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Explosion Pressure Design Criteria for New Seals in U.S. Coal Mines

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Executive Summary

Seals are dam-like structures constructed in underground coal mines throughout the U.S. to isolate abandoned mining panels or groups of panels from the active workings. Historically, mining regulations required seals to withstand a 140 kPa (20 psi) explosion pressure; however, the 2006 MINER Act requires MSHA to increase this design standard by the end of 2007. This report provides a sound scientific and engineering justification to recommend a three-tiered explosion pressure design criteria for new seals in coal mines in response to the MINER Act. Much of the information contained in this report also applies to existing seals.

NIOSH engineers examined seal design criteria and practices used in the U.S., Europe and Australia and then classified seals into their various applications. Next, NIOSH engineers considered various kinds of explosive atmospheres that can accumulate within sealed areas and used simple gas explosion models to estimate worst case explosion pressures that could impact seals. Three design pressure pulses were developed for the dynamic structural analysis of new seals under the conditions in which those seals may be used: unmonitored seals where there is a possibility of methane-air detonation behind the seal; unmonitored seals with little likelihood of detonation; and monitored seals where the amount of potentially explosive methane-air is strictly limited and controlled. These design pressure pulses apply to new seal design and construction.

For the first condition, an unmonitored seal with the possibility of detonation, the recommended design pulse rises to 4.4 MPa (640 psi) and then falls to the 800 kPa (120 psi) constant volume explosion overpressure. For unmonitored seals without the possibility of detonation, a less severe design pulse that simply rises to the 800 kPa (120 psi) constant volume explosion overpressure, but without the initial spike, may be employed. For monitored seals, engineers can use a 345 kPa (50 psi) design pulse if monitoring can assure 1) that the maximum length of explosive mix behind a seal does not exceed 5 m (15 ft) and 2) that the volume of explosive mix does not exceed 40% of the total sealed volume. Use of this 345 kPa (50 psi) design pulse requires monitoring and active management of the sealed area atmosphere.

NIOSH engineers used these design pressure pulses along with the Wall Analysis Code from the U.S. Army Corps of Engineers and a simple plug analysis to develop design charts for the minimum required seal thickness to withstand each of these explosion pressure pulses. These design charts consider a range of practical construction materials used in the mining industry and specify a minimum seal thickness given a certain seal height. These analyses show that resistance to even the 4.4 MPa (640 psi) design pulse can be achieved using common seal construction materials at reasonable thickness, demonstrating the feasibility and practical

Section 1 – Introduction

1.1. Report objective

Seals are used in underground coal mines throughout the U.S. to isolate abandoned mining areas from the active workings. Prior to the Sago disaster in 2006, mining regulations required seals to withstand a 140 kPa (20 psi) explosion pressure; however, the recently passed Mine Improvement and New Emergency Response Act of 2006 (the MINER Act) requires the Mine Safety and Health Administration (MSHA) to increase this design standard by the end of 2007. This report provides a sound scientific and engineering justification to recommend a three-tiered explosion pressure design criteria for new seals in coal mines in response to the MINER Act. The recommendations contained herein apply to new seal design and construction in U.S. coal mines.

1.2. Seals and ventilation systems in underground coal mining

To control methane in mined-out areas of coal mines, and thereby reduce explosion risk from methane build-up, current mining regulations (30 CFR 75.334) require companies to either ventilate or seal those areas. Continued ventilation of abandoned areas is costly and may divert ventilating air away from other, more productive uses. Seals are sometimes a more economical alternative to ventilation. Without sealing, large mined-out area still require regular inspections and can expose miners to underground hazards.

A ventilation system delivers fresh air to the mains, submains, gateroad entries, production panels and all the active areas of the mine via intake airways, while return airways remove contaminated air laden with dust and methane. Various ventilation control devices, namely stoppings, overcasts and regulators control and direct the airflow throughout the system. Fans, located on the surface, provide the power to move the required air quantity. In addition to the primary ventilation system for providing air to all the active mining faces, bleeder entries located around the perimeter of mining areas serve to dilute methane from all mined-out areas long after panels are extracted.

When an area of an underground coal mined is mined out, operators will frequently choose to isolate the abandoned area with simple dam-like structures called seals rather than continue to ventilate the area. Seals are walls constructed from solid, incombustible materials such as concrete, brick or cinder block that separate abandoned panels or groups of panels from the active areas of the mine. MSHA data indicates that over 13,000 seals in over 2,200 sets exist in active coal mines throughout the U.S. Estimates suggest that mining companies or their contractors build several thousand seals annually. ?

In active mining, primary access to production areas occurs via a system of "mains" and "submains" corridors. These corridors contain a conveyor system to remove the mined coal and the ventilation system. Production panels are developed from these corridors.

Section 6 – Minimum New Seal Designs to Withstand the Design Pressure Pulses

The explosion pressure design pressure criteria for new seals developed in the preceding sections serve as a basis for the structural design. In this section, NIOSH engineers present examples for possible approaches to new seal designs using simplified structural engineering methods.

Due to the complex nature of the structural interface between the mine roof and floor rock strata, the coal ribs and the seal, a general design for a mine seal is not possible. The fundamental design assumptions change from application to application so that each seal design will have to be engineered for a specific application and location in a given mine.

The following considerations should serve as conceptual ideas for new seal designs and demonstrate that it is possible to engineer a mine seal to withstand these possible explosion pressures. The two structural engineering approaches used, one-way arching and plug-type failure, only demonstrate two possible failure modes which are both dependent on the structural reactions of the surrounding strata. There are other structural engineering approaches to the design of such seals but a detailed discussion of these methods goes beyond the scope of this study.

The design pulses developed in the prior section depart significantly from the 140 kPa (20 psi) explosion pressure design criterion found in recent U.S. mining regulations and the 345 kPa (50 psi) standard currently in force. NIOSH engineers conducted structural analyses with these design pulses to develop practical design charts using three separate design approaches:
1) Dynamic structural analysis using the Wall Analysis Code (WAC) developed by the U.S. Army Corps of Engineers for the design of protective structures subject to blast loads.
2) Static plug analysis using quasi-static approximations to the dynamic design pulses.
3) Static arching analysis using the same quasi-static load approximations.
These three significantly different analysis methods generated similar seal thickness design requirements and confidence in the recommended design charts.

In conducting these structural analyses, NIOSH engineers considered eight typical materials covering the range of typical construction materials readily available to the mining industry. **Table 6** summarizes these material properties which range from high strength, low deformability to low strength, high deformability materials. Each material has potential application depending on the particular circumstances of the seal.

For structural analysis, the recommended design pressure pulses may have a quasi-static approximation that can apply in practical situations. The 800 kPa (120 psi) pulse (**Figure 21**) and the 345 kPa (50 psi) pulse (**Figure 22**) remain at these pressures for a long duration which implies that a static pressure of 800 and 345 kPa (120 and 50 psi) is equivalent. Furthermore, the rise time for these pulses is 0.25 and 0.1 seconds, respectively, which is much more than the transit time for a stress wave across a seal. NIOSH engineers estimate that this transit time ranges from 0.0001 second to 0.010 seconds which is much less than the rise times of these two design pulses.

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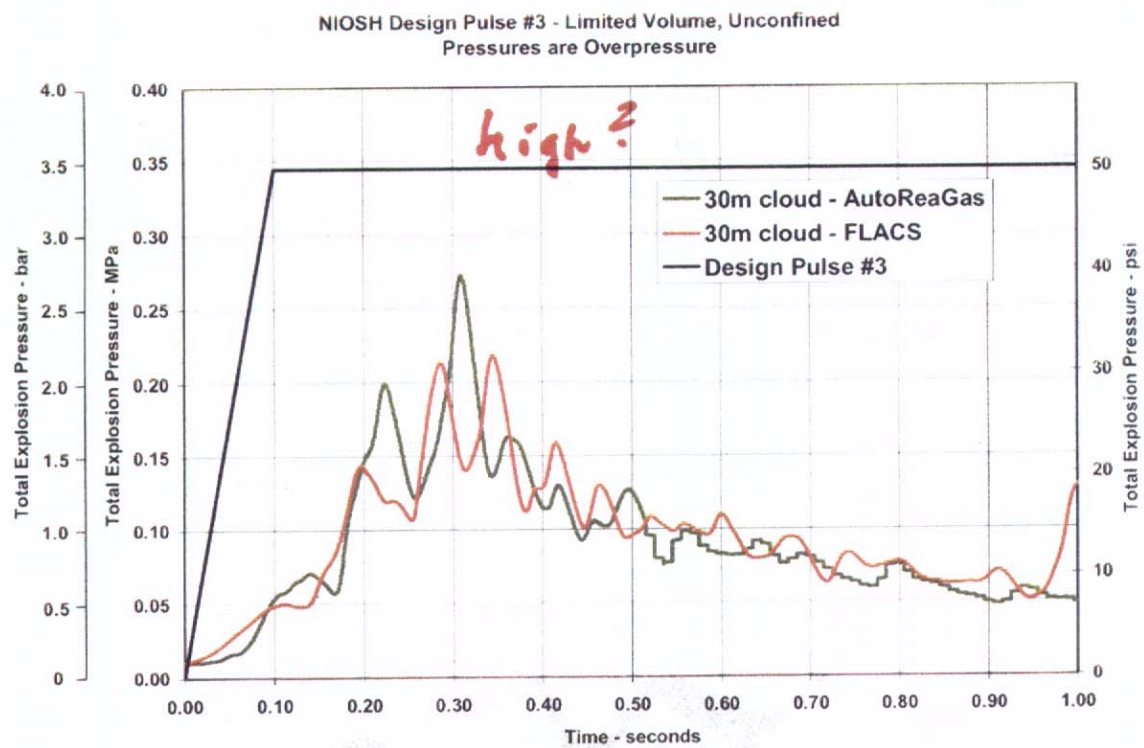

Figure 22 – 345 kPa (50 psi) design pulse and typical model calculations.

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Table 5 – Technical requirements for the recommended pressure pulses for structural design of new seals in different conditions.

Seal Type	SCENARIO 1 **Unmonitored Seals** • **No monitoring** • **No inertization**	SCENARIO 2 **Monitored Seals** • **Managed atmosphere behind seals** • **Inertization as necessary**
Panel and District Seals	• Sealed volume > 50 m (165 ft) long • Run-up length > 50 m (165 ft) • DDT possible • Confined, not vented • Explosive volume fill ≈ 100% • Use 4.4 MPa (640 psi) design pulse • See figure 20	• Sealed volume > 50 m (165 ft) long • Run-up length < 30 m (98 ft) • DDT less likely • Partially confined and vented • Explosive volume fill < 40% • Monitoring criteria at 5 m (16 ft) > 20% CH_4 and < 10% O_2 • Use 345 kPa (50 psi) design pulse • See figure 22
Panel and District Seals	• Sealed volume < 50 m (165 ft) long • Run-up length < 50 m (165 ft) • DDT less likely • Partially confined and vented • Explosive volume fill ≈ 100% • Use 800 kPa (120 psi) design pulse • See figure 21	• Sealed volume > 50 m (165 ft) long • Run-up length < 10 m (33 ft) • DDT less likely • Partially confined and vented • Explosive volume fill < 40% • Monitoring criteria at 5 m (16 ft) > 20% CH_4 and < 10% O_2 • Use 345 kPa (50 psi) design pulse • See figure 22
Cross-cut Seals	• Sealed volume < 50 m (165 ft) long • Run-up length < 50 m (165 ft) • DDT less likely • Partially confined and vented • Explosive volume fill ≈ 100% • Use 800 kPa (120 psi) design pulse • See figure 21	• Sealed volume > 50 m (165 ft) long • Run-up length < 5 m (16 ft) • DDT less likely • Partially confined and vented • Explosive volume fill < 40% • Monitoring criteria at 5 m (16 ft) > 20% CH_4 and < 10% O_2 • Use 345 kPa (50 psi) design pulse • See figure 22

* **NOTE** – Not meeting the requirements for limiting the run-up length, the explosive mix volume and the venting of a possible explosion or the monitoring criteria, necessitates use of the 4.4 MPa (640 psi) design pulse for seal design.