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THE SIGNIFICANCE OF DUST SURVEYS IN COLLIERIES

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CONFIDENTIAL MEMORANDUM

FOR LIMITED CIRCULATION ONLY

This memorandum is presented by Mr. F.E. Joubert to the members of the Explosion Hazards Sub-committee as a basis for discussion of the merits of surveys of conditions that can contribute to explosions in collieries.

THE SIGNIFICANCE OF DUST SURVEYS IN COLLIERIES

1. INTRODUCTION

Attempts to assess the value of surveys of dust conditions in collieries that may constitute explosion hazards are presented in this discussion.

The background to this work is the following. Since 1965 various surveys have been carried out by F.R.I. staff to investigate the occurrence of methane in collieries[1) 2) 3) 4)].

The object of these investigations was to obtain information on the quantity of methane present in the ventilation returns from working sections in collieries, how methane is distributed within a working section, and in what way the methane content varies from time to time in a particular location. A recording methanometer was developed and employed in the acquisition of some of the data required[5) 6)]. The quantity of methane in the return air was found to lie between zero and 3%, but the higher percentages were exceptions, the usual range being zero to 1%. As regards the distribution of methane within a section, more methane was found near working faces than anywhere else. The recording methanometer showed that there is always a minimum concentration of methane present and that the increase above this minimum is normally proportional to the quantity of coal mined.

As an extension of these methane surveys, explosibility of coal dust has been investigated in the laboratories of the F.R.I.[7) 8) 9)]. The first apparatus used for this purpose was built to specifications of the United States' Bureau of Mines.[8)] During 1970 another apparatus was built to specifications of the Berggewerkschaftskasse of Dortmund, Germany. The purpose of this project was to classify coal from all collieries on the basis of an explosibility index. (High index values indicate highly explosive coal dust.)

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In order to obtain a criterion of explosibility for South African coals three samples of coal were sent to the Berggewerkschaftskasse in Dortmund for explosibility tests.[10] A report submitted by the B.V.S. stated that dust from all three samples constituted an explosion hazard, as the explosibility indices were higher than five units which is the limit of safety employed in Germany. The indices obtained by them differed from those determined by the F.R.I. with similar equipment. In paragraph 3 an attempt is made to evaluate the significance of these differences.

2. ASSIGNMENT TO INVESTIGATE CONDITIONS IN COLLIERIES

The desirability of an on-the-spot investigation was discussed by a subcommittee of the Explosion Hazards Committee of the Coal Mining Research Controlling Council who made certain recommendations and commissioned the F.R.I. to conduct a survey. The terms of reference were not clearly defined, but the apparent idea was that F.R.I. staff should establish whether a correlation exists between the explosibility index of a certain type of coal as the first variable, and the conditions under which that coal is mined or the accident history of the mine, as the second variable. In the event of the existence of such a correlation, mines could be classified more or less strictly according to an explosibility index. In the absence of such a correlation the interpretation of the explosibility index values would pose a problem. This aspect is dealt with in the next paragraph.

3. SIGNIFICANCE OF THE EXPLOSIBILITY INDEX

An explosibility index gives an indication of the force or violence of the reaction of suspended coal dust when compelled to explode in a closed vessel. In terms of mining operations the explosibility index means that the dust of a highly reactive coal, when suspended in the air of mine works, can perpetuate an initial methane explosion as a coal dust explosion. The crux of this argument is that all collieries in which a highly reactive coal is mined, could be labelled as "dangerous".

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There are, however, other arguments to keep in mind. In Germany all types of coal with an explosibility index of five units or more are considered to constitute a coal dust explosion hazard, but the German authorities subject anthracite collieries producing coal with an explosibility index of two units to the same regulations as the "dangerous" collieries, because of the presence of methane in those collieries. Clearly then, explosibility tests are not the only criterion used when classifying a colliery as "safe" or as "dangerous". If any of the collieries in a given mining area had never been disrupted by explosions, no basis for the classification of a colliery as "dangerous" would exist, whatever the nature of the coal mined, unless methane is sometimes present. The interpretation of explosibility tests thus calls for the consideration of empirical data such as the accident histories of collieries. Explosibility indices must, therefore, be correlated with factual mining conditions prevalent in a country.

If these arguments are valid, the actual value derived from an explosibility test is to serve as a relative index, applicable to a specific country or district on the basis of past experience. Differences in indices obtained in different countries or districts for the same coal (as the results of the Berggewerkschaftskasse and of the F.R.I.) should be of no concern, as long as the coals are classified in the same sequence in both sets of results and as long as the ratios of explosibility index are also more or less the same for the two sets.

If an anthracite colliery containing methane is regarded as "dangerous" (that is, it presents a potential coal dust explosion hazard) it must follow that the presence (or absence)of methane is a dominant factor in the evaluation of the potential dangers of a colliery. In succeeding paragraphs arguments are put forward in favour of the assertion that methane is the prime factor to be considered in any colliery, and that the possibility of an explosion in the absence of methane is very slender indeed.

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4. AN EXPLOSION MODEL

An explosion, in general terms, is:- "... a chemical reaction which is effected in an exceedingly short space of time with the evolution of a large quantity of gas at a high temperature and accompanied by a shock."[11)]

This definition gives a good description of a methane explosion and its possible effects. Three ~~phases~~ which can spell death to a miner can be identified:-

(i) "chemical reaction", causing a deficiency of oxygen and/or creating carbon dioxide, carbon monoxide and nitrous oxides;

(ii) "high temperature", scalding a person fatally;

(iii) "shock", which on its own can crush a person to death.

Let us visualize a coal face or a mine road in a working section of a colliery. If an explosion should occur, it will occur in an atmosphere with various possible constituents like moisture, carbon dioxide and coal dust. A necessary constituent is methane, but the percentage of methane necessary for an explosion will depend on the above-mentioned possible constituents. After an explosion, two things may happen: firstly, the violence or extent of the methane explosion is not great, or the adjacent mine roads are so wet, or the loose material in the mine road has such a large proportion of inert content, that the explosion terminates after the consumption of all the methane; secondly, the initial explosion is so violent or conditions in the adjacent roadways so favourable for the extension of the explosion that a coal dust explosion ensues.

Consider the variables for a primary explosion and a secondary explosion separately.

/I. Primary .....

I. <u>Primary explosion</u>

It can be stated that a primary explosion (one requiring methane) depends on the following variables (or parameters):-

(a) percentage of methane in the atmosphere;

(b) quantity of dust in suspension in the atmosphere;

(c) flammability of coal dust in suspension;

(d) fineness of coal dust in suspension;

(e) moisture content of the atmosphere;

(f) temperature of the atmosphere;

(g) gases present, other than air and methane;

(h) turbulence of the atmosphere;

(i) energy of the spark or flame.

As an approximation to actual mining conditions, disregard variables (e), (f) and (g). Modify the percentage methane required (a), by the prevailing turbulence (h), if any, and name this modified variable (A). Also, substitute the quantity and properties of the coal dust in suspension, i.e. variables (b), (c) and (d), by a new variable (B). The only remaining parameters are (A), (B) and (i).

It is a sufficient condition for a methane explosion to occur if, at the same moment, parameter (i) exceeds a critical minimum value and parameters (A) and (B) are within the required limits, provided that the quantity of dust, (B), can equal zero, while the amount of methane, (A), must not be equal to zero.

Formulated in mathematical form, the occurrence of a methane explosion, U, is a function of the following two sets of parameters:

/(i) U, ...

(i) $U_1 = f(A,B,i)$

In this case suitable proportions of methane and dust as well as an energy source of sufficient intensity are present.

(ii) $U_2 = f(A,i)$

In this case the methane content is within the required limits and an energy source of appropriate intensity is present.

Conditions necessary for a methane explosion constitute a set of one parameter less than those present in the sets defined in U_1 and U_2. These sets of parameters are:-

(i) (A) - only methane is present. (Spark required.)

(ii) (i) - only a spark is present. (Methane required.)

(iii) (A,B) - a mixture of methane and coal dust is present. (Spark required.)

(iv) (B,i) - coal dust is present and so is a spark (normally methane required). This set could, in exceptional circumstances, constitute a sufficient condition for an explosion (local coal dust explosion), but few accidents of this nature are known to have occurred. In the next paragraph a few figures are quoted.

It should be noted that in two of the above sets only one parameter is present. To prevent the development of conditions sufficient for explosions, only this single condition must be prevented. The mineworker exercises more control over the prevention of a methane build-up to a dangerous level than over the generation of sparks. Sparks are known to occur frequently during coal cutting operations. This recalls one of the central themes of this report as discussed in paragraph 3, namely,that methane is the most important factor to be taken into consideration in any mine. The possibility of an explosion in the absence of methane is virtually nil in South Africa.

II Secondary explosions

A secondary explosion (one requiring suspended flammable dust) depends on the following variables:-

(j) extent or force of the primary explosion;

(k) quantity of coal dust or coarser fragments of coal available;

(l) moisture content of all loose material on a mine road;

(m) petrographic properties (or volatile matter content) of coal dust;

(n) size grading of coal dust and coal;

(o) quantity of stone dust available;

(p) stone dust or water barriers;

(q) moisture content of the air;

(r) pressure attained.

As in the case of primary explosions, let us simplify matters again by grouping certain parameters together and disregarding others.

Incorporate the force of a primary explosion, and the pressure attained, into the actual phenomenon of the explosion, U. Since (r) could vary from one moment to the next during a coal dust explosion, the foregoing transforms the occurrence of a primary explosion, U, into a dynamic variable in time, or U = U(t).

Group the variables (k), (m) and (n) together and name the properties of this suspendable material (K). Parameters (l), (o), (p) and (q) may all have quenching effects on an explosion. Group them together under variable (L).

It is a sufficient condition for a coal dust explosion to occur and be propagated if the value of (K) is adverse enough and the value of (L) is low enough during the occurrence of the dynamic parameter U(t) to sustain the explosion from point to point along a mine road. Formulated in mathematical terms the occurrence of a coal dust explosion, V, is a function of the following two sets of parameters:-

(i) $V_1 \doteq g(U(t),K,L)$

or, if all quenching effects are absent,

(ii) $V_2 = g(U(t),K)$

V_2 is a subset of V_1. Conditions necessary for a coal dust explosion constitute a set of one parameter less than that present in the subset V_2. These sets of parameters are:-

(i) (U(t)) - a primary explosion has occurred (adverse parameter (K) required for a secondary explosion).

(ii) (K) - enough dry coal dust present (primary explosion required for a coal dust explosion).

In contemporary mining techniques an attempt is being made to prevent both of these necessary conditions. The elimination of methane and consequently a primary explosion, U, ensures that the two conditions sufficient for the occurrence of a coal dust explosion cannot occur (except as stated in the next paragraph), even if the value of (K) is adverse and the value of (L) zero.

A more comprehensive discussion of the parameters (a) to (r) can be found in Appendix A.

It would be logical to evaluate the seriousness of the problem of methane explosions in our mines before deciding what amount of work should be done on the possible refinements of the model and to what extent such efforts might prevent explosions in collieries. Relevant statistics are furnished in the next paragraph.

5. MINE STATISTICS

To evaluate the seriousness of gas explosions and to compare it with other causes of accidents, the number of fatalities was taken as a basis. This resulted in magnifying the danger of methane explosions, as most people involved in these are killed outright, while the ratio of people killed to people injured is smaller for most other types of accidents.

Two sets of statistics, one for South African collieries (Tables 1, 2, 3 and 4) and another for British collieries (Tables 5 and 6) are quoted for the purpose of comparison.

The figures given in Table 1[21)] cover a few years during the period 1912 to 1947, and Table 2[21)] gives corresponding figures for the twenty years from 1951 to 1970. Table 3[21)] gives less information on different aspects than Tables 1 and 2, but covers the whole period from 1911 to 1960. The causes of the 31 deaths due to gas explosions during the past 10 years (1961 to 1970), are enumerated in Table 4[21)].

Table 5[15)] furnishes average figures for British collieries from 1851 to 1965, while Table 6[22)] reflects annual figures for the twenty-year period from 1950 to 1969/1970.

/TABLE 1 .....

TABLE 1

PRODUCTION, LABOUR AND FATALITY FIGURES FOR SOUTH AFRICAN MINES DURING THE PERIOD 1912 TO 1947

Year	Collieries					All Mines[xx]	
			Deaths			Deaths	
	Production in 1000 tons	Labour[x]	Total	Fall of ground	Gas explosions	Total	Gas explosions
1912	8 100	14 120	51	31	0	987	2
1917	10 400	29 834	68	33	7	664	8
1927	13 300	22 035	91	57	0	742	3
1937	16 000	31 672	81	49	4	869	-ø
1947	25 600	50 534	94	58	2	614	-

x The first two figures given are for "underground" workers, the third is not specified, and the last two figures are for "production".

xx Excluding alluvial diggings and "works".

ø "-" denotes figures not available.

/TABLE 2 .....

TABLE 2

PRODUCTION, LABOUR AND FATALITY FIGURES FOR SOUTH AFRICAN MINES FOR THE PERIOD 1951 TO 1970

	Coal Mines					All Mines*	
			Deaths			Deaths	
Year	Production in 1000 tons	Labour	Total	Fall of ground	Gas explosion	Total	Gas explosion
1951	28 800	54 780	111	32	31	736	36
1952	30 000	56 861	102	49	0	766	18
1953	30 600	56 026	102	52	5	761	15
1954	30 800	56 474	93	50	1	781	7
1955	33 100	59 428	88	49	1	713	14
1956	35 600	59 723	101	50	14	816	23
1957	38 300	62 372	108	57	8	783	13
1958	40 900	65 848	74	33	0	766	5
1959	40 200	66 997	72	39	0	816	32
1960	42 100	66 307	496	466	0	1 223	0
1961	43 600	70 293	90	60	8	786	11
1962	45 500	72 073	103	43	16	783	22
1963	46 800	72 777	87	49	1	785	4
1964	49 500	76 449	104	47	0	771	5
1965	52 000	80 858	84	44	0	839	15
1966	59 700	82 239	79	35	0	797	0
1967	61 000	78 186	73	31	3	825	20
1968	63 900	78 561	81	34	3	711	5
1969	64 600	76 201	77	41	0	872	28
1970	60 700	75 742	79	41	0	813	3
			2 203	1 302	91	16 143	276

* Includes alluvial diggings and "works".

/TABLE 3 .....

TABLE 3

FATALITY FIGURES FOR SOUTH AFRICAN COLLIERIES FROM 1911 TO 1960, GIVING, FOR MAJOR ACCIDENTS, THE NAME OF THE COLLIERY AND THE NUMBER OF PEOPLE KILLED IN BRACKETS.

Year	Deaths		Mine and number killed
	Total	Gas Explo-sions	
1911	48	0	
1912	51	0	
1913	76	3	
1914	52	2	
1915	57	10	
1916	60	3	
1917	68	7	
1918	51	0	
1919	- ⌘	-	
1920	83	3	
1921	67	11	
1922	85	23	Burnside Colliery (21)
1923	94	18	Hlobane Colliery (12)
1924	85	2	
1925	86	1	
1926	218	131	Durban Navigation Colliery (125)
1927	91	0	
1928	108	1	
1929	78	0	
1930	118	41	Dundee Coal (38)
1931	57	0	
1932	50	0	
1933	49	0	
1934	67	7	
1935	141	78	New Marsfield (78)
1936	79	0	
1937	81	4	
1938	69	0	
1939	79	0	
1940	65	0	
1941	84	16	Utrecht Collieries (15)
1942	95	0	
1943	170	78	Natal Navigation (78)
1944	166	58	Vryheid Railway Coal (57)
1945	116	15	S.A. Coal Estates (15)
1946	93	0	
1947	94	2	
1948	93	0	
1949	86	0	
1950	91	0	
1951	111	31	Cornelia Collieries (17); Vryheid Collieries (12)
1952	102	0	
1953	102	5	
1954	93	1	
1955	88	1	
1956	101	14	Schoongezicht Collieries (12)
1957	108	8	
1958	74	0	
1959	72	0	
1960	496	0	

⌘ Not available.

TABLE 4

CAUSES OF DEATHS FROM GAS EXPLOSIONS IN COAL MINES FOR 1961 TO 1970

Year	Mine	Number Killed	Cause
1961	Coalbrook Colliery	8	Illegal open light
1962	Springbok Collieries	6	Damaged electric cable
1962	Natal Navigation (Northfield)	10	Unknown
1963	(Not stated)	1	Blasting
1967	Indumeni Colliery	3	Flame-proof cover of motor removed
1968	Enyati Colliery	3	Blasting

TABLE 5

AVERAGE FATALITY FIGURES FOR BRITISH COAL MINES FOR THE LAST 115 YEARS

Years	Average number of fatal explosions per year	Average number of deaths due to gas explosions per year
1851-1860	82,0	244
1861-1870	56,5	227
1871-1880	42,4	269
1881-1890	24,5	166
1891-1900	18,9	102
1901-1910	18,2	136
1911-1920	13,5	94
1921-1930	13,6	43
1931-1940	9,4	86
1941-1950	8,2	44
1951-1960	3,0	25
1961-1965	1,6	14

/TABLE 6 .....

TABLE 6

PRODUCTION, LABOUR AND FATALITY FIGURES FOR BRITISH COAL MINES FOR THE 20 YEARS JANUARY 1950 TO MARCH 1970

Year Ending		Tonnage in 1000 All Mines	Labour All Mines	Killed Underground			
				Total	Fall of Ground	Gas Explosions	
Dec.	1950	216 100	697 000	447	186	6	
"	1951	222 300	698 600	448	198	99	
"	1952	225 000	715 800	376	187	1	
"	1953	223 500	716 900	344	181	15	
"	1954	223 800	707 200	328	180	5	
"	1955	221 600	704 100	366	185	7	
"	1956	222 000	703 400	295	159	9	
"	1957	223 600	710 100	367	169	48	
"	1958	215 800	698 800	287	149	0	
"	1959	206 100	664 500	326	142	16	
		NCB Mines	NCB Mines			Gas, dust and fires	Other causes
"	1960	183 800	602 100	286	124	50	13
"	1961	179 600	570 500	206	105	7	10
"	1962	187 600	550 900	231	85	31	13
March	1964	187 200	517 000	225	120	4	7
"	1965	183 700	491 000	160	76	1	5
"	1966	174 100	455 700	194	67	32	12
"	1967	164 600	419 400	125	58	2	5
"	1968	162 700	391 900	110	43	9	18
"	1969	153 000	336 300	101	39	- ж	14
"	1970	139 800	305 100	73	22	- ж	5
				5 295	2 475	342	

ж Figures are not reported any more.

/Some .....

Some conclusions to be drawn from the preceding tables:-

(i) During the years given, the number of deaths due to gas explosions decreased in both South African and British collieries. The decrease in Britain since the last century is dramatic. In South Africa the fatality rate was never very high.

(ii) South African collieries have a higher fatality rate due to gas explosions during the past twenty years (7 per 100 000 man-years) than British collieries (3 per 100 000 man-years).

(iii) Accidents due to "gas, dust and fires" have decreased to such an extent in Britain that separate figures are no longer furnished (refer Table 6). The same could have been true for South African mines if methane explosions in gold mines did not occur in such large numbers.

(iv) Figures for the past twenty years indicate that deaths due to gas explosions in South African collieries accounted for 4,1% of the total fatalities, and rock falls were responsible for 59,1% of the total fatalities, including the Coalbrook disaster of 1960, or 49,3% of the total deaths excluding Coalbrook.

The corresponding figures for British collieries are: due to gas explosions, 6,5% of the total deaths; and due to rock falls, 46,7% of the total deaths.

(v) While the number of workers increased about three-fold and the output of coal increased about five-fold in South African collieries, the annual number of fatalities due to all causes has remained remarkably constant during the past half century.

Initiation of coal dust explosions

Of the nineteen coal dust explosions in British collieries during the period 1936 to 1965, two were caused by runaway loaded coal tubs[23)] (the one cut an electric cable, causing an arc, and the other ignited the coal dust through frictional heat), and the other seventeen were initiated by methane.

In South Africa only one known coal dust explosion has occurred, namely D.N.C. in 1926. The accident at New Marsfield (1935), in which 78 people died, was ascribed to methane explosions occurring at more than one level. In the cases of Natal Navigation (1943), 78 killed, and Vryheid Railway Coal (1944), 57 killed, no Inspectors of Mines reports are available.

Taking into account the histories of coal dust explosions in Britain and in South Africa, as well as the ratio of non-methane to methane initiators of coal dust explosions, it can be stated that the probability of a coal dust explosion in South African collieries, which is not initiated by a methane explosion, is very slender indeed.

This concludes the mine statistics. If we want to influence future events, positive steps are called for. In the next paragraph a description of actual mining conditions is given.

6. SURVEYS IN COLLIERIES

Three collieries were visited at the end of 1971. It was attempted to measure as many of the variables described in paragraph 4 as possible.

In the Springbok Hope colliery as well as in D.N.C. two locations were visited, and at Sigma colliery one location.

I. Procedure followed during measurement of parameters

The parameters are discussed in the same sequence as they have been listed in paragraph 4.

(a) Percentage of methane in the atmosphere.

Glass sampling bottles were used to sample the mine air. These samples were subsequently analysed with a gas chromatograph.

(b) Quantity of dust in suspension in the atmosphere.

The one to five micron portion of the dust constitutes a health hazard. Only this fraction was measured because dust sampling apparatus used by the Inspectors of Mines or the Dust and Ventilation officers of the Chamber of Mines can determine this fraction only.

(c) Flammability of coal dust in suspension. (See (m))

(d) Fineness of coal dust in suspension.

Since only a portion of the dust was sampled in (b), a particle size distribution determination on that portion would serve no purpose.

(e) Moisture content of the atmosphere.

Relative humidity was measured with a meteorograph (an apparatus used by meteorological offices).

(f) Temperature of the atmosphere.

Also measured with the meteorograph.

(g) Gases present, other than air and methane.

Same as (a)

(h) Turbulence of the atmosphere.

Degree of turbulence cannot be measured directly but must be calculated from a model, taking into account the air speed, dimensions of the mine road, roughness of the walls, etc. Another complicating factor is offered when air is pumped to a coal face through a duct. No attempts were made to construct such models.

(i) Energy of the spark or flame.

Sparks and flames occur seldom and the term "measurement" does not apply here. Most of the sparks are generated during coal cutting operations when they cannot be recorded anyway.

(j) Extent or force of the primary explosion.

Not applicable.

(k) Quantity of coal dust or coarser fragments of coal available.

After a working coal face had been blasted and watered down, two ropes were laid down between 5 and 9 metres from the coal face and between 0,5 and 1 metre apart from each other. All coal lumps bigger than about 25 mm were thrown out and it was attempted to pick up all the wet coal between the ropes with the aid of a scoop and a carpet brush. The coal was placed in a canvas bag. If there was too much coal for the canvas bag, the percentage scooped up was measured.

(l) Moisture content of all loose material on a mine road.

The coal was watered down so well after blasting (maybe partly due to the presence of an Inspector of Mines) that it was impossible to take a representative sample of reasonable size of the wet coal and slurry.

(m) Petrographic properties (or volatile matter content) of coal dust.

For different size fractions the volatile matter content was subsequently determined on a few of the coal samples. The idea is to deduce the flammability index value of the coal from its volatile matter content.

(n) Size grading of coal dust and coal.

The air-dried coal was screened through a 25 mm, and through 30, 100, 200 and 300 mesh sieves.

(o) Quantity of stone dust available.

Not applicable - the sampling point was too near the face for stone dusting to have taken place.

(p) Stone dust or water barriers. Not applicable.

(q) Moisture content of the air. See (e).

(r) Pressure attained. Not applicable.

The results of all the above measurements and determinations are summarized in Table 7.

TABLE 7

NUMERIC VALUES FOR SOME EXPLOSION PARAMETERS

Parameter	Springbok Hope		D.N.C.		Sigma
	Central Section 6	North, Section 5	Section 72	Section 112	Section 2
(a) Percentage methane	0	0	0	0	0
(b) Respirable dust (mg/c.m.)	0,4	0,8	- x	-	6,5
(e) Relative humidity (%)	86	88	87	70	87
(f) Temperature (°C)	18	20	23	24,5	23
(g) Other gases	0	0	0	0	0
(h) Air speed (m/s)	0,1	0	0,1	> 50 xx	1,97
(k) Coal present (kg/c.m.)	3,6	4,5	5,5	6,5	5,1
Distance from face (m)	5	5	7	7	9
(m) Volatile matter content(%)					
+100 mesh	-	28,6	28,3	-	22,6
+200 mesh	-	27,6	31,6	-	23,5
+300 mesh	-	26,0	29,5	-	22,2
-300 mesh	-	21,5	33,8	-	21,4
(n) Size grading:					
-25 mm	100,0	100,0	100,0	100,0	100,0
-30 mesh	10,2	49,5	14,9	4,6	10,1
-100 mesh	5,2	29,5	10,3	2,2	5,1
-200 mesh	3,1	19,2	7,0	1,2	2,5
-300 mesh	2,4	14,8	4,9	0,9	1,2

x Not determined.
xx Air speed measured at outlet of air duct.

II Discussion of the procedure and of the results

(i) It is an open question at which point in a mine and at which point in time it should be attempted to measure a set of parameters. Ideally such measurements should be done at a dangerous point, while simultaneously sets of parameters should be obtained at various adjacent points. In this orientation survey only one set of measurements was attempted.

Methane is frequently emitted near working coal faces so that these points seem to be logical places at which methane explosions can occur. As to the time when measurements should be made, it was argued that after blasting plenty of coal is available for the possible extension of a methane explosion as a coal dust explosion. For these reasons the measurements were made as near to the coal face as practical, but far enough from it to be able to take a total coal sample of reasonable size.

(ii) Because of the complete absence of methane and the extremely wet conditions, it can only be concluded that the conditions necessary for a methane explosion (and therefore for a coal dust explosion) are absent. The other numerical values are of little or no consequence under these circumstances.

(iii) Staff from the Dust and Ventilation Laboratories of the Chamber of Mines, Inspectors of Mines from the offices of the Government Mining Engineer, and the managements of the collieries concerned, gave the F.R.I. personnel all the assistance they called for. Since apparatus and coal samples had to be handled underground and because distances to working faces were sometimes great, the mine managements had to

/provide .....

provide people to carry the loads and/or vehicles for underground transport. Senior officials of the collieries also accompanied the party to the coal faces. In view of this disruption of normal activities when explosion parameters are to be measured, the impression was gained that frequent visits of this nature will not be welcomed.

7. <u>WHERE ARE WE GOING?</u>

The accident histories of collieries as reflected in results contained in various reports have been dealt with in preceding paragraphs, but what does the future hold? In which direction should our efforts be channelled to achieve useful and practical results? The following are a few possibilities:-

(i) Continued measurements in collieries.

The practical significance and value of the measurements already made have a special influence on this issue. In a mine, most of the parameters of the explosion model vary continually, with the result that an infinite population of sets of parameters has to be tested against the necessary conditions for an explosion as described in the model. As a practical approach to conditions prevailing in collieries it is assumed that a set of parameters differs significantly from a previous set at intervals of ten minutes. The number of sets in one shift is at least 40 per working face. In a colliery comprising 6 working section, 5 coal faces per section, and 250 shifts per annum, the annual population of different sets of parameters will be in the order of 300 000. The measurements actually undertaken constitute a sample of 5 items from an annual total of 900 000 (three collieries). On this basis alone nobody

/could .....

could possibly be allowed to draw any conclusions from the five measurements.

To obtain a statistically significant sample from the population of sets of parameters would entail the full-time employment of at least one person per average-sized colliery. Such a person should operate independently from the mine management and must be able to move freely about the mine. This arrangement would be feasible only if this person were employed by the Government Mining Engineer, i.e. have the same statutory powers as an Inspector of Mines. The practical value of such measurements would even then be questionable, as control of the parameters that may cause necessary conditions for the occurrence of an explosion are already fully covered by existing legislation[18]. It should be borne in mind that Inspectors of Mines come into daily contact with these parameters. They seem to be the obvious people to guard against the occurrence of "necessary conditions" - a job they are already implicitly doing. If none of the additional measurements called for by the explosion model is taken, the net effect of the Inspectors of Mines' activities will probably remain unchanged, as the existing regulations are rather comprehensive. All that may be required from an Inspector of Mines is to keep the explosion model in mind in order to interpret the different variables as these occur in a mine, as an entity.

(ii) Laboratory refinements of the explosion model.

All the interrelations between the different parameters have to be determined to render the model mathematically exact. For this purpose one parameter has to be varied in small, discrete steps, while all the others are kept constant. Every change in a value in one of the latter parameters requires a repetition of this process. The number of variables for the explosion model is nine. If this is taken into consideration with the fact that a number of tests on one fixed set of parameters is necessary to obtain a good average, the effort required to conduct this series of experiments can be measured in the order of magnitude of tens of man-years. If the model for coal dust explosions is to be investigated as well, it will be necessary to acquire and utilize an explosion testing gallery.

While the refinements of these models may be of academic interest, their practical value still has to be proved.

(iii) Continuation of methane surveys.

Paragraph 5(iv) indicated that methane explosions accounted for 4,1% of all deaths in collieries for the past twenty years. This figure is 1,5% for the five years 1966 to 1970.

Seven years ago, when the project to investigate the occurrence of methane in collieries was started, the picture of all aspects of gas explosions was not as clear as it is today. It may now be appropriate to ask whether it is meaningful to continue doing research on the occurrence of methane. Does this phenomenon with its associated explosions still pose a problem today?

Explosions continue to occur:
Tendega in Natal, methane explosion, December 1971, about 26 people killed;
Wankie in Rhodesia, coal dust explosion, June 1972, more than 400 people killed.

/However ....

However, the author of this report is of the opinion that methane surveys will not prevent accidents, and neither will surveys to measure sets of parameters for the explosion model. The actions of Inspectors of Mines (people with statutory power) are much more likely to make people safety-conscious. The influence that the attitudes of people can have on the prevention of accidents is discussed in the next paragraph.

Quite apart from that, anybody spending public money must try to keep his perspective. During the past seven years an annual amount in excess of R50 000 was spent on coal mining research. If 30% was allocated to the problems raised in this report, the total expenditure for the seven years would exceed R100 000. The value of the research work done is questionable. During this period six people lost their lives in colliery explosions. The situation then is that more than R10 000 is spent on research for every person killed in explosions. An average of 15 people die on our roads every day and it is doubtful if R240 000 is spent daily on road safety research.

8. THE PERSONAL ELEMENT

If we have reached the stage where all the explosion parameters are known and are provided for in The Mines and Works Act and Regulations of South Africa[18)], then why do explosions still occur? The answer to this question may lie in the "human element" factor, the actions of people who are working underground. With hundreds of such people in a fiery colliery at a given time, the probability is small but ever-present that one person will do something wrong, resulting in an explosion. The most one can do now is to give a

/short .....

short (and admittedly incomplete) list of possible reasons why people would do the "wrong" things:-

(i) Ignorance of the effect of actions. Training may be comprehensive but conceivably some people, especially non-white, may not get the message.

(ii) Ignorance of a high methane content. This aspect can cover a whole spectrum of possibilities. Two examples at the extreme ends of this spectrum can be given,

(a) the "we never had methane" attitude, resulting in maybe one or two half-hearted tests per shift with a safety lamp, and

(b) methane is suddenly emitted in large quantities, which can result in an explosion before anybody even knows about the methane.

(iii) Pressure from levels higher in the hierarchy of authority. If the tonnage required from a person is too large to produce conveniently, he may slacken safety precautions to save time.

(iv) Contraband or any other willful breach of regulations.

The problem discussed in (i) above is tackled actively by the training schools of the mining houses; problem (ii) is discussed in the next paragraph; problem (iii) is never mentioned in good company in order not to give offence; and problem (iv) falls outside scientific research.

/9. DETECT .....

9. DETECT THE METHANE

The following comment is contained in a comprehensive survey on explosions in British collieries[15]).

"..... the most difficult step to eradicate in the train of events which culminates in a coal dust explosion is the presence of the firedamp. Before firedamp is eradicated, it must be detected, and if we are to obtain the reduction in the number of times that gas is ignited, which the sophisticated and superlatively equipped mines of the future will deserve, the instruments used and the organization set up for the detection of gas must be improved."

The same applies for gas explosions Instruments which should meet all the above requirements are available. One make of gas monitor available is inexpensive (under R300), easy to operate (eliminates training of miners), reliable, lightweight (about 3 kg), and equipped with an alarm. This instrument seems to be the ideal methane detector which can indicate minute quantities and give audible warning of sudden methane emissions. It can also be mounted on coal cutters and power loaders in such a way that it cuts off the electric power when a predetermined percentage of methane in the mine air is exceeded. We may be able to learn from European and American collieries in this respect.

Methane can be found in virtually any place, at any time. In 1962 there were nine gas explosions which occurred as follows: 4 in gold mines, 1 in a diamond mine, 2 in collieries, 1 in other mineral mines and 1 in "works".

It is said that a good miner can see a 1,5% methane cap in a safety lamp. Minute quantities (for instance 0,1% to 0,5%) can never be detected in this way. If a well-ventilated mine could contain 0,1% methane, a combination of adverse conditions could result in a dangerous accumulation. On more than one occasion gas explosions

/have .....

have occurred in non-fiery collieries, usually near a dyke, or after interruption of the ventilation over a weekend or due to power failure. The accident at Tendega can be taken as an example of such a combination of adverse conditions. The moral of the argument is that "gas-free" and "non-fiery" are not synonymous - a mine is non-fiery only if the absence of methane is constantly confirmed by sensitive monitors.

F.E. JOUBERT

Pretoria.
9th August, 1972.
FEJ/EMc

APPENDIX A

I Variables Involved in a Primary Explosion (one requiring methane).

(a) Percentage of methane in the atmosphere.

Lange's Handbook of Chemistry[12)] states that the limits, in percentage by volume, of methane that will explode are 5,3% and 13,9%. No experimental details are given. No values of any other variables, e.g. moisture content of the gas mixtures, or direction of the flame, are furnished.

In experiments by another author[13)] a 2 m high by 30 cm square vessel was placed over water. When a spark was introduced near the bottom of this vessel, a 5,1% methane-air mixture burned upward to a height of 30 cm but quenched itself. For a 5,6% methane content the flame moved through the total length of the vessel.

The limits of flammability also depend on the direction of the flame[14)]. Refer Table 8.

TABLE 8

LIMITS OF FLAMMABILITY OF METHANE-AIR MIXTURES FOR DIFFERENT DIRECTIONS OF THE FLAME.

Direction of flame	Percentage of methane in air	
	Lower limit	Upper limit
Upward	5,35	14,85
Horizontal	5,40	13,95
Downward	5,95	13,35

/The .....

The following extract is taken from the same reference:-

"Limits of inflammability are thus defined by experimentally determined mixture compositions. Although there exists a large body of experience on the subject, and the experimentally determined limits are proven to be reliable for safety and other uses, there is as yet no set of data available on which a reliable analysis of the phenomenon can be based."

The forming of layers of methane gas against the roofs of mine roads is a further complicating factor when methane-air mixtures are considered. Layering is generally considered to be dangerous even if the whole layer is outside the flammability limits, because it can extend an explosion, and it can ignite coal when it itself is burning.

(b) Quantity of dust in suspension in the atmosphere.

A quantity of 0,05 g of fine bituminous coal dust per litre of air is generally regarded as sufficient to sustain a secondary explosion on its own, and a methane content of about 5% is sufficient to cause a primary explosion on its own. In between, a mixture of coal dust (less than 0,05 g/l) and methane (less than 5%) can cause a primary explosion[17].

"Fine" coal dust means: 85% of the dust < 75 microns[23].

(c) Flammability of coal dust in suspension.

If the coal dusts have a volatile matter content less than that of "bituminous coal" (see paragraph (b)), more dust will be required for the same methane content to cause a primary explosion.

/(d) Fineness .....

(d) Fineness of coal dust in suspension.

The finer the coal, the greater its contribution towards explosiveness[23].

(e) Moisture content of the atmosphere.

Experimental results of investigations concerning the explosibility of methane-air mixtures with varying moisture content could not be traced in the literature.

(f) Temperature of the atmosphere.

As the temperature reached in an explosion is about 2000°C, and as the variation in temperature at the working faces is small (20°C to 25°C), the effect of this small variation on the final temperature of an explosion, or on the violence or extent of an explosion, can be regarded as negligible.

(g) Gases present, other than methane and air.

The presence of inert gases raises the lower inflammability limit of methane in air. The contents of Table 9 are derived from Lewis and Von Elbe[14].

TABLE 9

EFFECT OF INERT GASES ON LOWER INFLAMMABILITY LIMIT OF METHANE

Lower limit of inflammability	Composition of rest of gas mixture (%)		
Percentage of methane	O_2	N_2	CO_2
5,4	12,2	82,4	-
7,2	14,7	55,8	22,3

/(h) Turbulence .....

(h) Turbulence of the atmosphere.

Coward and Jones[13] report that a 5,6% methane content is the minimum to burn completely in a static atmosphere. With slight turbulence 5,0% of methane ignited throughout the container, but with heavy turbulence even a 5,6% mixture promoted only a short tongue of flame.

The velocity of the flame is also higher in a turbulent atmosphere[20], with the result that in general more violent explosions are to be expected under turbulent conditions.

(i) Energy of spark or flame.

Comprehensive figures on all aspects of ignition are not available. A few samples of energy requirements are given below:

1. To ignite 5% of methane in air, about 2 millijoules are required; to ignite 9% to 10% of methane in air, about 0,3 millijoules are required; and to ignite 15% of methane in air, about 3 millijoules are required[17].

2. The spontaneous combustion temperature of fine dispersed coal dust is 540°C[12].

3. If 1 gram of a mixture of Zirconium powder and Barium nitrate is ignited electrically, 1000 calories of energy is released in a very short time and this energy normally can ignite 25 gram of fine coal dust dispersed in a 40 litre closed vessel[10].

A good idea of the relative importance of different causes of gas ignitions can be formed from statistics for British collieries. See Table 10.

/TABLE 10 .....

TABLE 10[15)]

CAUSES OF ALL REPORTED GAS IGNITIONS IN COAL MINES

Year	Contra-band	Electri-city	Shot-firing	Friction		Flame (lamp)	Fires	Miscell-aneous	Total
				Power loaders	Coal cutters				
1961	2	2	7	1	6	-	-	3	21
1962	-	4	6	4	4	-	-	1	19
1963	1	2	4	3	5	-	-	3	18
1964	-	3	7	6	4	1	1	1	23
1965	-	2	7	8	1	-	-	2	20

II Variables Involved in a Secondary Explosion (ore requiring suspended coal dust).

(j) Extent or violence of the initial explosion.

This depends mainly on the volume, composition and turbulence of the explosive gases. The more violent the explosion, the greater the chances that sufficient coal dust will be lifted into the atmosphere to perpetuate the explosion as a coal dust explosion.

(k) Quantity of coal dust or coarser fragments of coal available.

Coal dust can be ignited in mines in the absence of methane[15) 23)], but modern explosives make such accidents highly unlikely. As stated previously, about 0,5 gram/litre of coal dust is sufficient to maintain an explosion. This fact makes the measurements undertaken by staff of the F.R.I. of little value.

A quantity of more than 0,5 g/l will of course cause more violent explosions, up to a certain limit where a deficiency of oxygen is created. The quantity of coal or coal dust that could be brought into suspension by an explosion, varies from point to point along all colliery roads.

(l) Moisture content of all loose material on a colliery road.

Figures as high as 47% of water, by weight of total material, have been quoted by Cybulski of Poland (referred to in reference 15) as necessary to quench a dust explosion or to prevent it. Some workers[15)] are of the opinion that a dust explosion could be sustained by visibly dry patches along a road.

/(m) Petrographic ...

(m) Petrographic properties (or volatile matter content) of coal dust.

If the volatile matter content of the coal dust is above 14%, the dust is considered to be dangerous[18]. Explosiveness increases up to a volatile matter content of 25%, but does not increase appreciably after that[19]. The Mines and Works Act and Regulations call for the addition of inert matter to reduce the volatile matter content of the mixture to less than 10%. (See section 10.24.4 of the Regulations.)

(n) Size grading of coal dust and coal.

Coarse coal has a smaller surface area per unit mass than finely divided coal. The surface area of coal per litre of air must be equivalent to the surface area of 0,05 gram of fine coal dust to have the same propagating potential. A coal sample with particle sizes of between 210 and 150 μ (72 and 100 mesh sieves) has a surface area of 290 m^2/g [24].

(o) Quantity of stone dust available.

An initial methane explosion will not result in a coal dust explosion if enough stone dust is present on the surface of material on a colliery road to ensure that the volatile matter content of all material that could be brought into suspension, is below 10%[18].

(p) Stone dust or water barriers.

Once a coal dust explosion has started, such barriers may be the only means to prevent the explosion from running right through a mine. In at least one mine a water barrier was able to stop a coal dust explosion[23].

/(q) Moisture .....

(q) Moisture content of the air.

The effect of this parameter is unknown, but it is assumed that moist air will have a small quenching effect.

(r) Pressure attained.

The greater the pressure wave of a blast, the more likely it is to force enough material from the floor, sides and roof of a roadway into the air to promote an explosion. A high pressure also propagates an explosion faster, resulting in turn again in a higher pressure. This vicious circle may result in an exponential rise in pressure, and an explosion of very large speed, which can in part explain why coal dust explosions are so destructive.

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