SAFETY IN MINES RESEARCH ADVISORY COMMITTEE SYSTEM

SIMRAC

Draft Final Project Report

Assessment of Machine Mounted Active Suppression Systems

Part of COL 322

Title: Systems to limit coal dust and methane explosions in coal mines

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SYNOPSIS

In response to the need for enhanced precautionary measures to safeguard mine workers in collieries from the consequences of methane ignitions in a heading, the coal mining industry has expressed the desire for the development and testing of active on-board suppression systems.

As overseas systems cannot be used directly in the bord-and-pillar geometry, it is necessary to adapt overseas and local technology to suit local mining conditions, as well as to test such developed systems for their compliance with the expressed needs. As the systems have to be tested in a specific roadway configuration, a facility was developed to enable them to be tested in South Africa.

A surface test facility has been established which can be used to develop and test suppression systems on continuous miners and roadheaders. This facility consists of a tunnel in which compliance tests can be conducted in simulated underground conditions.

A number of methane explosion tests have been conducted in the test facility. The explosions conducted varied in CH_4/air concentration (7,5 to 12 %) and volume (26 to 88 m^3). At the 7,5 % concentration there was a marked reduction in explosion strength and flame speed.

Tests carried out, according to the revised protocol, with the Explostop active suppression system successfully suppressed the propagation of methane ignitions for all full-face tests conducted. The flame extended a maximum distance of 4 m, with almost no temperature or pressure increases measured.

For the tests conducted with the shoulder in position, the flame extended beyond the operator's position. However, the temperature increase was below the 100 °C limit and the pressure increases within human tolerance levels.

A comparison of these results with equivalent German test results shows that the system operated in similar fashion: their maximum flame lengths also extended beyond the operator's position and there was a maximum temperature increase to 168 °C for one of the machines tested.

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1. INTRODUCTION

Most of the coal mined in underground sections in South Africa is extracted by means of continuous mining machines. As coal is hard and abrasive by nature, the machines have large power requirements to allow the required extraction rates to be achieved. Although a large number of the seams being mined have sandstone roofs, there are also sandstone and pyrite lenses in the seams which have a greater potential for frictional ignitions. Such ignitions can be the initiating source for explosions.

Even though the mining industry and the Department of Mineral and Energy (DME) have recognized the need for adequate ventilation and water sprays in the cutting region of a heading, a need for additional precautionary measures against possible methane ignitions in a heading has been identified.

One of the measures being considered is the use of active on-board suppression systems. These systems are mounted on mechanical miners and detect the occurrence of an ignition by means of light-sensitive sensors. The electronic signal from the sensor triggers the suppression system, creating a barrier of flame-suppressing material, containing and extinguishing the flame in the immediate vicinity of the initiation.

Such systems are employed at present in European mines, but the roadway configurations, having spherical roof profiles, differ significantly from those in South African collieries. As drum-type continuous miners are frequently used in South Africa, the roadways have a rectangular profile and have widths varying from 5 to 7 m, with mining heights varying from 2 to 6 m. Because the continuous miner cuts the heading in two lifts, it is not positioned centrally, thereby creating the need for the suppression system to cope with longer distances than would be the norm in Europe.

These considerations led to the South African coal mining industry's decision to conduct tests, specifically designed for South African conditions, to determine the suitability of the overseas systems for local usage. The testing facility had to be such that it could be used to adapt, or develop, these systems for use in local conditions, even if at first they did not comply with the local requirements.

Under the auspices of the Safety In Mines Research Advisory Council (SIMRAC), a project was established to design and erect such a facility and to conduct the required tests to prove the suppression systems. It was decided that this facility would take the form of a tunnel located on the surface at the CSIR Miningtek's Kloppersbos facility.

The test work is being conducted by the CSIR on behalf of SIMRAC. The work in the tunnel is, however, not restricted to the protocol testing of active suppression systems, but can also involve the development and adaptation of systems in collaboration with the manufacturers of such systems. It was agreed that the CSIR would function as an independent research and testing organization, but it would not develop new suppression systems unless it was found that no other system was available which could be adapted, or developed, to comply with industry requirements.

1.1 Background and criteria used

In terms of the scope of the project, the coal mining industry expressed the need to conduct two types of tests: the first to test a formal protocol and the second to evaluate the systems.

The objective of the protocol tests is to determine whether the system, or configuration, being tested is able to fulfil the needs of the mining industry, as embodied in the acceptance criteria. The objective of the evaluation tests, on the other hand, is to test the performance of the system (configuration) within a specific configuration, or within a range of configurations.

In accordance with the objectives, acceptance criteria have been developed for the protocol tests and from the results of these tests, the system or components have been accepted, or rejected, on a pass/fail basis. In the evaluation testing, the actual quantitative results have been presented.

For the protocol testing procedure (see Appendix 1) the following acceptance criteria were used:

* The flame propagation must be limited to such a distance that the operator is not in danger, i.e. it should be extinguished before reaching the operator's position in the cab of the machine.

* The pressure shock at the operator's position must be within human tolerance levels.

* The temperature rise must be within human tolerance levels.

* No false triggering may occur as a result of other equipment in use in an underground mine.

* The system must be able to be made operative again within eight hours of activation.

2. TEST EQUIPMENT

The tests were conducted on the surface under controlled conditions, i.e. the tunnel had to simulate closely the conditions that would be encountered underground.

2.1 Test tunnel

The tunnel design allows full-scale tests to be conducted on actual continuous miners and roadheading machines. The tunnel is 20 m in length and 7 m wide, allowing for the testing of machines that can work in seam heights ranging from 2 to 6 m. The roof of the tunnel can be set at various heights within this range in increments of 0,5 m.

To cater for the conditions that could prevail after a continuous miner has completed the first lift, a removable shoulder was installed in the front of the tunnel. This shoulder is able to simulate a cut of up to a depth equal to the approximate height being cut. The simulation of the heading at the start or end of the lifts is done without the shoulder. This is similar to tests conducted in the full heading width when testing full heading machines. The shoulder can be removed to give a full heading width of 7 m.

The tunnel is so constructed that it can withstand the full force of an unsuppressed methane explosion. To safeguard the tunnel, it is not rigidly fixed to the ground, thereby allowing a maximum lift of 140 mm. This allows the overpressure generated in the tunnel to escape through the vent created at the bottom of the tunnel during lifting.

2.2 Methane supply

Methane is supplied to the explosive chamber via a pipe network fitted with a number of nozzles and the flow rate of the methane is regulated from a central control room situated some distance away from the tunnel.

The nozzle outlets in the tunnel are designed to create turbulence when the methane is released through them. This turbulence helps to mix the methane, thereby making the measurement of the methane levels more representative, as well as ensuring that the methane levels achieved conform to a better standard. The number of nozzles utilized at a time depends on the volume of the chamber behind the plastic membrane. Further mixing of the methane is achieved by rotating the drum of the model or of the CM during the test.

2.3 Methane measurement

The methane-measuring system is able to record the methane/air mixture concentration at a number of random positions. This capability was achieved by creating two independent measuring circuits, each with an independent methanometer.

The number of measuring points varies with the roof height and the volume of the methane chamber, and there are also methane-measuring points outside the chamber to determine whether any leakage has occurred.

Switching between the various measurement positions is achieved through the use of electrically operated valves which allow the methane to be fed to a central measuring station. Mixing of the methane is deemed complete when all the stations record the same methane concentration.

2.4 Sensors

The sensors used in the tests are: flame sensors, pressure sensors and a temperature sensor.

The flame sensors are silicon photovoltaic cells and determine the extent to which the flames have spread or have been contained. This is achieved by measuring the intensity of the light of the flame at each of the sensors positioned in a grid around the tunnel. The sensors are arranged in groups, forming planes at right angles to the horizontal, around the roof and sides of the tunnel, with the planes at a distance of 1 m apart. By measuring the activation of the individual sensors, the speed of the flame advance can be obtained, as well as the final position reached by the flame front.

The pressure sensors measure the pressure shock at the operator's position and surroundings. They are piezoelectric sensors which convert mechanical forces into a proportional electrical charge which is captured by the data acquisition system.

A temperature sensor is used to determine the increase in temperature at the operator's position on the machine. The sensor, being a thermocouple, is not able to register the rise in temperature at the same rate as the flame sensors register changes in light intensity. In the tests, cognizance was taken of the fact that the temperature rise was measured on a different time-scale to the explosion itself. This means that in the adjudication process, comparisons, rather than absolute values, were used.

A video camera was installed so that a visual record of the whole test could be made and kept for reference purposes.

2.5 Data acquisition system

The system has 128 simultaneously sampled channels with a user-selectable sampling rate, the maximum sampling rate being 30 kHz for 2 seconds using all 128 channels. The system uses custom-made software so that the information can be stored for later use, with the results presented in a usable format.

3. TEST PROCESS

The tests conducted encompassed methane explosions with various volumes and concentrations, with a continuous miner model, and with an on-board suppression system mounted on the continuous miner as it would be when the system was simulating a cut. In all the tests the roof height of the test tunnel was set at 2,5 m and during the shoulder tests, the depth was 2,0 m and the width 3,5 m.

All the tests were conducted by simulating an ignition of a methane pocket enveloping the head of the machine. This was achieved using a plastic membrane which was connected to the walls of the tunnel and ensured that the pocket of methane was fully contained. The volume of the CH_4/air mixture is dependent on the membrane position, the seam height being simulated and the required concentration.

To ensure the repeatability of tests, the ignition point selected was in the middle of the test tunnel. The methane/air mixtures of between 7,5 % vol. and 12 % vol. were ignited by means of a fuse cap (200 J) or a chemical detonator. A summary of the tests conducted and the data captured is shown in Appendix 2. The different ignition positions for the full face and shoulder tests are indicated in Figure 4 of Appendix 1.

When suppression tests were conducted, the ignition source was between the drum and the face, positioned so that it was in the sighting shadow of the sensors of the suppression system. By following this procedure, the tests ensured that the system sensors had to react to the flame generated after ignition, rather than to the ignition source itself.

The ignition source and the data acquisition system were activated simultaneously, thereby allowing controlled capture of the explosion data. An in-tunnel video camera captured the visual material. The captured data were evaluated together with the video material to determine the extent of the flame, the flame speed, the static and dynamic pressure and the temperature rise at the operator's position.

4. RESULTS

A large number of methane explosions were initially conducted to determine the inherent strength of the test tunnel. Although no actual data on flame speeds and pressures were captured initially (data acquisition not operational), invaluable experience in operating the system was gained.

The tunnel has been utilized for the following tests since the commissioning of the data acquisition system:

- methane explosion tests (calibration and operational tests)
- active suppression test work with a continuous miner
- active suppression test work with a continuous miner model.

A summary of the tests conducted with the data acquisition system operational is shown in Appendix 2.

4.1 Methane explosion tests

4.1.1 Empty tunnel

Tests were conducted in the tunnel without the shoulder in position and in an empty tunnel. The purpose was to determine the extent of the flame, the flame speed and the dynamic pressure generated during a methane explosion.

The results for 9 and 12 % vol. CH_4/air concentrations are shown in Table 1.

Table 1
Methane explosion test results

TEST	CH_4/AIR (%)	FLAME SPEED (m/s)	DYNAMIC PRESSURE (kPa)
8	9	52,4	1,7
9	9	63,4	3,0
10	12	45,6	4,3
11	12	52,4	3,4
12	9	56,4	3,3

In tests 10, 11 and 12, the use of a stronger initiator was investigated. Although the initiator used was five times stronger than the standard initiator, no increase in flame speed or dynamic pressure was observed compared with tests 8 and 9.

The stronger initiator resulted in an increase in temperature of approximately 80 °C for the 9 % CH_4/air tests. It was furthermore observed that for the 12 % CH_4/air mixtures, there was an increase of approximately 100 °C, to 689 °C, above that measured for the 9 % CH_4/air tests.

4.1.2 Continuous miner

The results of the tests with a continuous miner present are shown in Table 2.

Table 2
Test results for continuous miner

TEST	CH_4/AIR (%)	FLAME SPEED (m/s)	DYNAMIC PRESSURE (kPa)
5	9	121	saturated*
6	9	82,7	saturated*

*above maximum instrument setting of 10 kPa for these tests

In tests with the continuous miner without a suppression system (tests 5 and 6), the flame growth extended throughout the tunnel. The average flame speed was determined as 101,9 m/s, over the operator's position, and the average static and dynamic pressures were 10,7 kPa and 13,0 kPa (estimated from graphs), respectively.

4.1.3 Model

The most recent part of the work has centerd on tests with a model of a continuous miner inside the tunnel (tests 13 to 28). The results of these tests are shown in Table 3.

Table 3
Model test results

TEST	CH_4/AIR (%)	FLAME SPEED (m/s)	DYN. PRESSURE (kPa)
13	9,0	71,7	7,9
15	7,5	41,0	2,0
16	9,0	83,0	15,0
17	7,5	57,1	4,0
18	7,5	65,0	4,7
19	9,0	106,8	17,8
20	9,0	99,1	14,0
21	9,0	98,8	11,2
28	7,7	61,6	faulty

The initial tests were similar to those conducted with the continuous miner with the boom position on the floor (tests 13, 19, 20 and 21). In tests 15 and 16, the boom position was in the middle of the tunnel. Two tests (17 and 18) were conducted with the boom raised to the roof position.

When comparing tests 15 and 16, it can be seen that the flame speed doubles, while the dynamic pressure increases more than sevenfold when the concentration is changed from 7,5 to 9 % vol. CH_4/air. The influence of the boom position on the flame speed, and on the dynamic and static pressure, is clear when test 15 is compared with tests 17 and 18, i.e. there was an increase in the dynamic pressure and flame speed.

Tests 19, 20 and 21 were done to determine the repeatability of tests, to evaluate these tests against those conducted with the continuous miner, as well as to calibrate the testing equipment prior to the test work with the active suppression system.

The average flame speed at the operator's position with the model was 101,6 m/s; in comparison, the flame speed with the continuous miner was 101,9 m/s.

The average dynamic pressure with the model was 14,3 kPa in comparison with the continuous miner's 13,0 kPa. The average static pressure was 11,6 kPa as against 10,7 kPa.

The only test conducted with the shoulder in position (test 28) indicated an increase in flame speed from 41,0 to 61,6 m/s compared with test 15. The static pressure measured was 5 kPa and the temperature measured at the operator's position was 641 °C.

The repeatability of tests, the testing process and the equipment proved successful in the following respects:

- good control of methane-mixing process
- proper operation of data acquisition and data presentation systems

- data capturing sensitivity more than adequate
- acceptable temperature measurement
- light sensor operation effective.

The total process of control and the construction strength of the tunnel proved that the tunnel would be able to withstand a test in which the suppression system failed to suppress an explosion.

4.2 Active suppression test work with a continuous miner (CM)

Limited test work on a continuous miner (14 CM 6) was conducted during 1995. The results of these tests are shown in Table 4.

Table 4
CM test results

TEST	CH_4/AIR (%)	MAX. FLAME LENGTH (m)	FLAME POSITION
0	9	> 20	roof & sides
3	7,5	2	roof left
4	9	3	roof left

The first test with an active suppression system mounted on a continuous miner (test 0) resulted in extensive damage to the tunnel, lifting the 68 ton structure more than 400 mm. Damage in the methane chamber area resulted in six weeks' repair time. The flame extended throughout the test tunnel.

The testing of the adapted international system was successful in both scenarios tried (tests 3 and 4). The flame did not extend more than 3 m from the point of ignition, and almost no increase in static and dynamic pressure was measured.

4.3 Active suppression test work with the CM model

The test work was done according to the revised test protocol as summarised in Table 5 (see also Appendix 1).

Table 5
Protocol testing requirements

TEST	IGNITION POS.	METHANE CONC. %	DRUM STATUS	TESTS
F1	A1	9	Stationary	1
F2	A1	9	Turning	1
F3	A2	9	Turning	1
F4	A3	9	Turning	1
F5	A4	9	Turning	1
F6	A5	9	Turning	1
S1	B1	9	Turning	1
S2	B2	9	Turning	1
S3	B3	9	Turning	1
S4	B4	9	Turning	1
S5	B3/4	12	Turning	1

The test results shown are for the Explostop system mounted on a model (simulation of a 14CM9 CM) and tested in the 20-m test tunnel at a height of 2,5 m. Various tests in a full-face heading and tests with the shoulder in place are discussed below.

4.3.1 Full-face tunnel

The results of the tests conducted with the suppression system, according to the test protocol, are shown in Table 6.

Table 6
Full-face active suppression test results

TEST	CH_4/ AIR (%)	IGNITION POSITION	FLAME LENGTH (m)	FLAME POS.	TEMP. INCREASE °C*	PRESSURE STATIC kPa	PRESSURE DYNAMIC kPa
22	9,0	A1	4	Roof left	< 10	0,43	≈ 0
23	9,0	A1	4	Roof left	< 10	1,65	≈ 0
24	9,0	A2	4	Roof left	< 10	1,30	≈ 0
25	9,0	A3	4	Roof left	< 10	1,98	≈ 0
26	9,0	A4	4	Roof left	< 10	1,98	≈ 0
27	9,0	A5	4	Roof left	< 10	1,57	≈ 0

NOTE: *The increase measured above the ambient temperature

In all the protocol tests, the system proved effective in suppressing the methane explosions if measured against the criteria set out in the protocol.

4.3.2 Shoulder in position

The results of the active suppression test work with the shoulder in position are shown in Table 7.

Table 7
Shoulder active suppression test results

TEST	CH_4/ AIR (%)	IGNITION POSITION	FLAME LENGTH (m)	FLAME POSITION	TEMP. INCREASE °C	PRESSURE STATIC kPa	PRESSURE DYNAMIC kPa
29	9,0	B1	10	roof right	9	1,10	≈ 0
30	9,0	B1	10	roof right	63	1,74	≈ 0
31	9,0	B2	10	roof right	47	1,20	≈ 0
32	9,0	B3	11	roof right	94	0,80	≈ 0
33	9,0	B4	11	roof right	86	1,04	≈ 0
34	12,0	B3	20	roof 8 sides	487	9,15	> 5*
36	12,0	B3	8	roof right	< 5	≈ 0	≈ 0

NOTE: *Sensor saturated

Changes were made to the system and test 30 was a repeat of test 29. As these changes resulted in less efficient operation (increase in temperature), the system was changed back to the original configuration. In all the tests, the flame extended beyond the flame stop position (8 m) as prescribed by the test protocol. The temperature increase at the operator's position was less than the maximum of 100 °C as specified by the protocol.

The results compare favourably with those of the tests conducted in Germany[1]. In tests conducted with the Roboter E 134, the flame extended to 7,0 m (operator position at 6,0 m) and the maximum temperature increase measured was 168 °C.

In none of the tests, except test 34, did the flame progress through the cloud of flame-suppressing dust. The flame was therefore contained behind the suppressant material. The expansion of the methane gas contained in the shoulder area resulted in greater flame extension than was initially anticipated. In test 34 with a 12 % CH_4/air concentration, the system failed to operate effectively. This was a result of the bank of bottles on the right-hand side failing to react to the sensing of the ignition. Nevertheless, the containment of the flame growth was rapid, with the left-hand bank of bottles releasing the dust. The pressure from this release pushed the methane flame into the shoulder area from where the methane explosion progressed rapidly.

Test 36 was a repeat of test 34, with the flame being extinguished within 8 m and no measurable increase in static or dynamic pressure.

5. CONCLUDING REMARKS

With the establishment of this facility, the South African coal mining industry now has the means to test and modify active suppression systems to suit its particular needs.

By using systems based on overseas technology and which have been adapted to suit South African conditions, valuable time is gained. Such systems can be customized for local implementation without incurring development costs. In the event of these overseas systems not being suitable, a facility now exists to assist in the development of local systems.

The successful suppression of the methane ignitions has highlighted the importance of the Explostop system in reducing the risk of underground methane ignitions developing into coal dust explosions.

The establishment and use of this facility has made and can make a significant contribution to the understanding of methane explosions and to reducing the residual risk of underground explosions.

From the results of the latest tests, it is evident that the system under investigation has the potential to reduce significantly the risk of methane ignitions developing into coal dust explosions.

6. RECOMMENDATION

It is recommended that the system be considered for use in situations where there is a high risk of methane ignitions.

7. REFERENCE

1. Faber, M. Entwicklung automatischer Löschsysteme für Strecken-vortriebe mit Schneidkopf-Teilschnittmaschinen. Bochum, 1990.

8. ACKNOWLEDGMENTS

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9. APPENDIX 1

SPECIFICATION FOR PROTOCOL TESTING OF ACTIVE IGNITION SUPPRESSION SYSTEMS IN COAL MINES

1. SCOPE OF SPECIFICATION

This document presents the procedure and adjudication criteria according to which an on-board flame-suppressant system will be tested to demonstrate, as far as is reasonably practicable, that it works. The purpose of this document is to establish the SIMCOL requirements to which the active suppression system must conform. This procedure has been agreed upon by CSIR Miningtek (as the testing establishment), SIMCOL (as the lead agent) and by the manufacturers of these types of system. Information supplied by the manufacturers has been incorporated to ensure that the test procedures and processes can accommodate all the differences in the proposed systems.

2. TEST OBJECTIVES

The objective of the protocol tests is to determine whether the system will be able to satisfy the needs of SIMCOL as embodied in the acceptance criteria.

The objective of the evaluation tests is to evaluate the working of the proposed system (configuration) in terms of how it performs, without actually considering how the needs are satisfied.

In order to evaluate and test the explosion-suppression systems for mechanical miners, a scale model of 1:1 will be used in the absence of actual mechanical miners.

Extreme conditions are deliberately chosen to evaluate the suppression system, thereby catering for worst-case scenarios. It is understood that such extreme conditions would not normally prevail underground. In the tests, large volumes of explosive atmospheres are used, whereby the whole face and first-cut region, as well as a large part of the cutter head, are exposed to an explosive mixture. Homogenous mixtures are used to achieve the most violent explosion possible. However, due to the dynamic nature of ventilation, the occurrence of such homogenous mixtures underground will be rare.

Although the occurrence of an explosive coal dust/air mixture around the cutter drum cannot be discounted when driving roadways with a mechanical miner, provision will not be made for such an explosion in the test procedures.

The fundamental combustion modes considered are fires occurring locally or over a certain area, methane flaming at the roof and a propagating methane explosion. As the first case will only involve the manual triggering of the system, this combustion mode will be used only to demonstrate the operation of the suppression system.

The evaluation of the effectiveness of suppression systems mounted on a mechanical miner is based on absolute results. It is expected that tests will be conducted without suppression systems to enable the extent of the flames to be determined. The tests done to see whether the system is in compliance will, however, use the results obtained in the tunnel for adjudication. It is accepted that similar tests may produce different results. Adjudication will therefore be based on a range of results rather than on an actual number of tests. The historical records of previous test work conducted on the system with other machine types and under different configurations will also be considered in evaluating the effectiveness of the system.

The tests conducted on the suppression system will be carried out on the surface in a specially designed and equipped test tunnel which will simulate conditions that could be encountered in the underground situation.

The suppressant system must comply with the following general criteria and should:

- contain the flames (and hot gases) resulting from the ignition of a methane/air mixture at the face of a heading in such a way that the operator of the mechanical miner is not endangered.

- suppress the flame in such a manner that it cannot extend further back than the operator's cab and create a coal dust explosion.

3. REQUIRED TEST EQUIPMENT

The equipment used to conduct the tests will consist of the following:

The tunnel in which full-scale tests will be conducted.

Either the actual machine to be used or a representation of the machine (model) manufactured out of steel.

Sensors to measure (i) the extent of the spread of the flame from the ignition source, (ii) the pressure generated by the explosion, and (iii) the temperature increases at selected points.

A data acquisition system allowing a comprehensive set of readings to be taken and stored for future reference in an accessible from. The data acquisition system will also cater for the recording of readings of the suppression system's performance, as well as all the readings from the sensors used in the test tunnel.

A methane-mixing and measuring system as well as an ignition source to ignite the methane/air mixture.

A video camera installed in the tunnel to allow visual recording of the event. The video recorder should have the ability to record and play back at 25 frames per second so that it can be used for visual inspection of the test results.

The layout of the tunnel is presented in Figure 1.

The methane/air mixture measuring points and electromagnetic valve mounting positions are shown in Figure 2.

The positions of the flame, pressure and temperature sensors and the video camera are shown in Figure 3.

The positions of the methane/air mixture ignition points are shown in Figure 4.

3.1 Test tunnel

The tunnel has been designed to allow 1:1 full-scale tests to be conducted, to cater for methane fires, roof layers and methane/air mixture ignitions on mechanical miners. No provision has been made to cater for coal dust explosions.

The dimensions of the tunnel will allow the testing of machines in seam heights ranging from 2,0 to 6,0 m in height. The roof of the tunnel can be set at variable heights within this range in increments of 0,5 m.

Provision has been made to simulate the conditions in a heading being mined by a continuous miner after the first lift or part of the first lift has been completed through the addition of a shoulder towards the front of the tunnel. This shoulder will be able to simulate a cut of up to a depth of 6 m for all the seam heights. The heading can be simulated at the start or end of the lift or can be done without the shoulder to give a full heading width of 7 m. This is similar to a test being conducted in a full heading as would be the case in the testing of full heading machines (roadheaders).

3.2 The "Model"

As the geometry of the continuous miner and thus the model can have an effect on the placement and design of the system, the model should at all times be representative of this critical geometry.

Nevertheless, tests done with the model will always be specified as such but with reference to the mechanical miner being simulated. Only when an actual machine is used will the tests indicate this.

Unless an actual continuous miner can be obtained to install the suppression equipment on, and to conduct the tests with, a "model" will be used. This will be a replica of a mechanical miner, manufactured out of steel, having the same attributes with regard to the use of the active suppression system as the real machine.

It will be the responsibility of the mine and the manufacturer on behalf of whom the testing is done to ensure that the model in the tunnel represents reality to the required extent.

3.3 Sensors

3.3.1 Pressure sensors

The objective of the dynamic (wind force) and static (quasi-static) pressure sensors is to measure the pressure shock at the operator's position and surroundings according to the criterion of human tolerance levels.

i) Dynamic pressure (wind force):

Quartz force transducer
This piezoelectric sensor converts a mechanical unit, pressure, wind force, etc., into a proportional electrical charge.

Type Kistler 9203 (used with Kistler 5007 charge amplifier)

Range:	- 500 .... 500 N
Threshold:	< ± 1 mN
Linearity:	≤ ± 1 % FSO
Rise time:	15 μs
Mass:	13 g
Operating temperature range:	- 150 .... 240 °C

Charge amplifier:

Type: Kistler 5007

(used for both static and dynamic piezoelectric sensors)

This amplifier converts the electrical charge yielded by the piezoelectric sensors into a proportional voltage signal.

Range:	± 10 .... 500 000
Transducer sensitivity:	0,1 .... 11 000 pC/M.U.
Linearity:	< ± 0,05 % FSO
Output:	0 - 10 V
Output impedance:	100 ohm

ii) Static pressure (dynamic and quasi-static pressure)

Type:	Kistler 7031
Range:	0 .... 250 bar
Linearity	± 0,06 % FSO
Rise time:	5 μs
Operating temperature range:	- 150 .... 240 °C

3.3.2 Flame sensors

The objective of the flame sensors is to determine the extent to which the flames have spread or have been contained. This is achieved by measuring the intensity of the flame at points arranged in a grid around the tunnel.

Silicon photovoltaic cells (IR detector)

Type:	TP60 (Siemens)
Operating temperature range:	- 25 .... 75 °C
Wavelength of max. sensitivity:	850 nm
Radiant sensitive area:	1,5 cm^2
Angle of sensing:	10° (for a length or width of 7 m of roadway)

Flame sensor amplifier:

Output: 0 .... 10 V

The output from each of the four sensors at 1 m intervals will indicate whether the flame has passed that point and along which side of the tunnel the flame has passed.

3.3.3 Temperature sensor

The objective of the temperature sensor is to determine the increase in temperature at the point where people could be present. The sensor must be able to measure temperature and to relate it to a time-scale for comparative analysis.

Thermocouple

Sensors:	Type K thermocouple
Temperature measuring range:	ambient to 500 °C

Thermocouple amplifier

Output:	0 - 10 V

3.3.4 Data acquisition system
(PC-based simultaneous sampling)

Processor:	Pentium (75 MHz)
Memory:	16 Mbyte RAM
	1,2 Gigabyte hard disk

i)

Number of channels:	(128 maximum single-ended)
Input voltage:	± 10 V
Over-voltage protection:	± 15 V
Max. sampling rate:	30 kHz per channel when using 128 channels (user-selective)
Max. sampling time:	2 s when using 128 channels (user-selective)
Resolution:	11 bits

ii) Software:

Menu-driven data acquisition software:

Set-up:	Test parameters (sampling rate and sampling time)
Plots:	2-D plots of experimental data

4. PROCEDURES

4.1 Equipment set-up

A test roadway with a length of 20 m is constructed for the explosion/ignition suppression tests on mechanical miners (Figure 1).

To simulate the face and second-cut end of the roadway, one end of the roadway is closed by means of a wall. In Figure 1 the layout of the test tunnel is shown. In Figure 2 the methane/air mixing chamber with control measuring points and electromagnetic valve mountings are shown.

In order to determine the extent to which the flame has progressed from the point of ignition, a number of flame sensors are used. These sensors are arranged in groups, forming planes at right angles to the horizontal, around the roof and sides of the tunnel, with the planes at a distance of 1 m from each other. By measuring the activation of the individual sensors, the speed of the flame advance can be obtained as well as the final position reached by the flame front. It should be noted that the system will have a distance sensitivity of 1 m of flame length as determined by the position of the last-activated detector in the direction of the flame propagation.

In order to measure the static and dynamic pressure in the explosion suppression tests, static pressure transducers are installed in the roof of the tunnel and a dynamic pressure transducer in the roof of the free roadway cross-section.

In the region of the machine operator's seat and surroundings, the temperature increase that occurs during suppression tests is additionally recorded by means of thermo-elements. A video camera is installed to record the fire and the ignition/explosion. In Figure 3 the positions of the light sensors, static and dynamic sensors, video camera and temperature sensors are shown.

In order to record the whole course of the test, starting with the ignition, the point at which the flame was picked up by the system sensor, the point at which the valves were activated, and the output signals from the flame detectors, pressure transducers and thermo-elements are recorded with a multi-channel data acquisition system so that the time correlation of all data is guaranteed. (The testing of this sequence is, however, dependent on the manufacturer's willingness to allow access to his system or on his need for such information.)

In order to simulate underground conditions more closely, the mechanical miner or the 1:1 scale mechanical miner model is placed in the tunnel with the cutting drum at the front. It is planned to keep the depth of the cut in the same order as the height of the seam to be tested.

The tests are conducted using the intended suppression system mounted in the manner in which it will ultimately be used in the underground situation.

A methane pocket is created over the cutting drum and part of the boom by connecting a sheet of PE foil to the walls of the tunnel in such a fashion that the pocket is fully contained. The volume of the methane/air mixture will depend on the height of the seam being simulated.

In keeping with the principle of testing worst-case scenarios, drum-type continuous miners will be tested by using the shoulder to simulate the effect of a heading after the first lift has been completed. As the standard continuous mining process uses a double-pass mining method to advance the heading, the worst ignition stage is at the start of the second lift. At this point the first lift may have formed a reservoir of methane in front of the machine which could be ignited. The size of this reservoir will be limited by not extending the depth of the lift.

The continuous miner will also be tested without the shoulder, using the full width of the tunnel.

In the event of a full-face machine or boom-type roadheader being tested, the shoulder will not be used as the mining process does not involve cutting in two lifts. In this case, tests will be conducted after the shoulder has been removed from the tunnel, giving a heading that is a full 7 m wide.

The methane mixture in the contained area will be ignited by means of a fuse cap. The ignition spark must be positioned between the drum and the face so that it is in the sighting shadow of the sensors of the suppression system. By following this procedure, the tests ensure that the system sensors have to react to the flame generated after ignition, rather than to the ignition source itself.

The ignition points are selected as being the most representative of places where ignitions could occur. The positions of the ignition points are shown in Figure 4. It is believed that they cover all possibilities relevant to ignitions and/or the course of a fire, as well as the suppression process.

Three types of fire or ignition simulations will be used for test purposes:

(1) The type of fire that would occur after methane emanating from a fissure or a cavity has been ignited.

(2) A methane layer 1,5 m thick against the roof that has been ignited.

(3) The ignition of a methane pocket enveloping the head of the machine. This explosion, in which the methane is contained by the foil, will be done using methane mixtures with concentrations of 9 and 12 % vol.

It should be noted that in some tests the shoulder will be used so that in effect the area involved will be significantly larger and the volume of methane involved in the ignition will also be larger.

4.2 Calibrating the test tunnel and test equipment

To ensure that the results from the test tunnel are reliable, the tunnel needs to be calibrated and tested for maintenance or repeatability. It is thus essential to test the repeatability of results from the different sensors being used in the tunnel. This will be achieved by simulating the same methane/air explosions/ignitions for five consecutive times and comparing the results of these tests. A standard methane mixture and volume will be used for all the calibration tests.

Acceptance criteria for calibration

The tunnel tests as described in Section 3.1 shall be regarded as acceptable when the deviation between similar sensor readings obtained for the various tests does not vary by more than ± 10 %.

5. PROTOCOL TESTS FOR SUPPRESSION SYSTEMS

Testing of fires

This test will only be done for demonstration purposes and will not form part of the normal process. The standard fire to be used in all tests of this nature is created by introducing and igniting about 200 m³ of methane per hour in the vicinity of the face. Two types of fires are investigated, namely local fires and area fires. (The amount of methane used in the simulation of fires will not vary with the seam height and will be kept constant for all the tests.)

In the simulation of local fires, the methane will be introduced through a 1-inch (2,5 cm) pipeline directly to point 2 in the face (see Figure 4) where it will be ignited by the standard means. This type of fire simulates accidental cutting through a methane reservoir which has resulted in a concentrated outflow that has been ignited. Two different positions of the cutter head are investigated for local fires. In the one instance, the cutter head is in position 2 in front of the fire and in the other case, the cutter head is in the position of ignition spot 4, at the roof (see Figure 4).

In the simulation of area fires, the methane flows out of a perforated H-form pipe on the floor in front of the face. This type of fire simulates the combustion of the mined coal in front of the machine. Accordingly, the cutter head is lowered into position 2 (see Figure 4).

Acceptance criteria

Local fires are extinguished by manual triggering of the suppression system. A test will be regarded as successful if manual activation of the system achieves complete extinction of the flames.

Testing of methane roof layers

For the suppression of methane roof flaming, methane roof layers 5 and 7 m in length and a thickness of less than 1,5 m, starting at the face/second cut and extending up to above the machine, are produced. This is done through the controlled release of pure methane in the tunnel while keeping the air in the tunnel static. The length of the roof layer is contained by the use of a PE foil against the roof. The position of the cutter head is at ignition spot 4 (see

Figure 4). Roof layers are ignited by means of an igniter and gun-cotton in the transition zone between the air and the methane roof layer.

The methane roof flaming is suppressed by the automatic triggering of the sensor system which activates the suppressant system. Methane roof flamings without suppression could reach flame running lengths of more than 40 m, associated with a temperature increase of up to 523 °C at the operator's seat. The use of a shoulder in the one case could cause the flame to run in two directions directly after the ignition; this is a situation that the system will have to contend with.

Acceptance criteria

The suppression system should be able to sense the flame and suppress it so that it does not extend further back than the position of the last nozzle of the suppression system. The temperature increase at the operator's position should not be more than approximately 100 °C during the time-period before the flame is extinguished. The system should also not allow residual flames in the first lift that might blow back past the position of the last installed nozzle in the direction of the operator. It is accepted that this type of occurrence is not accompanied by a severe increase in pressure.

Testing of the suppression of a methane/air mixture explosion

The object of this test is to suppress the expansion of an explosion propagating from a point source within an explosive or flammable mixture of methane and air. The suppression mechanism must stop the propagation of the explosion before it is out of control. It is further accepted that the suppression system is ultimately designed to cope with such incidents.

These tests are carried out in a methane/air volume of sufficient size to cover the sensor system as well as the suppression containers and nozzles. A chamber is formed to contain the mixture through the installation of a PE foil sheet behind the nozzle set furthest from the face. The volume of the methane/air mixture used will be determined by the height of the seam being simulated and the depth of the first lift behind the position of the shoulder.

Methane/air mixtures of 9 and 12 % vol. are ignited at the different ignition spots indicated in Table 1, with the cutter head in the corresponding positions.

The ignition is introduced in the sighting shadow of the sensor system behind the cutter head. The ignition source is an electric spark or fuse cap.

Two further variants of these tests using mixtures of homogeneous composition are used. In the first case, the methane/air mixture is ignited with a stationary cutter head and in the second case, with a rotating cutter head creating a turbulent condition. The idea is to test turbulent methane/air mixtures to simulate the underground conditions caused by the rotation of the cutter head and the ventilating air in the face region. Turbulent, i.e. moving, methane/air mixtures react faster. As a result, the flame spreads faster and the suppression system is tested under the worst-case conditions.

The proposed sequence of the suppression tests in this category is shown in Table 1.

Table 1
Protocol testing requirements

TEST	IGNITION POSITION	METHANE CONC. %	DRUM STATUS	TESTS
F1	A1	9	Stationary	1
F2	A1	9	Turning	1
F3	A2	9	Turning	1
F4	A3	9	Turning	1
F5	A4	9	Turning	1
F6	A5	9	Turning	1
S1	B1	9	Turning	1
S2	B2	9	Turning	1
S3	B3	9	Turning	1
S4	B4	9	Turning	1
S5	B3/4	12	Turning	1

In adjudicating the results, the maximum flame ranges in metres from the source, the temperature increases at the operators's seat, and the static and dynamic pressures as measured are considered for each of the different mixture concentrations, drum positions and situation variants. The results will be compared by referring back to a test done without suppression, but compliance will be measured against absolute values. Repeat tests will only be carried out when the acceptance criteria have not been met and the reason for failure has not been identified.

Acceptance criteria

The suppression system must stop the flames from spreading significantly beyond the line of outlets furthest away from the source of ignition, i.e. beyond the first line of flame sensors located furthest from the face after the suppression nozzles. The flame sensors placed just before the operator's position should not register the presence of flame at all.

No flame sensor before or beyond the operator's position should register any flame either during the progression of the explosion or at any time after the suppression system has been activated.

The temperature at the operator's position should not increase beyond human tolerance limits to ensure the operator's survival and physical safety. The temperature increase should not exceed 100 °C.

The pressure, as indicated by the dynamic and static pressure increases at the operator's position, should not increase beyond human tolerance limits to ensure the operator's survival and physical safety.

The video recording of the explosion-suppression test must not show any flames going past the mechanical miner that could reignite any methane that might be present behind or at the operator's position.

6. REPORT FORMAT

The results will be tabulated and presented in graphs to determine the velocity and extent of the flame spread.

Although these results will not be used in the adjudication of compliance tests, they will be available to determine, where appropriate, the reason why the acceptance criteria were not met and the extent to which they were not met.

In the event of the failure of a specific suppression system, these results can be used to determine the risk when that system was used.

The results of all tests will be logged and filed for future reference. In the presentation of the results of protocol tests, only the success or lack of success of the test will be reported. The results will, however, be available to the client sponsoring the test for reference purposes.

B673-1 SCALE 1=200

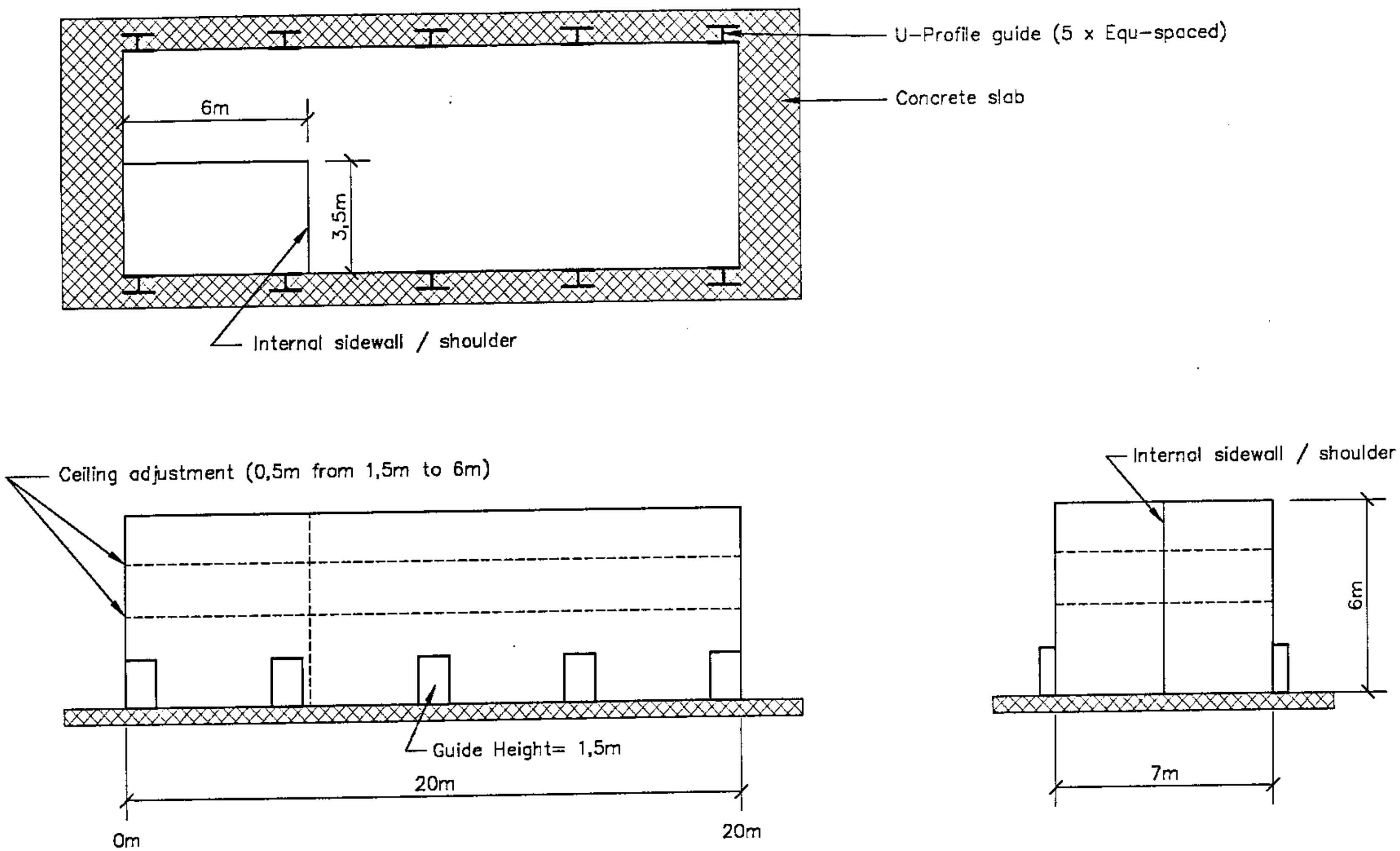
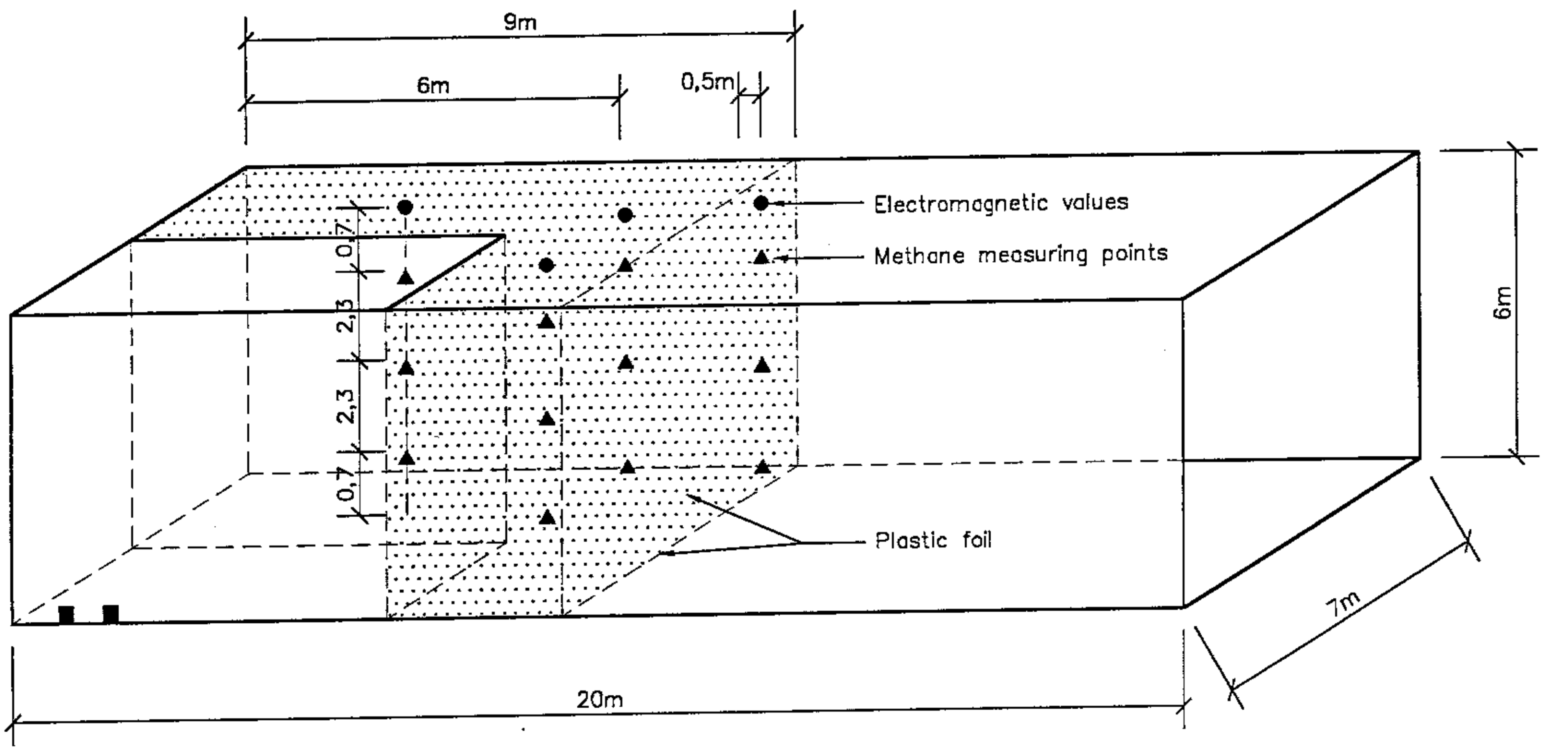


Fig. 1 Test tunnel



▲ Methane measuring points

● Electromagnetic valve mounting interface

■ Methane manifold interface

Fig. 2 Methane / air mixture measuring points and electromagnetic valve mountings

B673-3 SCALE 1=200

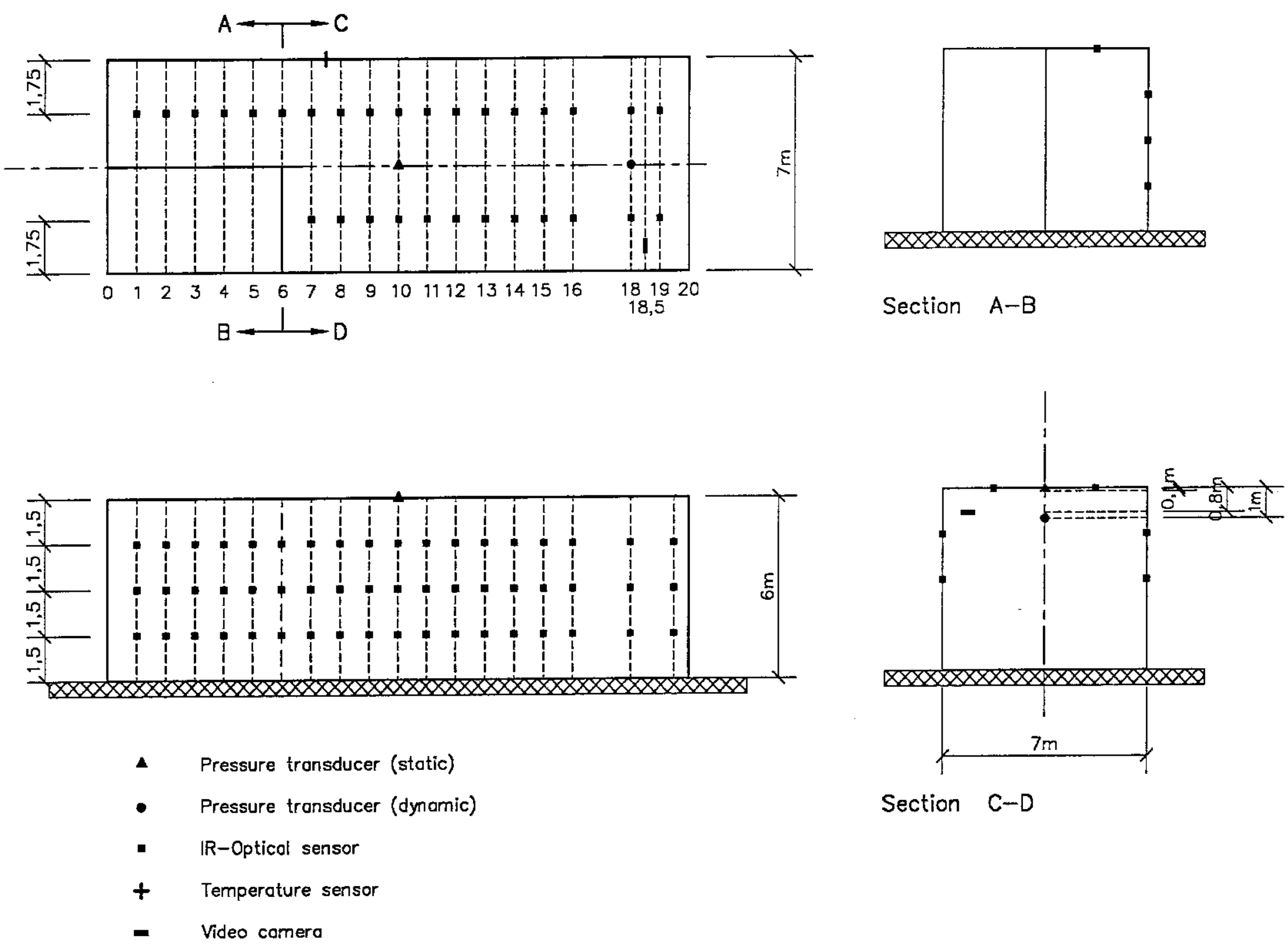


Fig. 3 Position of measurement equipment for evaluation of suppression systems

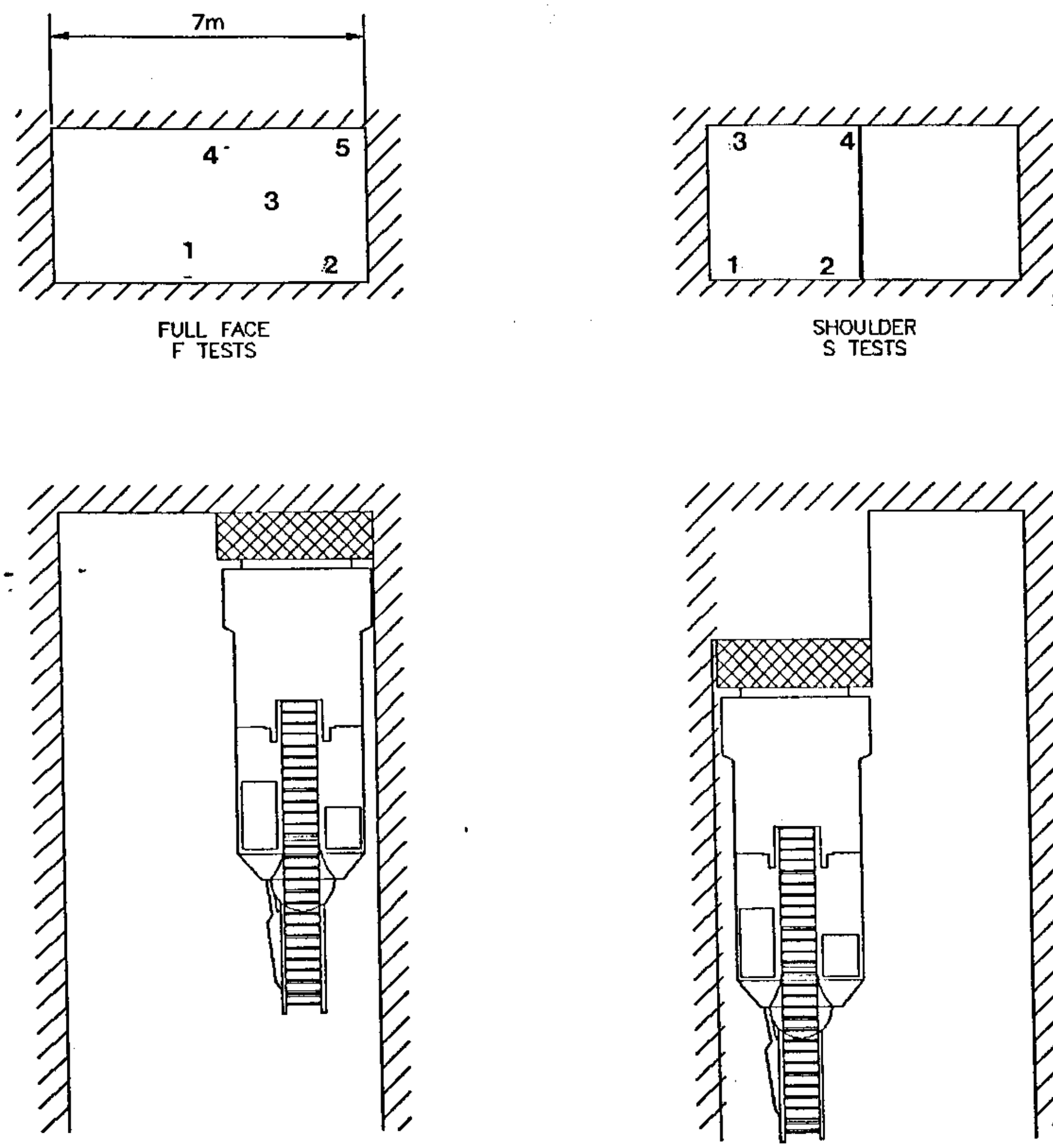


Fig. 4 Ignition positions

10. APPENDIX 2

20-metre tunnel tests

TEST	VOL (m^3)	CH_4/AIR (%)	IGNITION (joules)	SUPPRESSION SYSTEM	COMMENTS
0	67	9	200	local	CM*
1	26	9,0	200	-	empty
2	53	9,0	200	-	empty
3	87	7,5	200	adapted	CM
4	87	9,0	200	adapted	CM
5	87	9,0	200	-	CM
6	87	9,0	200	-	CM
7	87	9,0	200	-	empty, data acq. failed
8	87	9,0	200	-	empty
9	87	9,0	200	-	empty
10	87	12	1 000	-	empty
11	87	12	1 000	-	empty
12	87	9,0	1 000	-	empty
13	87	9,0	400	-	model**
14	87	9,0	200	-	model
15	87	7,5	200	-	model
16	87	9,0	200	-	model

*CM: continuous miner present in tunnel

**Model: continuous miner model in tunnel

TEST	VOL (m^3)	CH_4/AIR (%)	IGNITION (joules)	SUPPRESSION SYSTEM	COMMENTS
17	87	7,5	200	-	model
18	87	7,5	200	-	model
19	87	9,0	200	-	model
20	87	9,0	200	-	model
21	87	9,0	200	-	model
22	"	9,0	200	adapted	new model
23	"	9,0	200	adapted	"
24	"	9,0	200	adapted	"
25	"	9,0	200	adapted	"
26	"	9,0	200	adapted	"
27	"	9,0	200	adapted	"
28	105	7,7	200	-	new model, shoulder
29	105	9,0	200	adapted	"
30	105	9,0	200	adapted	"
31	105	9,0	200	adapted	"
32	105	9,0	200	adapted	"
33	105	9,0	200	adapted	"
34	105	12,0	2 x 200	adapted	"
36	105	12,0	2 x 200	adapted	"