer
 - P. Lynch Chemist
 - S. Bell Senior Chemist (Supervisor)

Test Method 2

The lamp glass was heated in a Carbolite Muffle Oven to a set temperature and then quickly removed and placed on its side 2cm below a bunsen burner flame. Coal dust from Moura mine (less than 75 micron diameter) was sprinkled through the flame on to the surface of the hot glass

Test Results

The results are outlined in Table 4.2 below:

Table 4.2

Glass Temperature and Particle Adherence

Glass Temperature (C)	Adherence
80	nil
175	nil
370	nil
500	nil
680*	partial adherence

* The deformation temperature of borosilicate glass is quoted in the literature (5) as approximately 650 C.

On the basis of gravitational force hot coal particles do not start adhering to the glass until the temperature of the glass surface is near to the deformation temperature of the glass.

*Roll hot glass
in coal dust
See p 4.7
slightly different
experiment*

4.6

Test 3 Measure Rate of Transfer of Heat Across Wall of Lamp Glass.

Investigators - As above.

Test Method 3

The lamp glass was heated with a bunsen burner flame on its outer surface at a temperature of 1150 C. The temperature of the inside wall of the glass was measured by a thermocouple in contact with the surface and connected to an instrument adjusted to give a digital temperature measurement. Time was measured with a digital stopwatch.

Test Results

The results are given in Table 4.3 below:

Table 4.3

Heat Movement Through Lamp Glass

External Flame Temperature C	Inside Glass Temperature C	Time to Reach Recorded Temp (sec)
1150	270	28.8
1150	450	50.4

A relatively long period of time is necessary for the inside surface of the glass to attain a temperature where explosion particles would adhere to the inside surface of the glass. This is particularly so if the heat source is external to the flame safety lamp.

*Would not
the speed of a
flame front
from an
explosion
enter a lamp
without prob*

4.7

Test 4 Measure Adherence of Particles on Glass of Flame Safety Lamp with Oxy Acetylene Flame.

Investigators - As above.

Test Method 4

Tests were carried out using an oxy-acetylene flame as the heat source. The flame was passed 1cm above a lamp glass at room temperature and at the same height above a glass at 500 C. Less than 75 micron coal was sieved through the flame and the temperature of the glass was noted.

The results are given in Table 4.4 below:

Table 4.4

Particle Adherence in Oxy Acetylene Flame

Outside Glass Temperature C	Adherence
200	nil
480	nil

The inner and outer surfaces of the glass were coated with coal dust (75 micron) and an oxy-acetylene flame (approx 2 000 C) was passed over the glass several times. This procedure proved to be unsuccessful due to extreme heat provided by the oxy-acetylene flame. In all cases the glass cracked before any cogent measurements could be made.

Test 5 - Measure Temperature for Explosion in Chamber for Electrically Heated Gauze.

Test Method 5

Section I of the chamber was modified by the inclusion of two high current terminals in the roof of the chamber.

The outer lamp gauze was accurately cut in a spiral with the assistance of the lathe and high speed abrasive disc. High current connections were made to the top of the gauze and the lower metal ring. A ceramic core was used to support the spiral metal strip.

Was his design to provide a resistor path? Whole section heated.

Thermocouple probes were attached to the position shown in Fig 4.2 and connected to recorders. High current was supplied through a variac which was connected to a welding transformer.

Methane was injected to the desired percentage by volume, the vane mixer turned on a weighed amount of dust injected as required. Voltage was gradually increased to increase the temperature of the gauze.

The test was repeated for various combinations of methane and coal dust.

Test Results

The results of 13 explosion tests are shown in Table 4.4 and 4.5 overleaf. The results of the tests are shown in Fig 4.3 and typical graphs in Fig 4.4 to Fig 4.11.

Table 4.3

Gauze Temperatures for Methane/Coal Dust Explosion Probe

- Probe Location
- TS - Top Seam
- SG - Side of Gauze
- RG - Rear of Gauze
- BS - Bottom Seam

Coal Dust 100% < 75 micron diameter

CH4 %	Coal Dust g/m3	Temperature (c) at				Ave Temp (C)
		TS	SG	BS	RG	
7.0	0	442	460	327	659	472
7.8	0	814	675	639	869	749
8.4	0	750	562	437	775	631
5.2	150	306	273	164	338	270
4.2	150	273	259	161	313	251

Gas only

Why these as low? area? combustibility?

Table 4.4

Gauze Temperatures for Methane Coal Dust Explosion

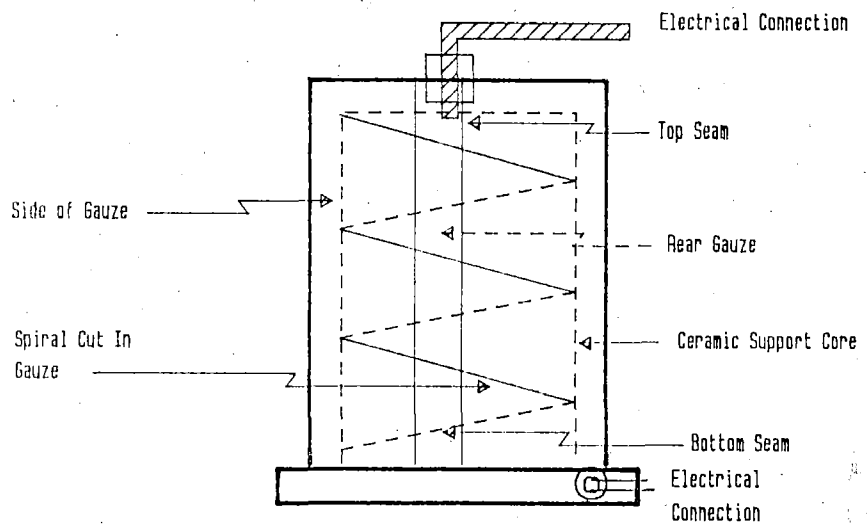
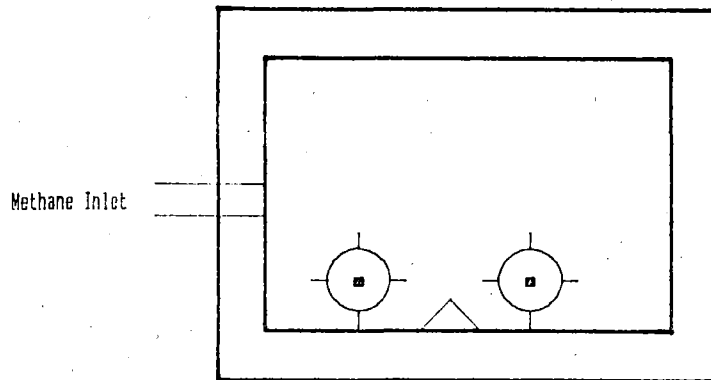
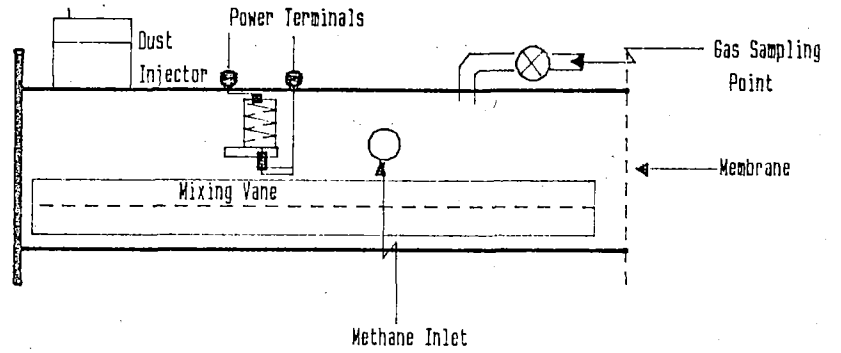
Probe Location
 TS - Top Seam Coal Dust 100% < 75 micron diameter
 LH - Left Hand Side Gauze
 RH - Right Hand Side Gauze
 BS - Bottom of Seam

CH4 %	Coal Dust mg/m3	Temperature (C) at				Ave Temp (C)
		TS	LH	RH	BS	
3.2	100	701	828	831	584	736
45.1	100	721	775	810	496	700
45.5	100	751	830	870	561	753
5.1	200	721	811	876	482	723
5.1	200	626	805	847	484	690

* No ignition of methane/coal dust cloud

The results are very preliminary. Many more tests would be needed to establish the statistical significance and confidence of the ignition temperature for methane/coal dust concentrations.

Fig 4.2
IGNITION BY ELECTRICALLY HEATED GAUZE
IN EXPLOSION CHAMBER

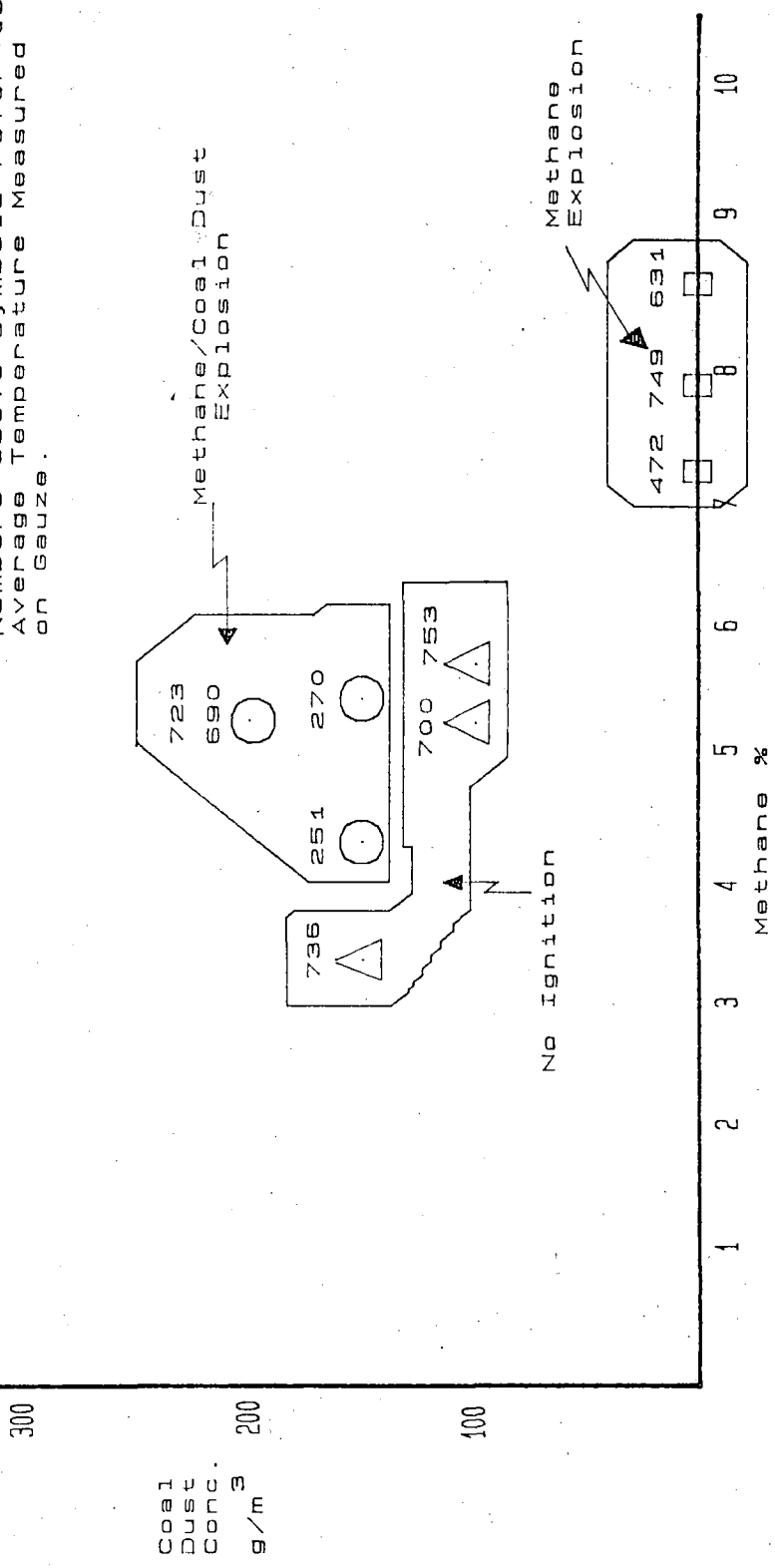


Section Of Gauze
Cut in Spirial

Fig 4.3

EXPLOSION TEMPERATURE ON GAUZE MOURA DUST

Numbers above symbols refer to Average Temperature Measured on Gauze.



MODEL 3655 LIST

MODE : MEMORY
 SAMPLE RATE : 100.00 ms

***** SET RANGE *****

CH.	INPUT	RANGE	FILTER
A	TEMP	K	1.5Hz
B	TEMP	K	1.5Hz
C	TEMP	K	1.5Hz
D	TEMP	K	1.5Hz

***** SET TRIGGER *****

TRIGGER LEVEL : 0%
 TRIGGER SOURCE : A
 TRIGGER SLOPE : POS
 PRE TRIGGER : 0%
 SAMPLE CLOCK : INT
 BUFFER MEMORY : 8000
 AVERAGING : OFF

***** SET PROGRAM *****

PROGRAM : ON

	UNIT	LOW	HIGH	
Y1 = A	°C	0.000	1200	
Y2 = B	°C	0.000	1200	
Y3 = C	°C	0.000	1200	
Y4 = D	°C	0.000	1200	
F = 0.000	G = 0.000	H = 0.000	I = 0.000	J = 0.000
K = 0.000	L = 0.000	M = 0.000	N = 0.000	O = 0.000
P = 0.000	Q = 0.000	R = 0.000	S = 0.000	T = 0.000

***** SET DISPLAY FORMAT *****

DISPLAY MODE : SINGLE

1 : Y1
 2 : Y2
 3 : Y3
 4 : Y4

***** OVER VIEW *****

NO. OF CHANNELS : 4
 BUFFER MEMORY : 32000
 GP-IB : YES
 DATA MEMORY MODULE : YES
 APPLICATION MODULE : FFT MODULE (3659-20)

***** SET MISC *****

DATE : 87/02/16
 TIME : 09:38
 ALARM BEEP : ON
 INITIALIZE :
 SELF TEST :

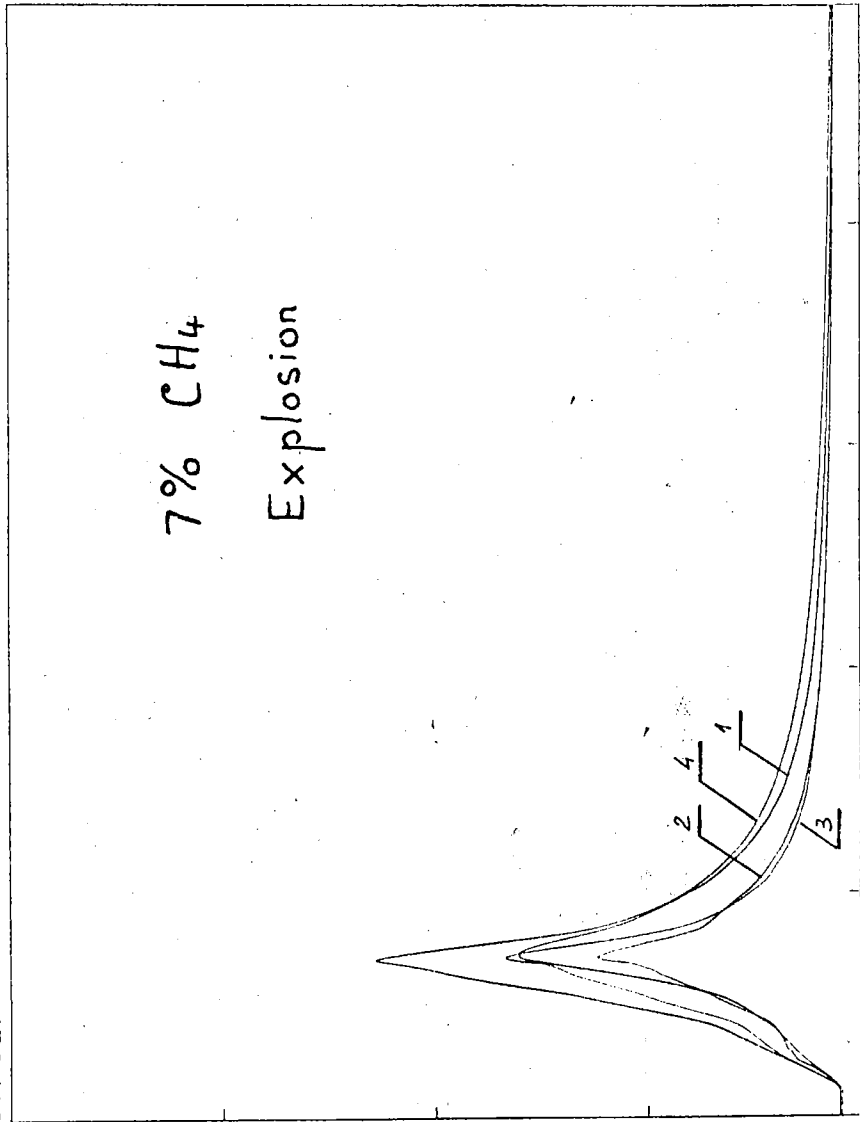
Fig 4.4

12/3

13/2/87

M O T O I B S / G 12/3
87/02/13 15:31 SAMPLE:100.00 ms

1200 °C
1200 °C
1200 °C
1200 °C



0.000
0.000
0.000
0.000

800.00s

1 - TOP SEAM
2 - BOT. SEAM

3 - SIDE
4 - REAR

Fig 4.5

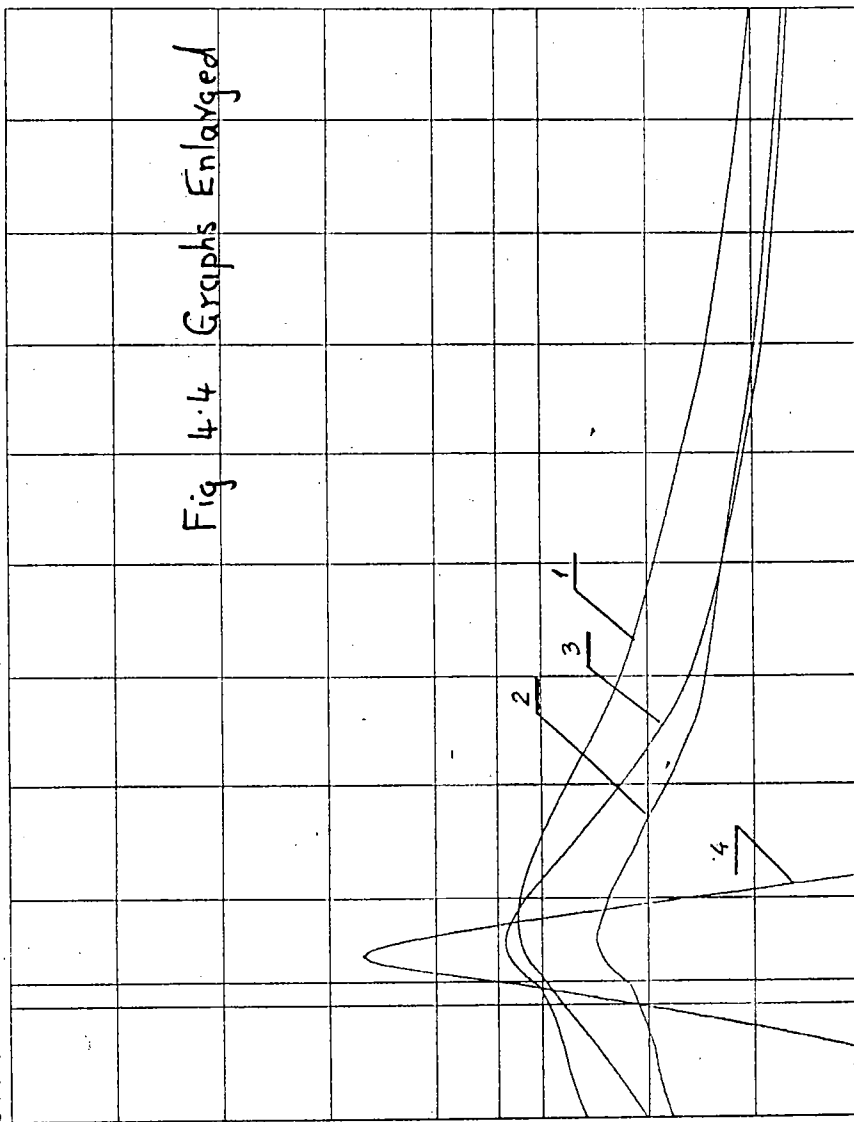
12/3
13/2/87

12/3

M O T O I B S / G
87/02/13 15:31 SAMPLE:100.00 ms

1200 °C
1200 °C
1200 °C
747.2 °C

Fig 4.4 Graphs Enlarged



661.3

0.000
0.000
0.000
597.2

97.3 109.5 197.3s

1 - TOP SEAM
2 - BOT. SEAM
3 - SIDE
4 - REAR

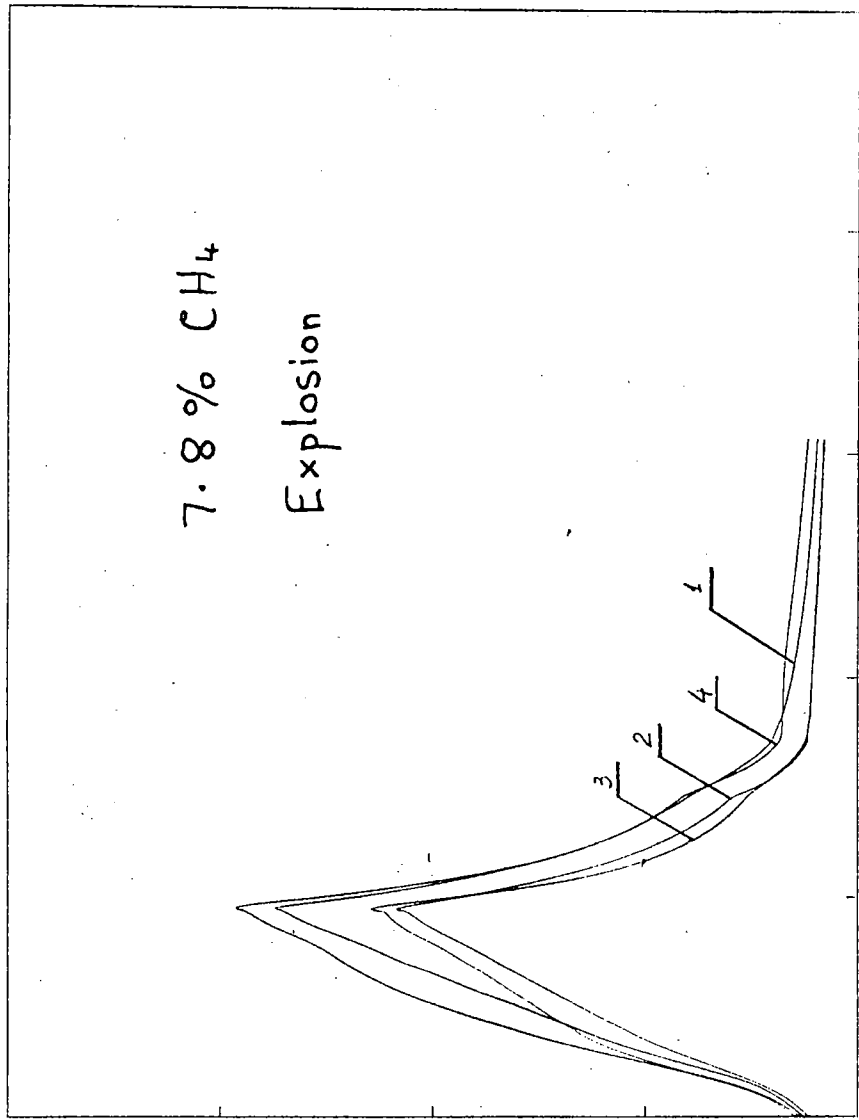
Fig 4.6

12/4

16/2/87

M O T O I B S / G 12/4
87/02/16 09:52 SAMPLE:100.00 ms

1200 °C
1200 °C
1200 °C
1200 °C



0.0

1 - TOP SEAM
2 - BOT. SEAM

3 - SIDE
4 - REAR

600.0s

12/4
16/2/87

Fig 4.7

12/4

M O T O I B S / G
87/02/16 09:52 SAMPLE:100.00 ms

1200 °C
1200 °C
1200 °C
915.5 °C

675.0

0.000
0.000
0.000
735.5

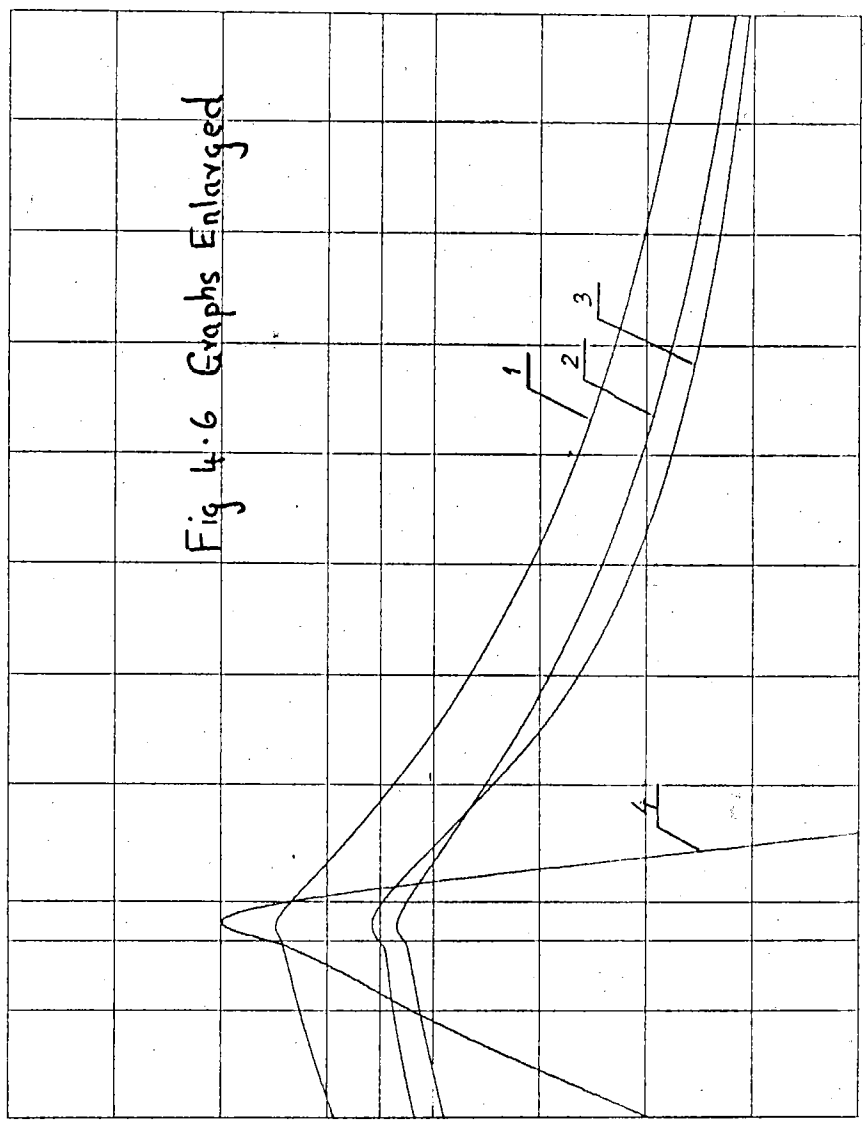


Fig 4.6 Graphs Enlarged

133.1 149.6 233.1s

1 - TOP SEAM
2 - BOT. SEAM

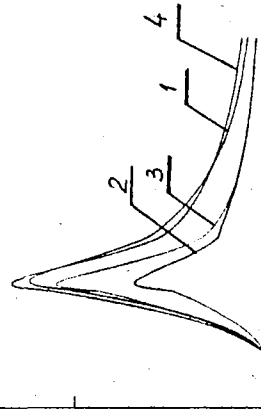
3 - SIDE
4 - REAR

Fig 4.8

M O T O I B S / G 12/6
87/02/16 11:35 SAMPLE:100.00 ms

1200 °C
1200 °C
1200 °C
1200 °C

5.2% CH₄
150g Coal Dust
Explosion



0.000
0.000
0.000
0.000

800.0s

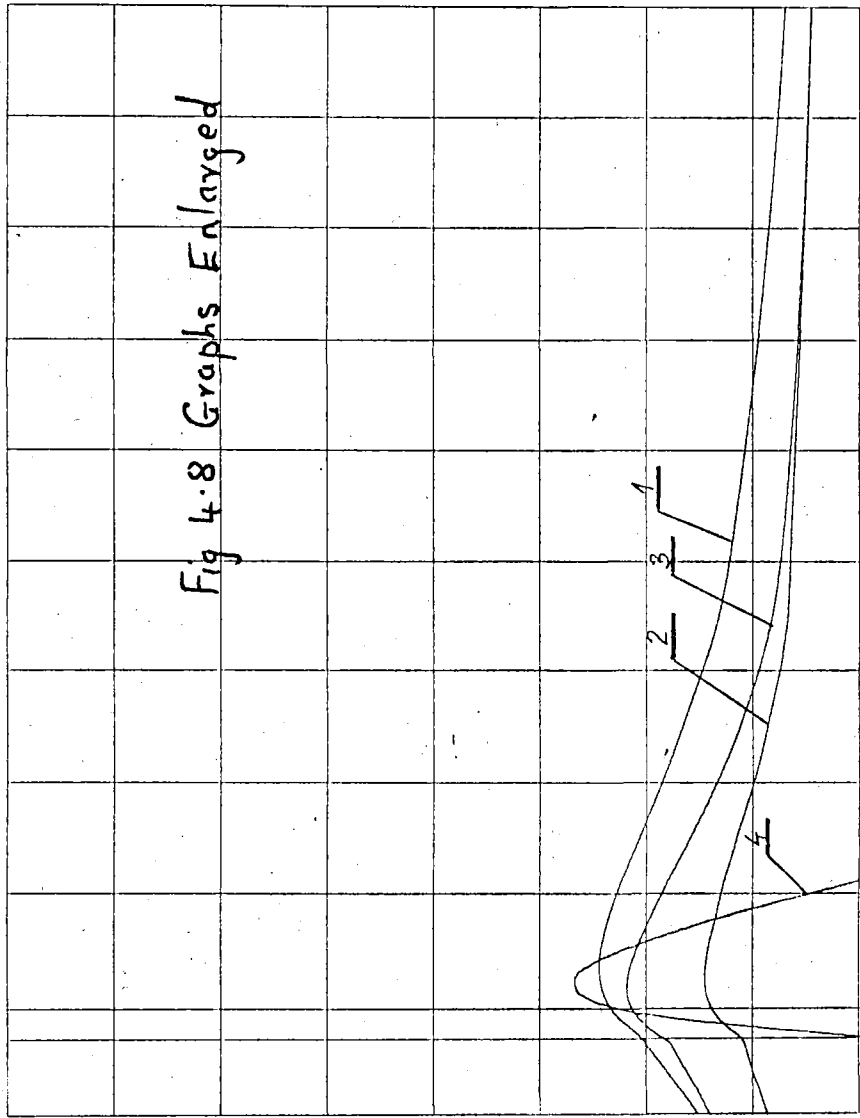
1 - TOP SEAM
2 - BOT. SEAM
3 - SIDE
4 - REAR

Fig 4.9

M O T O I B S / G 12/6
87/02/16 11:35 SAMPLE:100.00 ms

1200 .C
1200 .C
1200 .C
491.8 .C

Fig 4.8 Graphs Enlarged



338.7

0.000
0.000
0.000
341.8

77.7 84.9 177.7s

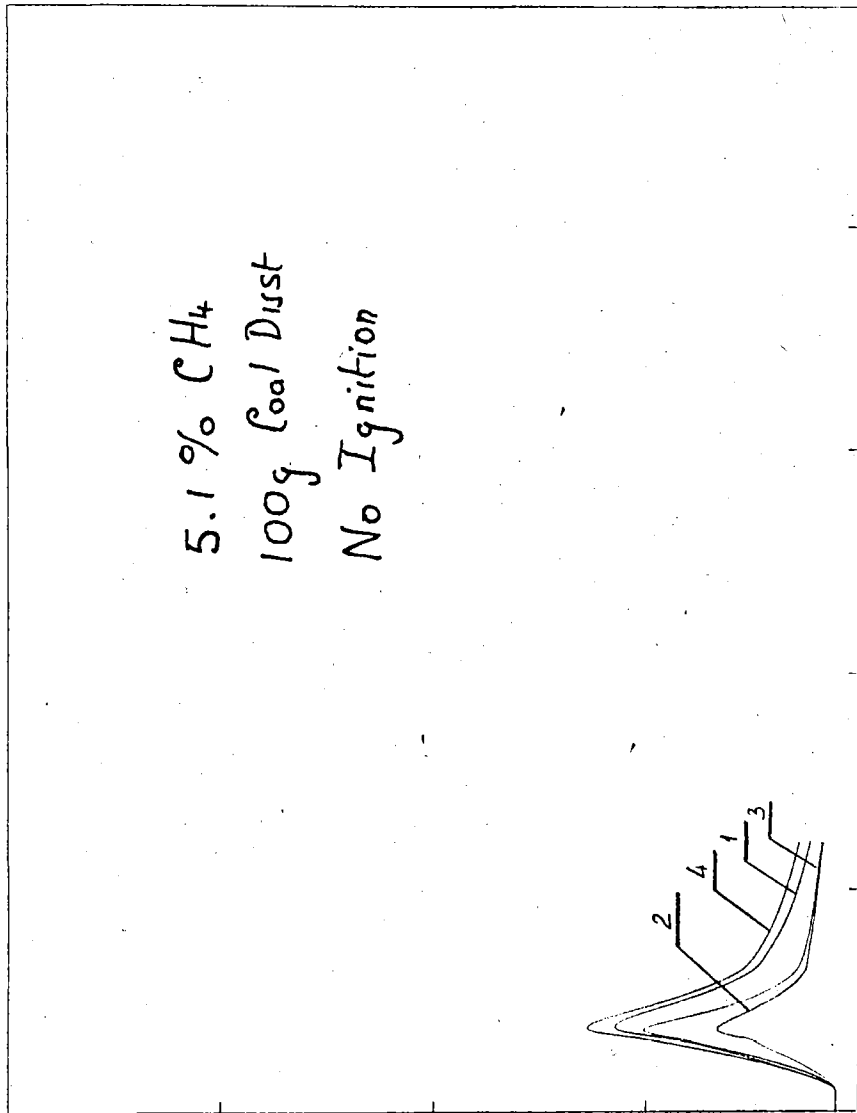
1 - TOP SEAM
2 - BOT. SEAM

3 - SIDE
4 - REAR

Fig 4-10

M O T O I B S / G 12/7
87/02/16 12:11 SAMPLE:100.00 ms

1200 °C
1200 °C
1200 °C
1200 °C



0.000
0.000
0.000
0.000

800.0s

0.0

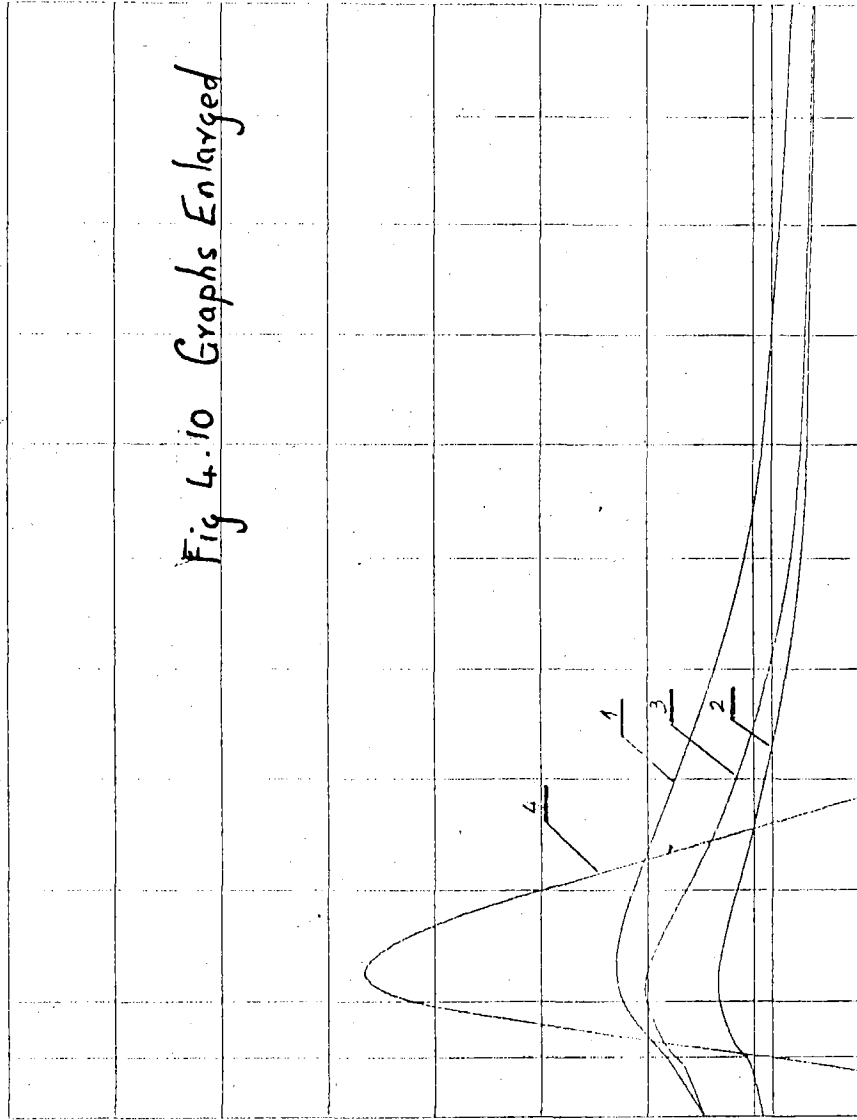
1 - TOP SEAM
2 - BOT. SEAM
3 - SIDE
4 - REAR

Fig 4.11

M O T O I E S / G 12/7
87/02/16 12:11 SAMPLE:100.00 ms

1200 .C
1200 .C
1200 .C
447.2 .C

Fig 4.10 Graphs Enlarged



312.8

0.000
0.000
0.000
297.2

49.2 54.5 149.2s
1 - TOP SEAM 3 - SIDE
2 - BOT. SEAM 4 - REAR

5.1

SECTION V

INSTRUMENT CALIBRATION

Investigators K.Harris Instrument Technician
 G.Hislop Senior Inspector (Supervisor)

Equipment Used

Two instruments were used for calibrating the other measuring and recording instruments used in many of the tests carried out at the Station.

They were the Kaye K140-4 Ice Point Reference and the Promac DHT 820 Calibrator.

The Kaye K140-5 Ice Point Reference was used as the 0 C reference point for calibration purposes.

The Promac DHT 820 Calibrator was used to inject a varying range of temperatures into the test equipment for calibration purposes.

A separate calibration procedure was used for each type test and was suited to the range and type of test equipment used.

Specifications of the Calibration and Test equipment is given at the end of this Section.

Conditions for calibration

Temp 24.8 C
Rel Humidity 52%
Dew Point 14.7
YEW Digital Hygrometer

Temp 25.0 C
Bar Pressure 1008 mbar
A.J. Franklin
Standard Barometer

5.2

Test 1 Calibration of YEW 3655 Recorder for Temp Measurements

Four Fluke 80TK thermocouple modules were selected and numbered A.B.C.D. These modules were then turned on and allowed to stabilised for 1 hour.

Each Module was then connected in turn to a thermocouple which was placed in the Kaye 140-4 Ice Point Reference and the zero adjustment on each module was set to give the best possible reading at 0 C.

A Fluke 80240 DMM was selected and turned on, then the 80TK modules were in turn plugged into the V.DC. input sockets of the meter.

Each 80TK module was then connected to the PROMAC DHT820 Calibrator and injected with a range of temperatures.

Below is a list of the test results.

Temp	80TK Module			
	A	B	C	D
0 C	-.84	0.79	0.85	0.73
500 C	503.7	504.0	503.7	504.0
750 C	761.8	761.9	761.8	762.2
1000 C	1007.7	1007.7	1007.5	1008.1

After this procedure, the 80TK modules were then plugged into the YEW 3655 recorder with module A in channel A etc. The recorder was turned on and allowed to stabilise for 1 hour. When the parameters of the test set up on the 3655 had been programmed in a test chart was done by injecting a ramping temperature into the recorders four channel simultaneously.

The ramp step for each of the tests was 100 C starting at 0 C a top range of 1300 C. A chart of the Recorder/80TK module response is attached to this report as the result of this calibration procedure.

Once this calibration was completed the 80TK modules remained in their respective channel throughout all the tests involving the YEW 3655 recorder.

5.3

Test 2 Calibration of HIOKI 8801 Hi Corder for Temp Measurements

The same procedure was carried out for calibrating the Hioki recorder. Four 80TK modules were selected and calibrated using the 8024B DMM. Below is a list of these results.

Temp	E	F	G	H
0 C	0.72	0.86	0.74	0.79
500 C	503.6	504.0	503.8	503.7
750 C	761.7	761.7	762.0	761.9
1000 C	1007.6	1007.7	1007.5	1008.0

Once calibrated the modules were placed in the HIOKI 8801 Recorders in the following order and remained in this position throughout all tests involving the HIOKI 8801 recorder.

Channel	Mark
1	E
2	F
3	G
4	H

The recorder was turned on and allowed 1 hour to stabilise. The Promac DHT 820 was programmed for a temperature ramp from 0 C to 1000 C in 100 C steps. This ramp was fed into all four channels of the recorder at the same time. A chart of the recorder/80TK module response is attached to this report as the result of these tests.

5.4

Test 3 Calibration of Analogue Devices & Fluke 8024B/80TK meters for Temperature Measurements

Conditions for Calibration

Temp. 25.2 C

Rel. Humidity 46.0%

Dew Point 25.2

YEW Digital Hygrometer

Temp 25.3 C 25.3 C

Bar Pressure 1010mbar

A.J. Franklin

Standard Barometer

Each instrument was prepared with its own thermocouple, which it retained throughout the tests, and allowed 30 minutes to stabilise at room temperature.

The Kaye K140-4 Ice Point Reference was turned on 24 hours before the calibration took place.

The PROMAC Calibrator was turned on for one hour and allowed to stabilise at room temperature. The required stabilising time is 60 seconds for all ranges to rated accuracies.

Both meter thermocouple probes were placed in the Kaye Ice Point Reference both along with a standard capillary type thermometer. The thermometers range was -40 C to +50 C.

After ten minutes and with the Ice Point stabilised, readings were taken on the meters as below.

B0TK	001.3 C
AD2051	000.0 C

The B0TK Module was adjusted so that the meter read +000.7 C.

There was no adjustment of zero 0 C setting done on the AD2051.

After setting the ICE POINT on both meters they were in turn connected to the PROMAC calibrator, and injected, via thermocouple cable with temperatures ranging from 50 C to 1200 C. The meters were found to be within specifications and the results are listed in the Table below.

5.5

Table 5.1

Results of Calibration of Analogue Devices and FLUKE Meters

Analogue Device		FLUKE Meter	
Input	Reading	Input	Reading
0	-001	0	00.5
50	+ .49	50	49.3
100	+098	100	99.7
150	+149	150	150.0
200	+199	200	198.8
250	+249	250	248
300	+299	300	298
350	+349	350	349
400	+400	400	401
450	+499	450	452
500	+499	500	504
550	+549	550	556
600	+599	600	608
650	+649	650	660
700	+699	700	711
750	+749	750	762
800	+799	800	813
850	+849	850	862
900	+899	900	912
950	+949	950	960
1 000	+999	1 000	1 008
1 050	+1049	1 050	1 055
1 100	+1099	1 100	1 102
1 150	+1149	1 150	1 148
1 200	+1199	1 200	1 193
1 250	+1248/9	1 250	1 237
1 300	+EEE	1 300	1 280

Specifications of Equipment used in Tests

Oven

Carbolite Muffle Oven
 Type LMF 12/3 + 103.
 Temperature Range Ambient - 100 C
 Controller Urotherm Type 103

Temperature Meters

Analogue Devices AD2051

Range -50 to 1250 C

Thermocouple Type K Pin Junction TC. Accuracy $\pm 9\text{ C} + 1/2$
 LSD. *

* Includes All Conformity Errors,
 CJC Errors, Gain Errors
 and Gain Errors.

Fluke 80TK Thermocouple Modules

Range 0 to 1000 C.

Thermocouple Type K. Pin Junction TC.

Accuracy $2\% + 2\text{ C}.$

Fluke 8024B Digital Multi-meter

Range 0-2V DC

Accuracy .1% of Reading +1 Digit

Reference Calibrators

Kaye K140-4 Ice Point Reference

Accuracy at 0 C + 0.01 C

Stability + 0.025 C

Drift with Time None

Total Instrument Error 0.02%

5.7

Promac Calibrator

Type K Thermocouple Range

Range 0 - 1316 C

Accuracy + 0.033 C

Cold Junction X20-CJTS

-20 to 45 C

Accuracy + 0.1 C at 25 C

Deviation + 0.01 C/ C

Readout 0 - 10 000

Accuracy + 0.015 +1 Digit with 10 000 Displayed

Overall Accuracy of Temp Range + Comp + Readout + 0.03%

Repeatability in All Ranges + 0.03%

SECTION VI

ANALYSIS OF RESULTS OF TESTS

From all the evidence gathered during the investigations at the Testing and Research Station the following facts have emerged:

1. The flame safety lamp involved in the Moura No 4 mine explosion was damaged externally during the explosion. At the time of examination of the lamp the critical safety components of the lamp appeared to be in a safe condition.
2. The inner and outer gauzes of the Moura lamp had been subjected to a source of heat of sufficient intensity and duration to have raised the temperature of the outer surface of the wire to a temperature of about 900 C. An identical assembled flame safety lamp, when exposed to the flame of a methane or methane/coal dust explosion in the explosion chamber, showed that the intensity and duration of heat was insufficient to completely char a small piece of tissue paper which had been placed on top of the outer gauze prior to re-assembly of the lamp. A piece of tissue paper placed above the inner gauze of the lamp during the same test showed no discolouration, or evidence of charring.
3. It is suggested that the even coating of dust 'fused' to the internal surface of the glass and bonnet of the Moura lamp would only occur if an explosion or severe heating had occurred inside the lamp. Evidence obtained from investigations carried out at the Station shows that when an object is placed in an exploded dust cloud even as close as 2m from the ignition source the pattern of dust deposition on the surface of the safety lamp is asymmetrical. There is always more dust on the surface facing the flame and little or no dust on the downstream surface. From any external coal dust explosion there was no evidence either visually or at the submicroscopic level of any deposit of exploded dust on the inside of either lamp glass or metal bonnet. For even deposition of dust to occur on the outer surface of the lamp bonnet the lamp must have been in such a position that the flame velocity was at or very close to zero. This very strongly suggests that the lamp was the source of ignition.

*What
conclusion.*

Experimental

4. The bonnet from the Moura lamp was not discoloured by exposure to the heat of the explosion at the mine. A similar bonnet was not discoloured during two of the Station explosion tests but there was some discolouration during a third explosion test. In all three Station methane/coal dust explosion tests the flame was present around the lamp for almost one second.

discoloration

Efficient mixing of the mine atmosphere, coal dust and methane is unlikely to be achieved in the mine due to a number of factors. For this reason the temperatures experienced at Moura during the explosion could be lower than those achieved under controlled laboratory conditions. However the flame length would probably have been longer and the time for its passage therefore increased. Time in this context relates to a few seconds rather than the one second of the laboratory. This could account for the absence of discolouration in the Moura lamp.

— ?

5. Electron microscopic examination of dust samples from the inner and outer lamp glass surface shows quite clear evidence that the dust has been exposed to very high temperature with particle surface characteristics typical of exploded coal dust.

S. Bell report.

6. Repeated experiments have demonstrated that methane/coal explosions can occur within the flame safety lamp. Such explosions can occur with the bonnet on or off and with the lamp in any position between vertical and 45° in a dust concentration as low as 50 gm per cubic metre and with a methane concentration as low as 3%. Explosions can occur within seconds of exposure to a methane/coal dust concentration and can continue within the lamp for some minutes after the flame of the lamp has been extinguished.

See test
for lamp
gas confined
to explode

7. Repeated experiments have demonstrated that small explosions occurring inside the lamp appear to have the same flame intensity as occurred in experimental methane/coal dust explosions in the explosion chamber. Such explosions cause heating of both inner and outer gauzes to a temperature in excess of 900 C for time periods far in excess of that necessary to initiate either a methane, coal dust or methane/coal dust explosion.

← Has this been measured in lab or by Uni

8. It would appear from our investigations that fusing of the dust to the cold surface of the lamp glass or bonnet will only occur if both dust particles and the glass and metal surfaces are at fairly high temperature albeit for a relatively short period of time.

What conditions
demonstrated

There is no experimental evidence from our investigations at the Station to support any hypothesis that the internal surfaces of the Moura lamp were coated by dust from an external explosion.

9. It has been determined from our investigations by different methods that the lamp gauze will initiate a methane explosion if its whole surface is heated to a temperature between 650 and 700 C. For a mixture of 4.2% methane and 150g/m³ of Moura coal dust the average gauge temperature was between 251 and 270 C.

Table 4.3

page 4.8

Test 7.80

CH₄ 749°C

10. There is ample evidence both from direct temperature measurement and video tape records of flame lamp explosions that the metal strip which joins the mesh together acts as a heat reservoir and provides the heat source for continuous coal dust explosions inside the lamp. Passage of the explosions from within the inner gauze to the superincumbent space between the inner and outer gauzes has been demonstrated.

Results? page?

11. With methane concentrations up to the point of extinction of the flame, the outer gauze temperature did not exceed 105 C while the maximum recorded on the inner gauze was 435 C at the metal strip.

OK

12. Owing to the difficulty of maintaining an airborne dust cloud above the lower explosive limit and the inability to monitor dust concentration continually during the experiments it has not been possible to demonstrate an explosion in the chamber with the lamp as an ignition source. This probably could be achieved at the Station but would require redesign of the explosion chamber which time and other resources did not permit.

13. The thickness of the particle film 'fused' to the inner surface of the lamp glass suggests that the coal dust concentration prior to the explosion in the flame safety lamp was relatively high. Some light fusing of dust on interior surface of the glass was achieved during the investigations but nowhere near the density observed in the lamp from the Moura mine.

Conditions?

P. 4.5
680°C

14. The flame safety lamp at Moura mine was found in a position very close to the area which showed the greatest loss of volatile content of the samples of coal dust. It is usually accepted that the flame in a coal mine explosion has maximum exposure to the coal particles in the area of the ignition source where the flame velocity is initially zero.

Were there not places of equal low volatiles

Dust also moves and is not absolute as an indicator

Do not ignore other indicators of flow/process heat.

APPENDIX 1

Extract of Statistical Analysis

STATISTICAL INTERPRETATION OF
CHEMICAL ANALYSIS
FOR
MOURA MINE DUST SAMPLES

Prepared by
Anne De Corso
Statistician, S.I.M.T.A.R.S.

A. De Corso
26 November, 1986

SECTION 4

SUMMARY

The analysis of data must be conducted separately for floor and rib samples in order to remove the possibility of misinterpreting effects due to the different sample composition as effects due to a coal dust explosion.

The lack of conclusive evidence from ZIC should not be surprising, because the ZIC in each sample is heavily influenced by how recently the area, where the sample was from, had been stone dusted.

A priori, it is expected that % Dry Ash Free Volatile is fairly uniform and that variation in ZDAEV is due to extensive heating. When the coal dust is subjected to a form of extensive heating the ZDAEV of the dust decreases.

The particles sized <250 were most sensitive in reflecting variation in ZDAEV. For these particles we found

a close correlation between increasing ZDAEV and the increasing distance from the coal face for

- | | |
|--------------------|----------------|
| Floor samples from | - Belt Road |
| | - South Return |
| | - Supply Road |
| Rib Samples from | - Belt Road |
| | - Supply Road |

Particles sized $<250\mu$ from the Rib were the most sensitive indicators of the differing intensity and degree of variability of ZDAEV for each road, whilst at the same time strongly reflecting the correlation between increasing ZDAEV and increasing distance from the coal face.

Homogeneous groups of ZDAEV of particles sized <250 for the floor and rib samples have been mapped to depict the intensity of the heat effect on coal dust samples, by showing the locations of groupings of low ZDAEV values relative to the higher ZDAEV values.

A complete picture of the changing heat intensity throughout the mine cannot be constructed because it was not possible to get samples from certain critical areas within the mine.

CONCLUSION

When taking the data from the Chemical Analyses into consideration to determine the possible path of the explosion, the ZDAEV values for rib particles sized $<250\mu$ should yield the most reliable information.

REFERENCE

1. Fire Protection Handbook, Thirteenth Edition, 1969.

George H. Tyron, Editor in Chief

George P. McKinnon, Manager Editor.

NATIONAL PROTECTION ASSOCIATION.

APPENDIX 2

Uniquet Report

REPORT

TO

Department of Mines
Safety in Mines
Testing and Research Station
2 Smith Street
REDBANK QLD 4301

ATTENTION: DR P. GOLLEDGE


ON

EXAMINATION OF TWO GAUZES FROM FIRE SAFETY LAMP
MOURA NO. 4 MINE EXPLOSION

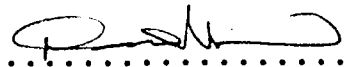
CONTENTS

1. INTRODUCTION
2. ELECTRON MICROPROBE ANALYSIS
3. METALLOGRAPHY
4. DISCUSSION
5. CONCLUSIONS

UNIVERSITY OF QUEENSLAND


.....
Associate Professor I O Smith
Head of Department
Department of Mining &
Metallurgical Engineering

UNIQUEST LIMITED


.....
Mr David G Millhouse
General Manager

309618

22 January 1987

UNIQUEST



1. INTRODUCTION

Two gauzes from a flame safety lamp recovered after the explosion at Moura No. 4 Mine together with two new gauzes for the lamp were supplied for examination. It was requested that the following questions be addressed.

- (a) Were the gauzes exposed at any time to a high temperature?
- (b) Can this temperature be determined?
- (c) Was there any difference in temperature between the inner and outer gauzes?
- (d) Can microprobe analysis identify the product of the gauzes involved in the explosion?

2. ELECTRON MICROPROBE ANALYSIS

A section of the top of the gauze taken from the lamp recovered from Moura No. 4 Mine was examined in the electron microprobe.

The results of this analysis showed the major elements present on the surface of the gauze in addition to iron was calcium. — *limestone?*

Additionally minor amounts of manganese, silicon, sulphur, chlorine, aluminium and potassium were detected.

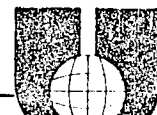
3. METALLOGRAPHY

Cross-sections of the inner and outer gauzes from the lamp involved in the explosion and the new gauze were cut and mounted for metallographic preparation and examination.

Figure 1 shows the section cut from the new gauze. This shows a longitudinal and transverse section of the wire in the gauze which appears to be a ferritic steel. The grain size is uniform across the section of the wire.

Figure 2 shows the section cut from the outer gauze from the lamp recovered from the Moura No. 4 Mine. In this case the grain size is non-uniform across the section. Grain growth has clearly occurred on the outer regions of the wire while the interior of the wire is unaffected.

Figure 3 shows the section cut from the inner gauze from the lamp recovered from the Moura No. 4 Mine. Again the grain size is non-uniform with the outer regions of the wire showing the larger grain size.



4. DISCUSSION

The metallographic structures are consistent with the wire having been exposed to a very high temperature up to about 900°C for a very short period of time. This temperature flash has allowed grain growth in the outer regions of the wire but has not been sustained for a sufficient period to raise the temperature of the interior of the wire to above a temperature of about 500°C.

A comparison of the inner and outer gauzes is complicated by a difference in the quality of the wire used to manufacture the gauze. The wire used in the inner gauze contains many more inclusions and precipitates which would inhibit grain growth. With this complication it is only possible to say that both inner and outer gauzes were subjected to a temperature flash but not to identify any difference in temperature achieved.

Is the
conclus
howev
Temp
longer
time?

Why not
do other
samples

5. CONCLUSIONS

- (1) The dark product on the surface of the gauzes retrieved from the flame safety lamp at the Moura No. 4 Mine has a major content of calcium.
- (2) Other elements in the dark surface layer are manganese, silicon, sulphur, chlorine, aluminium and potassium.
- /// (3) The gauzes show a structure consistent with exposure to a very high temperature for a very short time.

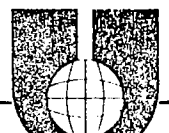
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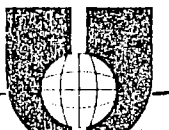
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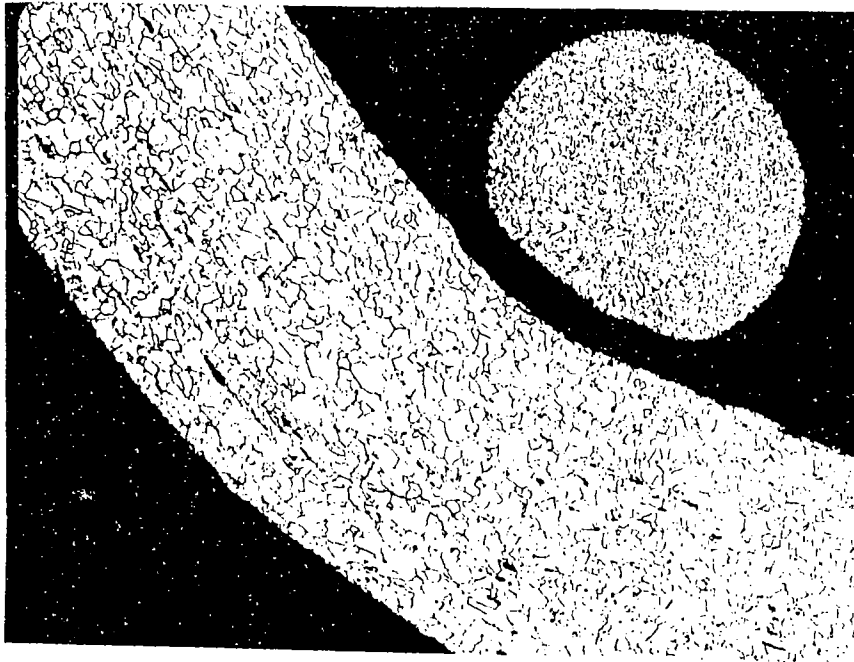


Figure 1: A metallographic section of the new gauze showing a uniform grain structure (x 120).

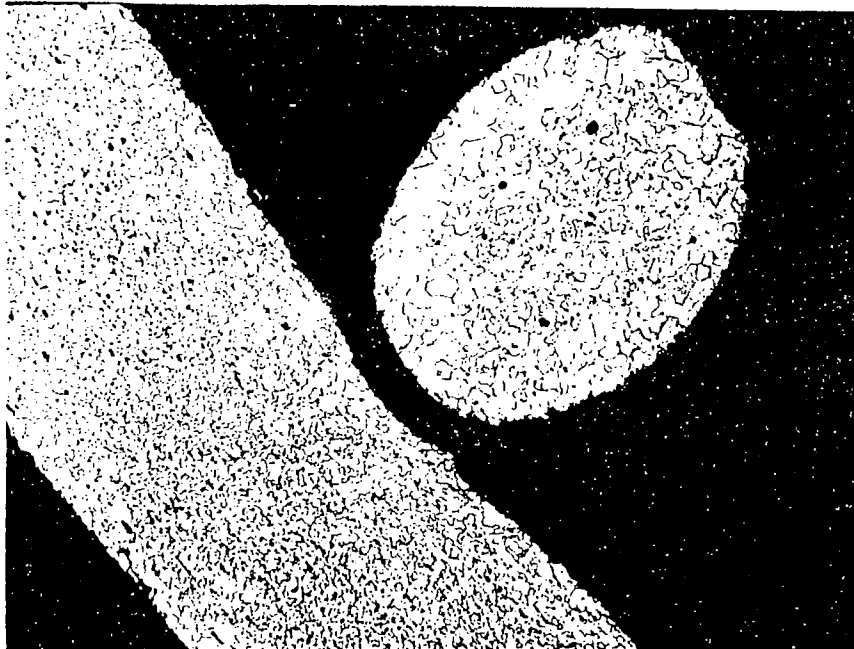


Figure 2: A metallographic section of the outer gauze of the lamp from Moura No. 4 Mine showing grain growth near the surface of the wire (x 120).



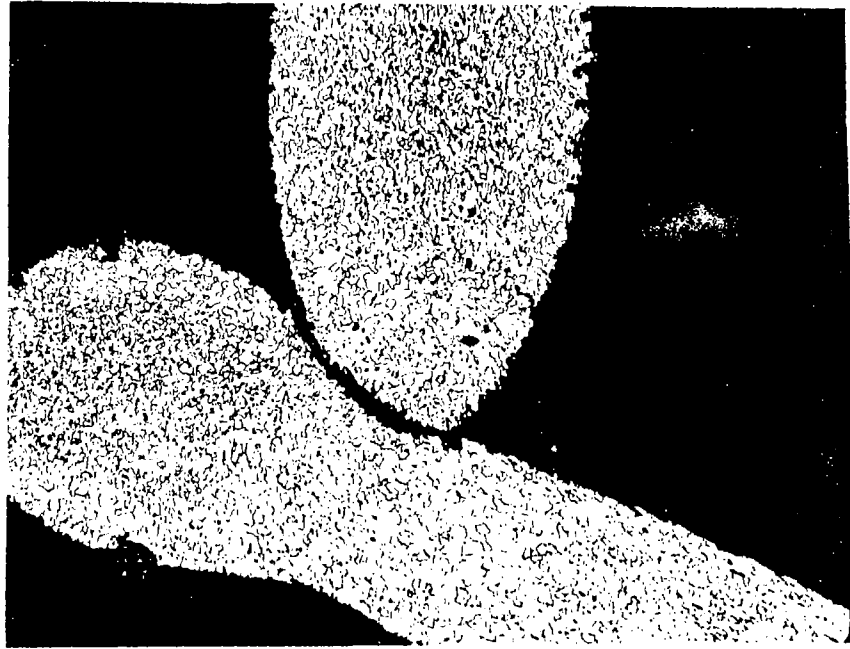


Figure 3: A metallographic section of the inner gauze of the lamp from Moura No. 4 Mine showing grain growth near the surface of the wire (x 120).



APPENDIX 3

Particle Adherence and Electron Microscope Evaluation

9th February, 1987.

File Ref. No.....Lab. No. 86L-565/567

Memorandum to:Chief Engineer.....

Re: Moura Investigation

Prior to further physical testing on the Flame Safety Lamp retrieved from Moura No. 4 mine, dust samples were taken from various areas on the lamp for electron microscope analysis. These samples compliment those analysed during the initial investigation.

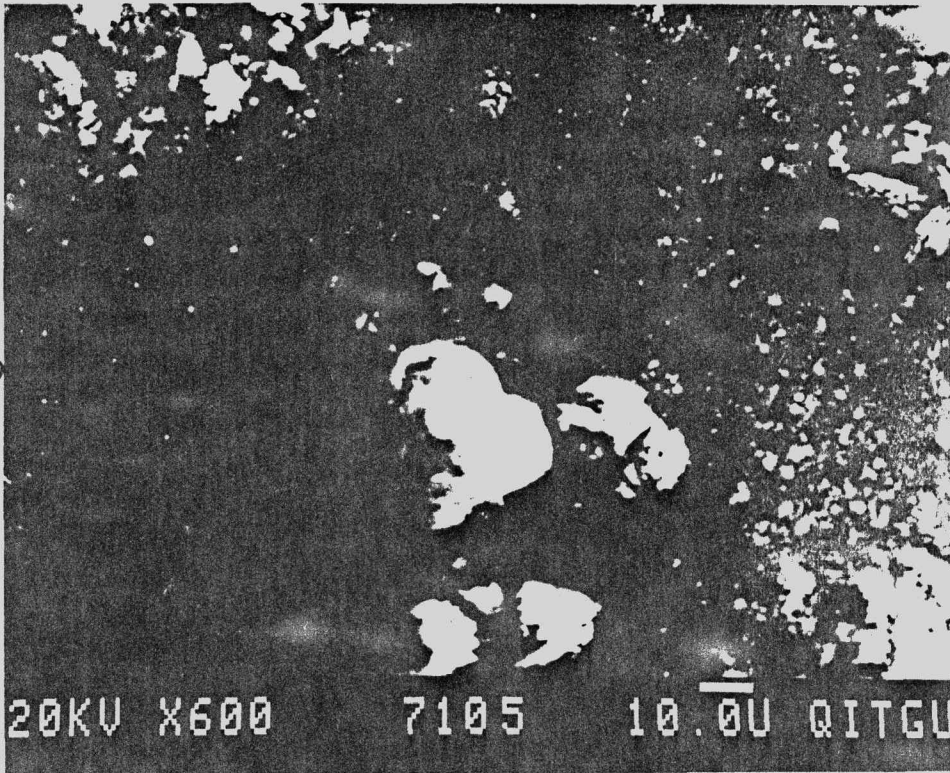
86L-565: dust from outer side of flame safety lamp bonnet.

negative 7105 shows a rounded coal particle past off gasing but prior to the cenosphere stage.

No off gased coal particles were observed; most were rounded indicating moderate/severe heating.

*Temp/
Time.*

*Temps assessed
by comparison
with UK profiles
but were they
same coal type?*



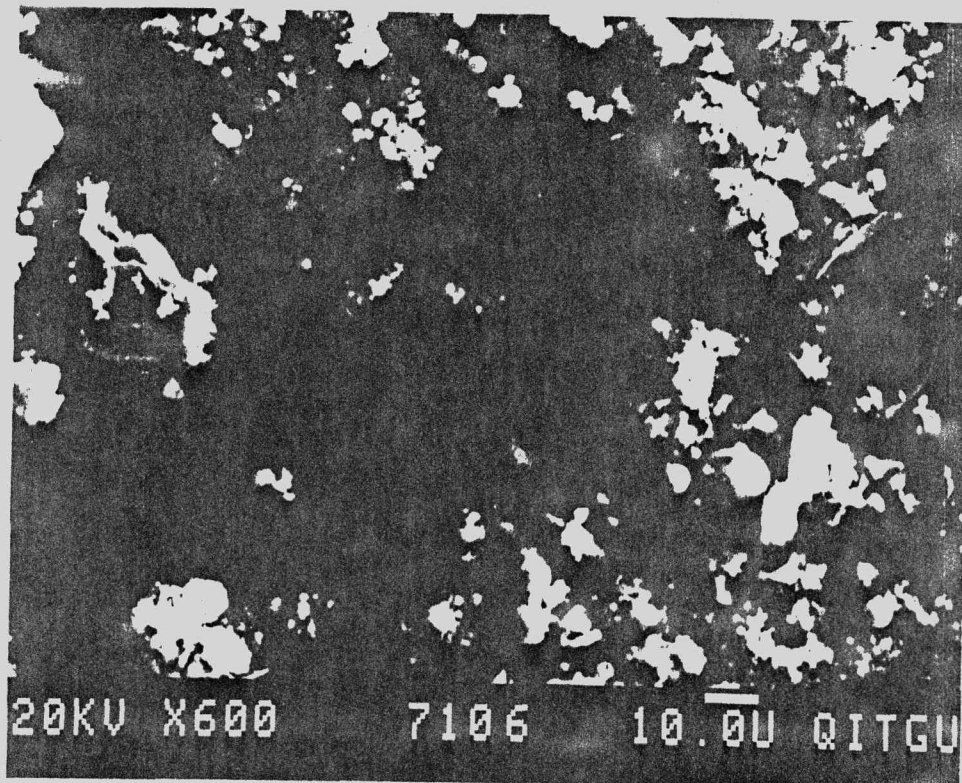
MAG 1-x 600

SPEC:- 86L-565

86L-566: dust from the top of the flame safety lamp bonnet.

Negative 7106 shows numerous cenospheres together with an off gased coal particle (mid left).

Overall, many lacy agglomerates were observed as well as cenospheres, indicating moderate to severe heating.



MAA 1-x 696

SPEC 1-86L-566

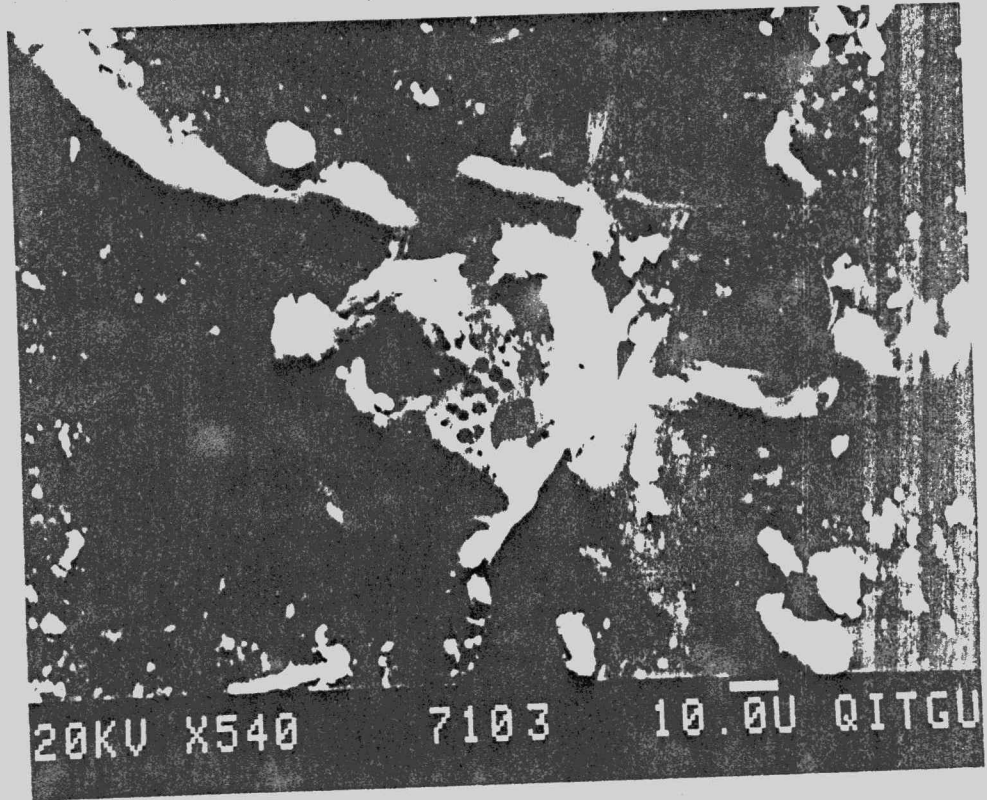
86L-567: dust from inside the flame safety lamp bonnet.

negative 7103 shows a coal particle just past the off gased stage.

negative 7104 shows an almost formed cenosphere (centre) and a part cenosphere (right centre).

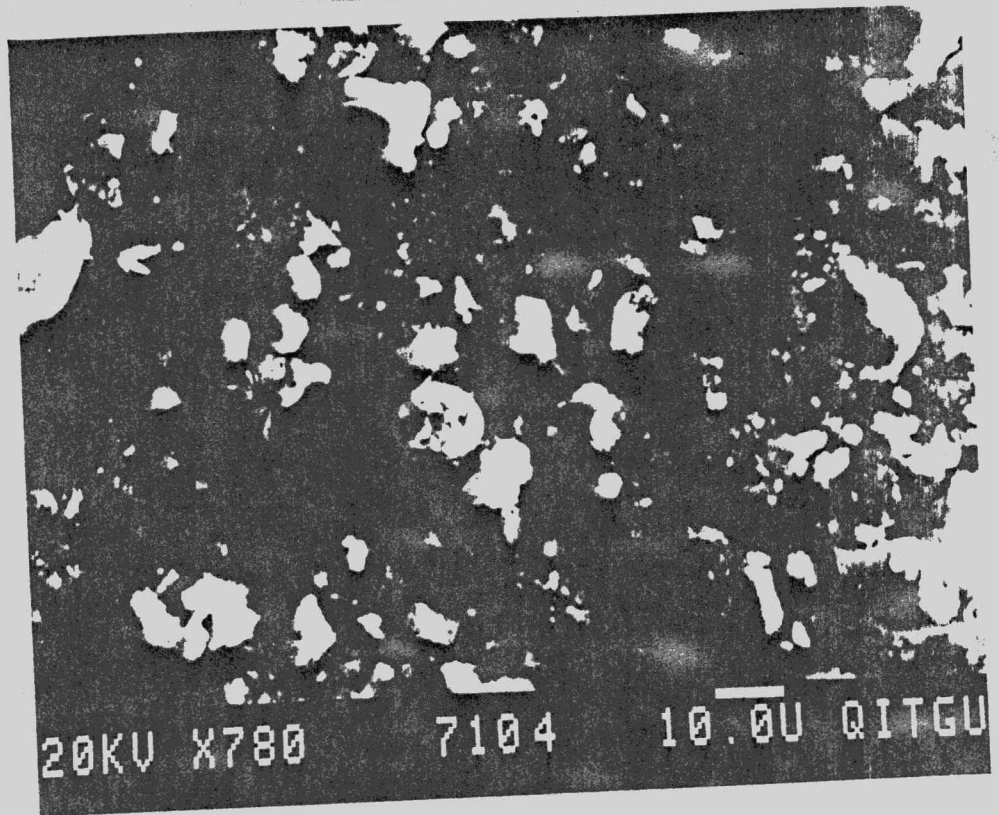
No off gased particles were observed, again indicating moderate to severe heating.

.../3-



MAG: -x 626.4

SPEC: - 86L - 567



MAG: -x 904.8

SPEC: - 86L - 567

P. Lynch

P. Lynch,
Chemist.

30th January, 1987.

File Ref. No.....

Memorandum to:..... Chief Engineer.....

Re: Moura Investigations

The following preliminary report deals with the adherence of coal particles on to the Schott Glass (Borosilicate) of a flame safety lamp.

The lamp glass was heated to a known temperature in a furnace and then quickly removed and placed on its side 2 cm below a bunsen burner flame. Coal dust (less than 75 micron) was sprinkled through the flame on to the surface of the hot glass. The temperature of the glass was monitored by means of a thermocouple.

The results are outlined in Table 1.

A further short study was carried out to determine the rate of heat travel through the lamp glass (Table II).

Table 1

<u>Glass Temperature(°C)</u>	<u>Adherence</u>
80	nil
175	nil
370	nil
500	nil
680 *	partial adherence

*What Temp
for similar
to Moura.*

* The deformation temperature for borosilicate glass is quoted in the literature (1) as approximately 650°C.

Table II

Inside Temperature	External Flame Temperature 1150°C Time to Attainment
270°C	28.8 sec
450°C	50.4 sec

On the basis of the above results further tests were carried out using an oxy-acetylene flame as the heat source. The flame was passed 1cm above a lamp glass at room temperature and at the same height above a glass at 500°C. Less than 75 micron coal was sieved through the flame and the temperature of the glass was noted. The results are listed in Table III.

Table III

Outside Glass Temperature °C	Adherence
200	nil
480	nil

The inner and outer surfaces of the glass were coated with coal dust (<75 micron) and an oxy-acetylene flame (approx 2 000°C) was passed over the glass several times. This procedure proved to be unsuccessful due to extreme heat provided by the oxy-acetylene flame. In all cases the glass cracked before any cogent measurements could be made.

Coal dust samples containing different percentages of limestone (stone dust) were sprinkled through the oxy-acetylene flame onto the lamp glass. These samples and a selection from the previous experiments were examined by electron microscopy.

Electron Microscope Observations on Flame Safety Lamp Experiments

86L-447: Dust off inside of glass
Surface of F.S.L. Expt 5 Test 1

No signs of off gased coal particles; part and full cenospheres observed: negative 0002 shows lacy deposits on unaffected coal particles - X-ray analysis indicated the presence of cerium as a major component of these lacy deposits; contamination?

86L-459: Dust off the inside glass
Surface of F.S.L. Expt 5 Test 3

No cenospheres observed: most coal appears unaffected; only a small percentage appear slightly pockmarked as if starting to off gas. (neg 0003)
Negative 0004 shows coal particles - top right and bottom left: mid right showed iron as major component by X-ray - gauze? mid left appears to be a dirt or dust particle.

86L-461: Dust off the inside glass
Surface of F.S.L. Expt 5 Test 4

Some part and full cenospheres observed along with sections of lacy deposits (Cerium no detected)
Negative 0005 shows slightly off gased coal: X-ray indicated sulphur still present - mild heat only?
Negative 0006 shows lacy deposit on left and part cenosphere on right, both with Si, Al major and S. minor.

86L-561: Coal Dust inside F.S.L. glass - Oxy flame up to 1200°C on the outside glass surface.

Off gased particles not predominant: most particles were rounded and several part and full cenospheres were observed.
Negative 0007 shows an off gased particle.

86L-562: 25% stonedust/coal heated on the side of the F.S.L. glass surface

negative 0008 shows off gased coal surrounded by coal covered with stonedust adhered to the surface: no cenospheres were found but coal was generally rounded.

86L-563: 50% stonedust/coal heated on the side of F.S.L. glass

no photograph

no cenospheres were found; a few particles showed off gasing beginning: most coal particles were angular and covered with stonedust.

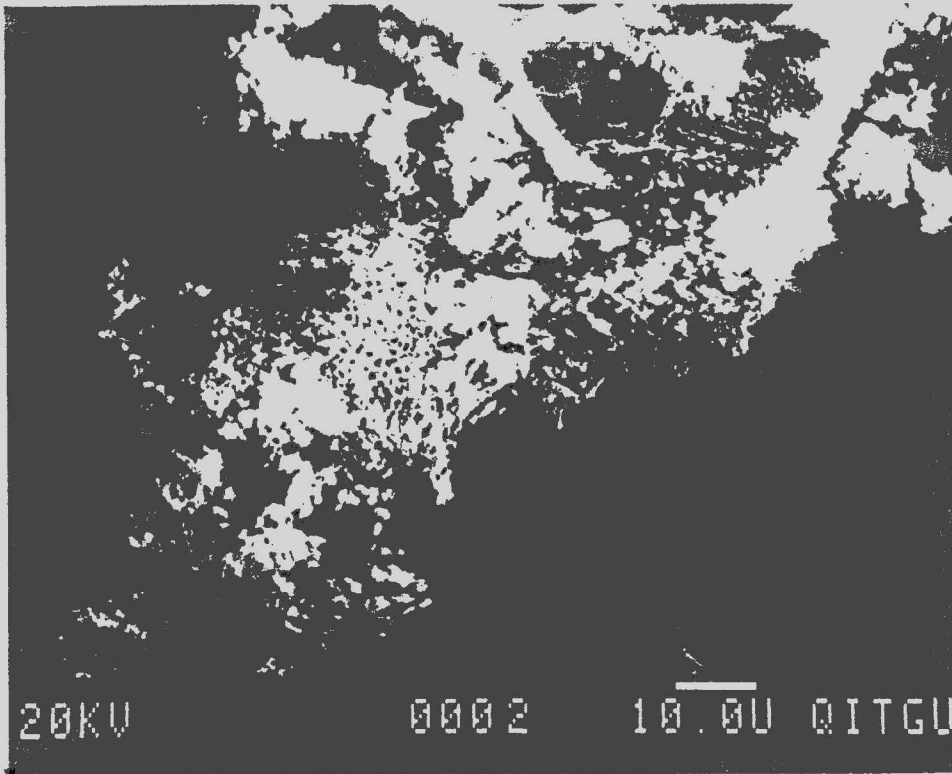
86L-565: 75% stonedust/coal heated on side of the F.S.L. glass

no photograph

no visible signs of heating observed: stonedust covered most coal particles and appears to stop the coal particles agglomerating.

S. Bell

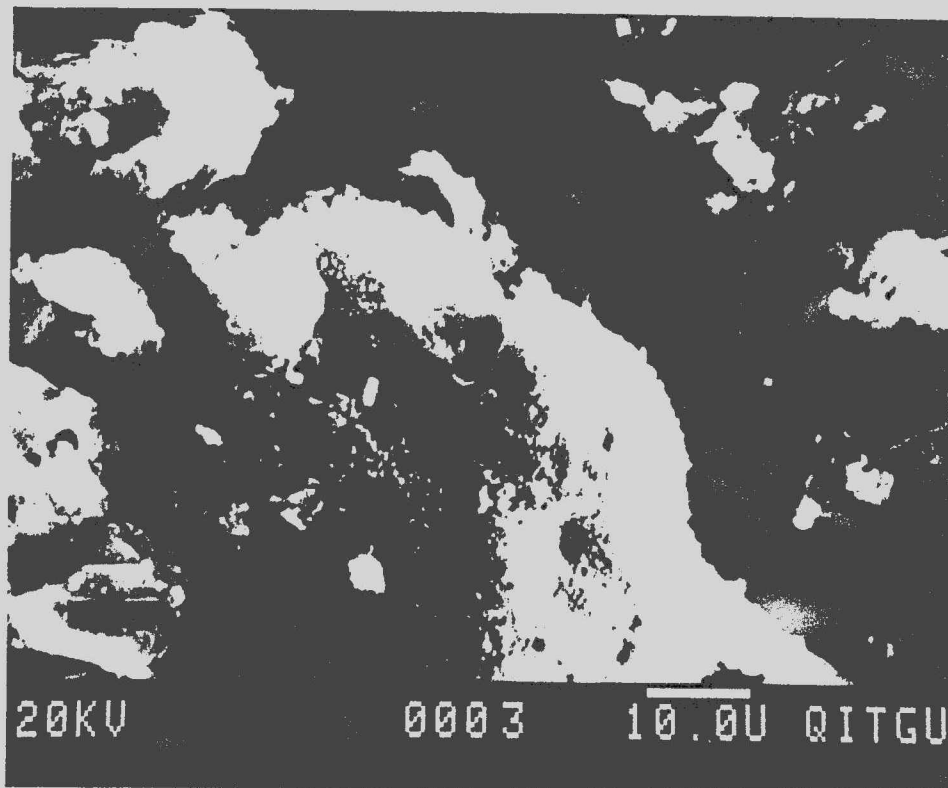
S. Bell,
Chief Chemist,
Research and Technical
Services Branch.



MAG:-X 1090.4

SPEC:-86L-447 (A2)

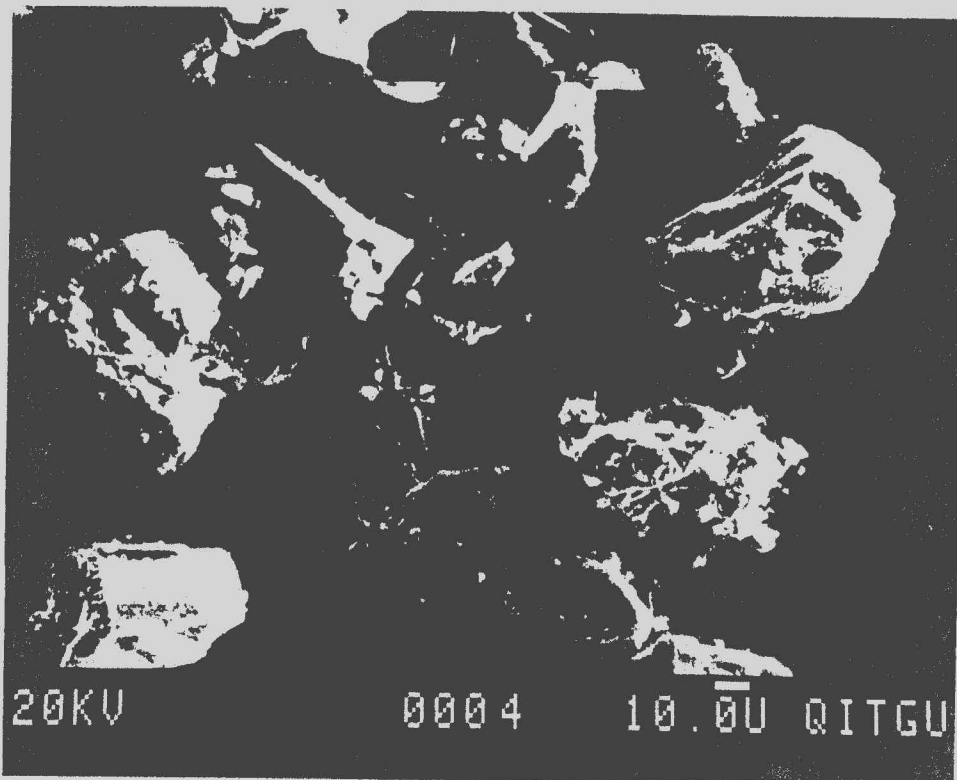
86L-447



MAG:-X 1392

SPEC:-86L-459 (A3)

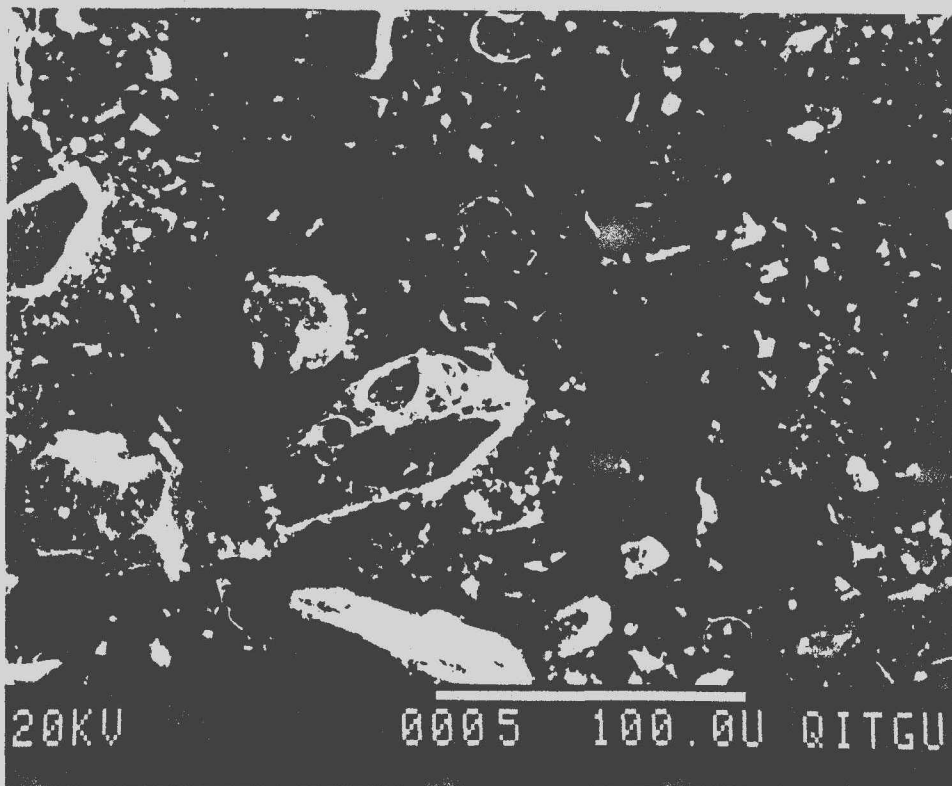
86L-459



MAG: -X 464

SPEC: - 86L-459 (A3)

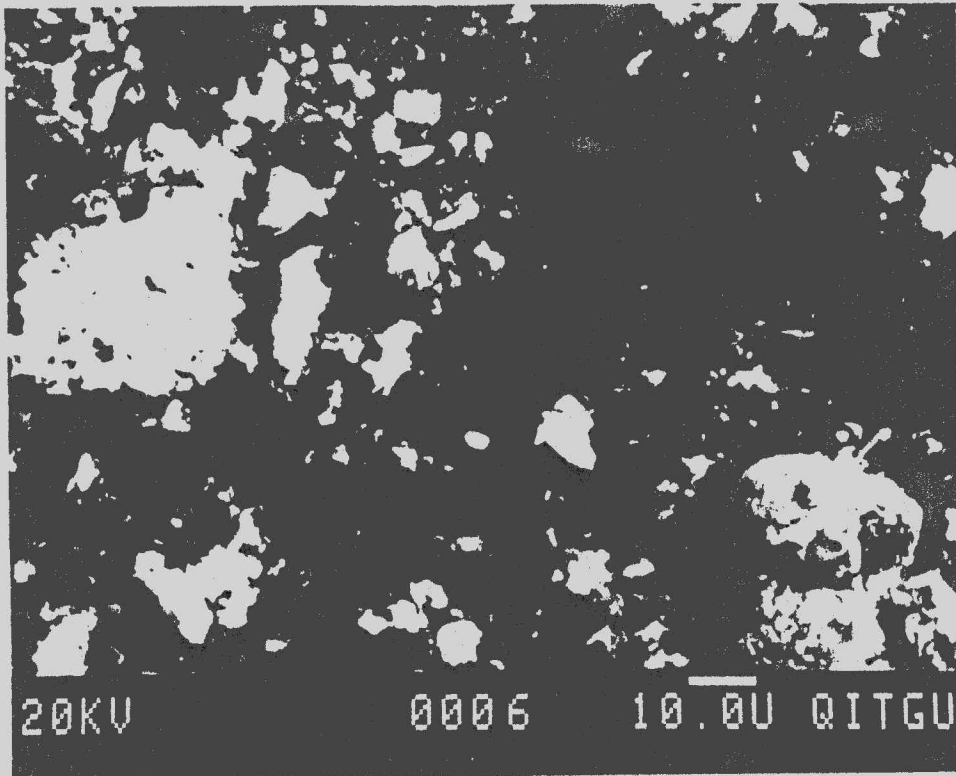
86L-459



MAG: -X 417.6

SPEC: - 86C-461 (A4)

86L-461

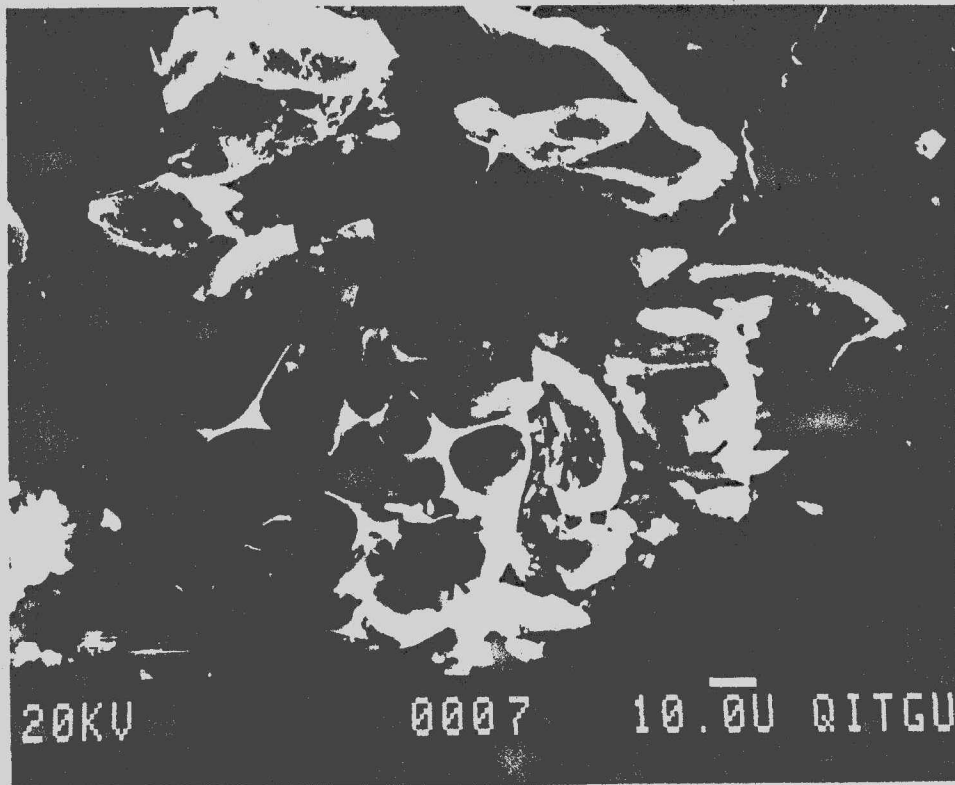


20KV 0006 10.0U QITGU

MAG :-x 904.8

SPEC :- 86C - 461 (A4)

86L-461

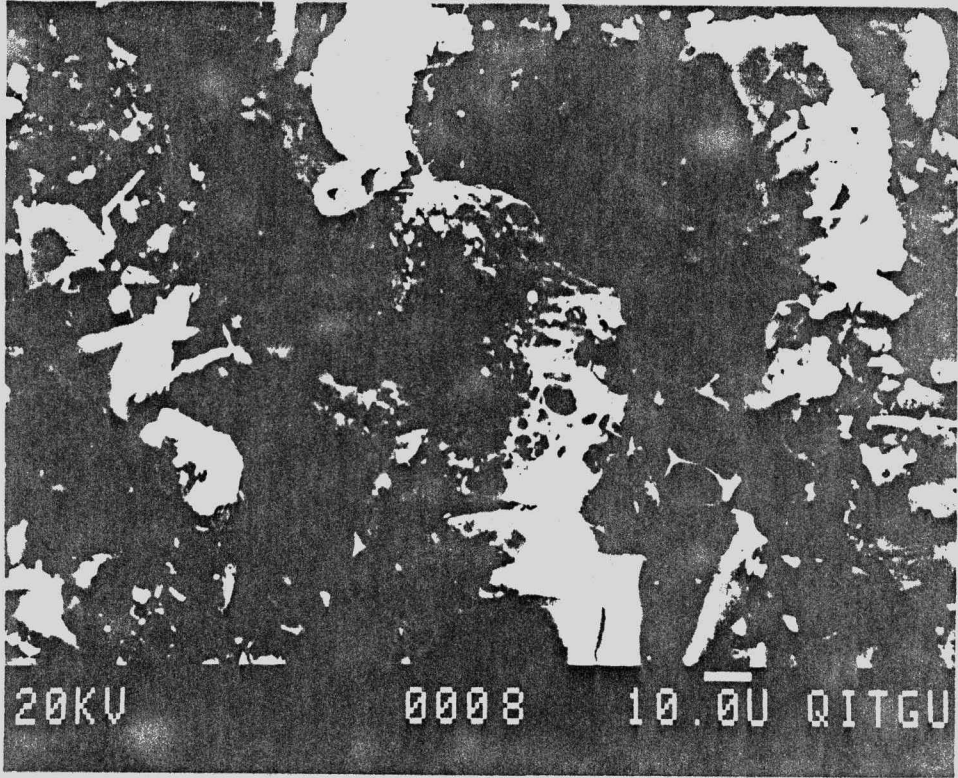


20KV 0007 10.0U QITGU

MAG :-x 626.4

SPEC :- (A5) 86L - 561

86L-561



MAG 1-x 626.4

SPEC :- (AG)

86L-562.

86L-562

APPENDIX 4.

Analysis of Moura Rock Samples

4th February, 1987.

Chief Engineer

Moura No. 4 Quartz Analysis

Three (3) samples of roof rock from the Goaf area of the Moura No. 4 Mine were analysed for quartz utilizing a Fourier Transform Infrared Spectrometer. Ten (10) analyses were carried out on each sample.

	% Quartz	Sample Standard Deviation
Sample MO 42 (L)	19.56	1.03
Sample 10040-3 (M)	16.91	0.89
Sample N (SIMTARS sample)	29.02	1.73

Rock containing the above levels of quartz would not be regarded as being of an incendiary nature.

S. Bell

S. Bell,
Chief Chemist,
Research and Technical
Services Branch.

APPENDIX 5

Further Analysis of Moura Rock Samples

16th February, 1987.

Chief Engineer

Re: Further analyses carried out on Mourn Roof Rock

Rock samples L, M and N (see previous memo 4/2/87) were analysed for quartz using a different technique from the previous analysis. A total dust sample rather than a respirable dust sample was used for form the potassium bromide disc. The disc was then analysed by Fourier Transform Infrared Spectrometry and the results are listed below.

	% Quartz
L	10.2
M	8.4
N	9.1

The above results are significantly lower than the respirable dust analyses and this is explained by the fact that in the infrared spectrum both intensity and resolution are influenced by particle size. As the particle size decreases the intensity of absorption and resolution increase. The elutriated respirable samples contain more smaller particles and thus tend to read higher.

Samples of the rock were also submitted to the Government Chemical Laboratory (GCL) for analysis by X-ray Fluorescence Spectrometry. See attached report. It should be emphasized that the 69.8% result in the GCL Report represents all forms of silicon contained in the sample and does not refer to quartz alone.

S. Bell

S. Bell,
Chief Chemist,
Research and Technical
Services Branch.

GOVERNMENT CHEMICAL LABORATORY

3700 Smith Street, Brisbane, Q., 4000

HAO:AH 86M 1880/82

Telephone 331 5605

13th February, 1987

Department of Mines
 Safety in Mines Testing and Research Station
 2 Smith Street
 REDBANK Q 4301

Re: Analysis of powdered rock material

Attention: Mr. S. Bell

We received from you on 11th February 1987 three (3) samples associated with the Moura No 4 Disaster Enquiry. They were labelled L, M and N. The samples were analysed by X-ray fluorescence spectrometry.

Results:

		L	M	N
SiO ₂	%	69.8	64.6	67.5
Al ₂ O ₃	%	14.4	18.1	17.1
Fe ₂ O ₃	%	1.2	1.8	1.1
MgO	%	0.7	0.7	0.6
CaO	%	1.0	1.1	0.3
Na ₂ O	%	2.8	2.9	1.8
K ₂ O	%	4.2	4.5	5.8
TiO ₂	%	0.51	0.56	0.61
P ₂ O ₅	%	0.13	0.15	0.18
MnO	%	0.02	0.02	0.02
SO ₃	%	0.06	0.03	0.03
LOI (1000°C/2 HRS)	%	5.00	5.50	4.82
TOTAL	%	99.82	99.96	99.86

Further to our telephone discussion, the following note regarding the silica (SiO₂) content applies. The silica figures quoted above represent the total silicon (expressed as % SiO₂) present in each specimen and this includes free forms of silica such as quartz, cristobalite etc as well as silicon derived from silicate matrices (ie silica which is bonded with other elements). Some examples of silicate minerals are feldspars, olivine, clays, garnets etc.

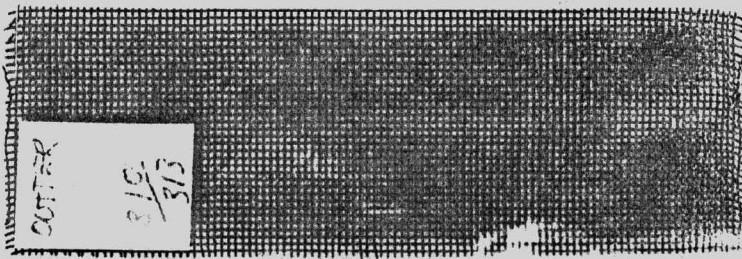
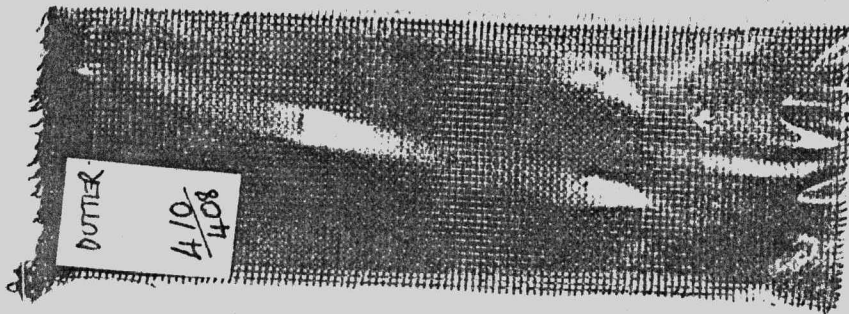
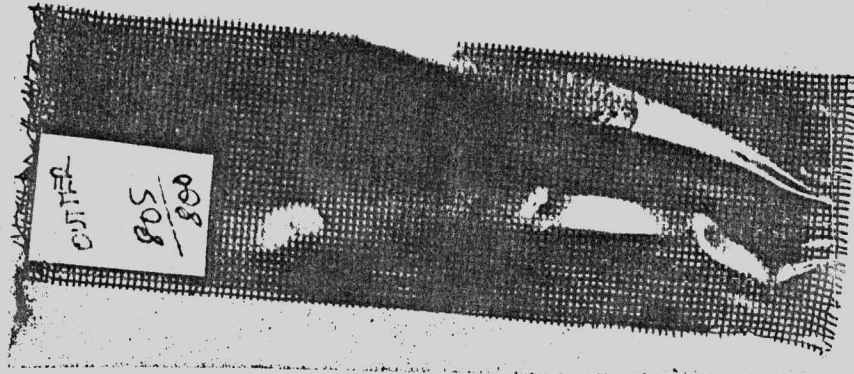
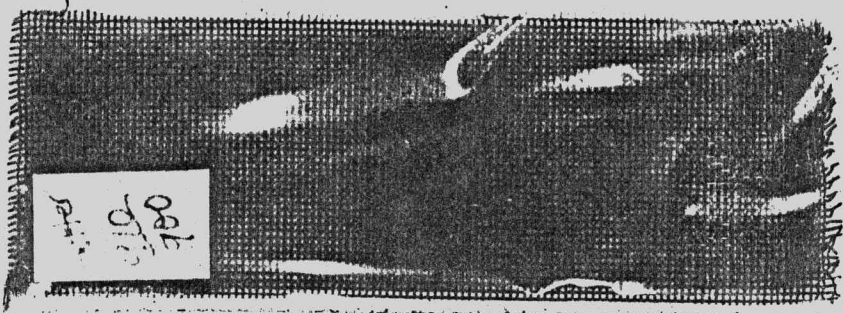
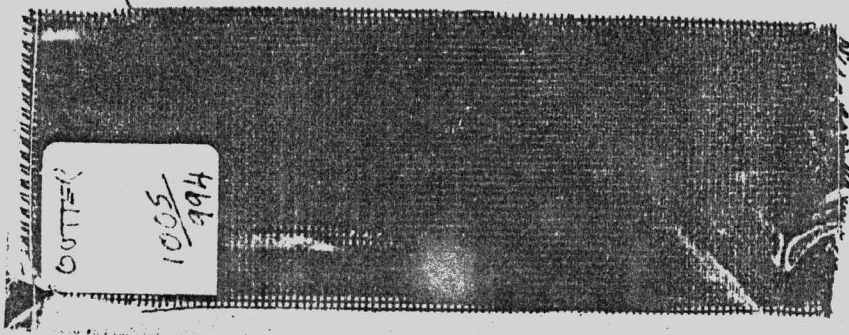
Yours faithfully,

T. J. Beckmann
 T. J. BECKMANN
 DIRECTOR

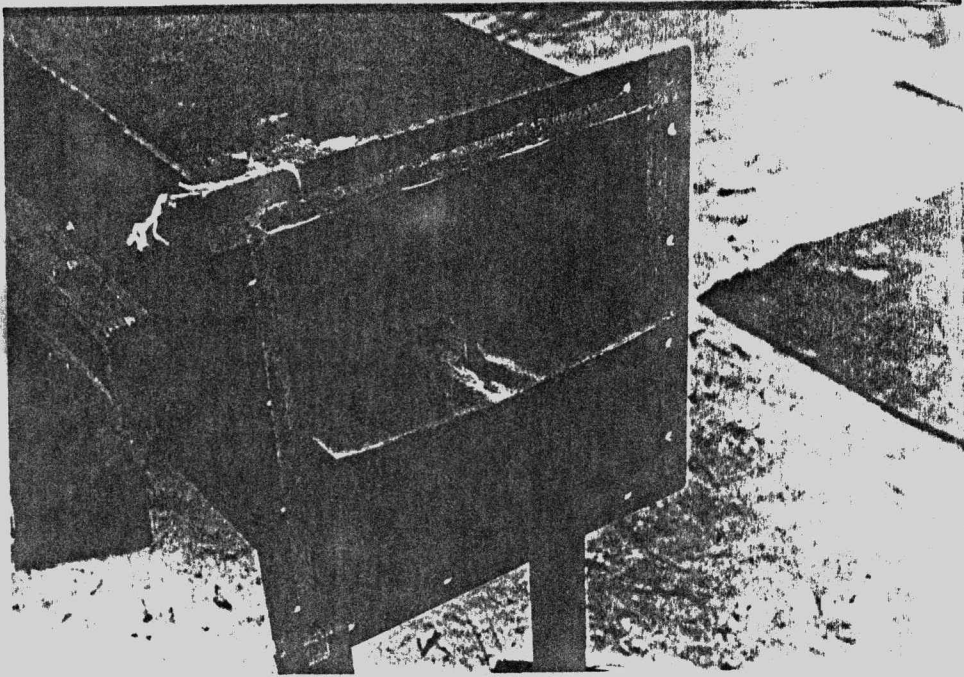


APPENDIX 6

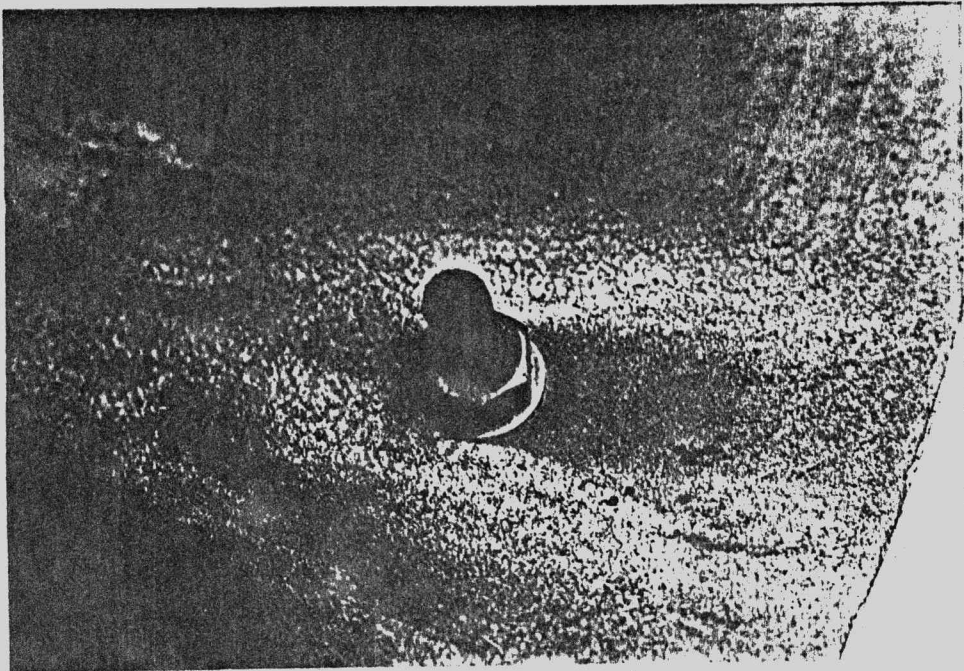
SELECTION OF PHOTOGRAPHS



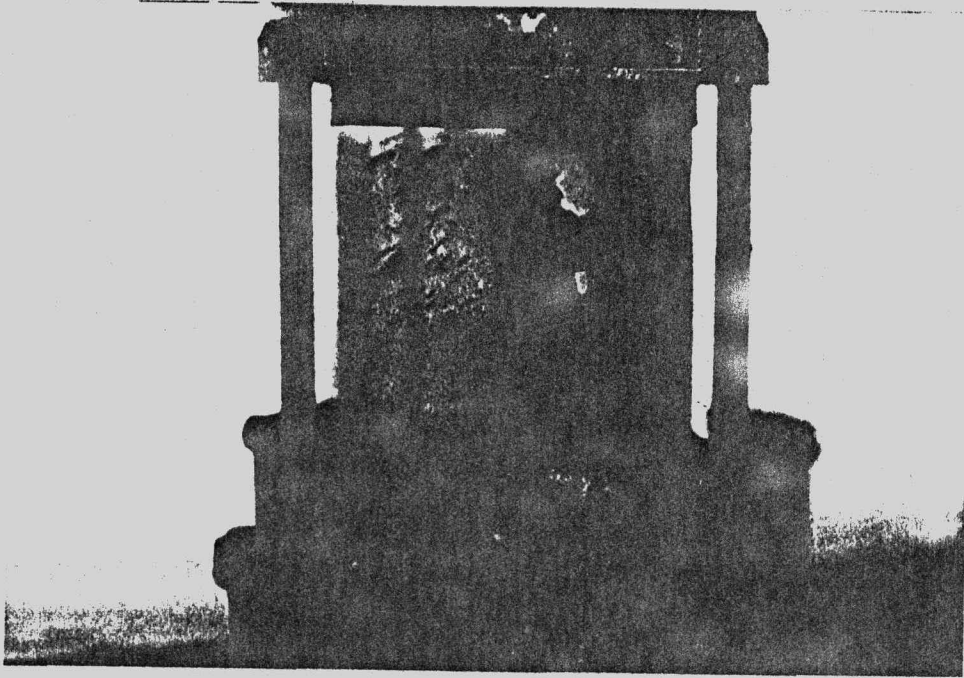
Gauze Test Strips



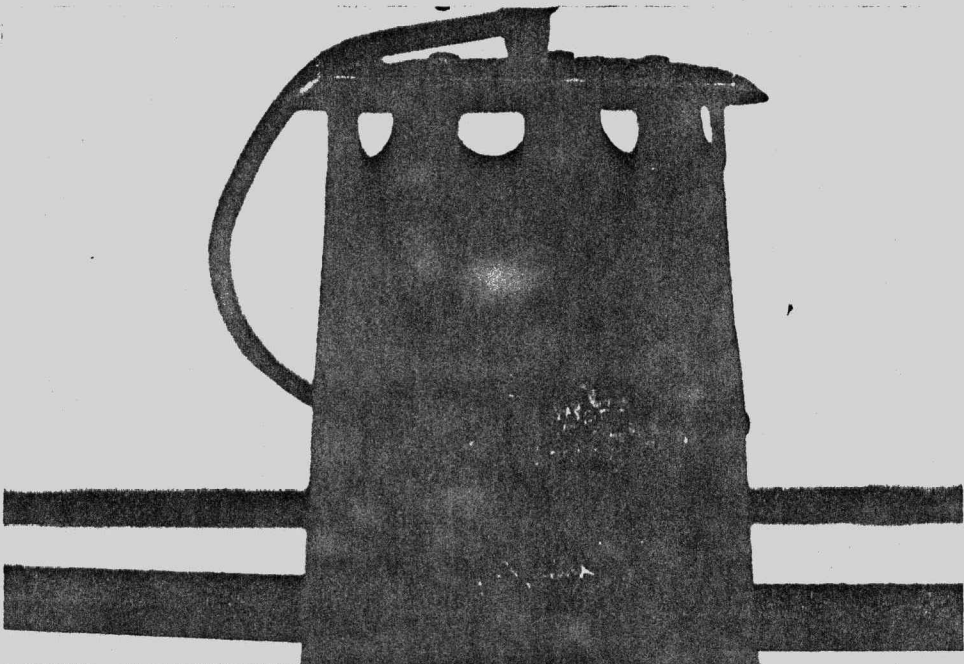
Dust Pattern Downstream of Bolt
after Dust Explosion



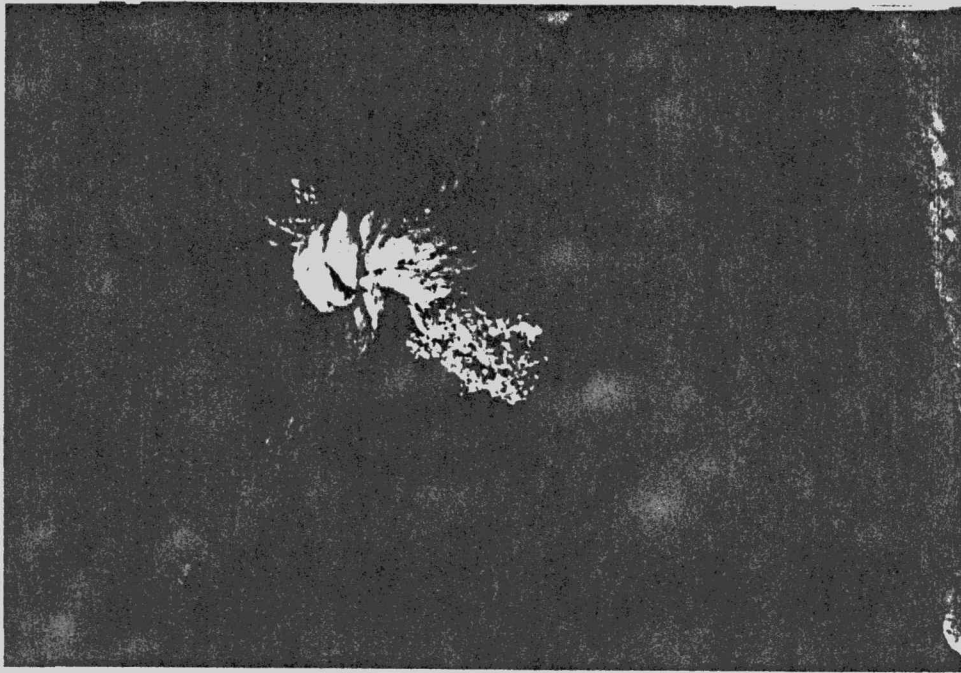
Dust Built upon Explosion Side of Bolt



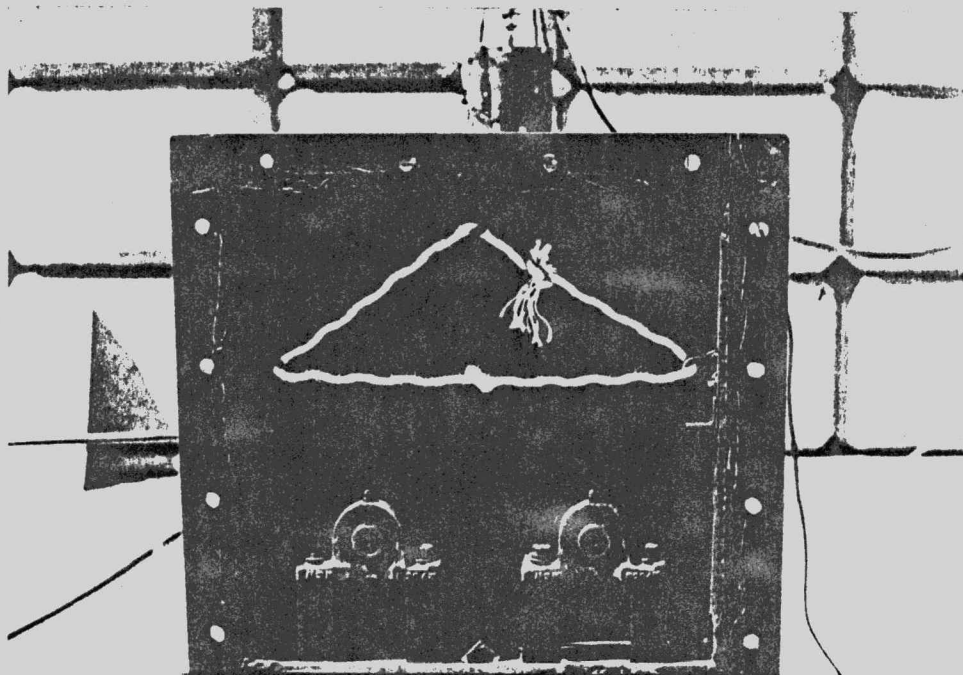
Dust Deposit on Lamp Glass
Dust Loose



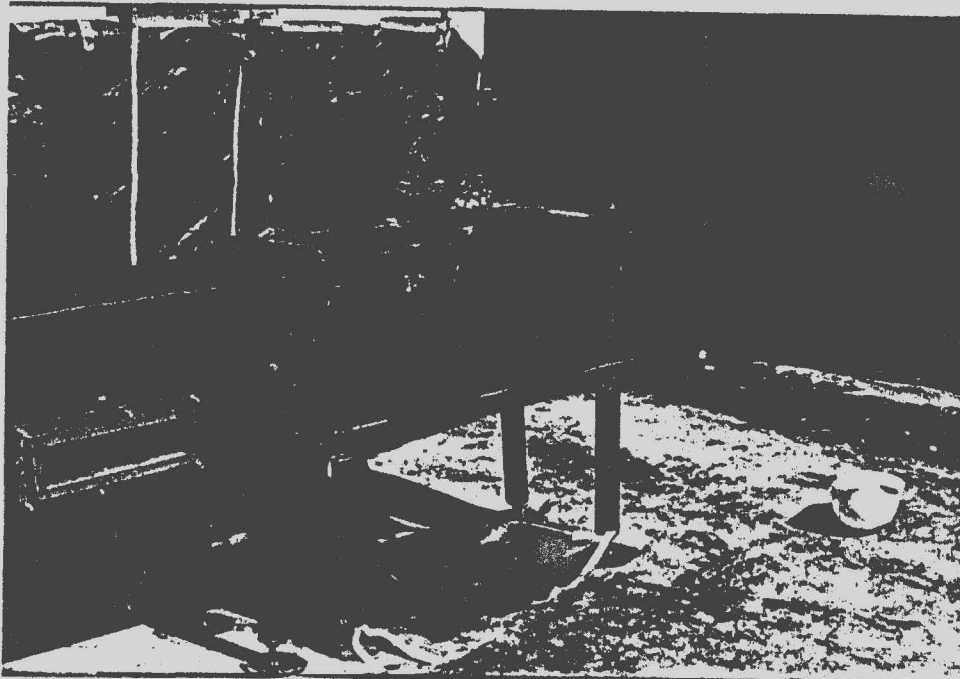
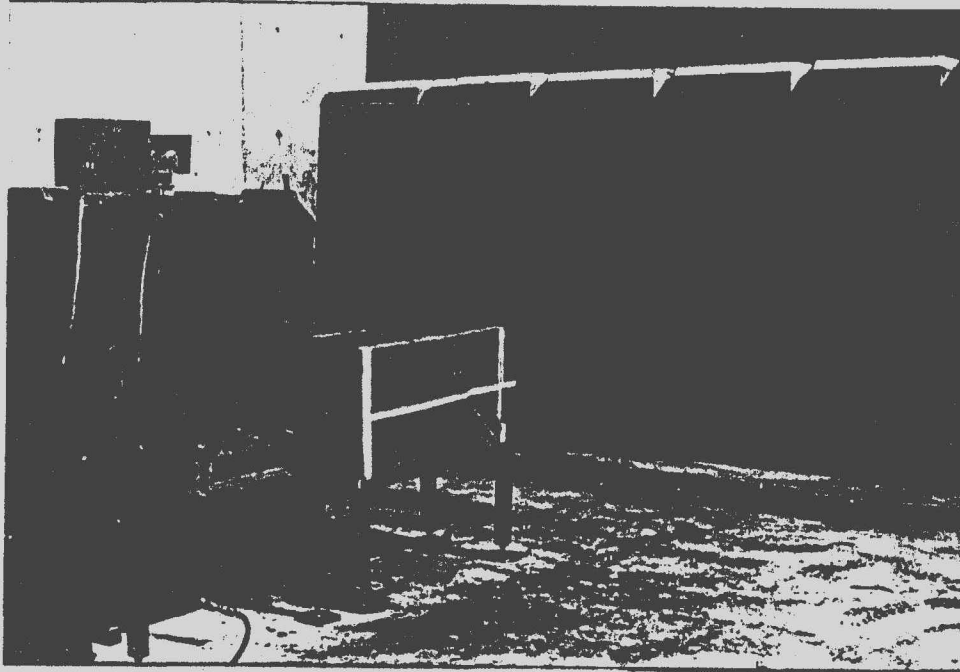
Dust Deposit on Bonnet
Dust Loose



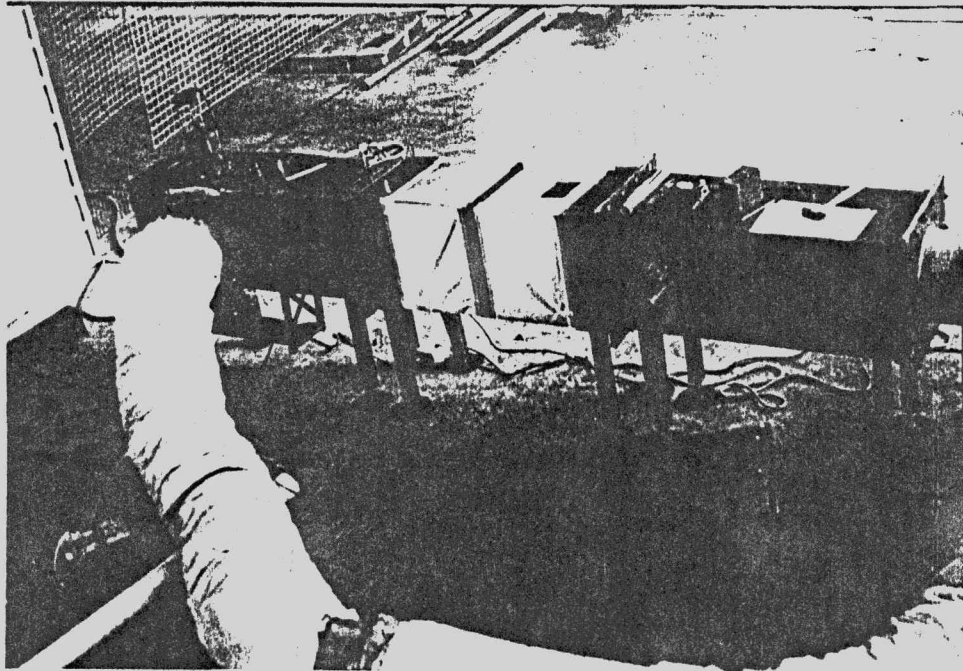
End of Rope Sample Fused by Heat



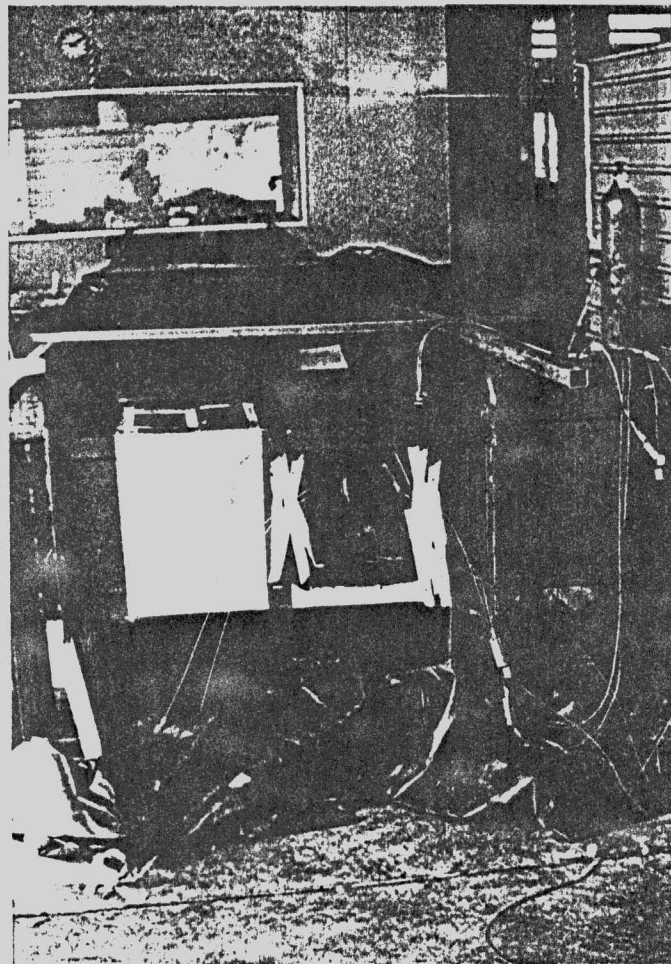
Rope in Position in Chamber



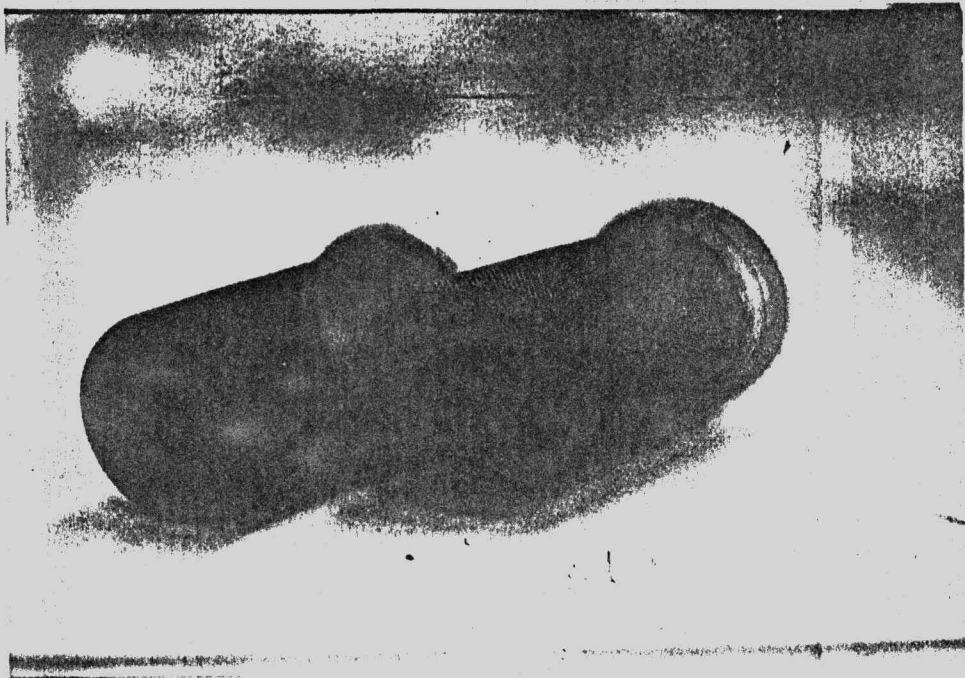
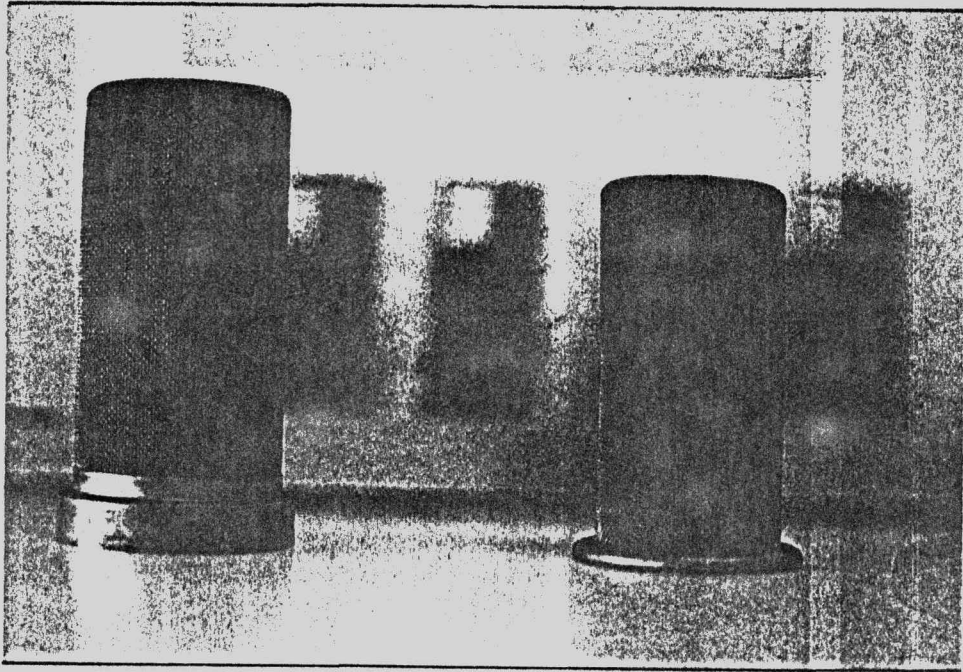
Views of Explosion Chamber



Chamber and Circulating Dust



Lamp in Test Position in Duct



Gauzes Discoloured by Heat in Lamp

APPENDIX 7
LIST OF REFERENCES

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