Explosion Proof Stoppings

Final Report

EXPLOSION PROOF STOPPINGS (OR SEALS) IN UNDERGROUND COAL MINING

Prepared for

The Underground Coal Mining Safety Research Collaboration (UCMSRC) administered by NRCan-CANMET Mining & Mineral Science Laboratories

By

DJF Consulting Limited
Report: 5-3416-002.1
Date: December 2003

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Explosion proof stoppings are substantial seals placed in underground tunnels to stop-off abandoned working areas. They are intended to contain any explosion occurring within the old workings, and, in cases where active mine fires are being fought, they are intended to prevent any explosion from being ignited by the fire by quickly sealing it off.

Today a wide variety of information exists on explosion proof stoppings but it exists in different, and often remote, places. In order to address this sparcity in readily available information, the Underground Coal Mining Safety Research Collaboration (UCMSRC) was asked by Participants from the British Columbia Ministry of Mines and Energy to research the topic of the use of explosions proof stoppings in underground coal mines and to collate information for future reference in a single report. This report is intended to be an overview and not a comprehensive treatise on the topic.

The report outlines in turn: the Background, the Philosophy of explosion proof stoppings, Principal Types of temporary and permanent stoppings, International Requirements and Summary. The information presented in this report is considered to be representative of the factors involved in the planning and application of explosions proof stoppings. The report has been prepared for UCMSRC Participants to use as a reference on the subject by Dr. David Forrester, DJFCL, a consultant based in Sydney, Nova Scotia, and active in coal mine safety and related issues.

Explosion proof stoppings are expedient means of ensuring both containment of potential explosions in disused/abandoned old working areas and in enhancing prevention of explosions when promptly sealing off underground fires. Prudent planning and diligent preparatory effort in the mine can also ensure that in an emergency situation, prompt erection of explosion proof stoppings can be done within a single shift (in fresh air conditions).

Applied research in the USA and Western Europe has over many decades developed methodologies and designs of monolithic stoppings of only 1.5 or 2.0m thickness that will withstand explosion overpressures of 525kPa associated with moderate strength explosions. Gypsum is the preferred material to be used in Europe, where it is readily available, because of its properties. It is pumpable, fills voids and cracks when pumped under pressure, sets quickly, is strong and also retains some of its pliability to maintain the seal under some deformation of surrounding rock. Various formula for the length of explosion proof stoppings are given in the report, one representative one standard in the UK, is that of the IminE report of 1983 for monolithic packs, but it is subject to a regulatory minimum length of 3m or 10ft: $L= ((H+W)/2)+2$, where L = length, H = height, W = width, all in feet.

Regulatory requirements vary by jurisdiction. All seem to require stoppings on disused working areas but, of the regulations reviewed here, explosion proof stoppings are only legislated in Alberta, USA, Australia (NSW, Queensland) and South Africa. Typical practice however in the UK, Germany and Poland also requires explosion proof stoppings. The UK, Poland and Alberta also require such stoppings to be placed within 3 months of the face ceasing work.

1. Introduction

Purpose

Explosion proof stoppings are substantial seals placed in underground tunnels to stop-off abandoned working areas. They are intended to contain any explosion occurring within the old workings, and, in cases where active mine fires are being fought, they are intended to prevent any explosion from being ignited by the fire by quickly sealing it off.

Today a wide variety of information exists on explosion proof stoppings but it exists in different, and often remote, places. In order to address this sparcity in readily available information, the Underground Coal Mining Safety Research Collaboration (UCMSRC) was asked to research the topic of the use of explosions proof stoppings in underground coal mines and to collate information for future reference in a single report. This task arose from specific queries raised by Participants from the British Columbia Ministry of Mines and Energy, resulting in this report, which is intended to be an overview and not a comprehensive treatise on the topic.

The report outlines in turn: the Background, the Philosophy of explosion proof stoppings, Principal Types of temporary and permanent stoppings, International Requirements and Summary. The information presented in this report is considered to be representative of the factors involved in the planning and application of explosions proof stoppings. The report has been prepared for UCMSRC Participants to use as a reference on the subject by Dr. David Forrester, DJFCL, a consultant based in Sydney, Nova Scotia, and active in coal mine safety and related issues. The conclusions drawn and recommendations made are those of the author and do not necessarily reflect those of the stakeholders and Participants in UCMSRC or the authors or regulatory bodies of source material.

Background

Mine fires in an underground coal mine present an immediate and serious threat to the safety of the mine, particularly those fires arising from spontaneous combustion. Such fires threaten the possibility of destruction of life, of equipment, of the coal resource itself and of a subsequent yet more devastating explosion of methane and/or coal dust. Coal mine fires and explosions can be catastrophic and much emphasis is placed on their prevention through not only ‘Emergency Preparedness Planning’, but also on implementing precautionary measures that can be taken in active parts of coal mines. These measures are required either through regulation or adoption of best practices (such as those of stone-dusting, explosion barriers, use of flameproof and intrinsically safe electrical equipment). A comprehensive review of some of these, in particular the use of stone dust to control dust explosions is presented in a companion report (Cain 2003).

Coal mine fires and explosions occur when there is a combination of three elements: fuel, heat and oxygen. Typical sources of each of these would be methane gas (in the explosive range), frictional ignition and air, respectively. One location where all three could combine away from active parts of mines is in old abandoned mined-out areas. Here the atmosphere is largely beyond control and can become potentially explosive. Firstly, methane can continue to be emitted in those areas after sealing off. Secondly, there is often some 'breathing' across seals, and/or leakage, allowing some fresh air into those areas, and thirdly, a source of ignition (heat) could possibly exist (e.g. in friction from falling rocks and or in heat from spontaneous combustion).

Should an explosion occur in an inactive, abandoned and sealed-off area, then the workforce in the active parts of the mine could still be threatened by virtue of not only explosive forces breaching any seals causing bodily harm but also, of poisonous gases like carbon monoxide formed during an explosion. These could leak/bleed/filter across damaged seals into the mine ventilation circuit adversely affecting workers.

The traditional practical precaution against these hazards is to ensure the seals are constructed strong enough to withstand an explosion, to make them "explosion proof stoppings" (Cooke & Van Der Merwe, 2000). The coal mining industry has long recognized the benefits of building substantial stoppings or seals and in 1943 the UK Institution of Mining Engineers published a comprehensive approach to 'Sealing Off Fires Underground', including the requirements of explosion proof stoppings. This was updated in 1983 (IMinE, 1983).

Much work has also been done over the last few decades to refine the design of such 'explosion proof' stoppings, to provide acceptable designs to suit local conditions and requirements, balancing the final strength of the stopping with realistic resource requirements and in a timely fashion. Such work has been largely based on experimental work done by the former US Bureau of Mines (USBM), The European Community Coal & Steel, the National Coal Board (NCB) in the United Kingdom and the Experimental Mine in Germany (Cooke & Van Der Merwe, 2000).

The UK Health & Safety Executive (HSE) also conducted an international review of the design criteria for explosion proof stoppings in 1992 (Brooks, 1992). The UK HSE also conducted some field testing to evaluate current design parameters and techniques in 1997, validating the adequacy of the UK 1943/1983 design (SMRAB, 1997).

Acknowledgements

The author gratefully acknowledges the assistance given throughout the preparation of the report given by UCMSRC members, particularly, Mr Gary Bonnell of NRCan-CANMET, Dr. Peter Cain, manager Underground, Grande Cache Coal Company, Grande Cache, Alberta and Mr Pleman Woodland of the Nova Scotia Department of Environment and Labour (NSDEL).

2. Philosophy of Explosions Proof Stoppings

Why Needed

Ventilation stoppings or seals are required to ensure safe and efficient ventilation by separating fresh intake air from contaminated return air. More substantial or 'explosion proof' stoppings are typically required either to seal off an active underground fire or to seal off an abandoned area to contain any subsequent fire or explosion behind it.

The specification of stoppings has long been a debate in coal mining circles as to how substantial different stoppings or seals need to be. Some would argue that simple permanent walls of nominal thickness, keyed in to surrounding strata and sealed to prevent ventilation across them are sufficient to safely seal old working areas. However, this minimum specification does not fully consider the fact that such stoppings/seals would not withstand an explosion on the sealed-side (e.g. ignited by an active fire) and that they 'breath'. Such 'breathing' can in specific circumstances, such as under high differential pressure across the stopping/seal, allow sufficient fresh air to diffuse through them, allowing oxygen into a potentially explosive area, high in methane content and prone to incendive sparking from falling rock debris onto steel or other rocks. Thus the concept developed whereby such permanent stoppings of old workings and of active fires should be resistant to moderate strength explosions or be 'explosion proof'. Thus, even if they breathed and a fire and/or an explosion of methane and/or coal dust occurred in the sealed workings, then the explosion would be contained against the stopping and would protect the mine from both noxious fumes and damage. Such explosion proof stoppings have to be of substantial thickness and construction and they can be time-consuming and expensive to construct.

Where and When to Use them

Prudent practice would require that all underground roadways not specifically needed for ongoing mining operations should be barricaded or stopped off, i.e. sealed. Typically, abandoned longwall and/or depillared sections would require substantial seals on all connecting roadways. Mine fires in active areas must also be sealed off promptly, preferably with substantial, i.e. explosion proof, stoppings, usually requiring substantial quantities of materials to be used in constructing the seal.

Ideally such seals would be located in undisturbed/solid ground which would not be affected by future ground movement, although this is not always possible, consequently sealing materials should preferably retain some pliability (e.g. gypsum). Such seals should be placed soon after working ceases and the area is abandoned. Practice in the United Kingdom, Poland and Alberta requires this within 3 months.

3. Principal Types of Ventilation Stoppings

Temporary seals

Ventilation Stoppings

Stoppings or partitions are used in underground mines to separate ventilation airways and ensure that ventilating air goes to the places needed and in the quantities required. These need to be solid and airtight. In some jurisdictions, such as Queensland, they also have to be able to withstand a specified, if relatively low, potential explosion overpressure. In Room & Pillar Mines ventilation stoppings can vary from brattice curtains near the face, to metal stoppings for districts and to concrete block walls for longer-term usage. The former two types have the cost advantage that they can be dismantled and transported elsewhere in the mine for reuse.

Temporary Stoppings used in Emergencies

In an emergency, such as a mine fire or explosion, ventilation flow in a roadway can be closed by rapid construction of a temporary stopping, traditionally made of sandbags and/or brattice on wooden frames. In the late 1970s another alternative was researched, namely parachute stoppings. (Kissel 1981). These are similar to a parachute used when exiting airplanes at great height and are made of an hemispherical canopy of impermeable fabric with straps connecting various points on the perimeter to a common point upwind. They can be installed in minutes and are particularly useful in rescue and recovery operations in metal and non-metal mines but in coal mines their application is limited due to the more critical role of differential pressures in ventilation circuits.

Permanent Stoppings

Seals

Permanent stoppings are used to seal old abandoned working areas of a mine. If not required specifically to be explosion proof, they must nevertheless have sufficient structural integrity to minimize leakage of fresh air across the seal. If the seals could be subject to mine fire conditions then their structural integrity must also withstand intense heat and must prevent the spread of flame, hot particles and toxic combustion products across the seal. (Lazzarra, Mura, et al 1988). Traditional methods of constructing permanent seals are labour intensive, time consuming and require large quantities of materials such as concrete/masonry blocks, sand, steel reinforcing, etc.

From 1970 to 1987 of the 235 reportable mine fires in the USA, 35 required sealing with accompanying large losses in terms of equipment and lost production. Generally the more rapidly seals can be constructed the more successful they are in containing the fire, rapidly sealing fire zones and preventing spread of toxic combustion products. Research has been conducted by the former USBM Weiss & Greninger1992) into various temporary and permanent seals including field testing of cementitious seals and of quick-setting, rigid foam seals for explosion isolation and fire containment using inflatable seals.

Other variations of seal developed and used are firstly, the strengthening of concrete blocks by the use of brush-on mortars that contain latex additives and fiberglass to increase strength and cohesiveness, which can double the breaking strength and reduce ventilation leakage by half (Murphy 1984). Secondly, the use of aerated cement, such as Aqualight, is a non-toxic pozzallanic cement with additives such as foaming agents. Usually used for filling underground cavities it can be used for ventilation stoppings 0.5m thick between two wood frame/brattice end-walls.

The introduction of metal stoppings in the USA in the 1980s apparently met regulatory requirements (such as incombustibility, strength and withstanding of transverse loadings) and had the potential of reducing time and cost of seal installation.

There were, however, concerns about transfer of heat across them to ignite combustible materials on the side away from the fire. The USBM tested the fire endurance of two stoppings of 8-inch concrete blocks and of one of galvanized steel. They found that the unexposed surfaces of both remained undamaged and the temperature of the concrete seals never exceeded 80 degree C, whereas that on the metal stopping reached 500 degree C (but this did not ignite combustible materials placed only 1 ft away on the unexposed side). In a further test, this high energy transmission through the steel was reduced by 50% by placing a 0.75-inch layer of construction plaster on the fire-side.

Explosion Proof Stoppings

Explosion proof stoppings are permanent seals built to withstand typical explosion pressures of varying strengths and are sometimes known as bulkheads. They are required either to seal off a fire and prevent/contain any possible explosion, or to seal off an abandoned working area to contain any future explosion within it. They are generally defined as capable of withstanding pressures of 20 psi but have been tested at pressures above 300 psi. They typically comprise two end walls some 1.5-20m apart depending on jurisdiction, method and materials,. The gap between them is tightly filled with bulk materials to completely fill the underground roadway. Typically they also contain across their length, two small sample tubes (capped) and a larger access tube, the latter being built of and sealed with substantial steel construction. They are usually located in solid ground, or ground that is no longer affected by ground movement from mining activities.

The need for and design of explosion proof stoppings has been driven by response to various mine disasters in Europe. One such response led to development of a standard reference on the topic by the Institution of Mining Engineers in the UK in 1943. This outlined the construction methods then in use such as use of rubble, rocks, bricks, timbers, sand, dust and cement, steel reinforcement, section walls and sandbags. However with the advent of new, quicker and more efficient and effective methods using monolithic construction (e.g. using pumpable gypsum or anhydrite) the 1943 edition was updated in 1983.

Research in the US and Europe has shown that explosion proof stoppings can be made from a variety of materials and designs but are generally built to suit availability of material and are generally over-designed (Cook & Van Der Merwe, 2000).

The difference in type essentially is dictated by the type of bulk material used to fill the roadway between the end-walls. Traditionally this was sand-bags but alternatives would be bulk sand or bulk mine stone or ‘rubbish’ (debris), all with steel girder reinforcement throughout. If time and circumstances allowed these would often be pressure grouted to seal any voids in the top of the seal and/or surrounding rock. Typically today, these techniques have been replaced in Europe by use of pumpable materials such as concrete, gypsum and anhydrite, fly ash and bentonite. All these materials have strength characteristics which are strongly dictated by the ratio of water to solids. These stoppings are generally quicker and easier to build, are more effective and less costly than the traditional ones. In the USA however, approved systems for seal construction from MSHA are concrete blocks, Omega 384 foam blocks, cementitious foam seals and polymer foam seals. The US definition of explosion proof seals is limiting and ensures an effective one hour post-explosion operation of a seal.

4. Typical Requirements – Design of Explosion Proof Stoppings

Preparation

Typically explosion proof stoppings are erected to seal off an active mine fire and as such they must ensure that ventilation to a fire is cut-off as speedily as possible, without creating an explosive atmosphere at the stopping site and without affecting personnel with toxic combustion products. Emergency Response planning for such scenarios requires much thought and effort beforehand and often includes preparatory work in the mine, which greatly assists the speed and effectiveness of dealing with such mine fires and related emergencies.

This preparatory work typically involves the following: site selection, accessible underground storage of materials and equipment, optimum transportation of men and materials, physical preparation of the site and even part-building of the seal (so as not to interfere with normal operations but to ensure that completion of the seal in an emergency would be done with maximum efficiency and minimum delay). Detailed consideration of the various stages involved and influencing factors can be found in the I. Min. E. Report of 1983.

Consideration would also be given to the use of a temporary inflatable seal inbye of the stopping site during construction which could be required to ensure the air at the site is not contaminated with fire gases. This means that workers can operate bare-faced rather than using full breathing apparatus in rescue teams.

Resistance to Explosion Pressure

UK Commissions into mine disasters in 1933 and 1960 reported that it is desirable that explosion proof stopping be designed to withstand pressures of 20 to 50 psig, concluding that 50 psig gives a good margin of safety in practice and so this value was adopted in the USA. Subsequent experience in UK experimental gallery testing of both methane and coal-dust explosions is that pressures can develop up to 524 kPa (75 psi). Similarly groups in Poland and Germany concluded that explosion proof stoppings should withstand 72 psig, the upper limit of static pressure reached by an explosion of moderate strength (DW Mitchell, 1970).

Cook & Van Der Merwe conclude that full-scale research in the USA shows that explosion pressures very seldom exceed 20 psi more than 200 ft from an explosion, unless there is an excessive accumulation of coal dust. So bulkheads are considered explosion proof if they can withstand a pressure of 20 psi (140 kPa) (Cook & Van Der Merwe, 2000).

Dimensions

Various formulae are used in different jurisdictions to determine the thickness of an explosion proof stopping (ie distance between end-walls). Those for the USA are given by Mitchell as:

Bulkhead/Stopping Material	Formula (H=height, W=width in ft)	Bulkhead Thickness (if W:20 ft H:6 ft)
Concrete	0.1 W	2 ft
Gypsum	0.4W	8 ft
Rock/cement grout	(H+W)/2	13 ft
Sandbags/steel reinforced	(H*W)/3	40 ft
Loose rock with dust or sand	3W	60 ft

For the UK, the standard formula is that of the IMinE report of 1983 for monolithic packs, but it is subject to a regulatory minimum length of 3m (or 10ft), in imperial units (i.e. feet), as follows:

$$L= ((H+W)/2)+2$$

Where, for example, if W=20 ft (6m) and H=6 ft (1.8m), then L= 15ft (4.6m). For an arched roadway 3.6m wide by 2.4m high, the stopping would be 3.7m long and would require 35 tonne of powder material (assuming a density of 1 t/m3). Details of filling materials and pumping equipment are given by Brooks 1992.

Brooks concludes that where the UK has a minimum length of 3m, Germany has derived minimum lengths from testing of 1.5m for cross-sections up to 16m^2 increasing to 2.0m for 20.8m^2, but notes these are for arch-shaped roadways. Poland in similar shaped-roadways has done tests, resulting in typical gypsum stopping lengths between 2.0 and 3.5m depending on the expected strength of explosion, material used and cross-sectional area, but they did not have a minimum length. Similarly, the USA does not have minimum length, their formula quoted above are all for rectangular-shaped roadways
.

Material

The strength of monolithic packs depends greatly on the water:solids ratio and on quality control. Monolithic pack materials are reviewed by Brooks 1992. His Table 5 is reproduced below:

Material	Water:Solids Ratio gal/lb	Setting Time, mins	Strength, psi	Strength, psi
			Compressive	Flexural
Concrete	0.06	>500	3,600	385
	0.09	-	-	330

Gypsum	0.06	30	500	180
	0.09	120	310	150
Synthetic Anhydrite	0.06	>500	900	240
	0.09	-	290	100

Brooks also refers to several UK propriety-brand-named gypsum products, namely "Hardstem" which has a setting time of 15mins whereas "Hard Stop" comes in two grades with setting times of 30 and 90 minutes respectively. Gypsum has the added advantages that (i) the slurry under pressure can penetrate voids and fissures in surrounding rock and (ii) it retains a degree of plasticity when hardened, allowing some ability to withstand ongoing rock deformation without necessarily weakening the stopping.

In the USA however, approved systems for seal construction from MSHA are concrete blocks, Omega 384 foam blocks, cementitious foam seals and polymer foam seals.

5. Testing of Explosion Proof Stopping Designs

Full-scale testing of coal mine explosions in experimental galleries has been used for many decades in the coal mining countries of Western Europe and North America. The tests used are either done in actual mine galleries in abandoned mines or in specially equipped surface galleries designed to simulate and fully represent coal mine conditions. Monolithic stoppings have been tested against maximum explosion pressures of 3.5 bar (50psi?) in the USA in rectangular cross-section roadways and of 5.2 bar (75psi?) in the UK and Germany in arch-shaped roadways (Brooks 1992). The US definition of explosion proof seals is limiting and ensures an effective one hour post-explosion operation of a seal.

In 1997 the HSE in the United Kingdom did some additional explosion testing at their Health & Safety Laboratory facility in Buxton Derbyshire. The intent was to test the UK formula for calculating the length of an explosion-proof stopping, as presented in the previous section, and in particular to determine whether there is an adequate factor of safety in the formula. (SMRB Annual Report 1997). These were carried out in an arch-shaped tunnel of 5.7m^2 cross-section and 17m long. Initial tests illustrated the challenge of maintaining good quality control during stopping construction, as the first test failed as wet slurry was found on the remains of the damaged stopping fragments.

The test was repeated using both a 3.1m thick permanent bulkhead and a 1.5m thick stopping both of gypsum. Both were reinstalled under the supervision of both the Manufacturer and the Mines Rescue Services. These stoppings were tested at four explosion pressures: 2.6, 3.2, 3.4 and 5.5 bar. Both the stopping and the bulkhead survived the test pressure without any signs of damage. This showed that the formula minimum length of 3.0m has a minimum safety factor of 100%, as the 1.5m stopping was undamaged, provided the manufacturer's recommendations are followed. Further testing proved a 1.0m gypsum stopping could survive the maximum test pressure of 4.2 bar.

After 12 explosion tests the 3.1m bulkhead failed when the internal access tube gradually collapsed and finally allowed the explosion pressure to weaken the stopping.

Currently, there seems to be little reported activity in this area of research. Recently, however, the 1992 review by Brooks of the HSE in Buxton United Kingdom did indicate that research to that date in Poland had shown that multi-stage stoppings have the potential to attenuate explosions. They do this by using an additional perforated or swinging element, located inbye of the main stopping thus reducing the length of the main stopping to 2.0m.

6. International Requirements for Explosion Proof Stoppings

Most jurisdictions for health and safety regulation of underground coal mines require old inactive working sections to be sealed or barricaded but not all require explosion-proof design and then rarely are the details specified. This leaves the choice of type and design of stopping up to the due diligence of the management of the mine.

The following review gives some of the regulatory references from selected jurisdictions:

6.1 Canada –‘ Coal mining’ jurisdictions

British Colombia

Health Safety & Reclamation Code for Mines in B.C. 2003

> *§ 6.40 Unventilated Workings §* 6.40.2 “All worked out or closed parts of an underground coal mine and those not part of the mine ventilation system shall be sealed with <u>substantial</u> stoppings”.
>
> *§ 6.41 Stoppings in Coal Mines* requires ventilation stoppings to able to prevent leakage of air, to be kept free of obstructions and to be able to monitor conditions behind the stopping.

Alberta

Alberta Regulation 292/95 Occupational Health & Safety Act – Mines Safety Regulation

> *Stoppings*
> §-220 “An employer shall ensure that
> (a) ventilation stoppings between intake and return airways are constructed to prevent leakage of air,
> (b) the space between the face of the ventilation stoppings and the roadways is kept free of obstructions,
> (c) all worked out or inaccessible parts of an underground coal mine are sealed with substantial stoppings,

(d) conditions at the face of the stoppings are monitored to ensure that a hazardous condition does not develop, and
(e) worked out districts are sealed off within 3 months of cessation of mining unless exempted by the Director".

Seals
$ 221 "The employer shall ensure that where seals are constructed to contain a hazard such as fire, spontaneous heating or other similar danger, they are certified by a professional engineer, constructed to withstand the force of an explosion in the sealed off area and are provided with a means for sampling the atmosphere and draining water from behind the seal".

Nova Scotia

Underground Mining Regulations, 2003
Stoppings in coal mine

249 **(1)** An employer must seal permanently abandoned workings in a coal mine with permanent stoppings that are designed by an engineer to minimize the transfer of gas or water over the area of the stopping and are certified by an engineer as adequately constructed to achieve their design intent.

(2) An employer must ensure that the engineering design and certification required by subsection (1) are countersigned by the manager.

(3) An employer must ensure that the space in front of all stoppings is kept free of obstructions.

(4) An employer must develop procedures that are certified as adequate by an engineer for monitoring the atmosphere behind a stopping for flammable and noxious gases: and water pressure behind the stopping

Federal

Coal Mines (CBDC) Occupational Safety and Health Regulations (SOR/90-97)

Part IV Ventilation: Stoppings and Barricades
$ *155. (1)* Before stoppings or barricades are installed for fire protection in an area of a coal mine, all persons, other than those persons required to install the stoppings or barricades, shall be evacuated from the area.

(2) No person shall enter an area referred to in subsection (1) for a period of 24 hours after stoppings or barricades have been installed, except for the purpose of saving life, preventing injury or relieving human suffering.

$ *156.* Where coal is left unmined as a barrier against fire or flooding or for any other safety purpose, no person shall remove the coal.

$ *157.* All openings to any underground area that is not being worked or developed shall be
(*a*) stopped off; and
(*b*) posted with a warning sign that states "DO NOT ENTER" and "ENTRÉE INTERDITE".

6.2 USA

Title 30 – Mineral Lands & Mining Chapter 22 Mine Safety & Health
Section 863. - Ventilation

Title 30 Subpart G – Ventilation Sec. 57.8535 Seals 57.22217, 57.22218 & 57.22219

Pillar extractions; bleeder systems and sealing requirements; standards
(1) While pillars are being extracted in any area of a coal mine, such area shall be ventilated in the manner prescribed by this section.
(2) Within nine months after the operative date of this subchapter, all areas from which pillars have been wholly or partially extracted and abandoned areas, as determined by the Secretary or his authorized representative, shall be ventilated by bleeder entries or by bleeder systems or equivalent means, or be sealed, as determined by the Secretary or his authorized representative. When ventilation of such areas is required, such ventilation shall be maintained so as continuously to dilute, render harmless, and carry away methane and other explosive gases within such areas and to protect the active workings of the mine from the hazards of such methane and other explosive gases. Air coursed through underground areas from which pillars have been wholly or partially extracted which enters another split of air shall not contain more than 2.0 volume per centum of methane, when tested at the point it enters such other split. When sealing is required, such seals shall be made in an approved manner so as to isolate with explosion-proof bulkheads such areas from the active workings of the mine.
(3) In the case of mines opened on or after the operative date of this subchapter, or in the case of working sections opened on or after such date in mines opened prior to such date, the mining system shall be designed in accordance with a plan and revisions thereof approved by the Secretary and adopted by such operator so that, as each working section of the mine is abandoned, it can be isolated from the active workings of the mine with explosion-proof seals or bulkheads

Title 30 – Mineral Lands & Mining Chapter 75
Section 335. – Construction of Seals
a) (2) Alternative methods or materials maybe used to create a seal if they can withstand a static horizontal pressure of 20 psi.

6.3 United Kingdom

While not clearly specified as explosion proof, the HSE Law Relating to Safety & Health in Mines & Quarries, requires stoppings in Part 2 relating to mines of coal, Section C The Coal & Other Mines (Ventilation) Regulations 1956 s 21 (1)Any road not required for the working of a mine and connecting airways, which as regards any working face are intake and return airways shall forthwith be so stopped off as to minimize air leakage through it. (2) In a mine of coal any such stopping …. shall be constructed of a tight packing of at least 5m thick, of stone, dirt, sand or rubbish; or (b) constructed of a tight packing at least 3m thick of stone, dirt, sand, or rubbish having the end nearest the intake airway faced with a wall of not less than 0.19m thick of masonry, brickwork or concrete the face of which is covered with a coating of mortar so as to prevent leakage of air. The Fire & Rescue Regulation of 1956 s11(5) also refers to a fire being "dammed off" which could imply explosion proof stoppings. However, the I Min E Memorandum on the Sealing off of Fires Underground is widely recognized in the UK and it is noted that it makes no mention of any statutory, regulatory or production instructions that relate to sealing off of fires and to explosion proof stoppings in particular. Further the UK NCB Production Instruction PI 1969/3 on Drawing Off and Sealing Off Disused Workings requires sealing off within 3 months of the coal face finishing.

6.4 Australia

New South Wales

COAL MINES (UNDERGROUND) REGULATION 1999
Section 99 "Stoppings and air crossings"

(1) All stoppings and air crossings constructed between main intake airways and return airways in a mine must be substantial in structure, airtight (so far as is practicable), fireproof and designed to minimise damage in an explosion.
(2) Stoppings and air crossings between split intakes and return airways in a mine must be reasonably airtight and fireproof and be of substantial structure up to the commencement of any hazardous zone.
(3) A stopping constructed for the purpose of sealing off a part of a mine must be substantial in structure, airtight and designed to resist damage in the event of an explosion. Provision to allow sampling of the atmosphere in the sealed off area must be made.

Queensland

Coal Mining Safety and Health Regulation 2001
Chapter 4, Part 10 – Mining Operations

$ 325 “Types of seals for particular circumstances and parts of mines”: specifies types B,C, D & E seals, defined in Schedule 4 to be designed to withstand overpressures of 14 to 345 kPa . Type D requires 345kPa applied in situations where persons are underground when an explosive atmosphere is known to exist and there is a potential source of ignition (including incendive sparking).

6.5 Japan

Coal Mine Safety Regulation March 1994

The language is vague:
Article 107.3 Isolation Walls “shall be made of noncombustible materials such as reinforced concrete, concrete block and brick and shall be strongly constructed to prevent air leakage (mortared wooden block walls are also acceptable)

Article 125 “The appropriate measures such as a filling, sealing and ventilation shall be taken in old workings or goafs where there is much inflammable gas or explosive coal dust.

6.6 South Africa

It is a Statutory requirement in South African coal mines to construct seals on sealed off areas which are strong enough to withstand an explosion in the sealed area. (Cook & Van Der Merwe 2000).

7. Summary

Explosion proof stoppings are expedient means of ensuring both containment of potential explosions in disused/abandoned old working areas and in enhancing prevention of explosions when promptly sealing off underground fires. Prudent planning and diligent preparatory effort in the mine can also ensure that in an emergency situation, prompt erection of explosion proof stoppings can be done within a single shift (in fresh air conditions).

Applied research in the USA and Western Europe has over many decades developed methodologies and designs of monolithic stoppings of only 1.5 or 2.0m thickness that will withstand explosion overpressures of 525kPa associated with moderate strength explosions. Gypsum is the preferred material to be used in Europe where it is readily available, to build explosion proof stoppings because of its properties. It is pumpable, fills voids and cracks when pumped under pressure, sets quickly, is strong and also retains some of its pliability to maintain the seal under some deformation of surrounding rock.

Regulatory requirements vary by jurisdiction. All seem to require stoppings on disused working areas but, of the regulations reviewed here, explosion proof stoppings are only legislated in Alberta, USA, Australia (NSW, Queensland) and South Africa. Typical practice however in the UK, Germany and Poland does require explosion proof stoppings. The UK, Poland and Alberta also require such stoppings to be placed within 3 months of the face ceasing work.

Useful references giving much supporting detail to the above review can be found for Europe in Brooks 1992 and the I Min E 1983 and for North America and South Africa in Cook & Van Der Merve 2000.

8. References

Brooks DE "Design Criteria for Explosion Proof Stoppings in Coal Mines" Section Paper IE/L/DE/92/03 HSE Research and Laboratory Services Division, Buxton, Derbyshire England, 1992

Cain P "The Use of Stone Dust to Control Coal Dust Explosions: A Review of International Practice" Internal Report for the Underground Coal Mining Safety Research Collaboration administered by Natural Resources Canada – February 2003 www.ugcoal.ca

Cook AP & Van Der Merwe JN "Design Construction and Testing of Underground Seals" Itasca Africa (Pty) Ltd. Safety in Mines Research Advisory Committee, Final Project Report COL 502, January 2000.

Institution of Mining Engineers "Memorandum on Sealing Off Fires Underground" 1983

Kissel FN & Thimons ED "New stopping designs – an update" Mining Congress Journal July 1981.

Lazzara, Mura, et al "Fire Endurance of Mine Stoppings" USBM RI 9207, 1988.
Mitchell DW "Explosion proof Bulkheads – present practices" USBM RI 7581, 1970.

Murphy JN "Overview of Bureau of Mines Coal Mine Research" Mining Technology August 1984

Safety in Mines Research Advisory Board (SMRAB) Annual Report 1997 Section "Fire & Explosions – Explosion Proof Stoppings", 1997 www.hse.gov.uk/hid/mines/shmrab/index.htm

Weiss ES & Greninger NB "Seals for fire and explosion control" unpublished – references by Brooks DE 1992.