Research in Active Explosion Barrier Systems for Underground Coal Mines

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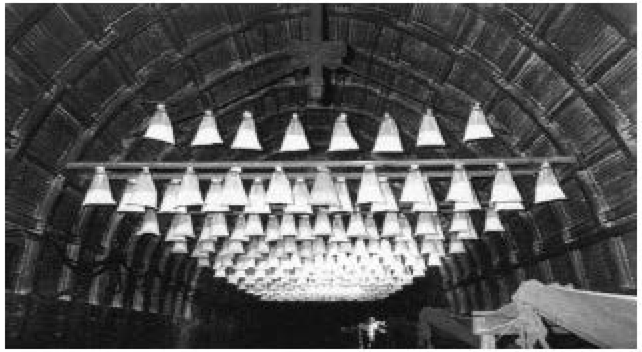
Introduction

- Explosion is one of the main hazards in underground coal mines.
- Explosion barriers cannot prevent an underground coal mine explosion but are used to mitigate the intensity of the explosion with respect to the over pressure (shock wave) and the propagation of the flame. https://www.youtube.com/watch?v=8p9HxH3Iht8

  Official Company Website: http://www.bmtwbm.com.au/
- Explosion barriers can be divided in two categories: passive and active.

Passive explosion barrier system

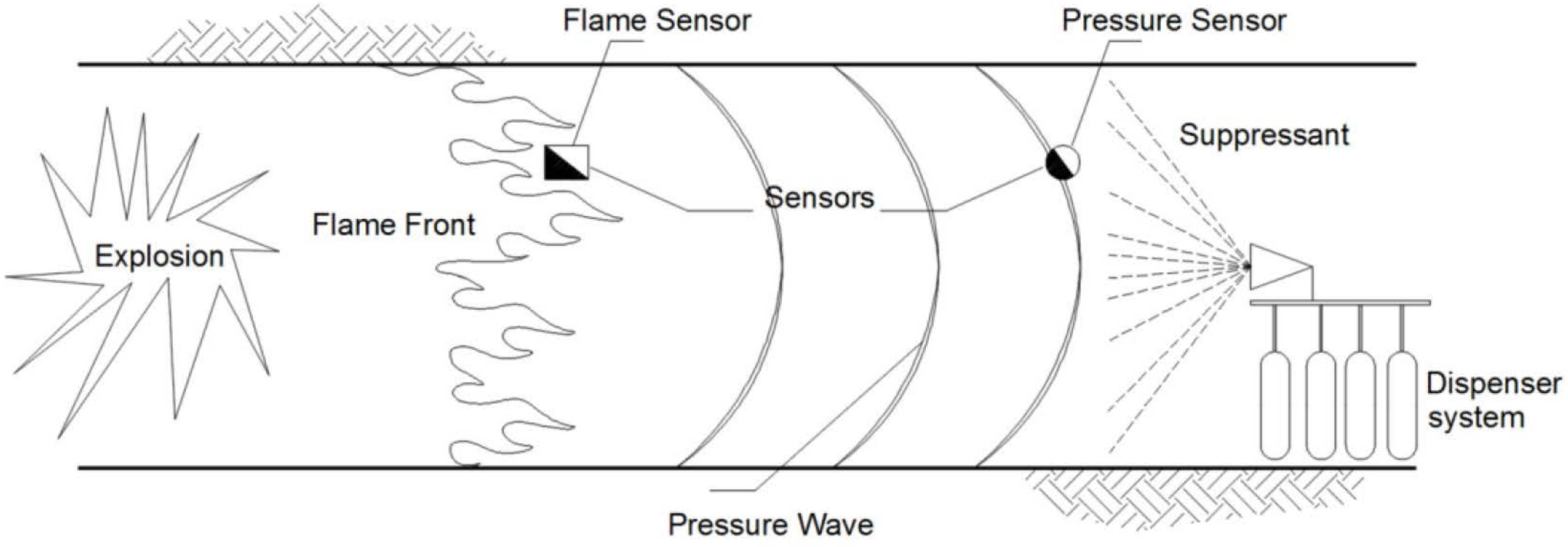
- Passive barriers use a suppressant material that is dispersed by the dynamic pressure wave to mitigate the pressure and extinguish the trailing flame front.



a) Passive barrier (Distributed/water)　　b) Passive barrier (Concentrated/stone dust)

Active explosion barrier system

- Active barriers use a suppressant material that is dispersed after a sensor is activated to mitigate the pressure and to extinguish the trailing flame front.



Sensors used in Active Systems

- Thermocouple → Heat from combustion reaction
- Infrared → Infrared radiation in flame (USBM)
- Ultraviolet → Ultraviolet radiation in flame
- Solar cell → Radiant energy in flame
- Thermo-mechanical → Heat from flame and dynamic pressure

Advantages of Active Explosion Barrier

Compared to passive explosion barrier, active explosion barriers have the following advantages:

- Suppressant is dispersed by an independent, self-contained energy source.
- Active barrier operation does not depend upon the static, dynamic force or pressure generated by an explosion.
- It is good for low height to width ratio roadways where height is less than 80% of the width. (Space)
- It is relatively suitable for fast moving face.
- It provides a good safety standard because it responds before the flame develops into a full-scale explosion.

Limitations of Active Explosion Barrier

Compared to passive explosion barrier, active explosion barriers have the following limitations:

- Electronic controls → Power supply, (overcome using internal power)
- Reliability because in some cases are complex systems something can fail. (insensitive/over sensitive sensors)
- Maintenance and cost.

Research in the Development of Active Explosion Barriers

- In design of explosion barriers, the suppressant agent should be ideally dispersed as the flame front reaches the barrier.
- If dispersed too early, the suppressant will be diluted before the flame arrives. If dispersed too early, the flame will pass by before the suppressant is dispersed.
- With the passive barriers, it is difficult to guarantee such a condition.
- This led to the development and evaluation of active explosion barrier systems which do not depend on the development of explosions of sufficient strength to activate it.

Active Explosion Barrier Systems Types

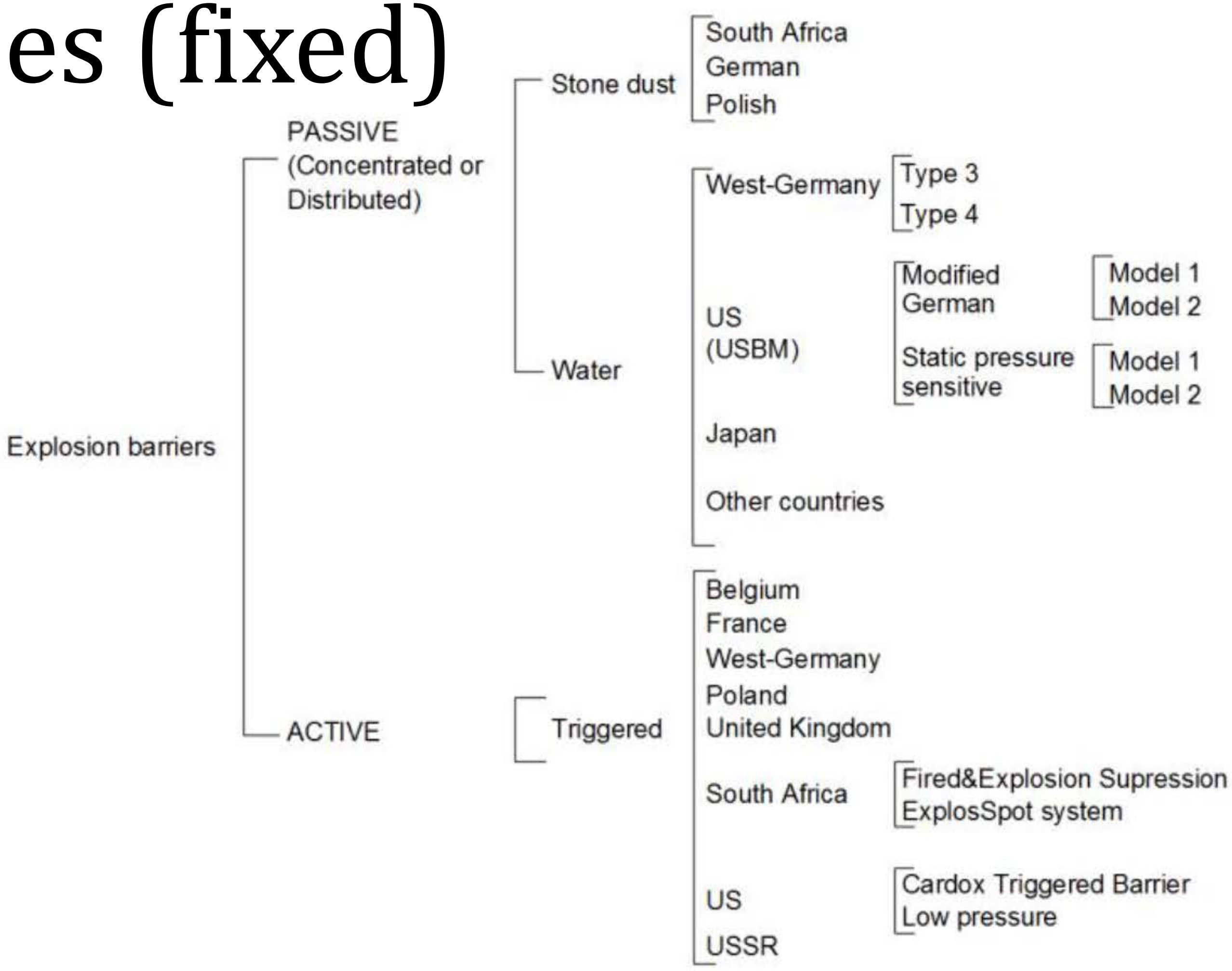
- Equipment – mounted systems

Country	Type	Extinguishing agent	Dispersal method	Vessels		
				No.	Size	Loading (kg)
Federal Republic of Germany	BVS system	Tropolar ammonium phosphate powder	Nitrogen 120 bar detonator. Activated valves	6	12,3 ℓ cylinder	48
UK	Graviner system	Furex 770	N_2 or halon 60 bar	4-6	7 ℓ (app.) cylinder	16-24
USA	PRC system	ABC powder	Linear-shaped charge and halon 13,6 Bar	6	Tabular canister 0,76 m 1,2 m 1,8 m 5 cm dia.	17

- Fixed point systems

(Zou, 2001)

Active Explosion Barrier Systems in Mining Countries (fixed)



(Zou, 2001)

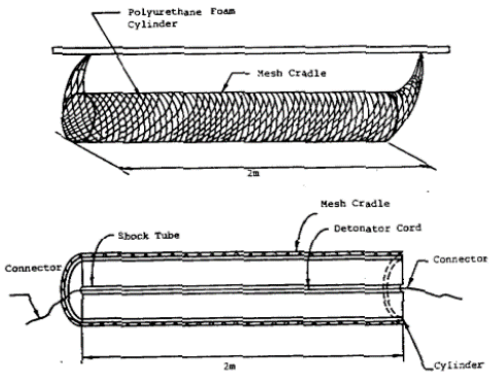
Active Explosion Barrier Systems in Mining Countries (fixed)

Country	Detector Type	Extin-guishing Agent	Dispersal Method	Vessels	
				Shape	Loading (l/m^2)
Belgium	Thermo-mechanical	Water: 90-100 l/unit	Detonating cord	2-m-long, 25-cm-diam., open-pore polyurethane foam	10
Federal Republic of Germany	BVS UV	Tropolar ammonium phosphate powder	Nitrogen 120 bar detonator-activated valves	12.3 l cylinder	48
Federal Republic of Germany	Thermo-couple	Water: 80 l/unit	Detonating cord	PVC trough	80
France	Thermo-mechanical	Water: 90-100 l/unit	Detonating cord	2-m-long, 25-cm-diam., open-pore polyurethane foam	10
UK	Thermo-couple	Water: 227 l/unit	Compressed N_2	Long cylinder	45
USA	Pressure and ultraviolet radiation	Water or mono-ammonium phosphate: 40l/unit	Sheet explosive	Ridged polystyrene container	80

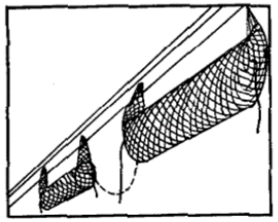
(DuPlessis, et.al 2002)

Active Explosion Barrier – 1970s

Belgian Water barrier (Gofart and Browayes)



- System type: fixed location system
- Sensor: thermo-mechanical sensor (pressure-flame)
- Disperser size or capacity: 2m long, 25cm diameter, 90-100 liters of water
- Dispersal method: Detonating cord
- Suppressant: water
- This system was also used in France.



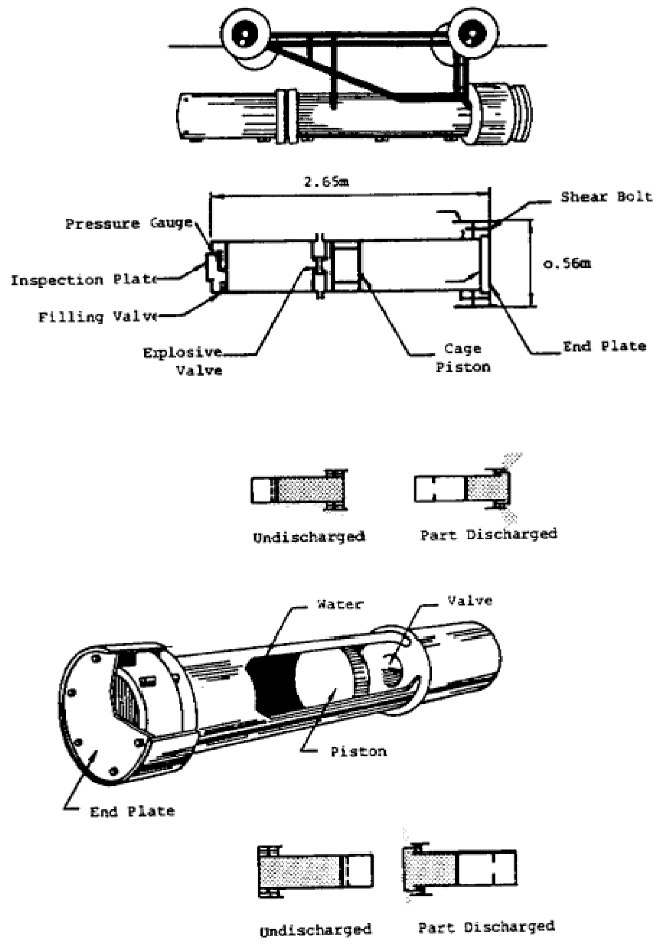
BELGIAN TRIGGERED BARRIER DETAILS

(Zou, 2001)

Active Explosion Barrier – 1970s

United Kingdom

- System type: fixed location system
- Sensor: thermocouple sensor (flame sensor)
- Disperser size or capacity: 227 liters
- Dispersal method: Compressed nitrogen
- Suppressant: water
- Trigger delay time: 40-60 ms
- Adequate dispersal time: 180 ms
- Effective for explosions with flame speeds between 20 and 300 m/s.



MARK II DISPERSER (Zou, 2001)

Active Explosion Barrier – 1970s

USA

- PRC system
- System type: machine mounted system
- Sensor: infrared sensor
- Disperser size or capacity: Tabular canister 0.76 m, 1.2 m, 1.8 m, 5 cm diameter
- Dispersal method: Linear-shaped charge and halon 13.6 bar
- Suppressant: ABC powder (ammonium phosphate)

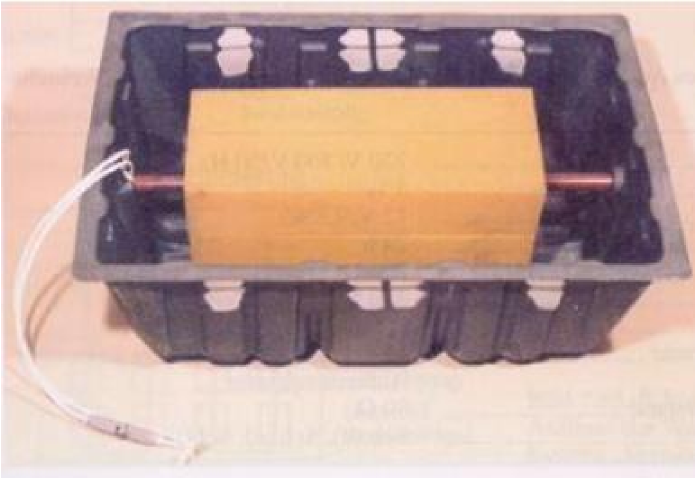
Active Explosion Barrier – 1980s

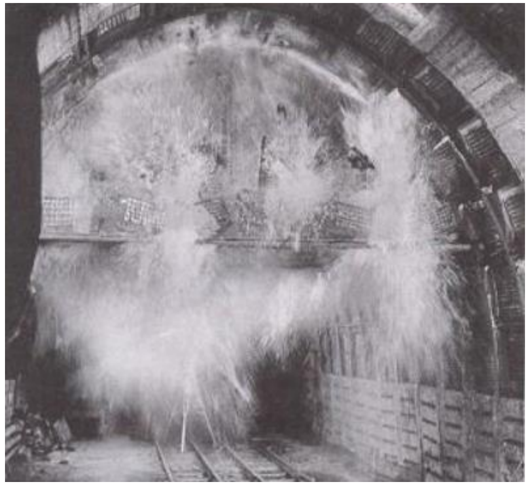
Germany

- Tremonia System (Tremonia experimental mine → Germany)
- System type: fixed location system
- Sensor: thermoelectric sensor based on the SMRE thermocouple sensor
- Disperser size or capacity: 80 liters
- Dispersal method: Detonating cord
- Suppressant: water
- Adequate dispersal time: 200 – 300 ms

Active Explosion Barrier – 1980s
Germany

- Tremonia System





SMRE thermocouple sensor

Water trough with built-in ignition system

Water distribution of the barrier

(DuPlessis and VanNiekerk, 2002)

Active Explosion Barrier – 1980s

Germany

- Advantages:
- They extinguish propagating low-pressure ignitions.
- Their water distributing ability is twice as high as that of passive water trough barriers and they are therefore more flexible.
- They are compact, thus saving space.
- They have a reduced water quantity requirement of 80 l/m^2 instead of 200 l/m^2 of cross-section.
- Even if the electrical triggering fails, they still operate as passive water trough barriers.

Active Explosion Barrier – 1980s

Germany

- Disadvantages:
- The initial installation of the triggered barrier is labor-intensive, as is the case with a passive barrier.
- They require qualified personnel for the installation of the electrical and blasting components.
- They have a high capital investment cost (10 times higher than the passive barrier systems).
- The system was withdrawn in 1996

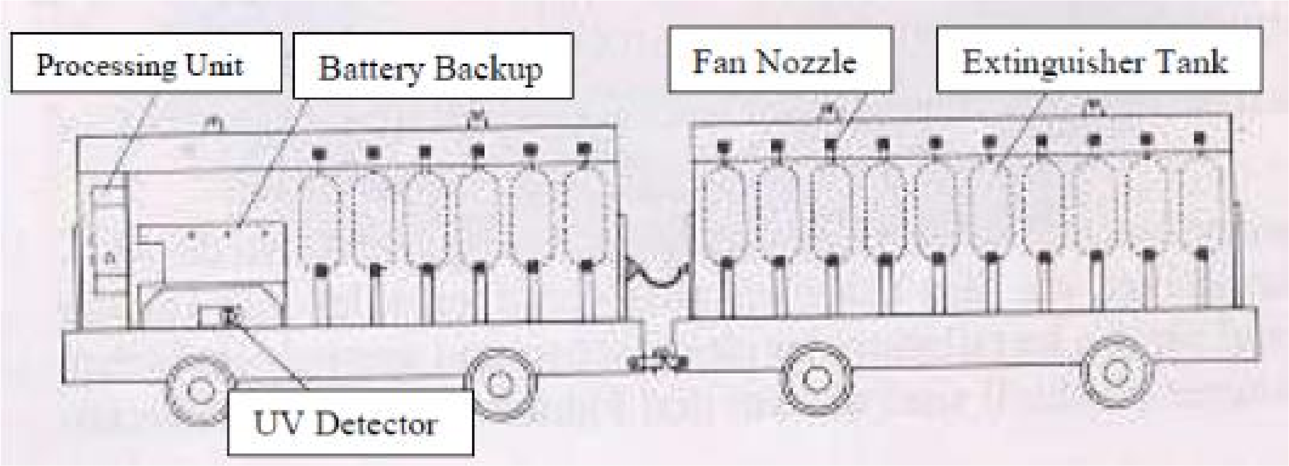
Active Explosion Barrier – 1980s

Germany

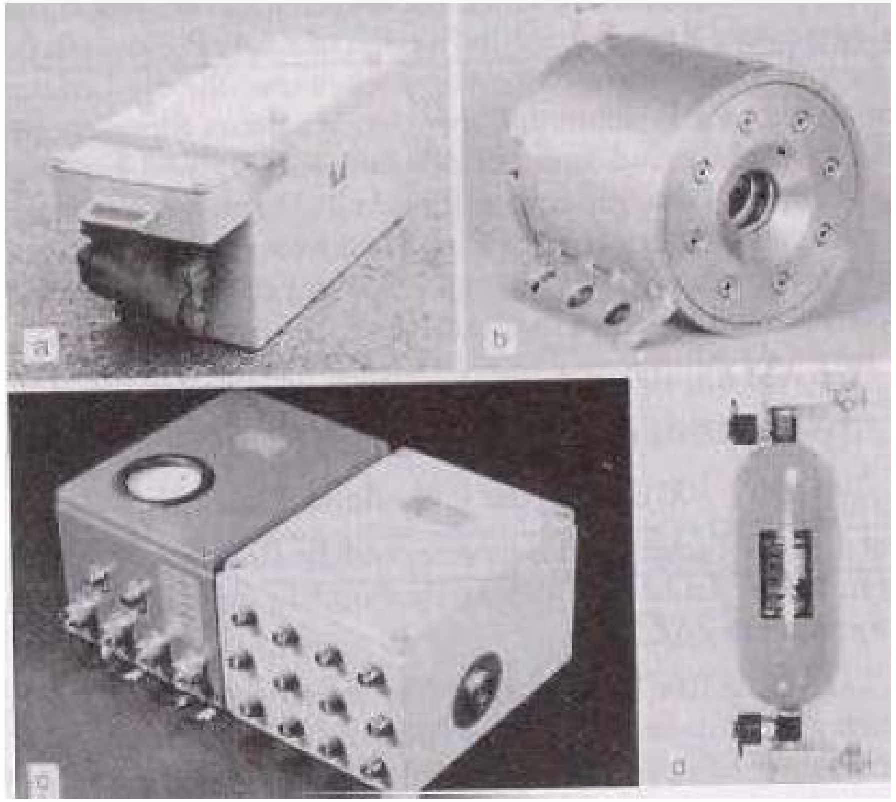
- BVS (Bergbau-Versuchsstrecke) System
- System type: machine mounted (also adapted for application in France and South Africa during 1990s) and fixed location system
- Sensor: ultraviolet sensor
- Disperser size or capacity: 12.3 litre
- Dispersal method: nitrogen gas at 12MPa pressure
- Suppressant: ammonium phosphate powder
- Trigger delay time: 5 – 10 ms

Active Explosion Barrier – 1980s
Germany

- BVS (Bergbau-Versuchsstrecke) System



Machine mounted BVS system (DuPlessis and VanNiekerk, 2002)

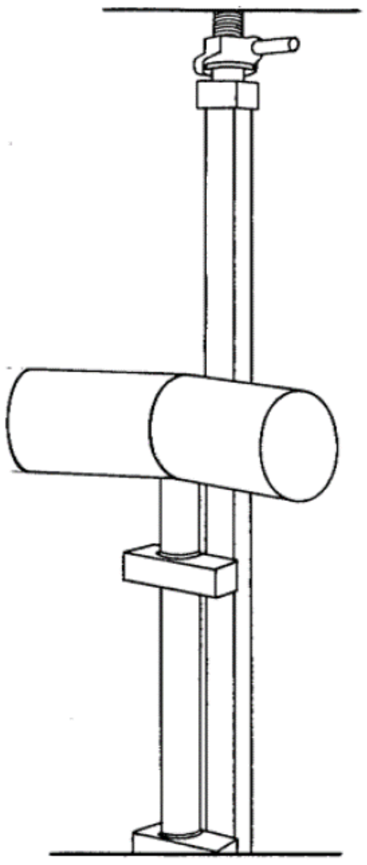


Components of a fixed BVS triggered barrier system a. Complete unit, b. UV flame sensor, c. triggered electronics, d. HRD suppressant container (DuPlessis and VanNiekerk, 2002)

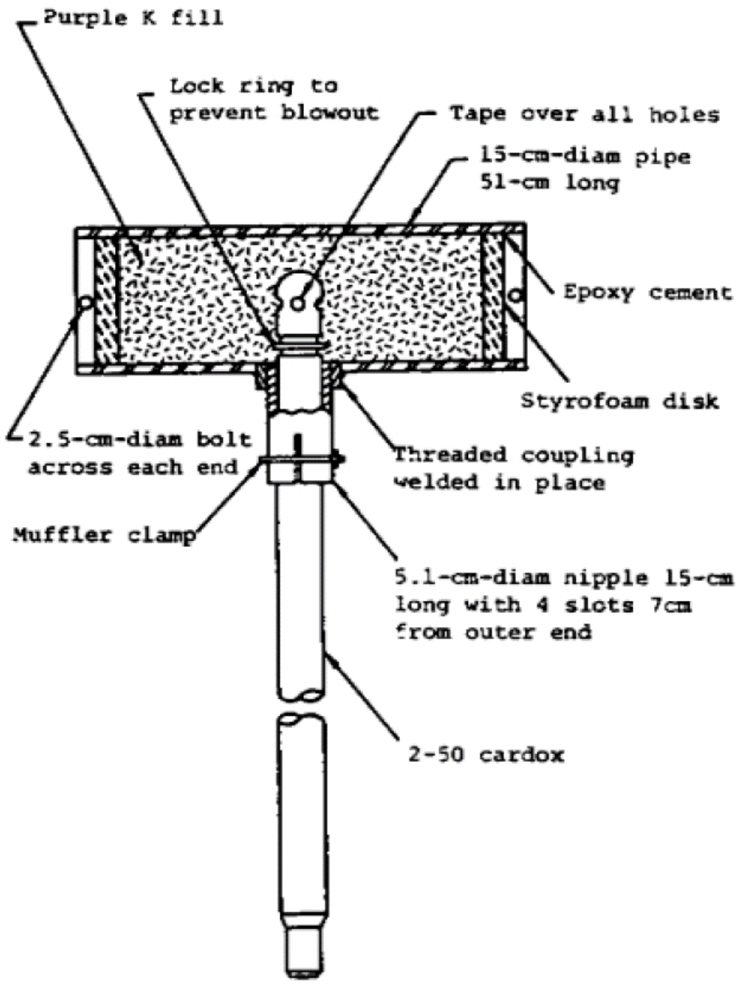
Active Explosion Barrier – 1980s

USA

- Cardox system
- System type: fix location system
- Sensor: Pressure and ultraviolet radiation
- Disperser size or capacity: 51 cm long, 15 cm diameter
- Dispersal method: Sheet explosive
- Suppressant: purple K or water
- High pressure (approximately 1000 atm made it be considered too hazardous to be utilized in mine areas where personnel are working.



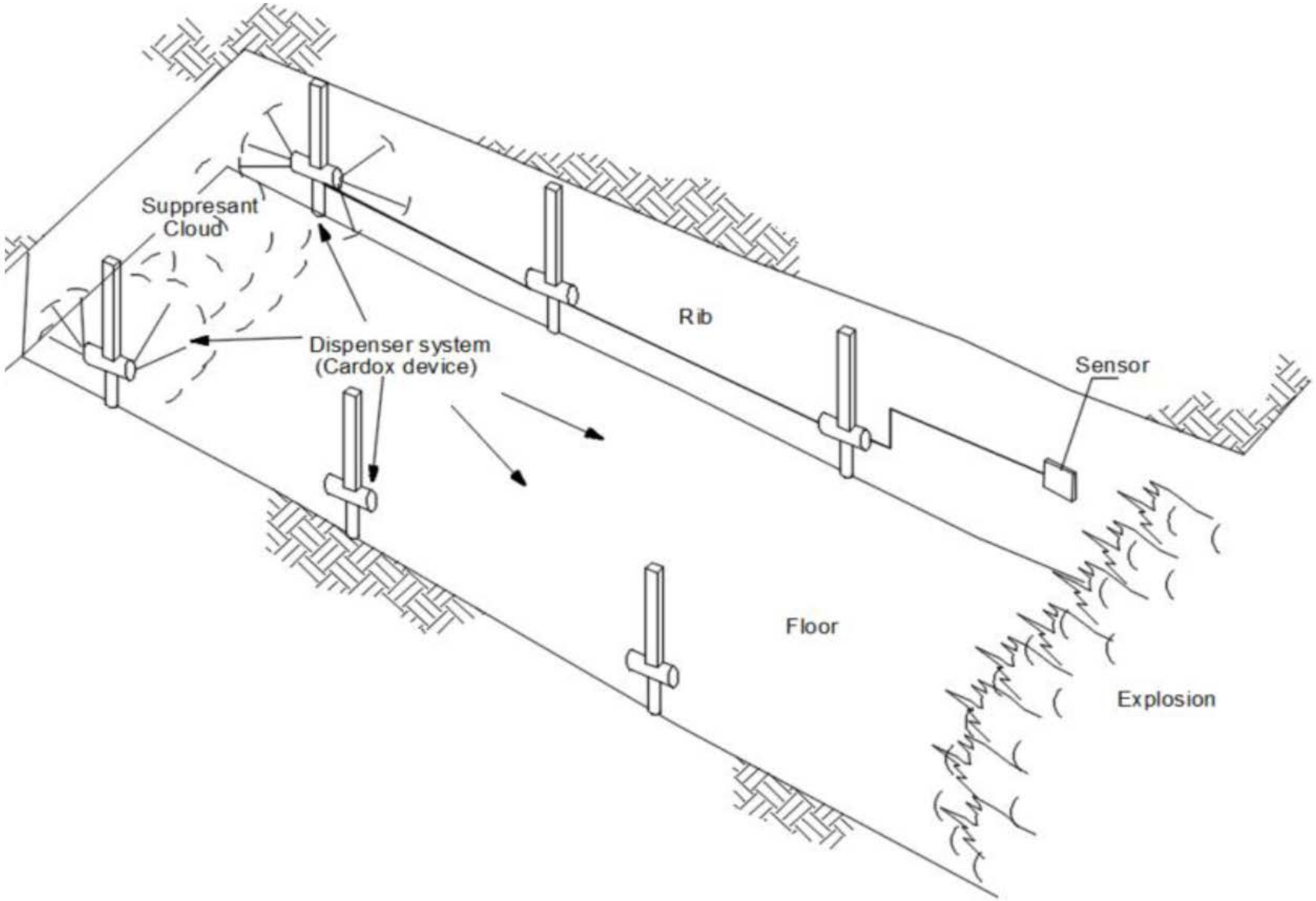
TYPICAL CARDOX INSTALLATION



CARDOX BARRIER DETAILS (Zou, 2001)

Active Explosion Barrier – 1980s

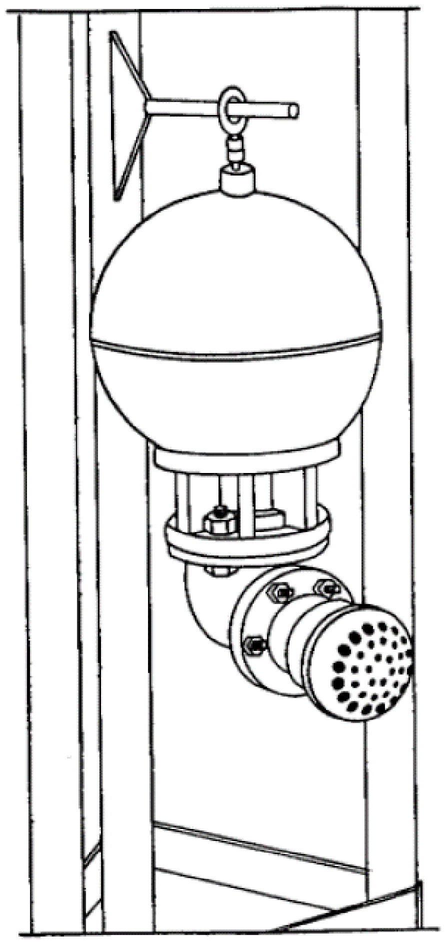
USA



Active Explosion Barrier – 1980s

USA

- FENWAL barrier (low pressure)
- System type: fix location system
- Sensor: Pressure and ultraviolet radiation
- Disperser size or capacity: 13.6 kg water or 20.4 kg purple K
- Dispersal method: nitrogen gas to a range of 1380 to 2070 kN/m^2 (13.62 atm to20.43 atm)
- Suppressant: purple K or water



FENWAL BARRIER (Zou, 2001)

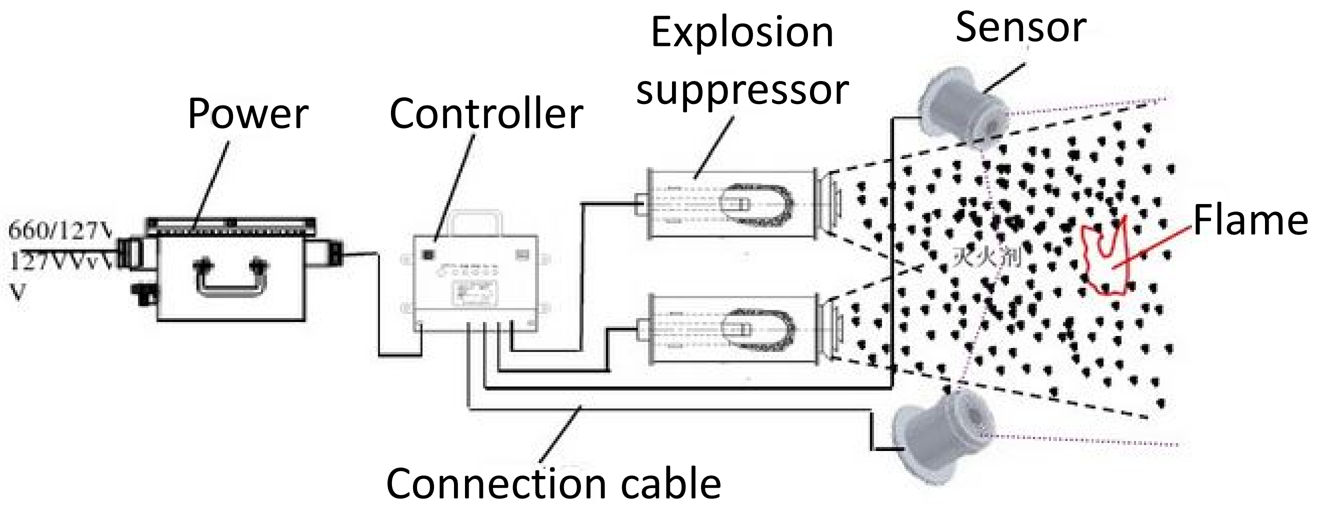
Active Explosion Barrier – from 1990s

China

- ZYB series systems
- System type: fixed location system
- Sensor: ultraviolet radiation
- Disperser size or capacity: $\Phi 425 \times 640$ (mm), 10 Kg
- Suppressant: inert powder
- Trigger delay time: <15ms

Active Explosion Barrier – from 1990s

China



Configuration of ZYB systems

Components of ZYB systems

Active Explosion Barrier – from 1990s

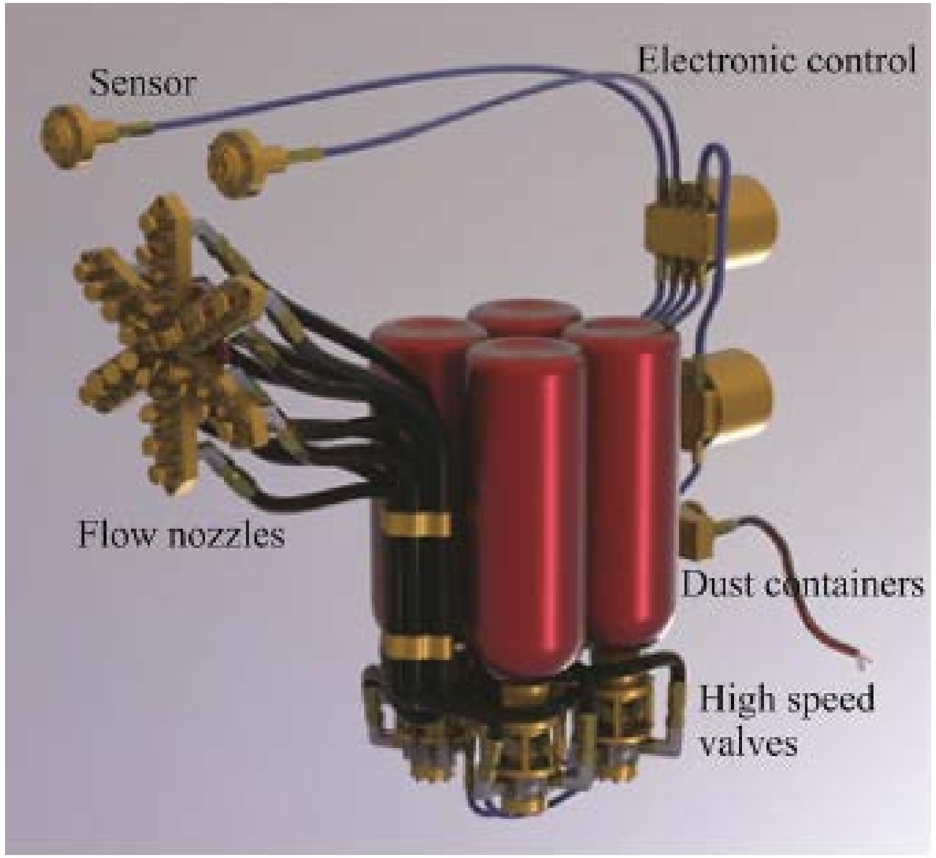
South Africa

- ExploSpot system or HS system
- System type: machine mounted and fixed location system
- Sensor: dual-spectrum sensor
- Trigger delay time: 4 – 15 ms depending on system model
- Dispersal time: <60 ms for a cross-section area of 5 m^2
- The ExploSpot system consists of three main components: the control electronics, the dual-spectrum sensor units and the discharge assemblies.

Active Explosion Barrier – from 1990s

South Africa

- The sensors are specially designed to react only to certain light wavelengths specific to burning methane and coal dust, thus reducing the risk of a false ignition.
- The discharge assemblies are configured for the particular conditions found within a specific mine, the cross-sectional area of the tunnel and the method of coal extraction being applied. They are also configured to ensure the correct powder distribution and concentration for the successful extinguishing of any explosion or ignition.



Graphical representation of the active barrier system Components (J. J. L. du Plessis, 2015)

Active Explosion Barrier – from 1990s

South Africa

- ExploSpot system development and tests:
- Tests were conducted in the 200 m explosion test tunnel at the Kloppersbos Research Facility of the Council of Scientific and Industrial Research in South Africa (CSIR)

https://www.youtube.com/watch?v=itYbSpEBP6U

The 200m test tunnel (J. J. L. du Plessis, 2015)

Summary

- Active explosion barrier systems were studied in US; currently they are used by other mining countries but have not been used in the United States. The use of active explosion barrier systems in the United States will enhance the safety of underground coal mines.
- The technology required for active systems is readily available based on the experience of other mining countries, but must be adapted for their use in US coal mines.
- The adaptation process will consider the particular characteristics of the hazard components such as methane and coal dust, the mine geometry and the mining equipment used in the US.

Our baby steps… (Our failure videos)

Summary

Reference

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Thank you !

Acknowledgement:
UKERT students,
Lifeng Li,
Dr. Calnan,