

THE USE OF STONE DUST TO CONTROL COAL DUST EXPLOSIONS: A REVIEW OF INTERNATIONAL PRACTICE

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For

The Stakeholders of the Federal Government / Industry
Underground Coal Mines Safety Research Collaboration
Administered by Natural Resources Canada.

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The Underground Coal Mine Safety Research Collaboration (UCMSRC) is an ad-hoc association of stakeholders in the Canadian underground coal mining industry. It was established in 1998 after the closure of the federal government's CANMET Coal Research Laboratory in Sydney, N.S. The UCMSRC provides a forum for the discussion of safety and health topics in underground coal mines. Stakeholders include operating companies, Federal and Provincial government agencies, universities and consultants.

In 2001 UCMSRC stakeholders responded to a request from the Nova Scotia Department of Labour to review methods of controlling coal dust explosions. At their specific request, a review of passive and triggered explosion barriers in underground coal mines was commissioned (Zhou and Panawalage, 2001).

To complement this work on explosion barriers, the UCMSRC commissioned a review of international practice relating to the use of stone-dust to control coal dust explosions after a request from several stakeholders.

The resulting report was compiled from technical reports and regulatory standards relating to coal dust explosions and stone-dusting practices in underground coal mines obtained from both library and on-line resources. It summarizes the present-day understanding of coal dust explosion hazards and presents a comparison of some national and international regulatory standards.

Of particular interest in the Canadian context is the relatively recent observation by Australian and South African regulators that stone-dusting standards in those countries, based on tests conducted on relatively coarse dusts from foreign (UK, USA, Poland) coal seams, were inadequate. Canadian stone dust standards are based on the same, foreign, test results, and may therefore also be inadequate.

The properties of the stone dust used in the inertisation of coal dusts are extremely critical. Stone dust is heavier than coal dust, and not as easily lifted into suspension in the air. The dust must be fine enough to be lifted in sufficient quantities to inert the suspended dust mixture.

The report identifies the dangers of float coal dust accumulations, and the need for mine operators to address both the production of this dust in the mine and its deposition in roadways outby, and also the need to ensure that any buildup of float coal dust is effectively rendered inert.

Finally, a form of Code of Practice is suggested, based on the recent work completed in South Africa.

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“Coal dust is a major health and safety hazard in underground coal mines. When the hazard of methane is combined with excessive and untreated dust, the potential for disaster, as tragically demonstrated at Westray, is very real.”

Richard, Justice K. Peter (1997); “The Westray Story – A Predictable Path to Disaster” Report of the Westray Mine Public Inquiry, November, 1997, Province of Nova Scotia.

BACKGROUND

The Underground Coal Mine Safety Research Collaboration (UCMSRC) is an ad-hoc association of stakeholders in the Canadian underground coal mining industry. It was established in 1998 after the closure of the federal governments CANMET Coal Research Laboratory in Sydney, N.S. The UCMSRC provides a forum for the discussion of safety and health topics in underground coal mines. Stakeholders include operating companies, Federal and Provincial government agencies, universities and consultants.

The UCMSRC has commissioned studies on various aspects of underground coal mine safety and health as directed and supported by its stakeholders. Examples include reviews of: geotechnical conditions in underground coalfields across Canada; the use of light alloys in underground coal mines; methane levels requiring machine shut-offs; and methanometers on diesel equipment.

In 2001 UCMSRC stakeholders responded to a request from the Nova Scotia Department of Labour to review methods of controlling coal dust explosions. At their specific request, a review of passive and triggered explosion barriers in underground coal mines was commissioned (Zhou and Panawalage, 2001).

Although explosion barriers used in conjunction with stone-dusting¹ are thought by many to be an essential tool in the control of explosions in underground coal mines, their use is by no means ubiquitous. In the United States, for example, protection against the propagation of coal dust explosions is provided by stone-dusting alone.

To complement the earlier work on barriers, the UCMSRC commissioned a review of international practice relating to the use of stone-dust to control coal dust explosions after a request from several stakeholders.

The following report presents the results of that review. It has been compiled from technical reports and regulatory standards relating to coal dust explosions and

¹ Stone-dusting, or rock-dusting, is the application to roadway surfaces of an inert dust, usually limestone dust, in amounts that render any coal dust incombustible.

stone-dusting practices in underground coal mines. It summarizes the present-day understanding of coal dust explosion hazards and presents a comparison of some national and international regulatory standards.

ACKNOWLEDGEMENTS

An initial draft of this report was prepared by Mr. Don Hindy, P.Eng. Mr. Hindy is Mines Health and Safety Program Coordinator at Alberta Human Resources and Employment. Much of the initial work, including the collection of the literature citations and the assembly of the Canadian regulatory standards, was completed by Mr. Gary Bonnell and Mr. David Young, of NRCan-CANMET, and Mr. David Forrester, Ph.D., P.Eng. Dr. Forrester is a consultant working in Sydney, Nova Scotia. Other members of the UCMSRC also contributed literature citations and helpful references.

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DISCLAIMER

The information presented in this report is believed to represent the current state of knowledge of the use of stone-dust to control the initiation and propagation of coal dust explosions. However, the conclusions drawn from this information, and the subsequent recommendations, represent the opinions of the author, and may not be shared by all stakeholders in the UCMSRC.

Many of the extracts from legislation presented in the appendices were obtained from web-pages and other on-line resources. On no account should either the texts, or the interpretations of the author, be considered to be the correct transcriptions and interpretations held by the various regulatory authorities.

Coal is only one of many materials which, when in the form of a fine powder, can form an explosive mixture with air. Iron sulphide, aluminium, tantalum, polyethylene and benzoic acid are possibly the least well known, with sugar, flour, paper, and sawdust representing the more common explosive powders (Nagy, 1981). The greatest killer of them all is coal dust, responsible for thousands of deaths in underground coal mine explosions.

HISTORY

The possible contribution of coal dust to underground coal mine explosions has been known for nearly two centuries. Mr. John Buddle of the United Kingdom identified the link as early as 1803. Sir Charles Lyell and Professor Michael Faraday, both eminent scientists of their day, identified the link after the Haswell Colliery explosion in Co. Durham had killed 95 miners in 1844. In 1847 Faraday even demonstrated experimentally to the Royal Institution that coal dust played a major part in underground coal mine explosions (Davies and Isaac, 1998).

Unfortunately these observations were neither accepted nor acted upon by the mining industry at large. Although the UK Coal Mines Royal Commission report of 1894 determined that the danger of an explosion, even in a mine with little methane, was greatly increased by the presence of coal dust, it was not until after the Courrieres les Lens Colliery explosion in 1906 in France that killed 1230 miners, that serious attention was paid to investigating the dangers of coal dust (Davies and Isaac, 1999).

It is no coincidence that much of the research and experimentation on coal dust explosions dates from around 1906; the loss of 1230 lives in one accident could not be ignored. Many countries established experimental facilities at which coal dust explosion testing was carried out, and public demonstrations drew large numbers of mining people and the public to view the test explosions. These tests largely convinced the mining community of the dangers of coal dust.

Since that time there have been a large number of studies of the dangers of coal dust, the properties of coal dust and how they affect the risk of explosions, and the various methods of eliminating or reducing the hazards of coal dust explosions. These studies have included both field and laboratory experimentation and have resulted in numerous technical publications which have influenced the direction of underground coal mining and related mining regulations throughout the world. Perhaps the most renowned of the researchers into the problem was Professor Cybulski, working in Poland, whose research has laid the foundation for the present understanding of the phenomenon and how to control it (Cybulski, 1975).

Not everyone was convinced, however. Nagy (1981) reported an article published in 1928 that continued to deny the link between coal dust and explosions experienced in mines. It was not until 1998 that the role of coal dust as a fuel in an underground coal mine explosion was legally established in South Africa, following a five year inquest into an explosion in May of 1993 at the Middelbult Mine in Trasvaal, RSA.

The most recent advances in the understanding of coal dust explosions and their control have come from Australia, and from joint investigations carried out by Australian and South African research laboratories. A series of explosions at Moura Collieries in the latter part of the 20th century prompted a renewed emphasis on the control of coal dust explosions. Since then, major changes have been legislated to the requirements for explosion suppression systems in both Australia and South Africa.

ANATOMY OF A COAL DUST EXPLOSION

The following succinct description of a coal dust explosion is taken from Humphreys and O'Beirne (2000):

“Coal dust explosions occur when fine coal particles become airborne and are ignited by some means. In a coal mine, the precursor to a coal dust explosion is usually the ignition of a quantity of methane. The resulting flame travels through the available fuel leaving behind hot expanding gases. In the presence of some degree of confinement from the roof floor and sides, the gases cannot expand in all directions and a pressure wave is produced that accelerates the flame and causes fine coal dust to become airborne. This is in turn, ignited by the flame that lags behind the pressure front, further driving the pressure front along and raising more dust ahead of the flame front. Until there is a break in this cycle of raising then igniting coal dust, the explosion continues to propagate generating destructive pressures and large quantities of irrespirable and toxic gases. Ultimately, a coal dust explosion could pass through the entire coal mine until it reached the surface.”

The various stages involved can be summarized as:

- Development of an explosive methane / air atmosphere.
- Ignition of the gas.
- Development of the primary (gas) explosion and acceleration of the flame displaced gases outward.
- Lifting of coal dust by airflow (the displaced gases), and creation of an explosive mixture.
- Ignition of the dust / air mixture.
- Further turbulent acceleration of the dust flame front, lifting more dust, mixing it with air, and creating an explosive zone in front of the flame.
- Propagation of a dust explosion throughout the mine.

Development of an explosive methane / air atmosphere

As coal is mined, the methane contained within the coal desorbs and methane from the surrounding strata escapes and mixes with the mine air at the working face. If the methane emission is high enough, or if the ventilation is weak enough, a potentially explosive mixture of methane and air may result.

Accumulations of methane are also possible away from the working face, but provided that ventilation plans are well engineered, well implemented and the ventilation devices well maintained, they are much less likely.

Although most coal dust explosions result from an initial ignition of methane and air, Nagy (1981) reported that up to 10% of coal dust explosions may involve only coal dust. Coal dust raised by a sudden change in ventilation (a ventilation control door opening or a wind blast from a gob fall) requires a heat source much stronger than that required by a gas mixture.

Ignition of the gas

Methane / air mixtures are explosive in the range 5% to 15% methane, with the most violent explosions resulting from a 9.5% methane concentration. Methane / air mixtures can be ignited by any heat source of sufficient energy. In practice as little as 0.0003 joules of electrical energy is required. A practical comparison is that this energy is about one fiftieth of the static charge accumulated by an average man walking on carpet on a dry day. Metal at a temperature of about 537°C (1000°F) will ignite methane. Metal at this temperature will glow a dull red in a darkened room.

The length of time required to generate an ignition by an energy source depends on the methane concentration. At optimum methane / air mixtures, an electric spark requires about $\frac{1}{3}$ of a second before propagation occurs. At less optimal mixtures, delays range from two seconds at 6% methane to 4 seconds at 13.5%.

Nagy (1981) identified a number of potential sources of ignition of methane / air mixtures (Table 1). There are many more in addition to these, such as thermite reactions, diesel equipment, conveyor roller fires, static discharge, and the results of poor electrical or mechanical maintenance, but most authorities agree that the most common cause of ignitions in modern mines is frictional ignition, caused by the smear of cherry-red or white-hot metal left on the rock after being struck by a blunt or damaged miner pick.

Contrary to popular belief, a cigarette may not always ignite methane, but a portion of the paper, turned out and burning, always will, as will a cigarette lighter or a match (Nagy, 1981).

Development of the primary (gas) explosion

The development of the primary gas explosion depends on a number of factors; methane concentration, uniformity of mixing, degree of confinement and the location and intensity of the ignition source. The most violent explosions are developed in homogenous mixtures ignited at or very close to the face.

Tests in the US demonstrated that the minimum amount of 9.5% methane / air mixture required to propagate a coal dust explosion was 4 m³. When coal dust alone was used as the primary source, about 2 .2 kg (5 lb) of coal dust was required to propagate an explosion.

Table 1: Common Sources of Underground Explosions and Ignitions (after Nagy, 1981)

- I Friction**
 - A Frictional sparks from machine bits striking roof, floor, or hard inclusions in coal
 - B Frictional sparks from drill bit striking hard material
 - C Drill steel striking iron frame
 - D Frictional sparks during roof fall from sandstone striking other hard rock
- II Electrical**
 - A Sparking in non-permissible electrical equipment
 - B Arcs from battery operated equipment
 - C Broken light bulb
 - D Trailing cable being pulled in two
 - E Faulty splice in trailing cable
 - F Arc on trolley wire
 - G Intermachine arcing
 - H Power line arc from roof fall or haulage wreck
 - I Arc at wheel of trolley vehicle
- III Flame**
 - A Welding and cutting torch
 - B Propane torch
 - C Fire
 - D Blow Torch
 - E Carbide lamp
 - F Match (smoking or otherwise)
 - G Cigarette lighter
- IV Explosives**
 - A Non-permissible explosives
 - B Mis-use of permissible explosives – overcharging, blown out shot, mud-capping
 - C Detonators
 - D Non-permissible blasting unit
 - E Long-delay blasting
- V Miscellaneous**
 - A Red hot drill bit
 - B Glowing particles from cutting and welding
 - C Safety lamp: defective, opening and striking key, or purging with compressed air
 - D Lightning

Lifting of coal dust by airflow

The expansion of the gaseous products of the primary explosion away from the ignition source results in the formation of a pressure wave closely followed by the flame front. This pressure wave can dislodge dust from the roof and sides into the roadway, and may raise dust from the floor into suspension.

Float coal dust in suspended concentrations of as little as 50 g/m³ can be ignited. This represents the minimum explosive concentration. There is no practical upper limit, although some researchers have claimed that it exists.

In a mine roadway 6 m. wide by 2.5 m. high, only 900g/m of dust would be required. Spread evenly over the floor, this represents a layer about 0.15 mm thick (assuming a density close to 1). Spread evenly over the roof and ribs only, this represents a layer of about 800 microns thickness.

Ignition of the dust / air mixture

The minimum energy required to ignite a cloud of coal dust is 0.03 joules. This is about 100 times as much energy as is required to ignite a methane / air mixture. In terms previously described, this is about the static charge accumulated by two average men walking on carpet on a dry day.

Coal dust suspended in air will ignite at temperatures as low as 440°C (Nagy, 1965), although this depends on the coal. For some coals, this limiting temperature is as high as 610°C. A cloud of coal dust can be ignited by a frictional spark in the absence of methane. By comparison, the minimum ignition temperature of a layer of dust is about 180°C.

Propagation of a dust explosion throughout the mine

Once ignited, the coal dust explosion generates its own pressure front that travels along the mine roadway and lifts more dust, continuing a chain reaction that can continue throughout the mine.

THE FIRE TRIANGLE AND THE EXPLOSION PENTAGON

Most engineers responsible for accident prevention are familiar with the “fire triangle” – the concept that in order for a fire to occur, there must be present heat, fuel and oxygen. The removal of any one of these eliminates the fire hazard.

Stephan (1990) described the “explosion pentagon”, which is the “fire triangle” with two additional sides – suspension and confinement. That is to say that a coal dust explosion cannot be propagated without suspension of the coal dust and the confinement of the event. Without confinement, a methane explosion cannot occur, and without suspension of coal dust, a methane explosion will not progress to a coal dust explosion. In the absence of fuel, or heat or oxygen, neither a fire nor an explosion can take place.

It is important to note that the heat source need not be the result of a methane ignition. A cloud of coal dust, raised into the air by a sudden change in ventilation (for example a gob cave) can be ignited by a suitable source, and can explode.

No-one has yet developed a method of mining coal without the presence of humans in the mine, although robotic technologies bring this closer every day. Therefore the elimination of oxygen from the mine workings is not possible. Control of fire and explosion hazards is obtained by addressing the heat and fuel components.

HEAT

Common ignition sources for underground explosions are shown in Table 1, and include, among others, electrical short-circuits, static discharge, thermite reactions resulting from light alloy oxide / iron oxide interaction, and from contraband use (smoking, matches). In normal mine conditions, these sources are protected by engineering and regulatory controls.

Surprisingly, despite their name, flame safety lamps have been demonstrated to allow the ignition of methane / air mixtures and cause explosions. The cause of the disaster at Moura No. 4 in Australia was attributed to a gob cave which resulted in a “wind blast” of a flammable mixture of methane and air. The blast raised coal dust in the active workings, and an official’s flame safety lamp ignited the methane / air mixture. The resultant coal dust explosion cost the lives of 12 miners (Queensland, 1986). This was only the most recent link in a chain of evidence that “safety” lamps can be lethal under certain circumstances.

McPherson et al. (1995) presented compelling arguments that adiabatic compression of mine atmospheres as a result of gob caves can generate sufficient heat to ignite a methane / air or coal dust / air mixture. This research arose after a number of unexplained explosions associated with gob cave events. A single large gob cave in a confined space with no easy escape for the displaced air volume is critical for this mode of ignition.

The most significant source of ignitions in coal mines is that of incendive sparking between the cutter picks and hard strata. Considerable research has shown that a blunt pick (one on which the carbide has been significantly eroded or broken), will present a partial steel surface to the rock being cut. If this rock is hard enough, the frictional heat generated between the steel pick body and the rock will be sufficient to produce a smear of red-hot metal on the rock behind the pick. This red hot metal is sufficient to ignite a methane / air mixture

FUEL

The two common fuels associated with underground coal mining are both generated by the mining process:

- methane, occurring in porosity in the surrounding strata and in the coal, and also chemically bonded to the surface (adsorbed) of the coal itself, and
- coal dust,

are liberated during the mining process.

Methane

Methane gas is an odorless, colorless gas that is lighter than air. It is the most abundant flammable constituent of the gas (firedamp) contained within the coal seams and surrounding strata. The methane content varies substantially from coal seam to coal seam. Not only that, the ability of the methane to escape from the seam also varies.

Once the mine opening is created, and the coal crushed by the mining machinery, methane from the coal and surrounding strata enters the mine atmosphere. Fortunately, methane accumulations can be dispersed fairly easily by applying turbulent ventilation. Unfortunately, methane is lighter than air, and will layer in the roof of a mine roadway unless roadway air velocities are maintained sufficiently high.

Methane / air mixtures will ignite at concentrations of between 5% and 15%, with the most violent explosions taking place at a concentration of about 9.5% methane in air. As little as 4 m³ of 9.5% methane / air mixture is sufficient to ignite a coal dust explosion.

Coal Dust

Coal dust is produced by mining. In the early 20th century, when the investigation of coal dust explosions was in its infancy, all coal was produced by hand. Special effort was made to produce the largest sizes possible, because much of the coal went for domestic use and could only be handled in fairly large sizes. Competitions were held between collieries to see which pit could produce the largest unbroken piece of coal.

The additional energy used in modern methods of mechanised mining results in a greater degree of comminution of the coal; modern users such as power generation utilities do not require larger lumps.

The trend towards a greater degree of comminution was reported by Hartmann and Westfield (1956), who suggested that continuous miner operations reduced nearly all the coal to less than 25 mm in size. This trend appears to be confirmed by more recent studies into respirable dust sources (Figure 1).

As the size of coal produced has decreased, so has the size of the dust associated with coal production. Various studies of coal mine roadway dust over the last century have demonstrated a continuing reduction in the fineness of the coal dust found in underground coal mine roadways (Table 2).

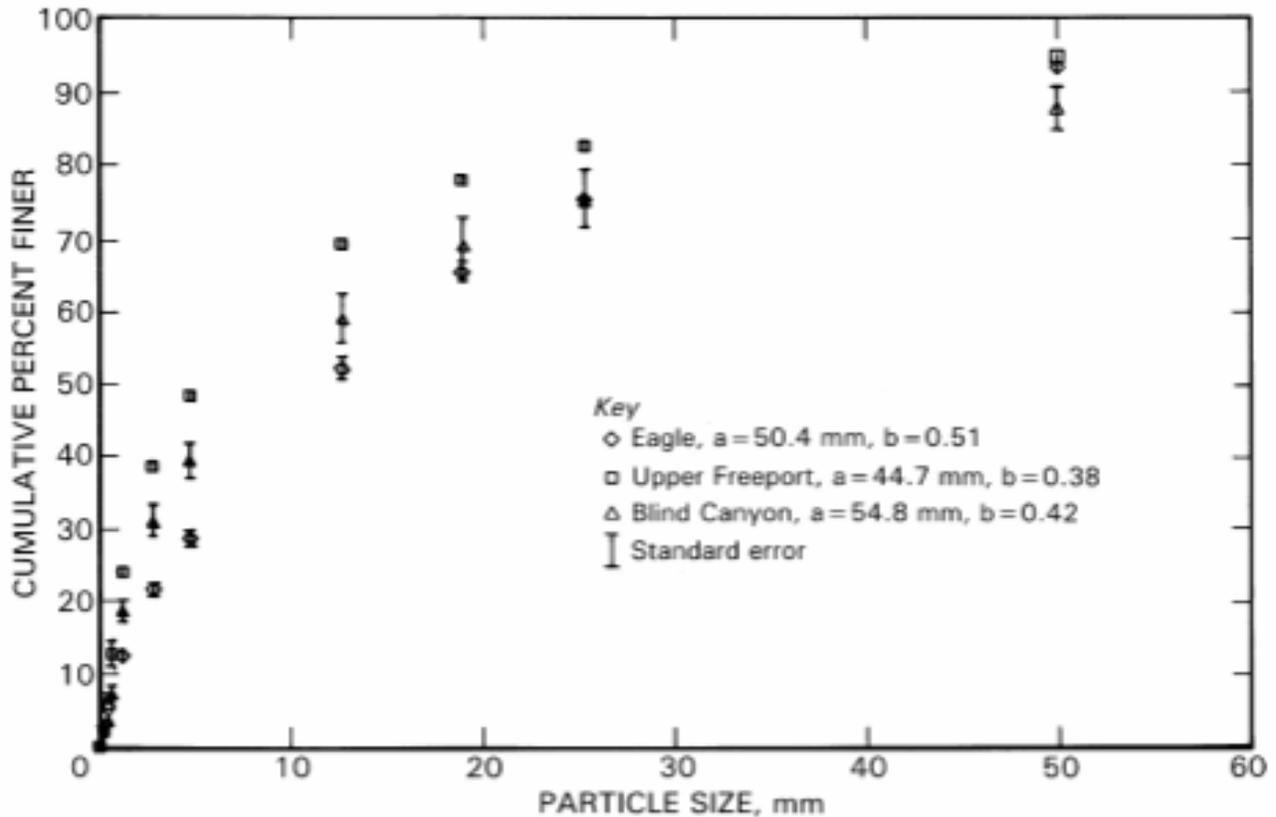


Figure 1. ROM coal product size distributions from underground continuous mining operations (after Organiscak and Page, 1998)

Table 2: Increasing fineness of Coal Mine Roadway Dust (after Sapko, et al., date unknown)

Year	Percent Passing 74 microns	
	Rib-Roof	Floor
1918	25	20
1954	49	28
1963	50	40
1964		83
1982		72 - 100

Most authors agree that coal dust greater than 850 microns in size does not contribute to coal dust explosions, although Maguire and Casswell (1970) suggested that the limiting size is smaller than this, at 240 microns. It is estimated that up to 20% of the total coal product of a continuous miner or longwall shearer might pass an 850 micron (US No. 20) sieve.

Table 3: Relation Between Particle Size and properties of Coal Dust (NCB, 1964)

Particle Size (microns)	Time to fall 1 m.	Hazard	Remarks
1	8 hours	Health and Explosion	Respirable
5	20 minutes	Health and Explosion	Respirable
25	1 minute	Explosion	Dust raised and ignited
100	4 seconds	Explosion	Dust raised and ignited
500	Very short	None	

The finer the dust, the more danger it presents. Table 3 describes the properties of the various size ranges of dust produced. The time to fall 1 metre is in still air. In a moving air stream, it can be seen that very fine dust can travel (“float”) considerable distances. Dust less than 20 microns in diameter can travel up to 200 m in a moderate ventilation current.

All authors agree that the size of the coal dust, among other things, influences the strength of a coal dust explosion. Explosibility increases linearly with specific surface (surface area of a unit mass of dust).

Another property that is thought to affect the explosibility of coal dust is the volatile content. Anthracite dusts with a volatile content of less than 10% do not explode. Higher volatile coals are more reactive. Table 4 below shows some of the explosive properties of various coals with a range of volatile content, methane (CH₄) content and fineness, including Minimum Explosive Concentration (MEC) and Minimum Ignition Temperature (MIT).

Table 4: Explosive Properties of Various Coals

Volatiles (%)	MEC g/m ³	CH ₄ present	Fineness	MIT Cloud	MIT Layer	Source
84*	35		73-81% -75 micron			Greninger et al. 1990
36	60		73-81% -75 micron			Greninger et al. 1990
34.85	66	0	100% - 60 mesh			Elfstrom, 1980
34.85	65	1	100% - 60 mesh			Elfstrom, 1980
34.85	60	2	100% - 60 mesh			Elfstrom, 1980
34.85	54	3	100% - 60 mesh			Elfstrom, 1980
34.85	47	4	100% - 60 mesh			Elfstrom, 1980
12				670	240	Holden 1982
25				605	210	Holden 1982
43				575	180	Holden 1982

The 84% volatile material shown in Table 4 is not actually a coal, but a bituminous mineral (gilsonite) mined in Utah. It provides a useful extension to the range of volatiles found in nature.

There is some divergence amongst researchers with respect to volatiles within coal; In the US, explosibility has been shown to increase as the volatile content increases, although this effect is reduced as the strength of the initiation increases. In Australia, researchers are of the opinion that volatiles have no effect on propagation above 10%, and that it is the fineness of the coal dust, among other factors, which has the most influence.

The minimum explosive concentration (MEC), the smallest amount of dust suspended in a cloud that will explode, varies with both the fineness of the dust, the volatile content and the presence of methane. Early testing in the United States used a standard dust classified as “mine sized”. This dust contained 100% material passing an 840 micron sieve, and 20% passing a 75 micron sieve. The MEC for this standard “mine sized dust” was about 100 g/m³ (Nagy, 1981).

Testing conducted on dusts that more closely resemble mine dusts produced in modern mining sections (more than 70% passing a 75 micron sieve) demonstrated an MEC of 50 g/m³. Recognition of this change with time was largely responsible for increasing the total incombustibles contents (TIC) in US roadway dusts to 80% in return airways where much of this float dust settles out.

Table 5 below lists the minimum ignition temperatures of clouds of various Canadian coals.

There is some debate as to whether an upper explosive limit exists for coal dusts, although Nagy (1981) reports an upper explosive limit of about 5 kg/m³.

Table 5: Minimum Ignition temperatures of Coal Dust Clouds From Canadian Coal Mines (after Elfstrom, 1980)

Coal Sample	Minimum Ignition Temperature °C
CBDC No. 26 – 12 South	480
Lingan Colliery	480
Canmore No. 1	620
Pittsburgh Standard	500
Luscar No. 687 7500 Belt	550
Luscar No. 688 3500 Belt	530
McIntyre No. 9	570
McIntyre No. 10	560
McIntyre No. 11	570
Coleman	570
Kaiser	500
Fording	500
Century, Atlas Mine	490

Experimental results also show that the explosibility of coal dusts also depends greatly on the means used to ignite them. Strong ignition sources will produce an explosion from weaker concentrations of dust than ignitors with lower intensities. This is especially true if the ignition source results in substantial air movement that lifts coal dust into suspension.

EXPLOSION PREVENTION

Just as the removal of any one side of the fire triangle will remove the threat of a fire, the elimination of any one of the sides of the explosion pentagon will eliminate the threat of an explosion. Of course, by eliminating the hazard of fire, the threat of an explosion is also removed, so the major defence against coal dust explosions is the elimination of all the possible sources of heat and fuel – two of the essential components of a fire.

Eliminating Heat

Eliminating heat sources in underground coal mines has been the goal of regulation ever since the discovery that methane explodes. Table 1 identified some common ignition sources. Of the 29 potential sources, only one lies outside the realm of human intervention – lightning. Every other listed source can be eliminated or abated in some way by good management and good practice.

The most common ignition source in modern underground coal mining is frictional ignition. The only two common minerals in collieries that can produce an incendive temperature are quartz and pyrites. In general the higher the quartz content and the stronger the rock, the greater will be the risk of producing an incendive temperature. The risk increases with the proportion of the rock as quartz grains larger than 5 microns in diameter.

The incendive temperature potential (ITP) is high for rocks containing more than 50% quartz bigger than 5 microns, intermediate for rocks with a content of 30% to 50%, and negligible for contents less than 30%. Common quartz contents are: sandstones 50% to 75%; siltstones 20% to 50%; mudstones below 20%. Rapid wear on drills and picks is a good clue to the hardness of a rock. The ITP for pyrites on its own is intermediate, but for pyrites in combination with highly quartzitic rock it is very high (NCB, 1974).

Frictional ignitions can be controlled by effective cutter drum maintenance (replacing blunt picks and maintaining water sprays), and the use of water sprays directed behind the pick path to cool any metal smears. French research has shown that replacing steel wear surfaces on picks with carbide wear surfaces results in a significant reduction in the risk of incendive sparking (Godard, et al, 1995).

Eliminating Methane

A frictional smear or spark will not ignite methane if there is no methane present. This is achieved by ensuring that the ventilation quantities supplied to the region of

the cutter head is sufficient to “dilute, remove and render harmless” any flammable gas.

The primary defence against accumulations of methane is effective ventilation. On longwall faces, through ventilation of the face area, assisted by water venturis in the cutter drum and in some instances by methane drainage, is usually effective in dispersing methane.

In room and pillar workings or in a single entry development in coal, through ventilation isn't possible. Fresh air has to be introduced to the cut to disperse the methane, and the methane air mixture forced out of the cut to prevent potentially explosive concentrations of methane from developing. The deeper the cut, the more difficult it is to supply large quantities of air to the point of cutting. In room and pillar operations cut depths sometimes regularly reach 12 m (40 ft.).

Experience has shown that to provide good ventilation in these conditions a combination of well placed, well engineered and well maintained water sprays behind the cutting picks is required, as well as auxiliary fans and ventilation tubes. Exhaust ventilation combined with dust filters at the fan has the best potential for dust capture (Davies and Isaac, 1998).

In addition to providing adequate ventilation of the mining area most jurisdictions require that mining machines have methane monitors fitted to them to monitor the concentration of methane in the cut. Above a predetermined level of methane electrical power to the miner is cut automatically.

It is a matter of record that many explosions have occurred as a result of illegal or unsafe acts committed by miners, either explicitly or implicitly condoned by their management. The Elfstrom (1979) report described tampering with methanometer detector heads at No. 26 Colliery before an explosion killed 12 miners. At Middelbult Colliery in South Africa a continuous miner had advanced 40 m into a blind, unsupported and unventilated heading, more than twice the distance allowed by the operating procedures at the mine, when it ignited a methane explosion. That explosion developed into a coal dust explosion that killed 53 people (Davies, et al. 2000). More recent Canadian experience at the Westray mine in Nova Scotia also serves to underscore the point (Nova Scotia, 1997).

Eliminating Coal Dust

The production of coal dust is as inevitable as the release of methane in an underground coal mine. Much of the coal dust is entrained in the coal that is removed from the mine. Some dust formed at the face is removed by the air stream along with the methane. Other coal dust, usually the coarser material, falls to the floor or clings to the roof and ribs.

Washing the roof and ribs to remove accumulations of dust assists in reducing the amount of dust present. Removal of accumulations of coal dust after mining, or at other spillage points such as belt transfer points and belt tail ends, is good mining practice.

Dust also accumulates over extended periods of time under belt rollers – dust is shaken through belt splices as they pass over the roller, or it falls from the surface of the belt to the floor.

The dust removed by the air stream, the float coal dust, is particularly difficult to treat. It can be deposited on the roof, ribs or floor, and accumulate in explosive quantities. The MEC of a typical coal dust represents a layer of dust about 800 microns in thickness in a 6 m by 2 m roadway.

Suspension, Confinement and Oxygen

Of the remaining three components in the explosion pentagon, suspension, confinement and oxygen, it is only the suspension of coal dust that can be controlled in an underground coal mine. By its very nature, underground mining creates confined spaces, and oxygen is required to operate diesel equipment, and of course, to allow the workforce to remain in the mine.

There are two approaches to preventing a suspension of flammable dust from forming in response to the initial ignition. The dust can be kept on the roof, sides and floor by ensuring that it is either wet enough not to be raised or otherwise bonded to the surface, or the properties of the roadway dust can be modified to ensure that it is not flammable.

Wetting the dust is frequently used close to the working face where men and machines might raise it during normal operations. Sprays and foggers at conveyor transfer points and other loading and unloading points also keep dust wet and reduce fugitive dust. Too much water, especially in pitching workings and workings with soft floors, can create operational problems. The water has to drain somewhere.

The use of saline solutions that evaporate and form a crust over the coal dust have been tried, but have been found to work only in relatively dry mines and mines with little variation in seasonal humidity. The salt solution also causes corrosion problems on underground equipment.

By far the most widely used approach to elimination of the coal dust problem is to add stone dust to the roof, ribs and floor to render the coal dust inert. In addition, many mines use explosion barriers which are designed to be activated by the pressure wave in front of an explosion, and flood the area with either water or stone dust which renders any suspended dust inert. The use of stone-dust and explosion barriers to control coal dust explosions is discussed in the next section.

The most effective way of controlling coal dust explosions is to eliminate them at their source – the initial ignition. As experience painfully shows us, this is not always possible, and the coal mining industry has adopted two approaches to controlling the spread of coal dust explosions; explosion barriers, which arrest an explosion, and stone-dusting, which renders accumulations of coal dust incombustible.

EXPLOSION BARRIERS

Explosion barriers control, and hopefully extinguish, coal dust explosions by removing one side of the explosion pentagon. They remove fuel from the explosion by engulfing the area of the barrier in an incombustible cloud of inert material or water, thus extinguishing the flame. Explosion barriers have been shown to be effective in controlling coal dust explosions in practice (Krzystolik, 1989; Eisner and Hartwell, 1964).

Passive barriers are by far the most common. Active barriers, which detect the presence of an explosion and deploy to quench it, are being developed, but the technology, particularly the explosion detection method, is far from mature, and there is considerable room for improvement. The state-of-the-art in explosion barrier design was the subject of a review commissioned by the UCMSRC in 2000 (Zou and Panawalage, 2001).

Passive barriers, and most of the active barriers so far developed, use water or inert dust as the quenching medium. In the case of passive barriers, the explosion shock wave traveling in advance of the explosion flame disturbs the barrier. This causes the area of the barrier to be deluged with either water or inert dust, which quenches the flame. In the case of active barriers, sensors detect the approach of the flame, and a positive pressure system deluges the area with water or inert dust, again, quenching the flame.

The design and construction of passive barriers has been the subject of much research. Guidelines for the use of both water and inert dust barriers have been developed from extensive laboratory and mine-scale testing. The work of Cybulski presented in Figure 2 illustrates the range of effectiveness of stone dust barriers. The amount of stone dust required to arrest an explosion increases dramatically as the distance from the initiation point increases. A typical “heavy” stone dust barrier contains 400 kg of stone dust per square metre of roadway area arranged on shelves erected just below the roof. “Light” or distributed barriers contain about half this amount.

Of great importance is the inference from the work of Cybulski and others that an explosion barrier may effectively suppress an explosion in a test gallery, but that the explosion can overrun the barrier by tens, perhaps hundreds, of metres. In this situation, it is perfectly possible for another explosion to be initiated if fuel is available and suspended.

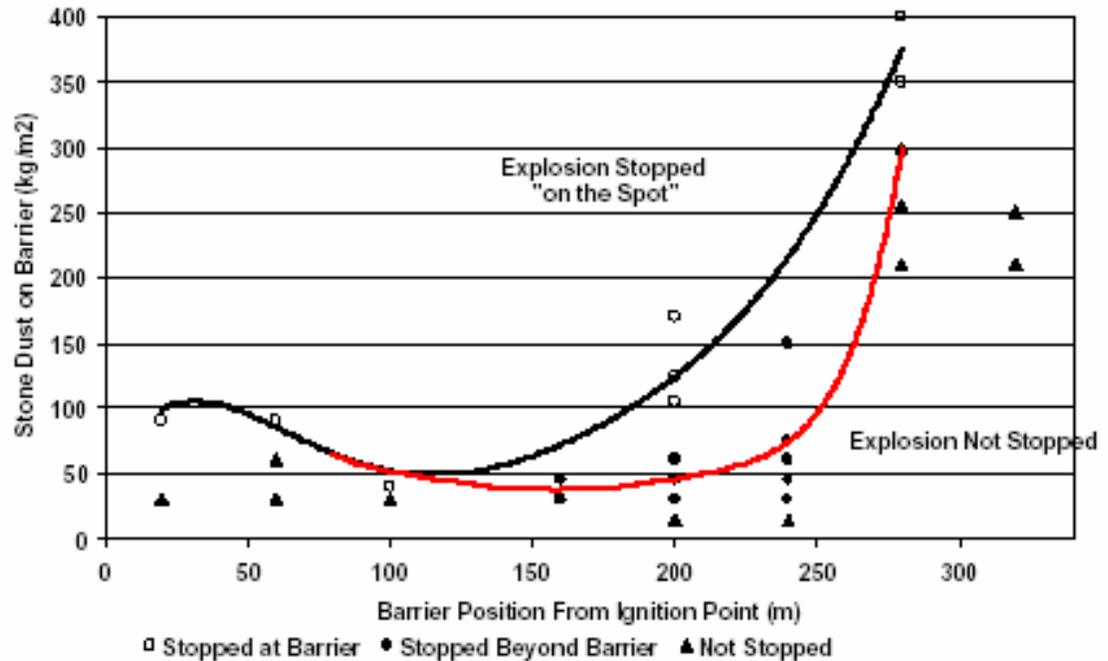


Figure 2: Effectiveness of a Discrete Explosion Barrier (after Cybulski, from Humphreys and O’Beirne, 2000)

Passive explosion barriers are required by Law in many coal mining areas. Notable exceptions are in the coal mines of the USA, and of Queensland, Australia, although in these jurisdictions the requirement for incombustibles content in roadway dust samples is substantially higher than in many of the jurisdictions that require explosion barriers – up to 85% in Queensland.

Almost all of the research into the suppression of coal dust explosions by passive barriers has been done in long single entries. Lebecki et al (1995) reported work in twin entries at the Barbara experimental mine in Poland, and Greninger et al (1995) reported experiments in triple entries at the Lake Lynn facility in the US. Other than this, very little work has been done to investigate the effectiveness of passive barriers in multiple entry room and pillar operations of the type commonly seen in the USA.

One potential problem arising from the deployment of passive barriers in multiple entry room and pillar sections is that passive barriers rely on the force of the pressure wave preceding the flame front to deploy. If the barrier is too close to the ignition, sufficient pressure may not develop to deploy it, and the explosion will not be controlled. A distance of 60 m from the point of ignition is usually given as the minimum distance. Typical room and pillar operations use pillar centers much less than the 60 m minimum distance. Cross-cuts within the 60 m distance reduce the confinement of the explosion, weakening it, and hence reducing the pressure wave’s ability to deploy the barrier (Mitchell, et al., 1975). Explosions can also change direction along cross-cuts. The ease of defeat of a passive barrier system by intersections common in room and pillar systems is the reason why passive barriers have not been adopted in the United States (Sapko et al., 1989a).

Since the work by Zhou, Humphries and O'Beirne (2000) have described bagged barriers, invented by CSIR Miningtek in South Africa, that initiate at lower explosion pressures than other types of barrier, and have been shown to be effective at suppressing explosions in large scale facilities in Germany, South Africa, and at the multi-gallery Lake Lynn facility in the USA. Testing in the multi-gallery environment showed that barriers in cross-cuts, through which pressure equalization occurs, did not function as effectively as those in roads, and also that there is the potential for explosions to bypass explosion barriers in marginally protected flanking roads.

Humphreys (1999) presented an analysis of typical costs associated with the construction of various types of explosion barriers. This showed that costs were mainly determined by whether the barrier was a stone dust or water barrier and whether there was a requirement to move the barrier as the face position changed. The most expensive barrier was a stone dust barrier as described by the Queensland regulations that was required to remain within a set distance of the mining face. For a 2000m gateroad development this was calculated to cost about AU\$228,000. An equivalent water barrier was calculated to cost about AU\$86,000. It was estimated that the costs of installing and maintaining an equivalent active barrier would be about AU\$17,000 for a 2000m development. Costs associated with such barriers in multiple entry room and pillar operations would be proportional to the number of entries.

Despite their almost universal adoption, passive barriers have several significant disadvantages (Jensen and O'Beirne, 1991):

- Passive explosion barriers will not provide protection for personnel in and near the flame initiation zone.
- Passive barriers are unlikely to arrest methane explosions at the coal face, weak coal dust explosions, explosions of hybrid mixtures of methane and dust, or very strong explosions.
- Stone-dusting inbye of passive barriers can reduce the chance of them operating effectively by reducing the strength of the explosion as it reaches them.

The effectiveness of passive barriers is further compromised by the presence of equipment such as monorail systems and conveyor belts in the barrier zone. Because ignitions at the face in continuous miner development headings may lead to development of powerful dust explosions there is a case established to investigate the use of small triggered barrier devices fitted to continuous miners.

STONE-DUSTING

Stone-dusting, the application of an inert dust to the roof, ribs and floor of the mine roadway to render coal dust inert, was one of the earliest remedies against coal dust explosions, and was employed even before the widespread gallery testing that began in the early 20th century.

Dust Requirements

The amount and type of stone dust required was determined quite early on based on the testing of coal dust found in the mines of that time, mines using exclusively non-mechanised coal winning and loading. Total incombustible contents (TIC's) of the order of 65%, increasing with increasing methane content, and decreasing as the volatile content of the coal went down, were common.

As Nagy (1965) discovered, modern mines produce much finer dust, requiring an increase in the TIC to prevent the propagation of an explosion. This revelation led to the increase in the TIC required under US 30 CFR in return roadways from 65% to 80%.

Richmond et al (1975), discussing incombustibles contents required to inert coals of various volatile contents, suggested that the 65% TIC was appropriate for 15% vol. coal, and should not be lowered, based on ignitability studies with strong initiators.

Elfstrom (1979) reported that TIC's of the order of 65% were insufficient to render inert the coal dust in the intake of No. 26 Colliery at Glace Bay.

Weiss et al. (1989) conducted explosion tests in the US Bureau of Mines Bruceton test galleries and at the newer Lake Lynn facility which had roadway sizes much closer to those used in modern mechanized mining. The TIC required to prevent propagation in the large rectangular entries at Lake Lynn (79% to 82%) were substantially higher than those required at Bruceton (65%).

When they tested coal from the Pocahontas seam with a volatile content of 18%, they found that the TIC required at Lake Lynn was 60% compared to 40% at Bruceton. Using strong initiators, Sapko et al. (1989a) confirmed that for fine coal, the Lake Lynn gallery required more than 70% TIC to inert an 18% volatile coal.

Weiss et al. also suggested that other coal properties were as or more important than volatile content when considering explosibility. They noted that the Pocahontas coal used had a larger surface area than, for example, the Pittsburgh seam coal, significantly increasing utilisation at the flame front.

Jensen and O'Beirne (1991) conducted a review of stone dust and passive barrier applications in Australian Mines. They concluded that:

- The stone-dusting regulations and practice at that time incorporated small safety margins in cases of very strong explosions, and that a review of them was justified
- The size distribution of stone dust required experimental review.
- General stone-dusting, when properly applied, appeared to be the most reliable combative solution to explosion propagation in coal mines.
- Weak coal dust explosions can propagate in well stone dusted roads if there is a film of as little as 0.2mm of coal dust present on top of the inerted material.
- There was no evidence to suggest that changing the location of passive barriers as specified in regulations will improve their reliability, and that

- There is evidence to suggest that the use of distributed barriers may be more effective for explosion suppression than concentrated barriers.

Table 6 illustrates some of the legislated total incombustibles content (TIC) contents from around the world.

Table 6: Legislated TIC Content – Worldwide Examples (after Saltsman and Grumer, and other sources cited in this report)

Jurisdiction	Year	TIC	Increase with:	Decreases	Minimum
Alberta, Canada	1995	65%	Methane – 1% per 0.1%	Volatile	50%
Nova Scotia, Canada	1987	65%			
Nova Scotia, Canada	Draft 2003	75%			
British Columbia, Canada	1997	65%		Volatiles	
Belgium	1965	78%		Volatiles 14% to 26%	60%
United Kingdom	1961	75%		Volatiles – roughly 5% per 2% volatiles below 35%	50%
USA		80%		Intakes – 65%	65%
New South Wales, Australia	1999	85%		Intakes – 80%	70% - all roadways more than 200 m outby the last complete line of crosscuts the face.
Canada – Federal Labour Code	1990	75%			
Czechoslovakia	1957	80%			
France	1965	70%		Volatiles 22% to 29%	50%
Germany	1965	80%			
Italy	1965	75%		Volatiles 20% to 35%	
Netherlands	1965	65%	Methane from 0 to 1.5%		
Poland	1959	70%	Methane – 80% in “gassy” roadways		
South Africa	2002	80%			
USSR	1953	60%	Methane – 75% in “gassy” roadways.		

Stone Dust Application

Stone dust can be applied in any one of several ways. Campaign stone-dusting is usually accomplished by mechanical means. Tanks or other bulk stone dust carriers are used to spread stone dust on the roof sides and floor to the required density. Because of the dust entrained in the mine air, this is difficult to do during operational shifts, and is usually done only once unless subsequent testing indicates a need for it. Over small areas, stone dust can be distributed by hand. If the surface of the roof and ribs is wetted prior to the application of rock-dust, the adherence is substantially increased (Hartmann and Westfield, 1956).

Wet dusting is practiced in some areas, especially when it must be done during production shifts. US stone-dusting standards (ASA, 1960) allow wet stone-dusting of the roof and ribs in the face area. The wet dust must cover at a rate of 900g/m² (3 oz/sq ft), and the slurry used should be mixed in the ratio of 1 L of water for each 1.5 kg of stone dust (8 gallons of water per 100 lbs of stone dust), either by premixed slurry or by mixing at the nozzle. The application of wet stone dust reduces the ability of the dust to prevent propagation until the dust is completely dry.

Automated rock dusters, or trickle dusters, are employed in return airways to dilute float dust entrained in the air from the production face. They are also deployed in belt roadways to inert dust generated by the operation of the belt.

Float Dust Hazards

As described earlier, float coal dust presents a continuing hazard in coal mines. Because it is continuously produced and dispersed into the air stream, campaign stone-dusting can be ineffective as a combative measure.

Surveys of float coal dust production in mines (Nagy and Mitchell, 1964) determined that float coal deposition in the return airway of an operating mine can be as much as 100g per tonne mined (0.2 lb/short ton), although they also found that substantially less dust was deposited when auxiliary exhaust fans were employed. Richmond et al. (1975) quoted 50g/t (0.1 lb/short ton) mined for float coal deposition.

Measurements of the depth of dust layers involved in explosions has shown that only the top 2-4 mm of roadway dust is stripped off of the floor layer in a float dust explosion. For inerting purposes, any float dust deposited between campaign dusting, plus this layer, must have the required TIC. The TIC contribution required of floor dust increases with float dust thickness. Even if the underlying incombustible rock dust content is greater than 80%, an upper float dust layer will propagate an explosion since only the top 2 to 4 mm of floor dust is stripped away during a typical explosion event.

Float coal dust can be deposited on the roof and sides of the roadway, as well as the floor, which makes it especially dangerous. Hartman et al. (1956) wrote that when the overhead dust is predominantly rock dust, the explosion hazard is reduced. This was echoed by Sapko et al. (1987), who wrote "it is well known that dust on elevated surfaces is dispersed by the developing explosion much more readily than dust on the floor." They found that float dust on the roof and sides could not be adequately inerted by high TIC's on the floor, although rock dust on the roof and sides could compensate somewhat for low TIC's in floor dust".

In the US it was concluded that float coal deposits in airways present a special explosion hazard when not neutralized by maintaining a 65% TIC, and as a result, the US 30 CFR was amended to require 80% TIC in returns.

There are few, if any, locations in an operating underground coal mine that do not contain sufficient fine coal dust to propagate an explosion if the dust was dispersed into the air. Combating the float coal dust problem requires the combination of several approaches:

- Elimination of the dust at source, by reducing the energy applied to the rock and by using cutter drum pick lacings that encourage the formation of larger fragments.
- Suppression of dust at source by using water sprays or foggers that trap the finest dusts and carry them out of the mine with the larger product. Coal itself is hydrophobic, so surfactants in the water can improve the collection of dust.
- The use of dust scrubbers on continuous miners to remove fugitive dust, and the inclusion of dust collectors on any exhaust auxiliary fans used.
- The use of trickle-dusters in return airways to constantly supply stone dust in sufficient quantities to inert the float dust.
- Constant vigilance, including roadway dust testing and analysis and prompt response to sub-standard results.
- The use of all available technologies and practices to eliminate any ignition of gas that could initiate a coal dust explosion.

The legislative approach to coal mining safety and health varies considerably. Some jurisdictions rely on a prescriptive approach, essentially compiling lists of things that must be done or not done. Others have preferred self-regulation, in some cases backed up by mandatory minimum standards, in other cases, not. All jurisdictions employ mine inspectors to ensure that whatever the legislative approach, the mines are maintained in safe condition.

PRESCRIPTION

Until recently, coal mining safety and health legislation in major coal producing jurisdictions had followed the “legislation by accident” approach. That is to say, following some horrific disaster, an inquiry would make recommendations, usually banning the practices that lead to the disaster. Legislation would be amended, regulations would be written, and normal service was resumed until the next public outcry.

In the UK this approach led to the development of more than 400 prescriptive sets of regulations issued under the Mines and Quarries Act, the Factories Act, and the Explosives Act. Each set of regulations covered some specific risk or activity. Many had their origins in accidents and disasters of the past; a few in specific health risks that had been identified.

By the 1960's the plethora of prescriptive and rigid regulation was discouraging people from thinking for themselves about health and safety. Industry came to rely on an accessible regulator to tell them what to do, rather than defining and regulating its own health and safety performance. Fatalities and serious injuries were unacceptably high in all industries including underground coal mining, and an antidote to a system where employers (the creators of risk) simply waited to be told what to do by the regulator, was urgently required (Langdon, 1998).

Many jurisdictions, not just the UK, have come to recognize that such an approach does nothing to encourage a culture of safety in the workplace, and modern examples of mining legislation fall into the category of “self-regulation” which requires mine owners to be proactive in their approach to mining hazards and the risks these present to the safety and health of their employees.

SELF REGULATION

In the UK, the antidote to the spiraling injury toll was provided by the Robens Commission (HMSO, 1972). Set the task of reviewing “...the provision made for health and safety of persons in the course of their employment (...) and to consider whether any major changes are needed...” the commission report endorsed the “self-regulation” approach.

The concept of self-regulation is as old as industry itself. It stems quite naturally from a moral view that people should not be killed, injured or suffer ill-health as a result of work. Some were good at self-regulation but history records many who

treated human life as just another expendable resource. Robens' suggestion was to develop a regulatory framework which would encourage duty holders to regulate their own activities effectively, accomplished in the Safety and Health at Work Act of 1974.

This approach has a huge advantage over prescriptive regulation in a fast moving and competitive industry. The “legislation by accident” approach, combined with prescriptive regulation, can only prevent what has happened in the past. Self-regulation, associated with rigorous hazard and risk analyses, can prevent new types of accidents from occurring and are thus adaptable to the development of new methods and equipment.

Recent changes to coal mine safety and health legislation in the United Kingdom, Australia and South Africa have subscribed to the self-regulating approach. In all cases, employers are required to conduct hazard analyses and risk assessments, and to develop engineering, administrative practices and procedures to eliminate or reduce the identified hazards. In many circumstances, the enabling legislation requires only a duty of care, and leaves it to the employer to ensure that this is fulfilled. In other circumstances, regulations set minimum standards. In all three jurisdictions, the prevention and suppression of coal dust explosions are subject to prescribed minimum standards.

INSPECTION

Langdon (1998) wrote;

“If the power which an inspector has to require improvements is to be sensibly deployed, the quality of staff must be high and neither we [the regulators] nor the industry can afford to compromise on it.

Such compromise was obvious in the Nova Scotia of the early 1990’s, a jurisdiction which neither dedicated the resources required for inspection nor established the required legislative framework to monitor and enforce the safety of a modern underground coal mine (Westray).

Some might look towards self regulation with a view to an easy escape from the costly process of maintaining an adequate, modern legislative framework and enforcing it. After all, one might reason, if the mines are regulating themselves, then the only involvement of the regulators is to ensure that they are doing just that. Unfortunately, this is not the case. A move to self regulation requires even greater diligence from the regulators. Langdon, again;

“It is particularly important that when a mines inspector calls, he should be regarded by the mine management not simply as an enforcer of regulations, but as someone able to contribute to its thinking, able to interpret legislation and formal guidance sensibly and reasonably in the particular situation and backed by scientific and technical resources which command respect.”

The modern coal mine inspector must have the same resources as the mine operator (engineers, consultants, and specialists in technical mining areas - ventilation, ground control, etc.) in order to be able to properly review the operator’s safety plan. This must be much easier in jurisdictions where the number of mines

and the infrastructure provides sufficient resources, but is ignored at the peril of all concerned in areas with few mines and limited infrastructure.

CANADIAN CONTEXT

Any recommendations regarding the development of Canadian guidelines for the prevention and suppression of coal dust explosions have to be viewed in the context of the regulatory and inspection framework existing in Canada. Each Province is responsible for legislating the safety and health of its workers. Federal legislation covers certain industries, and any Federally owned mines.

The self-regulation approach is beginning to appear in Canada, which has a very small underground coal mining industry spread over a number of provincial jurisdictions. Neither any one jurisdiction, nor the combined provincial underground coal industries, has the resources to support the depth of infrastructure found in major underground coal mining jurisdictions.

With new underground mines expected to open in British Columbia, Alberta and Nova Scotia in the near future, each regulated by its own provincial legislation, three separate, independent, and technically sophisticated sets of regulations and three independent, scientifically mature inspection services will be required to oversee four mines. If ever there was an opportunity to rationalize coal mine safety and health legislation and enforcement in Canada, it is now.

COMMON CONCEPTS

Notwithstanding the different approaches, common concepts with respect to the regulation of stone-dusting are:

- Control of the production, accumulation, and abundance of coal dust in the mine.
- The properties of the inert material used to reduce the level of combustible content in the roadway dust
- The incombustibles content required in the roadway dust to render it safe
- Sampling Methods used to ensure that incombustibles contents are maintained, and
- Methods of analyzing samples to determine the incombustibles content.

Relevant extracts dealing with concepts from a number of legislative examples are appended to this report (Appendix 1 to Appendix 7)

Dust Control

Measures to control the generation and accumulation of coal dust are usually specified with reference to explosion protection. Some measures may also be defined under regulations that are directed at respirable dust control. Control measures common to the prescriptive style of regulation include:

- The use of sprays on coal drills, undercutters and miners, as well as at loading and unloading points and conveyor transfer points, to remove dust from the air current,
- A requirement to clean up all accumulations of coal dust, and to remove all dust from a roadway prior to the application of stone dust.
- A requirement to wet down any areas where dust occurs, and to wet coal during handling

Stone Dust Properties

Stone dust is a pulverized inert material such as limestone, marble, dolomite, or anhydrite. Light colored material is preferred due to its light reflective characteristics (ASA, 1960). Limestone and similar carbonates produce the best rock, as their tendency to cake is low, and they have a light color, which aids illumination.

Most regulations specify the use of limestone, although more recent regulations allow the use of other materials provided their inerting abilities have been satisfactorily determined. Davies (2001) examined the use of rock phosphate as an alternative to stone dust based on results from the fertilizer industry that showed that the addition of 50% rock phosphate to sulphur substantially reduced the explosion pressures when ignited.

Various forms of rock phosphate were tested against stone dust with regard to their ability to inert coal dust explosions. In all cases the rock phosphate showed no appreciable advantage in inerting ability. However, ammonium phosphate, which is a processed form of rock phosphate, did show a significant advantage in inerting level, when compared to stone dust, with only one third of the amount of inert material required for full inerting of a coal dust explosion.

Rock salt (Jensen and O'Beirne, 1997) and magnesite (Amyotte, et al., 1991) also show enhanced inerting abilities, although their disadvantages preclude their use as a roadway treatment. Rock salt is soluble in water and magnesite less available and more costly than conventional calcium carbonates.

In South Africa fly-ash has been shown to have similar inerting properties to limestone dust when used in bagged barriers. Because of its high silica content the fly-ash is contained in bags that disintegrate when the barrier is deployed by an explosion. Soluble dusts such as ammonium phosphate and rock salt, both chemical flame retardants, may provide better suppression characteristics than traditional limestone dusts when used in bagged barriers.

The properties of the rock dust used for inertization are generally prescribed by legislation. Table 7 below describes the properties explicitly demanded by various jurisdictions. Other properties (such as silica content) might not be explicitly stated, but are often covered under other regulations (for example the silica content of airborne and respirable dust).

The particle size of rock dust deployed to reduce the TIC of roadway dusts is an important consideration. Stone dust is denser than coal dust, and is therefore harder to raise into suspension. The optimum stone dust fineness (Jensen and O'Beirne, 1997) is 70% passing 75 micron, and the same authors report evidence that a mean particle diameter of 20 microns presents significant advantages. Further reduction of

Table 7: Legislated Rock Dust Properties

Jurisdiction	Passing 850 micron (%)	Passing 75 micron (%)	Maximum Combustible Content (%)	Silica (Free and Combined) (%)	Other Comments
Alberta (1995)	100	70%	5	4	
Nova Scotia (draft)		70%			
British Columbia (1997)		50%			Neither "ineffective nor injurious to health"
USA (ASTM, 1983)	100	70	5	4	
South Africa (2002)	100	50	5	5	Neither "ineffective nor injurious to health"

size does not improve effectiveness because very fine stone dust tends to agglomerate and will not be lifted into suspension by the explosion pressure wave as effectively.

Jensen and O'Beirne, (1999) reported that the results from the limited local testing of the effect of stone dust particle size on inerting levels showed a broad improvement with decreasing particle size. This is probably related to the finding that of the order of only 2% of dust dispersed by the pressure front has particle sizes >250µm, irrespective of the particle size distribution of the settled dust from which it was raised.

Only two of the jurisdictions reviewed allow coarser material than recommended by Jensen and O'Beirne; South Africa and British Columbia. In South Africa the TIC required is 80% in the face area (extending 1000m outby). In British Columbia it is 65%. The Elfstrom Inquiry (1979) deduced that a TIC of 65% was not sufficient; SMRAB (1998) in the UK came to the same cautious conclusion. It would seem that most authorities consider a 65% TIC with a low quality dust (50% <75 microns) represents an unacceptably high risk of propagation.

Incombustibles Content

The ultimate test of the effectiveness of an inertization program is that it quenches an explosion when one occurs. Quenching will not occur if the incombustibles content of the roadway dust is not maintained at a safe level. The definition of a safe level is legislated in all mining jurisdictions, and ranges from 50% in intake roadways in the low volatile coal seams of Alberta to 85% in all roadways within 200 m of the last open cross-cut in Queensland (Table 6).

The amount of rock dust needed to neutralize coal dust in a mine depends on the:

- production of coal dust
- quantity of coal dust accumulated
- incombustible content of the coal dust

- amount of fine incombustible rock or clay material that mixes with the coal dust

The basis for legislated minimum total incombustibles content (TIC) in coal mine dusts stems from tests conducted as far back as the 1920's. Mining methods have progressed substantially since that time, with most of the world's coal won by machines that generate a significantly higher proportion of fine material. In addition, other coal mining areas have developed as significant producers, mostly within the last half century, and mostly in coalfields significantly different to the old European and Eastern US coalfields.

The most recent work on evaluating TIC requirements has been undertaken in Australia, and to some extent, South Africa, both major producers of Mesozoic thermal and metallurgical coal. Humphries (2000, 2002), reported on the results of explosion testing of Australian coals. A large number of coal samples were obtained from Australian mines and tested to determine individual inerting levels and other explosibility factors. These properties were correlated against other coal properties such as volatile content and vitrinite reflectance. The impacts of ignition energy in the test apparatus and of the presence of methane were also examined.

From the results obtained, it was clear that the inerting requirements for individual Australian coals were not correlated to volatile content or any other common coal property as previously thought. For the range of coals mined by underground methods in Australia, the individual inerting requirement varies from 83% to 85% total incombustible content (TIC) which is the stone dust plus ash and moisture from the coal. Only at less than 10% volatile content was there a lower requirement - 77% TIC.

Large-scale testing of five Australian coals was undertaken at the CSIR Kloppersbos Explosion Research Centre in South Africa as a comparison against the results obtained in the laboratory. The results obtained indicated an inerting requirement of between 80% and 85%, validating earlier work. The impact of methane is to increase the inerting requirement by 5% TIC for the first 1% of methane present.

Studies in Australia failed to generate a strong relationship between dust explosibility and volatile content as found in the UK and USA. This is because there is considerable variability in the macerals analysis and the grain size of vitrinite in Australian coals. The same conclusion has been drawn in relation to South African coals. Accordingly, a single value, or a value linked to the presence of flammable gas, was suggested as the most appropriate approach to determining TIC content.

Recent changes to the Coal Mining Safety and Health Regulations of Queensland, New South Wales and South Africa have increased TIC levels to reflect results of this research.

Sampling Methods

Roadway dust sampling is conducted to determine whether or not the total incombustible content (TIC) of the roadway dust is high enough to prevent or suppress an explosion. The sampling method must have;

- adequate coverage, to ensure that all parts of the mine meet the appropriate standard,

- appropriate frequency, to ensure that time dependent deterioration of TIC's do not present a hazard to the mine, and
- a methodology that allows accurate determination of the success or failure of the roadway dusting program.

Sampling protocols from Federal Canadian and MSHA inspection agencies are presented in Appendix 8 and Appendix 9 respectively.

Coverage

To ensure adequate coverage, the distance between samples is stipulated, as in the USA where intervals of 500 ft are mandated, or the mine is divided into zones.

In the UK and Federal Canada, zones are about 135 m in length (0.1 miles or about 500 ft.) in length in intake roadways and 270 m (0.2 miles or 1000 ft.) in returns. In the UK and Federal Canada coal conveyor belts are located in intake roadways. In British Columbia the zones are 135 m in length in all roadways.

In Queensland and New South Wales in Australia, and in South Africa, the zoning is somewhat different. A "face zone"- any roadway within 200 or 250 m of the coal face (1000 m in South Africa) – and outby zones are described.

(HRDC, 1995) recognised that samples may be required at more frequent intervals in dusty places – eg. loading or transfer points.

In Nova Scotia a sampling plan to ensure compliance must be submitted to the Director of Mines. In Alberta, an employer must simply develop and implement a sampling system; there is no regulatory requirement to share the plan with anyone.

Frequency

Regulation of sample frequency is inconsistent. For the most part, frequency is either left to the mine, or stipulated that sampling results for the entire mine must be reported monthly.

Only in Queensland and South Africa has the ability of float dust to render roadway dust explosive within three to four days been recognized in legislation. In Queensland, more frequent sampling is required; weekly in the "face zone", where TIC's must be maintained at 85%, and in South Africa stone-dusting of the "face zone" must be carried out every four production shifts.

Methodology

In general, two types of sample are recognized; spot samples and strip samples.

Spot samples are collected:

- from the floor, to a depth of one inch, over a 30 m roadway length in each zone at roughly 1 m intervals, zig-zagging across the roadway
- from the roof and rib, at various heights and locations, at roughly 1 m intervals.

Strip samples 150 mm wide and up to 25 mm deep are collected from the roof, ribs and floor in a continuous band, five or ten bands to a 30 m roadway length in each

zone. The evidence that only surface dust to a depth of 4 to 6 mm is scoured in an explosion has led some jurisdictions to limit the depth of sampling to 5 or 6 mm.

Separate floor, and roof and side, samples are required to ensure that TIC levels are maintained, and because of the relative size of each sample, they should be analysed separately. Soon after Hartmann et al. (1954) completed a study comparing single band sample TIC results with separate roof and sides, and floor sample results, US Federal inspectors stopped taking separate roof and side samples. They subsequently reevaluated that decision on the basis of testing failures, and now take separate samples where indicated by conditions.

Experiments have shown that moist coal dust upon dispersion is fully capable of propagating an explosion. US standard methods only eliminate the taking of samples if water can be squeezed from a sample held in the hand. Dust layers resting on standing water can also be raised into suspension.

Roadway Dust Analysis Methods

There are four recognized methods for the analysis of mine roadway dust samples (countries using each technique are given in parentheses):

- High temperature ashing (CANMET¹, UK, USA)
- Low temperature ashing (CANMET, UK, RSA)
- Volumetric (UK, USA), and
- Colorimetric (RSA, UK)

Both high and low temperature ashing are chemical methods enabling a precise measure of the inert content of the roadway dust. Low temperature ashing is not appropriate for dusts containing magnesium carbonate since this compound decomposes below 500°C, the temperature used in this method, but errors induced by the presence of small quantities of magnesium carbonate will in any case err on the safe side; the TIC would appear lower than it actually was.

Volumetric and colorimetric methods have been preferred because they are faster (hence less expensive) than the chemical methods. However, automatic coal analyzers have greatly improved the ability to conduct assays quickly and accurately by chemical methods (Kennedy and Bonnell, 1984).

In South Africa, samples must be analysed by either the colourimetric method or by a laboratory determination of mass of incombustible matter, or by both methods. Samples may also be analysed using a portable stone dust analyser. Only accredited laboratories and analysers approved by accredited certification bodies may be used for these purposes. (DME, RSA)

Dust collected at a mine must without delay be processed and the incombustible matter content of the samples determined. Descriptions of the principal methods are given in Appendix 10.

¹ CANMET – Canada Centre for Mineral and Energy Technology, Canada

MSHA funded the development and testing of radiometric methods of roadway dust analysis in an effort to develop a reconnaissance analysis technique that would allow inspectors to sample only areas with marginal or sub-standard TIC's (Greninger, et al., 1988), or allow MSHA local offices to perform compliance analyses. Some success was obtained with a Polish dust analyzer.

Sapko et al (1991) reported successful trials and a move to commercialization of an optical rock dust meter based on reflectance properties of coal / stone-dust mixtures. Underground trials demonstrated the ability of the unit to determine the adequacy of stone-dusting and eliminate unnecessary sampling by Inspectors. Use by industry would enable more efficient use of rock-dust.

The hazards associated with accumulations of coal dust in underground mines are clear, and have been demonstrated again and again in laboratory and experimental gallery testing.

The prevention of coal dust explosions is now mainly the challenge of how to avoid ignitions of small amounts of methane. Once a methane explosion has been initiated sequential change to a more violent coal-dust explosion is possible where coal dust with a volatile content in excess of 10% is present.

The knowledge of the fundamentals of methane ignitions and the technologies with which to defeat them are both widely known and widely available. Why then, are methane ignitions still occurring, and coal dust explosions developing from them? Garner, (1999), suggests that the development of a framework which recognizes the importance of human error in accidents is a fundamental step in improving and maintaining safety. Such a framework includes:

- comprehensive planning and design
- competent key personnel, including management, maintenance and specialist staff,
- communication and cooperation throughout all levels of the mine workforce,
- training of employees to ensure competency and understanding,
- effective management of system changes including examination of all consequences
- Effective maintenance of control measures, and finally,
- Monitoring and regular review of the framework.

Integration of available technology, legislation and guidance, sustained by high standards of health and safety management, provides the best mechanism to reduce the risk of a gas ignition.

Given that a gas ignition has occurred, the first line of defence against an ignition of coal dust is good housekeeping. The removal from the mine of accumulations of coal dust wherever they occur is an essential part of this housekeeping.

Coal lying on a conveyor can act as a fuse to transmit a coal dust explosion even where the application of stone dust to the roof, sides and floor has been adequate. Stone dust barriers or water barriers set over conveyors are essential to arrest possible coal dust explosions in these situations.

Stone-dusting to control and hopefully extinguish coal dust explosions has developed as laboratory and gallery scale experiments have improved the understanding of the phenomena.

In 1979, the statutory minimum incombustible content of intake roadway dust in the mines of Cape Breton was 65%. Following the explosion at No. 26 Colliery on February 24, 1979, Elfstrom (1980) pointed out that although “the level of stone-

dusting on the bottom (intake air) level was at or near the statutory minimums” it “proved inadequate to completely quench the explosion”. The recommendation was made in the text (but not in the report conclusions) that it would be advisable to apply stone dust to a higher standard in the bottom level. Subsequent regulations demanded 75% incombustibles in intake roadways.

A review of UK requirements for stone-dusting, which included experimental explosion testing in a 20 L spherical chamber, determined that there was no justification for a relaxation of UK stone-dusting requirements. In fact, the report noted that weak propagation was possible at the legislated TIC levels. The report noted that recent research had suggested that the proportion of stone dust should increase as coal particle size decreases (SMRAB, 1998).

The general trend has been towards an increase in the TIC required in roadway dust. In addition to this trend, the most recently developed regulations eschew the reduction in TIC with volatile content, instead maintaining constant TIC levels, albeit zoned in response to the degree of hazard presented.

Current best practice would appear to include explosion testing of coal and stone dust available at the mine. These more recent regulations also require a hazard analysis and risk assessment to be performed. It is fairly easy to assess the hazards presented by a common-place task, to estimate the frequency, the cost or damage, and hence to develop an appreciation of the risk involved and an appropriate means of dealing with the hazard.

The hazards presented by a coal dust explosion are well documented, but they occur rarely. Damage is in the millions of dollars even for a small mine, and dozens may be killed or wounded. Zero risk is statistically improbable. But what risk is acceptable and how can it be calculated? Humphreys and O’Beirne (2000) addressed this precise subject.

The risks associated with a coal dust explosion in a panel can be assessed by determining:

- The frequency of gas ignitions in the panel
- The probability of developing a coal dust explosion as a result of the gas ignition
- The probability of propagation down each panel entry, which in turn is determined by a combination of;
 - The probability of propagation through an area subject to trickle stone-dusting
 - The probability of propagation through an area of campaign stone-dusting,
 - The probability of propagation through a discrete explosion barrier, and
 - The consequences and risk of propagation to different positions in a panel.

Humphries and O'Beirne reviewed the history of gas ignitions in coal mines in Australia between 1988 and 2000 and determined that the frequency was 0.027 per longwall face per year, and 0.023 per continuous miner face per year.

None of the Australian face ignitions developed into an explosion; there were explosions in this time period, but none were initiated at the coal face. Assuming that future behaviour will not be worse than the predicted behavior, then the probability of triggering can be calculated in the following manner:

Let $\Pr(1/1)$ = Probability of a gas ignition resulting in a coal dust ignition

$\Pr(51/0)$ = Probability that 51 explosions do not result in a coal dust ignition

If the degree of confidence required is 98% then:

$$\Pr(51/0) \geq 1 - 0.98 \geq (1 - \Pr(1/1))^{51}$$

$$(1 - \Pr(1/1))^{51} \leq 0.02$$

$$1 - \Pr(1/1) \leq 0.02^{(1/51)} = 0.926$$

$$\Pr(1/1) \leq 0.074 \text{ or } 7.4\%$$

There is a 7.4% possibility that an ignition will develop into a coal dust explosion each year, with a confidence level of 98%.

Given that a gas ignition has resulted in a coal dust explosion, explosion suppression measures come into play. The effectiveness of these measures can be expressed as the probability of propagation through the control, with lower probabilities representing higher effectiveness.

Using Cybulski's extensive investigation results and a graphical representation of the probability of an explosion propagating through a 200 m zone of stone dust (Figure 3), it was determined that with an incombustible content of 85% in the 200 m long zone, the probability of a coal dust explosion propagating through the zone was 10% (0.1).

A conservative approach to calculating the probability of propagation through a zone greater than 200 m long is to divide the zone into a number of 200 m long segments. The product of the probabilities of propagation through the individual segments represents the probability of the zone.

From the information given, the probability of a coal dust explosion propagating through a 200 m zone of 85% TIC roadway dust is 0.0074. For a 400 m long zone, the probability is 0.00074, and for a 600 m long zone, the probability is 0.000074. How long a zone of stone-dusting is required to achieve an acceptable risk? That depends on what is considered an acceptable risk.

Possible guidance can be obtained from Figure 4. The chemical industry has developed guidelines for land use around a facility based on the risk of a major accident. A risk of between 100 in a million and 10 in a million is considered acceptable for industrial use adjacent to the facility, the implication being that this risk is less than or equal to the risk of the activity specified for the land use (McCutcheon, 2002).

In the example given, a zone between 600 and 800 m long would present an equivalent risk to the industrial use risk in Figure 4.

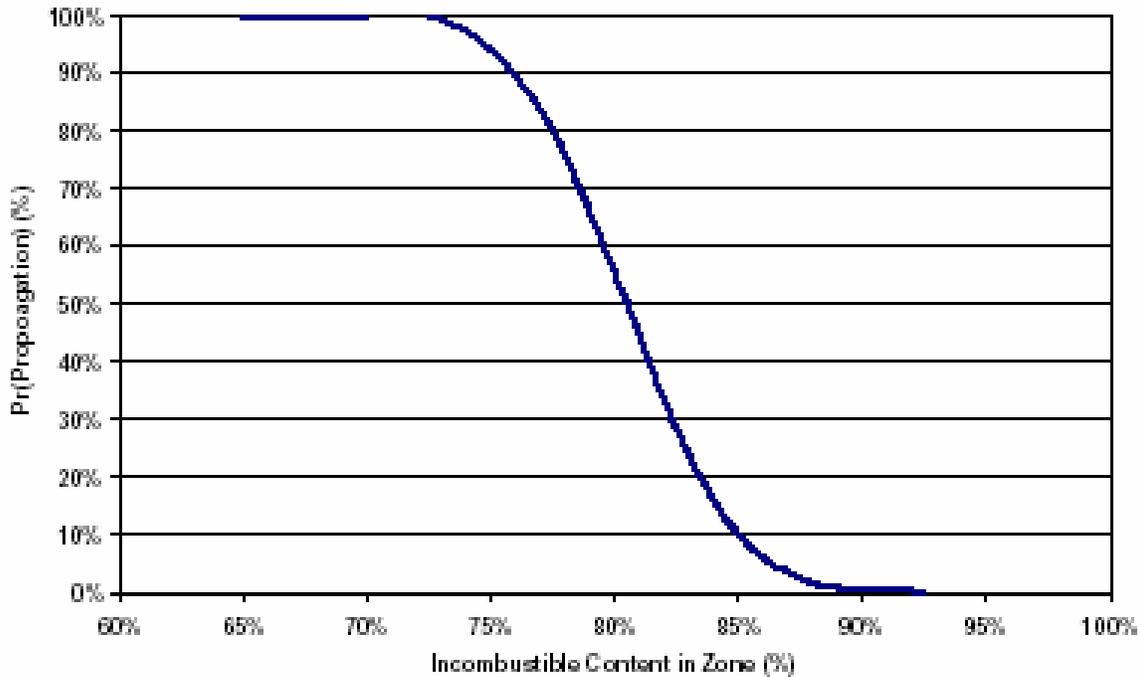


Figure 3: Probability of Propagation Through a 200 m long Stone dust Zone

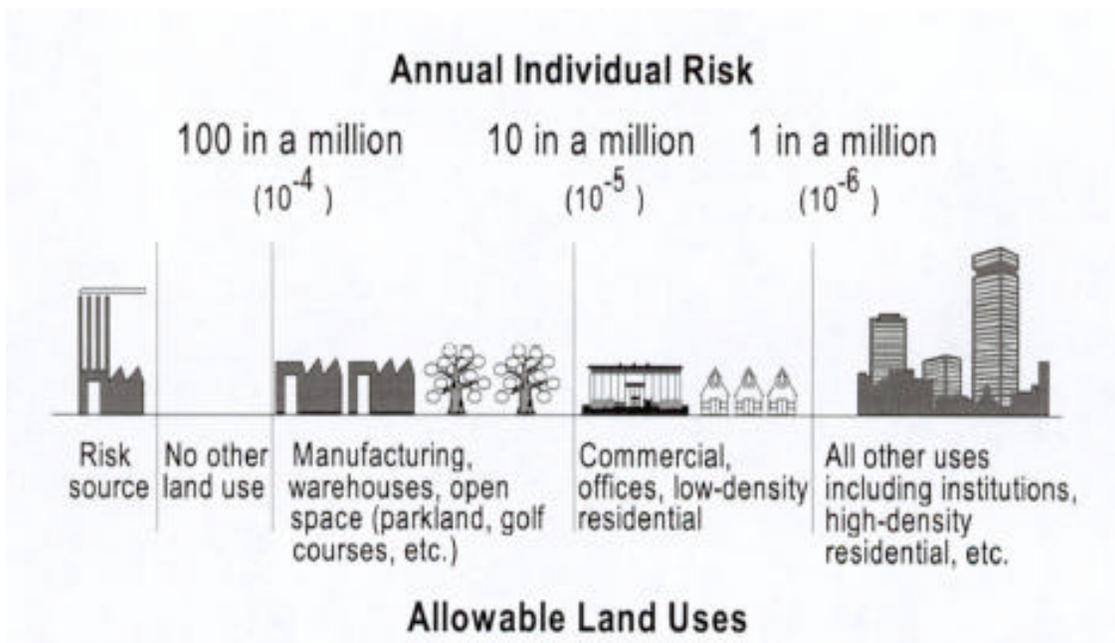


Figure 4: MIACC Acceptable Risk Criteria (after McCutcheon, 2002)

In US coal mines, stone-dusting is the primary defense against coal dust explosions. Explosion barriers of the type deployed in European mines are not generally used. Historically this may be due to the preference for in-seam roadways even at very low seam thicknesses. Roof mounted stone dust or water barriers are very difficult to contemplate in a roadway that may be 4.8 to 6 m (16 to 20 ft.) wide but only only 1 m (3.2 ft) in height. In addition to the practical considerations, the frequent cross-cuts in room and pillar workings allow the relief of confinement, and reduce the power of an explosion as it develops.

Water barrier performance in wide, flat-topped entries typical of North American coal mines was investigated by Sapko et al. (1989) at the Lake Lynn Experimental Mine.

It was found that stacked tub water barriers erected against the rib were effective in suppressing explosions. The experiments were carried out to determine methods of explosion suppression in areas of the mine that are difficult to protect from explosions solely by generalized stone-dusting, such as:

- Conveyor beltways
- Belt transfer points
- High float coal dust deposition areas
- Wet roadways
- Parked mine cars
- Development sections and methane drainage areas
- Return airways
- Longwall faces
- Isolated sections
- Room and Pillar region near an active face, and
- Very gassy mines.

Only constant vigilance and attention to the details of these requirements can prevent coal-dust explosions from continuing to be a menace (Davies and Isaac, 1999).

The preceding review of the current state of the art in preventing the initiation and propagation of coal dust explosions allows the following conclusions:

1. The most effective means of preventing a coal dust explosion is to prevent the initial ignition. In most cases, this means the prevention of frictional ignitions at the coal face. Ventilation of the cutting face must be designed to prevent accumulations of methane. Some frictional ignition prevention technologies, such as water sprays and carbide-capped picks, are mature and warrant use if the level of risk is high enough. Others, for example the use of active suppression systems on continuous miners, offer the prospect of suppressing ignitions at a very early stage, but require additional research for practical application.
2. Once ignited, a coal dust explosion is not at all easy to suppress. Even coal dust and float dust present at “incombustible” concentrations, add to the initiation event, and while an explosion may not propagate throughout the mine, it often travels several hundred feet from the point of ignition, or past an explosion barrier.
3. The total incombustibles content (TIC) required to suppress an explosion depends on many factors, only one of which is the volatile content of the coal, and research in Australia has shown that for their coals the volatile content is rarely a factor. Canadian TIC standards are derived from the results of tests conducted on carboniferous coals in Europe and the USA. Western Canadian and Western US coals are by and large cretaceous in age, as are Australian coals. There is very little testing information available for these coals, and most of it was done on a lab scale.
4. The float coal dust produced from highly productive multiple heading room and pillar sections can travel many hundreds of metres on the return air stream and settle on the roof, sides and floor in the return airways. Depending on the coal properties and the ventilation parameters, this float dust can render conventional roadway rock-dusting ineffective in a few days, and certainly well within the sampling periods demanded by most authorities.
5. Research shows that rock dust on the roof and sides can aid in the suppression of explosions if the floor dust is marginally compliant. Floor dust does not assist marginally compliant roof or rib dust. Roof and rib dust is more easily dispersed into the roadway in an explosion event. Deposits of non-compliant dust on the roof and ribs can propagate an explosion. The presence of water in the roadway floor may not indicate that roof and rib dust sufficient to fuel an explosion is wet enough to be inert. Compliance can only be determined by sampling.
6. All jurisdictions barring South Africa and British Columbia have adopted a fineness standard for rock dust that requires 70% to pass a 75 micron sieve. In South Africa, 80% TIC is required over 1000 m outby the last crosscut. In British Columbia the minimum TIC is 65%. A TIC of 65% was too low in Nova Scotia (Elfstrom, 1979), and considered too low to suppress a weak explosion

CONCLUSIONS

in the UK (SMRAB, 1998). In both circumstances the fineness of the rock dust used was stipulated as 70% passing 75 microns. It is suggested that a 65% TIC with the rock dust coarser than the two failures would be incapable of suppressing an explosion.

7. Research shows that in explosions involving float coal dust on a rock/coal dust substrate that only about 4 to 6 mm of the substrate is scoured, hence that only this amount will assist in suppression. The thicker the float dust layer, the higher the TIC must be in the scoured layer to ensure suppression. Sampling floor dust to a depth of 25 mm can seriously over-estimate the TIC of the floor dust.
8. Most of the large scale research into the effectiveness of explosion barriers and rock dusting has been undertaken in single entry test galleries. Size effects are present, i.e. a larger gallery or roadway can present different (higher) TIC requirements for explosion suppression because of the differences in the thermodynamics of propagation. Very few large scale tests have been done in multiple entry configurations. Those that have been conducted have shown that in certain circumstances explosions can outflank barriers by traveling in adjacent roadways.
9. Most explosion barriers have a limiting initiation pressure, below which they will not deploy. Rock dust applied immediately outby the working face will reduce explosion pressures if it does not totally suppress the explosion. Reduced explosion pressures may prevent explosion barriers close to the face from deploying at all. The implication is that if rock dusting is going to be used, ensure that it is used in sufficient quantities to totally suppress propagation, because if it doesn't, explosion barriers are unlikely to work.
10. While the most likely location for an ignition leading to a coal dust explosion is at the coal face during mining, other sources must also be considered. The Moura No. 4 explosion in Australia was the result of the ignition of an explosive mixture of coal dust in suspension and methane well outby the working face. A gob cave generated a windblast that raised coal dust and forced methane from the gob into the active roadways where it was ignited by a flame safety lamp. Any combination of heat and suspended coal dust can result in an explosion. Dust raised at a ventilation door, for example, can be ignited by faulty equipment.
11. With new underground mines expected to open in British Columbia, Alberta and Nova Scotia in the near future, each regulated by its own provincial legislation, three separate, independent, and technically sophisticated sets of regulations and three independent, scientifically mature inspection services will be required to oversee four mines. If ever there was an opportunity to rationalize coal mine safety and health legislation and enforcement in Canada, it is now.

The need for research in the following areas is obvious:

- Triggered explosion suppression systems, deployed both on the continuous miner and in roadways.
- Review of passive barrier systems to meet the requirements of rapidly advancing multiple entry room and pillar sections.
- Basic research into the propagation of explosions in multiple entry mining systems.
- Testing of Canadian coals in laboratory and gallery tests to determine required TIC levels.
- The rates of deposition of float coal dust specific to each underground coal mine under typical operating conditions.

Laboratory scale testing of coal samples from a particular mine is within reach, but must be done at a facility using methods that can be correlated with large scale testing – in the USA or Australia. Float coal dust deposition can be determined fairly easily at each mine site and used to develop stone dusting strategies that effectively eliminate the risk of propagation.

In the absence of a credible research organization in Canada to perform the other work, Canadian coal miners must depend on research results developed in the USA, Australia and elsewhere. However, research involving Canadian coals and rock dust is unlikely to be performed because of the logistical problems and costs involved.

Following past practice in Canada, where coal dust regulation has been based on the work of other nations, international best practice must define the safety of Canadian coal mines. The following recommendations, if implemented in Canada, can be expected to reduce the risk of coal dust explosions here to the same level as that enjoyed by other western coal producing nations.

1. **Accumulations of coal dust:**
All legislation reviewed required the elimination of accumulations of coal dust. A stipulation to this effect should be included in regulation as a minimum standard. Because fine coal dust is also a health hazard, more progressive regulation might link dust control measures to the provision of explosion suppression systems, and allow reductions in TIC and frequency of sampling in response to monitoring results that demonstrate the effectiveness of float coal reduction.
2. **Rock dust properties**
The minimum standard should require a rock dust fineness of 70% passing a 75 micron sieve, unless testing has shown that the TIC levels maintained in-situ with a dust of a different fineness can suppress an explosion.
3. **Total Incombustibles Content**
There appears to be consensus in the most recent reviewed regulations (Queensland and New South Wales) that TIC levels of 80 to 85% are required

within 200 to 250 m of the face or last open cross-cut (described as the “face area”). Outside these areas, levels of 80% in return roadways and all panel roadways within 200 m of the main intakes, and 65% to 70% in other areas of intakes would appear to be prudent.

In South Africa the standard is 80% within 1000 m. In South Africa, return roadways protected with explosion barriers may have TIC's to 65%. In the USA, TIC's of 80% are required in return roadways, 65% elsewhere.

These schemes assume that the most likely source of ignition is at the coal face. Other areas that might provide a fuel source, either methane or suspended dust, must also be protected by stone dusting. Examples are roadways leading to areas being sealed off where gob caves or barometric pressure drops might cause the build-up of methane, or places where dust can be raised, such as ventilation doors. South African standards legislate TIC's of 80% within 250 m of these locations.

In none of the recent regulations is there any lessening of TIC in the case of reduced volatile content, although in NSW reductions in TIC's are allowed for methane concentrations below a certain level subject to strict conditions including monitoring and regular review.

4. **Maintaining Total Incombustibles Content**

The effect of float coal dust generated at the face and its ability to dramatically increase the risk of propagation requires an aggressive program of TIC maintenance. In South Africa, stone-dusting within 1000 m of the face must be conducted after every fourth production shift. In the absence of regular stone-dusting, sampling intervals must be short, at least in the face zone. Periods of one week are defined in Queensland for the face zone, but even this may be too long if other measures to reduce or inert float coal dust are not taken.

5. **Sampling Procedures**

Stone dust sampling procedures must reflect the danger of float dust on the roof and sides, not just the floor. For this reason, separate samples of dust from the roof and sides must be collected in addition to samples from the floor, unless analysis over a period of time shows that this is unnecessary.

Water on the floor should not be assumed to render dust on the roof and ribs inert.

Collection of samples should be restricted to the top 6 mm of roadway dust.

6. **Explosion Barriers**

Given the present state of knowledge and the increased TIC's proposed, the South African practice of maintaining explosion barriers on conveyor roads within 180 m of the face is recommended as a prudent minimum standard, and all single entries should be protected by an explosion barrier as well, unless a comprehensive hazard analysis and risk assessment completed by a competent person recommends alternate suppression measure meet the requirements.

7. **Code of Practice**

International best practice includes minimum standards to be achieved (above) and either a Code of Practice (COP) or Standard Operating Procedure (SOP). Such a COP or SOP should, as a minimum, make provision for and document:

- the required application rates and means of application of stone dust to be applied in working places,
- the methods by which parts of advancing working places that have not yet had stone dust applied are to be maintained in a safe condition,
- the means by which stone dust is to be applied to surfaces in return roadways in close proximity to working faces,
- the application of stone dust to previously untreated roadway surfaces (resulting from roof or rib spall, the movement of equipment or otherwise)
- the procedures, methods or indicators to be used to give an indication whether or not required levels of incombustible content of roadway dust are being maintained,
- the procedures for, and frequency of, examination, sampling and testing of roadway dust to confirm whether or not required levels of incombustible content are being maintained,
- the procedures for the re-application of stone dust in parts of a mine (with particular reference to roadways containing conveyor belts),
- the procedures for the installation and maintenance of other explosion suppression measures,
- the means for the determination and recording of maximum likely concentrations of flammable gas in parts of the mine,
- the making and retention of reports of examination, sampling and testing of roadway dust and the examination of other explosion suppression measures,
- periodic reviews (at intervals not exceeding 2 years) of the system's effectiveness,
- documentation, with the relevant document or documents kept at the mine,
- consultation with, and participation of, employees' representatives possessing appropriate skills, knowledge or experience regarding the development and revision of a mine's explosion suppression system.
- provision of copies of the plans, and any revisions, to the regulatory authorities,
- periodic audits (at intervals not exceeding one year) of the system's operation by a competent person to determine whether or not the system is being followed at the mine, and whether or not the intended purposes of the system are being met.

The preceding review has demonstrated clearly the inter-relatedness of many colliery operations and their effect on the potential for the initiation and propagation of a coal dust explosion. The only rational approach to countering coal dust explosions is a holistic one that takes into account all these inter-related operations.

The South African "Guideline for the Compilation of a Mandatory Code of Practice for the Prevention of Flammable Gas and Coal Dust Explosions in Collieries" (DME, 2002) appears to provide a sound basis for any Canadian standard, subject to

revision to allow blending with the provincial regulations. The South African document is freely available from the world wide web, but a copy has been attached to this report as Appendix 11.

It is suggested that a COP or SOP, based on a comprehensive hazard evaluation and risk assessment, and completed under the direction of a competent person or persons, could result in the relaxation of the minimum standards – for example, TIC levels based on the results of explosion testing of mine specific dusts (coal and rock-dust) might be reduced from those given in the standard.

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Rock dusting

- 249 (1) In this section, "road" includes any part of the mine to within 10 metres of the working face.
- (2) The employer shall ensure that the floor, roof and sides of each road that is accessible are treated with incombustible dust to ensure that the dust on the floor, roof and sides always contains not less than 65% of incombustible matter, unless
- (a) the dust mixture on the floor, sides, timbers and roof of the road contains at least 30% by weight of water, or
- (b) other methods and materials for dust stabilization or consolidation are used in a manner acceptable to the Director.
- (3) If flammable gas is present in the ventilating current, the minimum amount of 65% of incombustible matter prescribed by subsection (2) must be increased by 1% for each one-tenth of 1% of flammable gas in the atmosphere.
- (4) The 65% incombustible matter specified in subsection (3) applies where the volatile matter of the coal is 32% or more.
- (5) When the volatile matter of the coal is less than 32%, the minimum amount of incombustible matter may diminish by 1.5% for each 1% of volatile matter below 32% but to not less than 50% of incombustible matter.
- (6) The mine manager shall ensure that, before a part of a road is dusted for the first time with rock dust, it is cleaned as thoroughly as possible of all combustible dust.
- (7) The incombustible dust used for the purpose of this section means the pulverized inert material of light colour,
- (a) of which 100% passes through a 20 mesh sieve,
- (b) of which not less than 70% by weight passes, when dry, through a 200 mesh sieve, and
- (c) which does not contain more than 5% of combustible matter or 4% of free and combined silica.

Dust sampling

- 250 An employer shall
- (a) implement and maintain a sampling system to ensure the requirements of section 250 are adhered to, and
 - (b) maintain a record of the results.

Certified barriers

- 251 The employer shall ensure that the scheme for design, erection, location and maintenance of explosion barriers is certified by a professional engineer.

Explosion barrier placement

- 252 Unless issued an acceptance by the Director, the employer shall ensure that explosion barriers are established at
- (a) every entrance to every production section,
 - (b) every entrance to every development district as soon as the development district has advanced 200 metres, and
 - (c) every entrance to every ventilation split intake and return.

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Coal Mines – Combustible Dust

Treatment	6.29.1	The floor, roof and sides of every road or part of a road that is accessible shall be treated (1) with water in the manner and at intervals that will ensure that the dust on the floor, roof, and sides, respectively, is always combined throughout with 30% by weight of water in the intimate mixture, or (2) with incombustible dust in a manner and at intervals that will ensure the dust on the floor, roof, and sides, respectively, shall always consist throughout of a mixture containing not more than 50% of incombustible matter if the volatile matter content of the coal does not exceed 22% as determined by one of the standard methods of analysis and computed on a dry, ash free basis.
Permissible Levels	6.29.2	The maximum permissible percentage of combustible matter under section 6.29.1(2) shall diminish by 1.5% for each 1% increase of volatile matter of the coal until it has been reduced to 35 in the case of coal having a volatile matter content of 32% or more
Samples	6.29.3	For the purpose of determining the volatile matter content of the coal under section 6.29.1(2), samples shall be taken either from representative sections of the seam or from a representative quantity of the run of mine coal from the seam.
Methane	6.29.4	The permissible percentage of combustible matter in the dust found in an underground roadway shall be further decreased by one for each increment of 1/10 part of 1% in the methane content of the mine air beyond ¼ of 1%.
NMoisture	6.29.5	The percentage of incombustible dust required under this section may be reduced by an amount equivalent to the percentage of water present in the mixture.
Exception	6.29.6	The obligations imposed by this section do not apply to a roadway, if the natural conditions of it as regards the presence of incombustible dust and moisture are found by tests made in accordance with this section to be such as to comply with the foregoing requirements.
Fineness of Dust	6.29.7	The incombustible dust used for the purpose of this part of the code shall, whenever possible, contain not less than 50% by weight of fine material capable, when dry, of passing through a No. 80 sieve of the Canadian Metric Sieve Series
Sampling	6.29.8	If the amount of incombustible dust passing through the No. 80 Sieve is less than 50%, the percentage of combustible matter specified as being the maximum permissible by sections 6.29.1(2), 6.29.2, and 6.29.5 shall be decreased proportionately, but the percentage of the fine material shall never fall below 25%.

- 6.29.9 To obtain the composition of the dust mixture in a road or part of a road, the following procedure shall be adopted
- (1) representative samples of the dust shall be collected from the floor, roof and sides over a section of road not less than 30 m in length, the sections being not more than 135 m apart in the same roadway, and
 - (2) each sample collected shall be thoroughly mixed and quartered, and a portion of the mixture shall then be sifted through a No. 315 sieve of the Canadian metric Sieve Series.
- Analysis of Roadway Dust 6.29.10 If the roadway dust is known to contain only negligible percentages of either gypsum or carbonates
- (1) a weighed quantity of the dust that has passed through the sieve shall be dried at a temperature of 105 degrees Celsius, and the weight lost shall be reckoned as moisture, and
 - (2) the sample shall then be brought to a red heat in an open vessel until it no longer loses weight, and the weight lost by incineration shall be reckoned as combustible matter for the purpose of the test.
- Gypsum 6.29.11 If the incombustible dust applied to a roadway consists of gypsum wholly or in part
- (1) a weighed quantity of the sieved dust shall be dried at a temperature between 135 degrees Celsius and 140 degrees Celsius and the weight lost shall be reckoned as moisture, and
 - (2) the sample shall then be kept at a red heat in an open vessel until complete incineration, and the weight of residue added to that of the moisture shall be reckoned as incombustible matter and expressed as a percentage of the total weight of sieved dust treated.
- Carbonate 6.29.12 If the roadway dust contains an appreciable proportion of carbonates, the following method shall be followed
- (1) a weighed quantity of the dust that has passed through the sieve shall be dried at a temperature of 105 degrees Celsius, and one hundred times the weight lost divided by the number of grams of dust submitted to the test shall be reckoned as the percentage of moisture, and
 - (2) one gram of the sample so dried shall then be treated with dilute hydrochloric acid in a suitable apparatus; the weight lost through the decomposition of the carbonates shall be ascertained and subsequently added to that of the incombustible solid residue of another gram of the same sample having been subjected in an open crucible and for not less than one hour to a temperature exceeding 925 degrees Celsius, and this total, plus the moisture previously determined, shall be recorded as incombustible matter.
- Tests to be recorded 6.29.13 The results of the tests of the roadway dust shall be recorded in a book kept at the mine for the purpose, and three copies shall be made, one of which shall be posted in the mine entrance and the other two sent to the district inspector.
- Frequency of Tests 6.29.14 Subject to section 6.29.15, tests of samples of roadway dust, so taken as to be representative of the normal composition of the roadway dust throughout the mine and on the roof floor and sides, respectively, shall be made as often as may be necessary, but not less frequently than once in each month.

	6.29.15	If the tests made on representative samples of roadway dust show in respect of a mine or part of a mine that the conditions prevailing in it as regards presence of the incombustible dust and moisture comply with this part of the code, and these conditions are unlikely to change, tests of representative samples may be made at intervals not exceeding three months or at longer intervals approved in writing by the district inspector.
Method	6.29.16	Before the first application of incombustible dust as required by this part of the code, accumulated coal dust shall be removed from the roof, floor and sides of the roadway, so far as practicable.
Exception	6.29.17	Section 6.29.16 does not apply to mining operations in coal seams containing less than 7% of volatile matter, as determined by one of the standard methods of analysis and computed on a dry, ash free basis.
Injurious Dust	6.29.18	Incombustible dust that is ineffective or injurious to health shall not be used in a mine.

Coal Mine Explosion Barriers

Type	6.30.1	(1) In any underground coal mine which is dry and dusty, rock dust or water barriers of a type authorized by the chief inspector shall be installed at places designated in a scheme prepared by the manager and authorized by the district inspector.
Order		(2) The district inspector may order the manager to prepare a similar, authorized scheme at any mine where the district inspector believes that a hazard may exist from the ignition of flammable gas or dust.
Inspection		(3) where explosion barriers are required in an underground coal mine, the manager shall appoint a person who holds an underground coal mine shiftboss certificate to examine the condition and position of the barriers.
Frequency		(4) The person appointed under subsection (3) shall examine the barriers at intervals of not more than 4 weeks and shall report the results of the examination in writing in a book to be kept at the mine.

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Part 12 Coal dust explosion prevention and suppression

Division 1 Preliminary

170 Definitions

In this Part:

- **face zone** means that area of a mine inby of all points 200 metres outby of a last completed line of cut-throughs or that area inby of all points 200 metres outby of a longwall face.
- **roadway dust** means dust on the floor, roof or sides of a roadway or on any other surfaces in a roadway.
- **working panel** includes all roadways, both intake and return, ventilated by a separate ventilation split that provides ventilation to a working face within the panel (unless an inspector determines otherwise).

Division 2 General

171 Explosion prevention and suppression generally

- (1) A mine manager must ensure that means are in place to prevent any explosion underground at the mine involving coal dust and to suppress any such explosion should it occur.
- (2) Such means must include, but are not limited to, the following:
 - (a) the application of sufficient quantities of stone dust to surfaces in roadways,
 - (b) the prevention of accumulations of coal dust that may contribute to an explosion,
 - (c) the installation and maintenance of explosion barriers.
- (3) In complying with this clause, a mine manager must have regard to any relevant guidelines applied to the mine.

172 Implementation of explosion suppression systems

- (1) A mine manager must, within 6 months after the commencement of this Regulation, develop and implement an explosion suppression system providing for:
 - (a) the maintenance, through the application of stone dust or otherwise, of the incombustible content of roadway dust required by this Part, and

- (b) the prevention of accumulations of coal dust, and
 - (c) the installation and maintenance of explosion barriers and other explosion suppression measures.
- (2) In particular, an explosion suppression system must provide for the following matters:
- (a) the required application rates and means of application of stone dust to be applied in working places,
 - (b) the methods by which parts of advancing working places that have not yet had stone dust applied are to be maintained in a safe condition,
 - (c) the means by which stone dust is to be applied to surfaces in return roadways in close proximity to working faces,
 - (d) the application of stone dust to previously untreated roadway surfaces (resulting from roof or rib spall, the movement of equipment or otherwise),
 - (e) the procedures, methods or indicators to be used to give an indication whether or not required levels of incombustible content of roadway dust are being maintained,
 - (f) the procedures for, and frequency of, examination, sampling and testing of roadway dust to confirm whether or not required levels of incombustible content are being maintained,
 - (g) the procedures for the re-application of stone dust in parts of a mine (with particular reference to roadways containing conveyor belts),
 - (h) the procedures for the installation and maintenance of explosion barriers and other explosion suppression measures,
 - (i) the means for the determination and recording of maximum likely concentrations of flammable gas in parts of the mine,
 - (j) the making and retention of reports of examination, sampling and testing of roadway dust and the examination of explosion barriers.
- (3) An explosion suppression system must include provisions for periodic reviews (at intervals not exceeding 2 years) of the system's effectiveness.
- (4) An explosion suppression system must be documented and the relevant document or documents must be kept at the mine.

173 Employees' representatives to be consulted

Employees' representatives possessing appropriate skills, knowledge or experience must be consulted regarding (and be given an opportunity to participate in) the development and revision of a mine's explosion suppression system.

174 Copy to be supplied to district inspector and district check inspector

A mine manager must supply a copy of the mine's explosion suppression system, and any revisions of it, to the district inspector and the district check inspector within 7 days of the system or revisions being put into effect.

175 Periodic audits of explosion suppression systems

- (1) An explosion suppression system must include provisions for periodic audits (at intervals not exceeding one year) of the system's operation.
- (2) An auditor must be a person who is accredited by the Chief Inspector as a person who is qualified to conduct audits for the purposes of this Part.

- (3) A mine manager must, in respect of each audit of the mine's explosion suppression system's operation, obtain from the auditor a report:
 - (a) as to whether or not the system is being followed at the mine, and
 - (b) as to whether or not the intended purposes of the system are being met.
- (4) A mine manager must provide a copy of each report to the district inspector and the district check inspector as soon as practicable after the conduct of the audit (together with a report by the manager as to how any shortcomings revealed by the audit are to be rectified).

176 Maintenance of incombustible content of roadway dust

- (1) The incombustible content of that portion of roadway dust that is finer than 250 micrometres must be maintained at the following levels through the application of stone dust:
 - (a) in the case of dust in an intake roadway within a face zone not less than 80 per cent by mass,
 - (b) in the case of dust in a return roadway within a face zone not less than 85 per cent by mass,
 - (c) in the case of dust elsewhere in a mine not less than 70 per cent by mass.
- (2) Subclause (1) does not apply to roadway dust that is so wet as to be incapable of being forced into suspension in the air by the concussion of a gas explosion or otherwise.
- (3) The distance advanced between applications of stone dust at each working face must be kept to not more than 30 metres but in no case is a working place to remain without an application of stone dust for a period in excess of one working day.
- (4) In subclause (1):
 - **incombustible content**, in relation to roadway dust, includes any moisture contained in the dust.

177 Reduction of levels of incombustible content of roadway dust in certain circumstances

- (1) A mine manager may determine the maximum likely concentration of flammable gas (maximum likely gas concentration) in intake roadways within face zones and in return roadways within working panels.
- (2) In the case of an intake roadway within a face zone the manager's determination must be based on readings obtained from:
 - (a) an automatic methane monitor or a recording methane detector installed on a continuous mining machine operating in the zone, or
 - (b) an automatic methane monitor or a recording methane detector installed on the return side of a longwall working in the zone.
- (3) In the case of a return roadway within a working panel the manager's determination must be based on readings obtained from a gas monitoring system required by this Regulation.
- (4) A mine manager must record any determinations of maximum likely gas concentrations and notify the district inspector immediately in writing of the determinations and the parts of the mine to which they apply.

- (5) If a mine manager determines the maximum likely gas concentration for a part of the mine, the minimum incombustible content level that is required by clause 176 to be maintained in relation to roadway dust in that part is reduced by:
 - (a) in the case of dust in an intake roadway within a face zone? 1 per cent for each 0.1 per cent that the maximum likely gas concentration is below 1 per cent, and
 - (b) in the case of dust in a return roadway within a working panel? 1 per cent for each 0.2 per cent that the maximum likely gas concentration is below 2 per cent.

178 Review of mine manager's determinations of maximum likely gas concentrations

- (1) An inspector who is of the opinion that a concentration of flammable gas present in a part of a mine has been, is or is likely to be greater than a maximum likely gas concentration currently determined by the mine manager for that part must immediately serve on the manager a notice requiring the application of stone dust to that part as though the determination had not been made.
- (2) An inspector may require a mine manager to arrange for the conduct of measurements of flammable gas concentrations in a manner and at a frequency required by the inspector for the purpose of testing the manager's determination of a maximum likely gas concentration.
- (3) A mine manager may apply to the Chief Inspector for a review of a requirement under subclause (1) or (2) (other than a requirement made by the Chief Inspector) and the Chief Inspector may revoke, confirm or amend the requirement.
- (4) A mine manager must comply with a requirement under subclause (1) or (2) unless it is revoked or amended. If a requirement is amended it must be complied with as amended.

179 Restrictions on use of stone dust

- (1) Stone dust must not be used for the treatment of roadway dust unless it is of a specified type or grade.
- (2) The Chief Inspector may specify the use of particular types or grades of stone dust for particular purposes.

180 Explosion barriers and other explosion suppression measures in roadways

- (1) An explosion barrier must be installed and maintained in the part of any roadway (other than part of a single entry roadway) containing a conveyor belt within a face zone.
- (2) An explosion barrier must be installed and maintained in the part of any return roadway (other than part of a single entry roadway or a part of a roadway referred to in subclause (1)) within a face zone.
- (3) Adequate explosion suppression measures must be installed and maintained in single entry roadways.
- (4) In installing and maintaining explosion barriers or other explosion suppression measures regard must be had to any relevant guidelines applied to the mine.

Division 3 Sampling and testing of roadway dust**181 Appointment of departmental roadway dust examiners**

The Chief Inspector may appoint officers of the Department as departmental roadway dust examiners. The officers appointed must be the holders of at least a deputy's certificate of competency.

182 Functions of departmental roadway dust examiners

A departmental roadway dust examiner has the following functions:

- (a) after notifying a senior mining official present at a mine, to enter the mine at any reasonable time for the purpose of determining roadway dust conditions,
- (b) to collect and remove from a mine samples of roadway dust,
- (c) to require the production of, to inspect and to copy from, any records or reports required to be kept under this Part,
- (d) to make inquiry and examination in order to ascertain whether the provisions of this Part are being complied with,
- (e) to require any person having responsibilities under the Act or this Part to provide such assistance and facilities with respect to any matter or thing to which the responsibilities of that person extend as are necessary to enable the departmental roadway dust examiner to exercise any power conferred by this clause.

183 Appointment of persons to collect roadway dust samples

- (1) A mine manager must appoint a person or persons in writing for the collection of roadway dust samples at the mine.
- (2) A person appointed must, before the appointment, have undergone a period of instruction and satisfied the manager as to the person's ability to perform the duties required.

184 Person to accompany departmental roadway dust examiner on visits to mine

A person appointed by a mine manager to collect roadway dust samples, or in that person's absence a mining official nominated by the manager, must, at the request of a departmental roadway dust examiner, accompany the examiner during visits to the mine.

185 Method of taking roadway dust samples

- (1) If roadway dust is to be sampled for the purpose of ascertaining its incombustible content for the purposes of this Part:
 - (a) subject to paragraph (b), samples must be taken:
 - (i) where practicable, from the complete perimeter of the roadway and the structures in it, and
 - (ii) where possible, over a length of roadway of at least 45 metres, by a method of strip sampling by which the dust is collected from a succession of transverse strips as nearly as possible of equal width and equally spaced, not more than 5 metres apart and of an aggregate area not less than one per cent of the total area sampled, and
 - (b) if it appears that dust on the floor of a roadway contains a different incombustible content from dust on the roof and sides of the roadway, the

dust on the floor must be sampled and tested separately from the dust on the roof and sides, and

- (c) each sample must be collected as near as practicable from a maximum depth of 5 millimetres.
- (2) If a location is resampled, the individual strips from which the increments for a strip sample are taken must not coincide with those from which a previous sample has been taken.
- (3) In sampling roadway dust regard must be had to any relevant guidelines applied to the mine.

186 Testing roadway dust samples

- (1) In preparing roadway dust samples and determining their incombustible content regard must be had to any relevant guidelines applied to the mine.
- (2) In the event of a dispute concerning the incombustible content of samples of roadway dust, the determination of the incombustible content by use of a specified method will prevail.

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Title 30 Code of Federal Regulations

Subpart E--Combustible Materials and Rock Dusting

30 CFR § 75.400

Accumulation of combustible materials.

Coal dust, including float coal dust deposited on rock-dusted surfaces, loose coal, and other combustible materials, shall be cleaned up and not be permitted to accumulate in active workings, or on diesel- powered and electric equipment therein.

30 CFR § 75.400-1

Definitions.

- (a) The term coal dust means particles of coal that can pass a No. 20 sieve.
- (b) The term float coal dust means the coal dust consisting of particles of coal that can pass a No. 200 sieve.
- (c) The term loose coal means coal fragments larger in size than coal dust.

30 CFR § 75.400-2

Cleanup program.

A program for regular cleanup and removal of accumulations of coal and float coal dusts, loose coal, and other combustibles shall be established and maintained. Such program shall be available to the Secretary or authorized representative.

30 CFR § 75.401

Abatement of dust; water or water with a wetting agent.

[STATUTORY PROVISION]

Where underground mining operations in active workings create or raise excessive amounts of dust, water or water with a wetting agent added to it, or other no less effective methods approved by the Secretary or his authorized representative, shall be used to abate such dust. In working places, particularly in distances less than 40 feet from the face, water, with or without a wetting agent, or other no less effective methods approved by the Secretary or his authorized representative, shall be applied to coal dust on the ribs, roof, and floor to reduce dispersibility and to minimize the explosion hazard.

30 CFR § 75.401-1**Excessive amounts of dust.**

The term "excessive amounts of dust" means coal and float coal dust in the air in such amounts as to create the potential of an explosion hazard.

30 CFR § 75.402**Rock dusting.****[STATUTORY PROVISION]**

All underground areas of a coal mine, except those areas in which the dust is too wet or too high in incombustible content to propagate an explosion, shall be rock dusted to within 40 feet of all working faces, unless such areas are inaccessible or unsafe to enter or unless the Secretary or his authorized representative permits an exception upon his finding that such exception will not pose a hazard to the miners. All crosscuts that are less than 40 feet from a working face shall also be rock dusted.

30 CFR § 75.402-1**Definition.**

The term "too wet" means that sufficient natural moisture is retained by the dust that when a ball of finely divided material is squeezed in the hands water is exuded.

30 CFR § 75.402-2**Exceptions.**

Exceptions granted under §75.402 by the Secretary or his authorized representative shall be reviewed periodically.

30 CFR § 75.403**Maintenance of incombustible content of rock dust.****[STATUTORY PROVISION]**

Where rock dust is required to be applied, it shall be distributed upon the top, floor, and sides of all underground areas of a coal mine and maintained in such quantities that the incombustible content of the combined coal dust, rock dust, and other dust shall be not less than 65 per centum, but the incombustible content in the return aircourses shall be no less than 80 per centum. Where methane is present in any ventilating current, the per centum of incombustible content of such combined dusts shall be increased 1.0 and 0.4 per centum for each 0.1 per centum of methane where 65 and 80 per centum, respectively, of incombustibles are required.

30 CFR § 75.403-1**Incombustible content.**

Moisture contained in the combined coal dust, rock dust and other dusts shall be considered as a part of the incombustible content of such mixture.

30 CFR § 75.404**Exemption of anthracite mines.****[STATUTORY PROVISION]**

Sections 75.401, 75.402, and 75.403 shall not apply to underground anthracite mines.

(Note: These provisions are reprinted without permission from the relevant government web-site. No guarantee is given or implied that the following contains an accurate transcription of the legislation described. For an accurate reference, refer to the issuing authority.)

**PART V
EXPLOSION AND FIRE PROTECTION**

Dust Reduction Measures

133. (1) Every area underground shall be kept free from accumulations of coal dust.
- (2) Dry areas underground in which coal dust is produced shall be systematically wetted down with water.
- (3) To reduce coal dust underground,
- (a) where dry coal is cut by a coal-cutting machine, a jet of water shall be directed over the picks of the machine; and
- (b) mined coal shall be kept wet during handling.

Dusting Procedures

134. (1) Every roadway underground shall be treated with incombustible dust in such a way that the dust on the floor, roof and sides of the roadway contains
- (a) where the concentration of flammable gas in the air in the roadway does not exceed 1 per cent, not less than 75 per cent by weight of incombustible dust; and
- (b) where the concentration of flammable gas in the air in the roadway exceeds 1 per cent, not less than 80 per cent by weight of incombustible dust.
- (2) Subject to subsection (3), the incombustible dust referred to in subsection (1) shall contain not less than 70 per cent by weight of fine material that is capable, when dry, of passing through a sieve of 200 mesh.
- (3) Where a larger percentage of incombustible dust than the percentage referred to in subsection (1) is used, the percentage of fine material referred to in subsection (2) may be reduced in proportion to the increase in the amount of incombustible dust, but in no case shall it be less than 25 per cent.

135. (1) At least once every month, samples of dust shall be taken from the floor, roof and sides along the length of each roadway underground and shall be analysed to determine the percentage of combustible material therein.
- (2) The employer shall, in respect of the analysis referred to in subsection (1),
- (a) keep a record of the analysis; and
 - (b) submit a written report of the results of the analysis to a safety officer at the district office before the 15th day of the month following the analysis.
136. Not less than 20 bags of incombustible dust, each weighing not less than 25 kg, shall be stored for emergency use within 150 m of each working face in the intake airway and within 40 m of each working face in the return airway.

Explosion Protection Barriers

137. (1) In each intake airway leading to a working face, a stone-dust barrier or a water barrier shall be placed within 300 m of the working face.
- (2) A stone-dust barrier referred to in subsection (1) shall hold not less than 100 kg of stone dust per square metre of area of the roadway that it serves.
- (3) A water barrier referred to in subsection (1) shall contain not less than 200 L of water per square metre of area of the roadway that it serves.

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Mine explosion suppression procedure required in a coal mine

- 86 (1) At a coal mine an employer shall develop a mine explosion suppression procedure, including plans and procedures, that is certified as adequate by an engineer, countersigned by the manager and filed with the Director, that is suitable to the conditions and mining system of the mine, for the detection and suppression of explosions of coal dust and flammable gas underground.
- (2) An employer shall review the mine explosion suppression procedure developed under subsection (1) at least once a year and revise it as necessary.
- (3) An employer shall ensure that a device required by the mine explosion suppression procedure developed under subsection (1) is
- (a) designed in accordance with good engineering practice;
 - (b) certified as adequate by an engineer;
 - (c) constructed, operated, and maintained as designed; and
 - (d) inspected weekly

Dust minimization plan in a coal mine

- 87 (1) At a coal mine an employer shall prepare and file with the Director a coal dust minimization plan that includes
- (a) a procedure to minimize the generation of coal dust;
 - (b) a procedure to remove coal dust and other combustibles from the mine to the extent reasonably practicable;
 - (c) a description of the equipment and method for stone-dusting and frequency of stone-dusting;
 - (d) procedures complying with subsection (2) for sampling settled dust underground that list the equipment and method used, the frequency of the sampling and testing procedures; and
 - (e) the location and quantity of stone-dust stored in the mine for purposes of an emergency.

- (2) At a coal mine the employer shall implement a procedure, for the sampling and analysis of dust from underground locations including travelways, that is
 - (a) suitable to the conditions and mining system of the mine indicating locations and frequency of sampling;
 - (b) certified as adequate by an engineer; and
 - (c) countersigned by the manager.

Dust reduction measures in a coal mine

- 88
- (1) An employer shall ensure that every area underground in a coal mine is kept reasonably free of accumulations of coal dust.
 - (2) An employer shall ensure that dry areas underground in which coal dust is produced are systematically wetted down with water.
 - (3) To reduce coal dust underground, an employer shall ensure that
 - (a) all coal-cutting heads are equipped with water-spray jets of sufficient number and size to ensure that the areas of the coal face being worked are maintained in a damp condition so as to render any coal dust incombustible;
 - (b) all transfer points where coal is moved from one mode of transfer to another, including all dumping stations, are equipped with water-spray devices sufficient to render any coal dust incombustible; and
 - (c) mined coal is kept wet during handling underground.

Requirements for stone-dust in a coal mine

- 89
- (1) At a coal mine, an employer shall ensure that a travelway or other surface underground, other than one that is within 12 m of the working face, is treated with stone-dust in such a way that the dust on the floor, roof and sides of the travelway contains not less than 80 percent by weight of incombustible dust.
 - (2) The stone-dust required under subsection (1) shall contain
 - (a) not less than 70 percent by weight of material that is capable, when dry, of passing through a sieve of 75 microns;
 - (b) less than 1 percent combustible material as determined by a test of the combustible content of the dust as a whole; and
 - (c) less than 1 percent free crystalline silica.
 - (3) An employer shall ensure that not less than 20 bags of dry stone-dust, each meeting the requirements of subsection (2) and weighing not less than 25 kg, is stored underground in a coal mine at each
 - (a) shop;
 - (b) flammable material storage area;
 - (c) belt drive area;
 - (d) belt head loading area;

- (e) ventilation door or curtain;
- (f) location where electrical equipment is installed;
- (g) crusher station;
- (h) pump station;
- (i) shaft station;
- (j) tippie;
- (k) service garage;
- (l) fuelling station;
- (m) other location where a fire hazard could exist;
- (n) within 150 m of each working face in the intake airway;
- (o) within 40 m of each working face in the return airway; and,
- (p) at every 60 m along a belt line.

Sampling and analysis of dust in a coal mine

- 90 (1) An employer shall review the procedure developed under subsection 87(2) for the sampling and analysis of dust underground at least once a year and revise it as necessary.
- (2) At a coal mine an employer shall ensure that, at least once every week,
- (a) representative samples of dust are taken, in accordance with the procedure for sampling developed under subsection 87(2), from the floor, roof and sides along the length of each travelway underground and analysed to determine the percentage of combustible material; and
 - (b) the manager receives the results of the sampling not later than one week following the date on which the sample was taken.
- (3) An officer may order an employer at a coal mine to take the samples described in subsection 87(2) more frequently if the officer deems it necessary to ensure the safety of a mine worker.
- (4) The employer shall
- (a) keep a record of the results of the analysis required under subsection 87(2) along with a plan that identifies the location where each sample was taken; and
 - (b) notify and report to the committee or representative, if any, the results of the analysis required under subsection 87(2), as required under clause 12(2)(c).

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PART 10 -MINING OPERATIONS

Division 1 -Coal dust explosion prevention and control

300 General

- (1) An underground mine's safety and health management system must provide for the following -
 - (a) minimising the risk of coal dust explosion;
 - (b) suppressing coal dust explosion and limiting its propagation to other parts of the mine.
- (2) The system must include provision for the following -
 - (a) limiting coal dust generation, including its generation by mining machines, coal crushers and coal conveyors and at conveyor transfer points;
 - (b) suppressing, collecting and removing airborne coal dust;
 - (c) limiting coal dust accumulation on roadway and other surfaces in mine roadways;
 - (d) removing excessive coal dust accumulations on roadway and other surfaces in mine roadways.
- (3) The mine must have a standard operating procedure for the following -
 - (a) calculating -
 - (i) the rate of coal dust accumulation on roadway surfaces; and
 - (ii) the stonedust application rate necessary to prevent coal dust explosion;
 - (b) regularly inspecting, sampling and analysing roadway dust layers, including laboratory analysis for incombustible material content;
 - (c) suppressing coal dust explosion, including, for example, by applying stonedust or another explosion inhibitor.
- (4) The procedure must provide for the dust sampling and analysis mentioned in subsection (3)(b) to be carried out at least -
 - (a) for a spot sample of dust mentioned in section 301(1)(a) or (b) -weekly;
or

- (b) for a strip sample of dust mentioned in section 301(1)(a), (b), (c) or (d) - monthly; or
 - (c) for a strip sample of dust mentioned in section 301(1)(e) –every third month.
- (5) The procedure must also provide for the analysis of each sample mentioned in subsection (4)(b) or (c) to be carried out in a laboratory.

301 Incombustible material content for mine roadway dust

- (1) The underground mine manager must ensure the content of incombustible material in roadway dust at the mine is kept at or above -
- (a) for dust in a panel roadway within 200 m outbye the last completed line of cut-throughs in the panel -85%; or
 - (b) for dust in a 200 m section of panel roadway within 400 m of a longwall face -85%; or
 - (c) for dust in a panel roadway within 200 m from the main roadway, if paragraphs (a) and (b) do not apply to the 200 m section of the roadway -80%; or
 - (d) for dust in a return roadway not mentioned in paragraphs (a) to (c) -80%; or
 - (e) for dust in an intake roadway not mentioned in paragraphs (a) to (d) - 70%.
- (2) The underground mine manager must also ensure -
- (a) each 50 m length of a roadway that is being driven at the mine is stonedusted, or treated with another coal dust explosion inhibitor immediately after the length is driven; and
 - (b) each part of the roadway is stonedusted or treated with another coal dust explosion inhibitor within 24 hours after the part is driven.
- (3) Subsections (1) and (2) do not apply to dust in a roadway where there is a sufficient natural make of water associated with the mining operation to prevent a coal dust explosion.
- (4) Also, subsection (1) does not apply to dust in a part of the mine mentioned in the subsection if -
- (a) an explosion inhibitor, including, for example, a chemical, is used as a coal dust suppressant in combination with stonedust in the part; and
 - (b) a physical test, other than a laboratory test, of the combination carried out by a nationally accredited testing station has shown the combination to effectively suppress a coal dust explosion.

302 Action to be taken if incombustible material content not met

- (1) This section applies if an analysis of a dust sample from an underground mine shows the dust does not comply with the incombustible material content for the dust stated in section 301(1).
- (2) The underground mine manager must ensure -

- (a) the area from which the sample was taken is re-stonedusted within the following period after the underground mine manager receives the analysis result -
 - (i) for dust mentioned in section 301(1)(a), (b) or (c) -12 hours; or
 - (ii) for dust mentioned in section 301(1)(d) or (e) -7 days; and
- (b) a record is kept of the date and time when the area was re-stonedusted.
- (3) The underground mine manager must ensure the ERZ controller for the area is given notice of the analysis result.

303 Record of roadway dust sampling

- (1) The underground mine manager must ensure a record is kept of the following for each roadway dust sample taken at the mine -
 - (a) the date it was taken;
 - (b) the location from which it was taken;
 - (c) its incombustible material content;
 - (d) the method used for analysing the sample.
- (2) The underground mine manager must also ensure the sample's incombustible material content result is marked on a mine plan showing the boundaries of the mine ERZ locations as soon as practicable after the underground mine manager receives the result.

STONEDUST SAMPLING

1. Sampling Plan
 - 1.1 On main coal transport roads, samples will be taken at the rate of 10 to the mile
 - 1.2 On all other roadways, samples will be taken at the rate of 5 to the mile.
 - 1.3 A sample will be taken within 600 ft. of any working face.
 - 1.4 Each roadway will be clearly marked to identify each sample section
 - 1.5 Every sampling section of every roadway will be sampled at least once a month.
 - 1.6 In the case of retreat longwalls, stonedust samples will not be required in the caved section of roadway behind the face, or other sections of the mine barricaded to travel.
 - 1.7 Where a mining section ceases production, stonedusting and sampling of the sections roadways will continue until such time as the section is sealed off.
2. Method of Sampling
 - 2.1 Samples taken should be representative of the whole surface of the whole floor, roof or sides. Representative samples of dust will be collected from the roof, floor, and sides, respectively, over an area of road not less than fifty yards in length, and one sample shall comprise the dust collected on the roof and sides, and a second sample will comprise the dust on the floor. The method of sampling will be by a series of transverse strips not more than 15 ft. apart.
 - 2.2 On roadways with belt conveyors, the area directly over the belt, underneath the belt and the rib closest to the conveyor may be excluded from the sampling for personal safety of the sampler.
 - 2.3 In the case of dust on the roof and sides, the sample will be taken to a depth not exceeding one quarter inch.
 - 2.4 In the case of dust on the floor, the sample will be taken to a depth not exceeding one inch.
 - 2.5 Each sample collected will be well mixed and a portion of the mixture will be sieved through a piece of metallic gauze having a mesh of 60 to the lineal inch. The dust passing through the screen will represent the sample for analysis. If the sample collected is too moist to be screened, the sample portion should be bagged and marked "unscreened".
 - 2.6 The sample will be placed in sealable polyethylene bags and properly marked as to the colliery and zone number and date, then shipped to the laboratory.

- 2.7 If excessive moisture exists in the sampling zone, the method of sampling will be by a series of spot samples taken at one point for every three feet of roadway length. The sample collected will be mixed and either the whole or a portion of the sample will be bagged and marked "unscreened".
- 2.8 Sampling zones where conditions on the floor, roof or sides are very wet (i.e. water accumulations, wet slime, muck, etc.) in the section of road where the sample is being taken, the sample will be marked "TOO WET" and regarded as meeting the requirements of the Regulations.
3. Increase in length of Roadways
 - 3.1 As longwall levels and other roadways are advanced, sample zones will be added in accordance with the rate of sampling approved for that particular roadway.
 - 3.2 The sampling plan will be updated quarterly

For comparison purposes, the sampling method approved prior to the current method is given below

2 Scheme for Sampling

2(a) Sampling has to be carried out in a systematic way and it is necessary to define what is meant by a sample

A sample of mine roadway dust is a mixture of portions of fine dust taken in a prescribed manner from a section of roadway 1/10 of a mile in length in the case of an intake roadway or 2/10 of a mile in length in the case of a return roadway. The portions are taken from a minimum length of 150 ft. in the section and are collected from the roof, sides, and floor of the roadway. The portions taken from the roof are mixed with those taken from the sides to form one sample ("R & S"). The portions taken from the floor are placed in a separate container and mixed to form the floor ("F") sample from the same length of roadway.

Two samples must be collected from each section of the roadway, "F" and "R & S" unless the safety officer has definite instructions from the Chief Inspector to do otherwise.

2(b) Zones

The section of roadway from which a sample is taken is called a zone and each section is coded according to a stonedust sampling plan. This plan is approved by the Chief Inspector or a Safety officer as per Section 72.5 of the Coal Mines (CBDC) Safety Regulations.

2(c) Dusty Places

At places such as loading or transfer points where coal dust is excessive, a Safety Officer may make arrangements for more frequent sampling.

3 Methods for taking a Sample

3(a) Equipment required:

- (1) Sieve – 60 mesh ASTM standard type 5” to 8” outside diameter, 1.5” deep complete with internally fitted lid and receiver.
- (2) 2” Paint brush.
- (3) 2” Scoop
- (4) Sample container – sealable plastic bags with label..
- (5) Carrier to hold sample bags and equipment
- (6) Notebook and pen
- (7) Brattice or similar sheet for quartering.
- (8) A 6 mesh sieve may be required if the road dust is too damp, to be sieved through a 60 mesh sieve.

3(b) Spot Sampling Method

Floor Samples – the sampler collects with the scoop small portions of dust at approximately 3 ft. intervals (that is, at each stride), along a zig-zag path on the floor of the roadway. These portions should be taken to a depth not exceeding $\frac{1}{4}$ inch since it is this top layer of dust that is involved in a coal dust explosion. When all the portions along the 150 ft. length of roadway have been collected, the whole is thoroughly mixed, reduced in quantity, sieved, and placed in a plastic sample bag.

Roof and Sides samples – the sampler collects portions of dust from the roof and sides over the same 150 ft. length of roadway. These portions are taken at approximately 3 ft. intervals over a zig-zag line covering the two sides from immediately above the floor to the crown of the roof and are collected by brushing directly into a container or scoop with the paint brush. The container must be held downwind of the brush, so that the ventilating current tends to blow the dust into the container. The surfaces of fixed structures in the roadway are considered part of the roof sides or floor depending on which they are nearest. When the 150 ft. length of roadway has been sampled, the portions are mixed, reduced, and sieved as described in section 3(d).

3(c) Strip Sampling Method

Floor Samples – every 15 ft. in the 150 ft. of the zone to be sampled a strip 2” wide across the whole width of the roadway is collected to a depth not exceeding $\frac{1}{4}$ inch. The dust from not less than 10 such strips is mixed together, from which a sample is taken to form the floor sample.

Roof and Sides – All the dust to a depth not exceeding $\frac{1}{4}$ inch is collected in similar strips across the roof and sides of the roadway, these strips linking up with the floor strips. The dust collected from at least 10 such strips is mixed together and a sample is taken from this to form the roof and sides sample.

3(d) Sieving the Sample

Having collected the portions from the roof and sides or the floor of the 150 ft. length of roadway, the total sample collected is usually much greater than necessary and it must be reduced in size and sieved through a 60 mesh

screen before placing it in the plastic bag. After reduction in quantity, the remaining sample must still be representative of the original. All the dust is placed on the square of cloth and thoroughly mixed by turning the pile over and over with the scoop. The pile is then formed into a conical heap, flattened at the top and divided into 4 quarters. Two grooves are drawn at right angles across the pile cutting down to the bottom and the 4 quarters are moved slightly apart from each other. Two opposite quarters are rejected and the other two mixed together on the cloth as before. If the total amount remaining is more than about 1 lb., the procedure is repeated in this case rejecting the pair of quarters that are in the position of those taken in the first quartering. Finally the whole of the remaining sample (about ½ lb.) is sieved through the 60 mesh and the plastic bag is filled with the undersize material. During screening, the dust on the sieve must not be rubbed through the sieve. If it is so damp that it will not pass through the 60 mesh sieve, then this sieve is replaced by the 6 mesh sieve. The sample of the 6 mesh material is sent to the laboratory where it is dried before re-sieving through a 60 mesh sieve.

3(e) Identifying the Sample

A sample is taken over a 150 ft. length of a stonedust zone. For identification purposes each 1/10 mile zone is divided into 2 sub-zones and each 2/10 mile zone is divided into 4 sub-zones. The following information should be written on the label affixed to the sample bag:

- Colliery
- Date
- Location
- Zone and Sub-Zone
- Type of Sample (“F” or “R & S”)
- Initials of Safety Officer

COAL GENERAL INSPECTION PROCEDURES HANDBOOK CHAPTER 4

III. Rock Dust Samples

- A. Collecting Samples. Collect samples to substantiate the violation when citing inadequate rock dust. Collect the usual samples of mixed dust by the band or perimeter method from the entry or room, including a 1-inch depth of the material on the floor. Combine dust from the roof, ribs, and floor into one "band" sample. If the amount collected is more than required, thoroughly mix the sample, cone and quarter to cut the bulk to the desired amount. Occasionally, it may be necessary to take more than one strip, but in such case, the total width of the strip must be the same for the roof, each rib, and floor. Collect separate supplies of dust from either the roof, ribs, or floor when deemed necessary.

Where the coalbeds are so thick that it is impractical and unsafe to collect full perimeter samples, collect a floor sample and a sample from the ribs to the maximum height at which this can be done safely and practically. The rib sample and the floor sample may be either combined or prepared separately. When rib samples are collected and reported separately, assume the incombustible content of the rib sample represents the incombustible content of the rib and roof surface at the sampling location.

- B. Rock Dust Surveys. To obtain data to form conclusions regarding adequacy or inadequacy of rock dusting in a mine, the following sampling is required in addition to spot location sampling:
1. During each regular inspection, make uniform rock dust surveys in each advancing section. Also, areas not sampled during prior regular inspections because of wet conditions shall be identified. Locations where two or more consecutive samples were not collected shall be inspected and samples collected when conditions permit.
 2. Identify samples as shown on the sketch for rock dust surveys. (Refer to Figure 5.)
 3. The first line of samples A-1, B-1, C-1, D-1, and E-1 are zero points and are 15 feet inby the reference point, which is the centerline of the right air course of main west.
 4. The other lines of sampling are at 500, 1000, and 1500 feet inby the zero point.

Include in the collection of dust samples a representative number of crosscuts. Where possible, the maximum interval between sample locations shall be not more than five or six crosscuts. The survey number shall precede the sample number when two or more surveys are made.

When filling out the Dust Sampling Lab Report (MSHA Form 2000-156, Figure 6 [not reproduced in this Appendix]), type or use a pen to fill in the information.

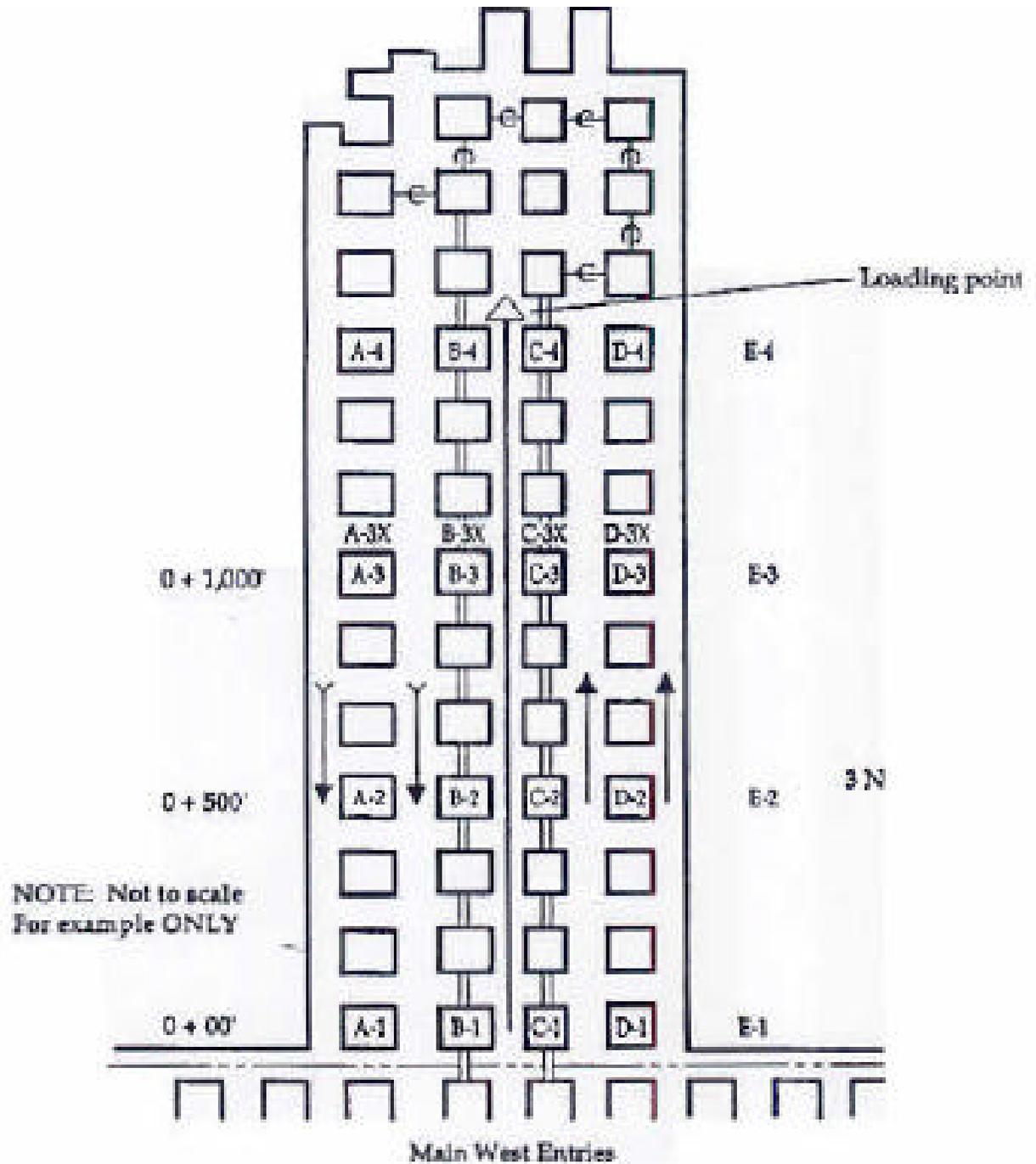


Figure 5

1. **Date Received, Lab, Numbers, and Results** - for laboratory use only and must not be filled in by the inspector.
2. **Company and Mine** - name of company and mine name or number.
3. **Collector** - name(s) of inspector(s) that collected the samples.
4. **MMU Number (Mechanized Mining Unit)** - this number is 'available from the mine file.
5. **Date of Sampling** - date the sample was taken.
6. **Field Office Code and Name** - the correct District Code must be used as this will give sufficient data for the laboratory records as to the state, county, and field from which the report originates.
7. **Sampling Area** - the length and description shall be kept to an absolute minimum.
8. **Zero Point** - must be tied to something relatively permanent.

Do not use the normal sampling point designation for a particular point at some other location. For example, if there were a roof fall, bad roof, or the place was too wet to sample at B-3, the designation "B-3" would appear on the sampling report with the proper statement under "Location in Mine." If the sampling location is less than 40 feet from the face, do not take a sample.

Determine the starting point from the face for such surveys, and that point must be tied into something relatively permanent such as an intersection, survey station, pump room, or borehole. To say that a sample was collected a certain distance from a working face is meaningless. The sampling area must be well described and tied down firmly so it can be located on the mine map by either the operator or another inspector.

Where surveys are made in more than one section or area of the mine, the samples in each survey shall be numbered as shown below with each sample letter being preceded by the survey number.

Survey No.1	Survey No.2	Survey No.3
1A1	2A1	3A1
1A2	2A2	3A2
1B1	2B1	3B1
1B2	2B2	3B2

Where only one survey is made in a mine, numerals preceding the sample letter are unnecessary.

- C. Spot Location Samples Consecutively number the spot location samples with numbers only. Do not use letters since letters are used to designate the dust survey sample. List the spot location samples and dust surveys on separate sample cards, but they can be mailed in the same box.
- D. Use of Plastic Bags. Use only red and blue plastic bags for uniform rock dust survey samples. Ship the dust samples collected at spot locations in other areas 'of the mine in uncolored bags. Use blue rock sample bags for rock dust samples collected in return air- courses. The use of different colored bags for

the different types of samples helps the laboratory separate and identify the samples. Fill the plastic bags at least half full.

Use the following procedures when using plastic bags:

1. The identifying tags are blank and each inspector can use his or her own numbering system on the face of the tag. Include the name of the inspector and the name of the mine on the back of the tag. Consecutively number or code the samples for anyone inspection. The numbers or code used shall not exceed three digits. The numbering system may start with "No.1" or with "A," "B," "C," etc. Be certain that the identification is legible.
2. The bags are long enough to permit tying a knot in the open ends when they contain the average size sample. Securely tie the string of the tag within the formed knot of the sample bag. The laboratory requires the inspector's name, the name of the mine, the properly numbered tag attached firmly to the sample, and a completed sampling card.

If the mine name is clearly printed on the A-I sample tag and about every other 10th bag of the survey samples, it will be sufficient for the laboratory's needs.

Do not put these sample numbers in the column for "Lab. No." (See Figure 6 [not included in this Appendix]) For the "Sample of" column, the word "band" is acceptable for a sample representing the full perimeter at the point of sampling.

Where dust samples have been collected at spot locations in return air courses or intake air courses, include the words "return airway" or "intake airway" in parentheses, as applicable, after the location of each sample on the card forwarded with the samples.

All samples submitted without the collector's name and office address will be analyzed but the report will be held until this information is received.

- E. Mailing Dust Samples. Mail the samples as soon as possible in accordance with postal regulations. Securely seal the shipping boxes to prevent loss of samples in transit, Do not use cellulose adhesive (scotch) tape to seal boxes. Include the return address on the shipping label.

Use a regular corrugated pasteboard carton, but fill voids around the bags with crumpled newspaper to keep the bags from breaking open from rough handling. Do not use crumpled manila envelopes, excelsior, paper towels, or tissues as packing.

IV Analysis of Dust Samples

- A. Volumeter Analysis. The dust laboratory will use the volumeter method for analyzing and reporting the contents of all dust samples received except for samples that, when analyzed by the volumeter method, indicate an incombustible content ranging between the allowable limit and 10 percent below the allowable limit. These samples will also be analyzed chemically, and the chemical analysis will be given in the analytical reports.
- B. Analysis Results. When the analysis of mine dust samples taken to determine the incombustible content discloses a violation, proceed as follows:

1. If more than 10 percent of the dust samples collected in a dust survey of a particular area or section are substandard, as shown by analysis, issue a citation.
2. In those cases where less than 10 percent of the samples collected in a dust survey are substandard, as shown by analysis, notify the company and have such areas rock dusted to meet the required standards. Then examine these areas again, and if suitable corrective action has not been taken, issue a citation.
3. When an inspection report has been released prior to receiving results of the samples and if the samples are "bad," make a spot inspection and make the actions taken to correct the condition a part of the spot inspection.

High Temperature Ashing Method

The high temperature ashing method essentially involves the determination of % incombustibles by measuring % moisture, % ash and then % carbon dioxide and adding them together. The high temperature method decomposes all carbonates, including calcium carbonate.

Moisture is determined by oven drying the as-received road dust. This may potentially involve 2 steps – 1. If the sample is too wet for dry sieving, then the sample is oven dried to determine moisture content, and 2. A one gram sample of the sieved material is then weighed and a second moisture determination is undertaken. Ash content is determined by incinerating the sample in a muffle furnace at 950°C – 1000°C. The difference in mass before and after ashing is the ash content. Carbon dioxide is measured by decomposing the carbonates present in the sample with hydrochloric acid and either absorbing the CO₂ on ascarite (ascarite weighed before and after) (ASTM D1756-96) or by determining the volume of CO₂ using the Godbert Method. Descriptions of the high temperature ashing method as used by CANMET, UK and USA are as follows:

CANMET Procedure

In order to determine the % incombustibles vs % combustibles, roadway dust samples are analyzed using the following individual steps/tests:

1. Weigh out approximately 100 g of the as-received sample in an open faced pan (e.g. aluminum) to the nearest 0.01 g.
2. Oven dry the samples at 107°C ± 3°C for a minimum of 2 hours (dried to constant weight).
3. Weigh the dried sample to the nearest 0.01 g.
4. Calculate % moisture.
5. Sieve each sample through a No. 50 (300 µm)/No. 80 (180 µm) Sieve and retain the “minus” portion for further testing.
6. Weigh out approximately 1 g of the “minus” portion of the sample in a crucible to the nearest 0.0001 g.
7. Oven dry the samples at 107°C ± 3°C for 1 hour and then allow the sample to come to room temperature in a desiccator.
8. Weigh the dried sample to the nearest 0.0001 g.
9. Calculate Total % Moisture.
10. Place the crucible/sample in a muffle furnace and heat at 1000°C for a minimum of 1 hour (ashed to constant weight).
11. Remove crucible/sample, allow it to cool and then reweigh to the nearest 0.0001 g.
12. Convert ash analysis results to dry basis and then correct % Ash to the total moisture content basis.
13. Determine % Carbon Dioxide using ASTM D1756-96 “Standard Test Method for Determination as Carbon Dioxide of Carbonate Carbon in Coal”. The determination is made by decomposing with hydrochloric

acid a 5 g sample in a closed system and absorbing the carbon dioxide in an absorbent (ascarite). The increase in weight of the absorbent is a measure of the carbon dioxide in the sample used.

14. Convert % carbon dioxide results to dry basis and then correct to the total moisture content basis.
15. Calculate % Incombustibles by simply adding % Moisture (Total), % Ash and % CO₂.
16. Calculate % Combustibles by simply subtracting % Incombustibles from 100%.

Note: The high temperature used will decompose calcium carbonate and magnesium carbonate.

UK Procedure

High temperature ignition at about 950°C is used to remove all the combustible matter and completely decompose any carbonates. The carbon dioxide content of the carbonates is determined separately. The test is thus more accurate than the low temperature ignition for the determination of Incombustible Matter content. The higher accuracy results because the test fully accounts for the carbon dioxide lost in incineration. Furthermore it is possible to allow for the different suppressive powers of stone dusts by calculating an additional allowance based on the measured amounts of combined carbon dioxide and combined water in mine roadway dust. This allowance is added to the sum of the percentages of incombustible matter remaining after high temperature ignition and the carbon dioxide and water content. However, this additional allowance is relatively small for combined carbon dioxide and very variable for combined water. Also it is difficult to determine accurately the amount of combined water in gypsum, for example. Thus it is expedient to neglect this additional allowance which then ensures that the proportion of stone dust required in practice is safely overestimated. Although the high temperature ignition may be used to give a more accurate result, low temperature ignition will normally be sufficient for routine use. (HSE, UK)

In order to determine the % incombustibles vs % combustibles, roadway dust samples are analyzed using the following individual steps/tests:

1. Weigh approximately 1 g of sample from the through-250 µm sieve fraction into a suitable dish.
2. Heat the sample in the oven at 140°C for one hour.
3. Allow to cool to room temperature in a desiccator, re-weigh and calculate the percentage loss in weight. This gives moisture content.
4. Heat the remaining sample in the oven at 950 ±30°C until no further loss in weight is observed (this may take 2 hours or more)
5. Cool, reweigh and then calculate the residue as a percentage of the original 1 g sample. The high temperature incineration decomposes carbonates, and the carbon dioxide lost must be estimated as follows:
6. Weigh 1.000 ± 0.002g of the through-250 µm sieve fraction of the mine road dust.

7. Using the Godbert Method apparatus (See Below) bring the containing liquid to the zero mark in the eudiometer of the Godberg apparatus, fill the flask B three quarters full of acid and put the 1 g sample into flask A.
8. Close the flask with the bung and connect to the eudiometer. Tilt the flask to mix the acid and the dust and boil the mixture for 2 minutes.
9. Cool the flask and contents by submerging it for 10 minutes in water and then in air until the laboratory temperature has been reached; the latter equilibrium period is generally 20 minutes.
10. Raise the levelling bulb C until the liquid levels in this and the eudiometer are the same and read the gas volume, now at atmospheric pressure.
11. Read the temperature of the jacket from thermometer F and note the barometric pressure.
12. The procedure should be repeated without dust, to measure the dissolved gas evolved from the acid, and the carbon dioxide volume should be corrected for this.
13. Correct the volume of carbon dioxide to Standard Temperature Pressure (STP) and then convert this volume to g. The equation is:

$$\text{Grams of } CO_2 = V \times \frac{273}{273+t} \times \frac{p}{760} \times \frac{44}{22400} = 0.000705 \times \frac{p}{273+t} \times V$$

14. Calculate the percentage of carbon dioxide in the dust using the following equation:

$$\%CO_2 = \frac{0.0705 \times p}{273+t} \times V$$

15. The percentage incombustible matter I is the sum of the percentage moisture and percentage residue after the high temperature incineration, and the percentage carbon dioxide. (HSE, UK)

Note: If the sample as received in the laboratory is too wet for dry sieving, it is weighed, dried at 90°C for one hour, cooled, re-weighed, and the percentage moisture content M of the original is calculated. The dried mine road dust is then sieved through a 250 µm sieve, using the dry sieving method of BS 1796. The coarse fraction is discarded, and the fine fraction subjected to further testing as outlined above. (HSE, UK)

If drying was necessary before sieving, then the percentage of incombustible matter, determined by the low or high temperature analysis, must be corrected. The corrected incombustible matter value is calculated using the following equation: (HSE, UK)

$$I' = M + I \times \left(\frac{100 - M}{100} \right) \quad (\text{HSE, UK})$$

Apparatus for determination of carbon dioxide by the Godbert method:

The apparatus is used for estimating combined carbon dioxide in carbonates in order to correct the high temperature ignition result. The method employed involves the decomposition of the sample by hydrochloric acid, the reaction being completed by boiling the mixture. The volume of carbon dioxide evolved is measured and corrected for pressure and temperature. From the corrected volume the percentage

of carbon dioxide in the sample is calculated. The method is suitable for all dusts containing carbonates. The calibration of the eudiometer should be checked, by weighing quantities of water whose volumes are measured in the eudiometer. (HSE, UK)

The reaction vessel is a wide-necked flask of about 150 ml capacity. A brass ring around the neck of the flask acts as a weight to keep it submerged when it is cooled at the end of the reaction. The acid used to decompose the dust is contained in a bulb, 20 ml capacity, perforated near the top and supported within the flask by a stem of glass tubing which passes through the bung in the flask. The object is to allow the acid to be added to the dust without changing the volume or pressure in the system, except as a consequence of the production of carbon dioxide. The outlet tube is attached by flexible tubing to the top of the eudiometer, of 250 ml capacity. At the bottom, below the 250 ml mark, the eudiometer is expanded to a bulb of about 200 ml capacity to cope with the expansion of the gas during heating of the reaction vessel. The bottom of the eudiometer is connected to a levelling bulb. The eudiometer is filled with a 1:1 mixture of water and glycerol, to prevent the dissolution of carbon dioxide and surrounded by a water jacket whose temperature is given by the thermometer. (HSE, UK)

USA Procedure

The US Method is very similar to that used by CANMET and the UK. The main difference is that an ashing temperature of 750°C is used.

Low Temperature Ashing Method

The low temperature ashing method essentially involves the determination of % incombustibles by measuring % moisture and % ash and adding them together. The low temperature method is not applicable if significant amounts of magnesium carbonate is present, as magnesium carbonates decompose below 500°C.

Moisture is determined by oven drying the as-received road dust. This may potentially involve 2 steps – 1. If the sample is too wet for dry sieving, then the sample is oven dried to determine moisture content, and 2. a one gram sample of the sieved material is then weighed and a second moisture determination is undertaken. Ash content is determined by incinerating the sample in a muffle furnace at 500°C. The difference in mass before and after ashing is the ash content. Descriptions of the low temperature ashing method as used by CANMET, UK and RSA are as follows:

CANMET Procedure

In order to determine the % incombustibles vs % combustibles, roadway dust samples are analyzed using the following individual steps/tests:

1. Weigh out approximately 100 g of the as-received sample in an open faced pan (e.g. aluminum) to the nearest 0.01 g.
2. Oven dry the samples at 107°C ± 3°C for a minimum of 2 hours (dried to constant weight).
3. Weigh the dried sample to the nearest 0.01 g.
4. Calculate % moisture.

5. Sieve each sample through a No. 50 (300 μm)/No. 80 (180 μm) Sieve and retain the “minus” portion for further testing.
6. Weigh out approximately 1 g of the “minus” portion of the sample in a crucible to the nearest 0.0001 g.
7. Oven dry the samples at $107^{\circ}\text{C} \pm 3^{\circ}\text{C}$ for 1 hour and then allow the samples to come to room temperature in a desiccator.
8. Weigh the dried sample to the nearest 0.0001 g.
9. Calculate Total % Moisture.
10. Place the crucible/sample in a muffle furnace and heat at 500°C for 5 hours (ashed to constant weight).
11. Remove crucible/sample, allow it to cool and then reweigh to the nearest 0.0001 g.
12. Convert ash analysis results to dry basis and then correct % Ash to the total moisture content basis.
13. Calculate % Incombustibles by simply adding % Moisture (Total) and % Ash.
14. Calculate % Combustibles by simply subtracting % Incombustibles from 100%.

Note: The lower ashing temperature (500°C) will not decompose calcium carbonate, thus eliminating the need to undertake the $\% \text{CO}_2$ analysis procedure (assuming that the stone dust used is comprised only of calcium carbonate). As noted above, low temperature ashing is not appropriate for dusts containing magnesium carbonate since this compound decomposes below 500°C . Errors induced by the presence of small quantities of magnesium carbonate will in any case will err on the safe side, i.e. the Total Incombustible Content (TIC) would appear lower than it actually was.

UK Procedure

The low temperature involves ignition at about 500°C to burn off the combustible matter. It may underestimate the incombustible matter (IM) content, thus “failing safe”, because samples containing magnesium carbonate, e.g. from areas where dolomitic limestone has been used for stone dusting, may lose carbon dioxide which is not corrected for. A sample which gives a satisfactory result by low temperature ignition will therefore normally be satisfactory. (HSE, UK)

In order to determine the % incombustibles vs % combustibles, roadway dust samples are analyzed using the following individual steps/tests:

1. Weigh approximately 1 g of the through-250 μm sieve sample into a suitable dish and dry in an air oven at 140°C for one hour.
2. Allow to cool to room temperature in a desiccator, re-weigh, and calculate the percentage in weight. This gives the moisture content.
3. Heat the remaining sample at $500 \pm 20^{\circ}\text{C}$ for 2 hours or until no further loss in weight is observed, whichever is the shorter period.
4. Cool before weighing. The sum of the weights of moisture and incinerated residue is the incombustible matter and is recorded as a percentage of the total weight of the dust. (HSE, UK)

Note: If the sample as received in the laboratory is too wet for dry sieving, it is weighed, dried at 90°C for one hour, cooled, re-weighed, and the percentage moisture content M of the original is calculated. The dried mine road dust is then sieved through a 250 μm sieve, using the dry sieving method of BS 1796. The coarse fraction is discarded, and the fine fraction subjected to further testing as outlined above. (HSE, UK)

If drying was necessary before sieving, then the percentage of incombustible matter, determined by the low or high temperature analysis, must be corrected. The corrected incombustible matter value is calculated using the following equation:

$$I' = M + I \times \left(\frac{100 - M}{100} \right) \text{ (HSE, UK)}$$

South Africa Procedure

Laboratory Method

Analysis of samples in a laboratory must be carried out by the following method or by other methods approved by the laboratory concerned (DME, RSA).

- the residue of a weighed quantity of dust, after that quantity has been dried at a temperature not exceeding 140°C, and the loss of mass attributable to moisture ascertained, must be heated in an open vessel to a temperature not less than 480°C, and not more than 520°C, until the coal is completely burnt away. The incinerated residue must be weighed; (DME, RSA)
- the sum of the masses of moisture and incinerated residue must be recorded as incombustible matter and be expressed as a percentage of the total mass of the dust; and (DME, RSA)
- where samples were air dried before analysis by the laboratory method, a correction may be made to the incombustible matter content of the dust sample analysed by laboratory method. The corrected total incombustible content is equal to $M+I(100-M/100)$ where M is the percentage loss of mass during air-drying and I is the percentage of total incombustible matter in the dust as determined by the method described in the preceding paragraph. (DME, RSA)

Volumetric Method

UK Procedure

The volume of solid matter in a weighed quantity of dust shall be ascertained by immersion in a fluid and the incombustible matter in the dust estimated by a comparison of the volume so ascertained with volumes of other similar dust containing known proportions of incombustible matter. This method can be used except where gypsum is used for stone dusting. (HSE, UK)

USA Procedure

In the US, MSHA first crushes the dust sample to pass a 250 micron (No.60) sieve, after which they perform an exploratory analysis by measuring the increase in the volume of alcohol on a volumeter. The test rapidly determines if a sample greatly exceeds either the 65% or 80% TIC standard, and reduces the number of samples that must be subjected to more detailed analysis, such as the high temperature method noted above.

Colorimetric Method

South Africa Procedure

Colourimetric Method

- (a) analysing of samples by using the colourimetric method can be done on surface or underground. In both cases the method described remains the same. For the underground option drying facilities and adequate lighting must be provided. This option evaluates the degree of inertisation in the shortest possible time, permitting immediate remedial action. (Moisture correction is not considered in this option); (DME, RSA)
- (b) the colour of a sample of dust must be compared with that of a scientifically prepared standard colour sample, known to contain eighty percent, or sixty five percent as the case may be, of incombustible matter content. When on such comparison, the colour of the sample is found to be the same colour or lighter than that of the standard sample, the incombustible matter content in the dust must be taken to comply with the prescribed percentage of the total incombustible matter content; (DME, RSA)
- (c) any sample that appears to be below the prescribed percentage of incombustible matter content must be analysed using the laboratory method described below; and (DME, RSA)
- (d) in addition to (c) above, at least ten percent of the remaining samples must be analysed using the laboratory method. (DME, RSA)

A separate standard colour sample must be prepared for each geographical/working area of a mine in the following manner (DME, RSA) –

- (a) grind some dry coal dust from the seam in each area for which the standard colour sample is being prepared so that it passes through a 250 micrometers sieve;
- (b) determine the ash content of the sieved coal dust. The ash content must not exceed 20 percent by mass on a dry basis;
- (c) pass through a 250 micrometers sieve some dry stone dust of the type used in the mine;
- (d) weigh quantities of the sieved coal dust and sieved stone dust in proportions that will give the desired incombustible matter content i.e. 65% and 80%;
- (e) mix the dust thoroughly by stirring, shaking or rolling but do not grind the mixture;

- (f) using the approved laboratory method, determine the incombustible matter content of the mixture and verify that it is not less than the required;
- (g) whenever there is change in the colour/reflectivity of the stone dust supplied to the mine, and whenever the colour of the coal seam changes distinctly, new standard samples must be prepared; and
- (h) at intervals of not more than 3 months, re-test the standard and keep a record of the results of these tests. If the standard has an incombustible matter content which is less than that required, replace the standard with a new one. (DME, RSA)

The procedure for the preparation and evaluation of collected dust samples is as follows (DME, RSA):

- split the sample and retain one half of the sample, if required, for laboratory analysis. Air-dry the portion to be compared if necessary. Sieve the sample through a 250 micrometers sieve and mix the sample thoroughly but do not grind it. (DME, RSA)
- compare the colour of the mixed sieved sample with that of the standard colour sample. The comparison must be made under good and even illumination. When conditions permit, and if by choice, this comparison is done underground, it must take place at a designated site. The comparison must be done in a suitably designed light box. The person performing this duty must be trained to prepare the samples and to conduct the colourimetric test. Furthermore, his ability to distinguish between the colour ranges, must have been determined. (DME, RSA)
- if any sample fails the comparison test, this must be reported without delay to the employer who must ensure that the area concerned is properly inertised timeously. (DME, RSA)

UK Procedure

The colour of a sample of dust shall be compared with that of a representative sample of similar dust known to contain eighty per cent or a higher percentage of incombustible matter and if, on such comparison, the colour of the sample is found to be lighter than that of the representative sample, the incombustible matter in the dust shall be taken to exceed eighty per cent or, as the case may be, the higher percentage of the total weight of the dust. (HSE, UK)

If the sample as received in the laboratory is too wet for dry sieving, it is weighed, dried at 90°C for one hour, cooled, re-weighed, and the percentage moisture content M of the original is calculated. The dried mine road dust is then sieved through a 250 µm sieve, using the dry sieving method of BS 1796. The coarse fraction is discarded, and the fine fraction subjected to the colour test. This test can be done by eye or reflectometer. The eye comparison can be conducted by placing the sample beside a standard or standards in similar plastic bags on a flat surface. Standards should be chosen and used as in the reflectometer calibration. For the reflectometer test, the sample is placed in the tray, mixed well, and pressed down and levelled with a spatula. It can be re-stirred, re-levelled and re-measured if there is doubt about consistency of mixing, and consistency can also be checked by taking

further samples from the bulk as received, if only part of this was used in the first test.

If the colour test shows the mine road dust to be clearly > 75% incombustible matter (IM), taking into accounts errors found by quality assurance, the sample is reported as > 75% and no further test is necessary. Samples not giving a clear result should be incinerated.

Reflectometer:

In order to more accurately measure % incombustible matter using the colourmetric method, a reflectometer can be used. A uniform sample of dust is placed in a small tray about 45 mm in diameter. The dust is illuminated and the reflected light is measured. In the form of the instrument used by HSE, the light source is a 3W bulb and the detector is an annular photocell connected to a microammeter. A potentiometer in parallel with the meter permits zero adjustment. However, other designs (including portable reflectometers for field use) can be used provided that they are subjected to quality control, and can be shown to give results agreeing with standard samples and with thermogravimetric and chemical tests (in classifying materials above 75%). (HSE, UK)

Any form of reflectometer must be calibrated. Ideally this should be done using standard mixtures of the same coal dust and the same stone dust as in the mixture under test, making up about ten mixtures of dry sieved dusts with known proportions of stone dust between about 60% and 100% by weight. If the constituent coal and stone dusts are not available, calibration must be conducted using various combinations of different types of coal and stone likely to be encountered. This will clearly yield a range of calibrations, and a response should be selected which will take account of the possible range of calibrations in classifying materials as clearly > 75% IM, so that mixtures with about 75% IM or less are very unlikely to be misclassified. Standard grey cards may be checked against the calibration and used as secondary standards to check the response of the reflectometer before each test. They should be kept clean and compared regularly with standard dust mixtures. When chemical analysis follows the colour test, the results from the two methods should be compared, and this will give a frequent check of the calibration. (HSE, UK)

Note: The following is taken from the "Guideline for the Compilation of a Mandatory Code of Practice for the prevention of Flammable Gas and Coal Dust Explosions in Collieries" published by the South African Department of Mines and Energy. It is available for download from their web-site at http://www.dme.gov.za/publications/pdf/guidelines/Coal_Dust.pdf

PART C: ASPECT TO BE ADDRESSED IN A MANDATORY COP

8. ASPECTS TO BE ADDRESSED IN THE MANDATORY COP

The COP must set out how the significant risks identified and assessed in terms of the risk assessment process referred to in paragraph 7.1 will be addressed. The COP must cover at least the aspects set out below unless there is no significant risk associated with that aspect at the mine. (The COP must clearly indicate who is responsible for undertaking each task and what should be achieved. See paragraph 1.1 of Part D).

8.1 PREVENTING THE ACCUMULATION OF AN EXPLOSIVE CONCENTRATION OF FLAMMABLE GAS

The employer must ensure that a management system is in place that prevents the accumulation of an explosive concentration of flammable gas. The COP must consequently address the following.

8.1.1 Ventilation

Layout for all production sections or changes in ventilation systems must include:

- 8.1.1.1 sequence of the ventilation related work to be done and completion dates;
- 8.1.1.2 areas of the mine where there possibly might be flammable gas;
- 8.1.1.3 ventilation structures;
- 8.1.1.4 mining sequence that complements the ventilation flow;
- 8.1.1.5 air quantities, velocities and airflow patterns;
- 8.1.1.6 procedures for its approval by the employer, manager or competent person;
- 8.1.1.7 special precautions where two or more sections are situated in the same ventilation district; and

- 8.1.1.8 any other special measures to be adhered to such as the holings through and sizes of barrier pillars.

8.1.2 Mining near or through Dykes, Burnt Coal or Geological Discontinuities

Measures to ensure that the layout excavation and process conforms to the requirements stipulated in 8.1.1. In addition to the above, measures that will ensure:

- 8.1.2.1 the most appropriate mineral excavation process (explosive route or mechanical breaking);
- 8.1.2.2 availability of correct geological information;
- 8.1.2.3 the prevention of dangerous accumulations of flammable gas;
- 8.1.2.4 adequate supervision;
- 8.1.2.5 proper monitoring and control of environmental conditions; and
- 8.1.2.6 that any other special precautions required, are identified.

8.1.3. Main Fans

- 8.1.3.1 The making and keeping of records for the operation, monitoring, maintenance and inspection of main fans.
- 8.1.3.2 Measures to be taken to ensure the health and safety of persons who may be affected due to unplanned stoppages of fans.

8.1.4 Barometric Pressure

- 8.1.4.1 Monitoring and recording of the fluctuations in the barometric pressure.
- 8.1.4.2 Measures to reduce the significant risks associated with such fluctuations.

8.1.5 Secondary Mining (Top/bottom coaling or total extraction methods)

- 8.1.5.1 Ventilation system to include aspects required by 8.1.1.
- 8.1.5.2 The system for the ventilation of goafs and bleeder roads.

8.1.6 Intake, Return Airways and Belt Roads

- 8.1.6.1 Measures to ensure that intake, return airways and belt roads remain unrestricted, accessible and that safe roof and side wall conditions prevail.
- 8.1.6.2 Measures to ensure that air velocities prevent dangerous accumulations (explosive concentrations) of flammable gas from coal and other sources and dust from becoming airborne; and

8.1.7 Other Areas

Measures for the ventilation of underground dams, sealing of abandoned areas, seals, workshops, substations, transformers, pump stations, staple pits, shaft bottoms, boxholes, underground and surface bunkers and ancillary workings to conform to the requirements of 8.1.1.

8.1.8 Sealing of abandoned areas

- 8.1.8.1 measures to ensure that, where workings of the mine are abandoned for any reason, they remain ventilated to prevent a build up of an explosive concentration of flammable gas, or are sealed off.
- 8.1.8.2 Measures to ensure that the planning and maintaining of ventilation, tests for flammable gas and stone dusting as per COP are conducted up until final sealing has been completed.
- 8.1.8.3 Measures to ensure the removal of conductors, bonding straps in boreholes and shafts. In the case of boreholes the removal of casings and plugging thereof as well as the record keeping of the above in a book provided for the purpose.

8.1.9 Choice and type of walls/seals

- 8.1.9.1 Measures to ensure that containment walls built for the purpose of containment of flammable gas are installed with means for the monitoring of the atmosphere behind such walls.
- 8.1.9.2 Measures to address the risk posed by walls/seals built before the coming into effect of this guideline.
- 8.1.9.3 Measures to ensure that explosive proof seals are used where the atmosphere of sealed areas stabilises within the explosive range or takes a long time to do so or remains in the explosive range for a long period.
- 8.1.9.4 Measures to ensure safe working conditions for employees working near abandoned areas.

8.1.10 Opening of old areas

The employer must establish a system for monitoring and evaluating the atmospheric conditions and other relevant parameters for the re-opening of old areas.

8.2 PROVIDING FOR THE EARLY DETECTION OF FLAMMABLE GAS

- 8.2.1 An appropriate gas testing and gas monitoring strategy including the type/s of instruments to be used.
- 8.2.2 A procedure that ensures that employees are competent to test for flammable gas and dangerous accumulations of any explosive mixture of flammable gases.
- 8.2.3 The compliance of all devices and measuring instruments used for the detection and measurements of flammable gases with the OEM specification.
- 8.2.4 Maintenance, calibration and record keeping in respect of gas testing monitoring systems/instruments.
- 8.2.5 Users pre-use tests and checks of the flammable gas warning and measuring instruments, including on-board monitoring devices, by users in accordance with a procedure drawn up by the employer.
- 8.2.6 Testing for the presence of flammable gas or dangerous accumulations of any explosive mixtures of flammable gases, frequency, responsible persons and localities.
- 8.2.7 Procedures to be followed if flammable gas is detected and for the clearance thereof.
- 8.2.8 Procedures for the determining of sufficient numbers of gas detection instruments.

8.3 PREVENTING THE IGNITION OF FLAMMABLE GAS

Measures to prevent frictional ignitions

- 8.3.1 The method and procedure for the examination and changing of cutter picks.
- 8.3.2 Measures to ensure a continuous flow rate and pressure of water supply to a mechanical miner.
- 8.3.4 Measures to be applied for minimising the risk of ignitions from occurring during goafing where total extraction takes place.
- 8.3.5 Where a mechanical miner is used, excluding shearers employed in wall mining, a system to ensure that a mechanical miner will not ignite flammable gas, and that includes user pre-use checks, operational checks, maintenance programmes, and any other means of preventing a frictional ignition.
- 8.3.6 Measures to ensure that the use of electricity or electrical equipment does not create the risk of igniting flammable gas.

- 8.3.7 Where lightning could ignite flammable gas, compliance with SABS specification 0313 is required.
- 8.3.8 Where spontaneous combustion could ignite flammable gas, measures for the inspection and monitoring of abandoned areas and atmospheres behind seals must be stipulated.
- 8.3.9 Measures to ensure that the use of explosives does not create the risk of igniting flammable gas.
- 8.3.10 Measures to prevent contraband from being taken underground.
- 8.3.11 Measures to ensure that any welding, flame cutting, flame heating, grinding, vulcanising, soldering, pick sharpening, photography video or audio taping will not ignite flammable gas or any explosive mixture of flammable gas.
- 8.3.12 Measures to prevent holing into any area which may contain a dangerous accumulation of flammable gas.
- 8.3.13 Where flammable gas could enter the workings under pressure, measures to prevent the ignition of such gas.

8.4 LIMITING THE FORMATION AND DISPERSION OF COAL DUST

- 8.4.1 Measures to ensure the limiting of formation of coal dust at coal mining faces, conveyor and transfer points and tramming routes.
- 8.4.2 Measures to ensure the regular clean up and removal of coal accumulations in face areas before stone dust applications, conveyor belt roads, transfer points, travelling roads, return airways and equipment.

8.5 INERTISATION OF COAL DUST

- 8.5.1 Degree of Inertisation
Measures to ensure that the following minimum levels of inertisation are adhered to:
 - 8.5.1.1 Inbye of the face area, intake airways must be maintained at a minimum percentage by mass of incombustible matter content of 80%.
 - 8.5.1.2 Outbye the face area, intake airways must be maintained at a minimum of 65% incombustible matter content. Workshops, substations, battery charging stations and other similar places where work is done or equipment is maintained, situated in intake air must nevertheless be maintained at a minimum of 80% incombustible matter content.
 - 8.5.1.3 In return airways a minimum percentage by mass of incombustible matter content of 80% must be maintained up to a minimum distance of 1000 m from the face. Beyond this distance, a minimum percentage by mass of incombustible

matter content of 65% must be maintained. Where barriers are installed, the incombustible matter content by mass, outbye the face area and outbye of the barriers must be maintained at not less than 65%.

- 8.5.1.4 All accessible roads within 250m radius from areas in the process of being sealed off, must contain a minimum percentage by mass of incombustible matter content of 80%, unless the area has been sealed off with explosion proof seals, or other seals as determined by the risk assessment.
 - 8.5.1.5 In conveyor roads a minimum percentage by mass of incombustible matter content of 80% must be maintained up to a minimum distance of 180m from the face. Beyond this distance, a minimum percentage by mass of incombustible content of 65%. The installation of stone dust/water barriers is mandatory.
 - 8.5.1.6 Before any area is sealed off, the roof, sides and floor, as far as reasonably practicable, must be stone dusted to ensure a minimum percentage by mass of incombustible matter content of 80%.
- 8.5.2 Inertisation of coal dust by the use of water
Where it is proposed that water be used to inertise coal dust, the following must be specified-
- 8.5.2.1 the areas of the mine to be treated by this method;
 - 8.5.2.2 the method of applying water;
 - 8.5.2.3 the frequency of application;
 - 8.5.2.4 methods for the determination that sufficient water has been applied; and
 - 8.5.2.5 responsible persons to ensure that these requirements are adhered to.
- 8.5.3 Inertisation of Coal Dust by the Application of Stone Dust
Measures to ensure that the suppliers of stone dust comply with the following minimum quality requirements:
- 8.5.3.1 stone dust must preferably be pulverized limestone or dolomite and light in colour;
 - 8.5.3.2 it contains not less than 95% by mass of incombustible matter, and with a density similar or equal to pulverised limestone;
 - 8.5.3.3 it contains not more than 5% by mass of free silica, or any other toxic substance in concentrations detrimental to health;
 - 8.5.3.4 it is of such fineness that, when dry, all will pass through a sieve of 600 micrometers aperture and at least 50% by mass through a sieve of 75 micrometers aperture;

- 8.5.3.5 unless directly wetted by water, it does not cake and will readily disperse into the air;
 - 8.5.3.6 test each batch delivered and issue a certificate showing the results of these; and
 - 8.5.3.7 should any other incombustible dust be used, compliance with the ability to stop flame propagation of a coal dust explosion must be tested and approved for use at a SANAS accredited institution.
- 8.5.4 Extent of stone dust application
Measures to ensure that the underground workings of a bituminous coal mine are protected by the application of stone dust within 10m from all the working faces, unless such workings are-
- 8.5.4.1 inaccessible, unsafe to enter; or
 - 8.5.4.2 extend to the face from and including the last through road, in which the coal dust has been washed from the roof and sides and the floor is too wet to propagate an explosion.
- 8.5.5 Frequency for the application of stone dust
Measures to ensure that the frequency of applications of stone dust adheres to the following -
- 8.5.5.1 Face Area
Stone dust must be applied, and re-applied, as often as is necessary, to maintain the incombustible matter content by mass at a minimum of 80%. The frequency rate of application must not be less than once in every four production shifts, unless a risk assessment, which includes rates of deposition of float coal, or other sampling indicates otherwise. This also applies to roads within the face area including roads carrying return air.
 - 8.5.5.2 Pillar extraction operations
In pillar extraction operations, stone dust must be applied on a retreat basis at the same frequency rate as in paragraph 8.5.5.1 above.
 - 8.5.5.3 Total extraction operations
In total extraction operations, stone dust must be injected regularly into the mined areas before the occurrence of the initial goaf, so as to inert the dust cloud that will be raised when it occurs.
 - 8.5.5.4 Return Airways
In both longwall and shortwall mining, stone dust must be introduced, during coal winning, into the return airways.

8.6 COMPLIANCE WITH REQUIREMENTS RELATING TO SAMPLING AND ANALYSIS OF SAMPLES

Measures to ensure that the requirements set out in Annex 1 are adhered to. (Annex 1 must be complied with and incorporated in the COP).

8.7 COMPLIANCE WITH REQUIREMENTS RELATING TO THE DESIGN OF BARRIERS TO PREVENT THE PROPAGATION OF COAL DUST EXPLOSIONS

Measures to ensure that stone dust/water barriers adhere to the criteria set out in Annex 2. (Annex 2 must be complied with and incorporated in the COP).

8.8 COAL DUST EXPLOSIONS IN CONFINED AREAS

The measures to prevent the accumulation and ignition of flammable gas and/or explosive mixtures of flammable gases in confined areas on surface such as beneficiation plants, silo's and bunkers must be stipulated.

PART D: IMPLEMENTATION

1. IMPLEMENTATION PLAN

- 1.1 The employer must prepare an implementation plan for the COP that makes provision for issues such as organizational structures, responsibilities of functionaries and programmes and schedules for the COP that will enable proper implementation of the COP. (A summary of, and a reference to, a comprehensive implementation plan may be included.)
- 1.2 Information may be graphically represented to facilitate easy interpretation of the data and to highlight trends for the purpose of risk assessment.

2. COMPLIANCE WITH THE COP

The employer must institute measures for monitoring and ensuring compliance with the COP.

3. ACCESS TO THE CODE AND RELATED DOCUMENTS

- 3.1 The employer must ensure that a complete COP and related documents are kept readily available at the mine for examination by any affected person.
- 3.2 A registered trade union with members at the mine, or where there is no such union, a health and safety representative on the mine, or if there is no health and safety representative, an employee representing the employees on the mine, must be provided with a copy on written request to the employer. A register must be kept of such persons or institutions with copies to facilitate updating of such copies.

- 3.3 The employer must ensure that all employees are fully conversant with those sections of the COP relevant to their respective areas of responsibility.