

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

**R. Karl Zipf, Jr., Ph.D., P.E.**

**Michael J. Sapko, M.Sc.**

**Jurgen F. Brune, Ph.D.**

**NIOSH**

**Pittsburgh Research Laboratory**

[www.cdc.gov/niosh/mining](http://www.cdc.gov/niosh/mining)



# 3 Tiered Explosion Pressure Design Criteria

- Monitored seals with limited volume explosive methane-air mix – 345 kPa (50 ksi) pulse
- Unmonitored seals without possible detonation – 830 kPa (120 psi) pulse
- Unmonitored seals with possible detonation – 4.40-0.83 MPa (640-120 psi) pulse



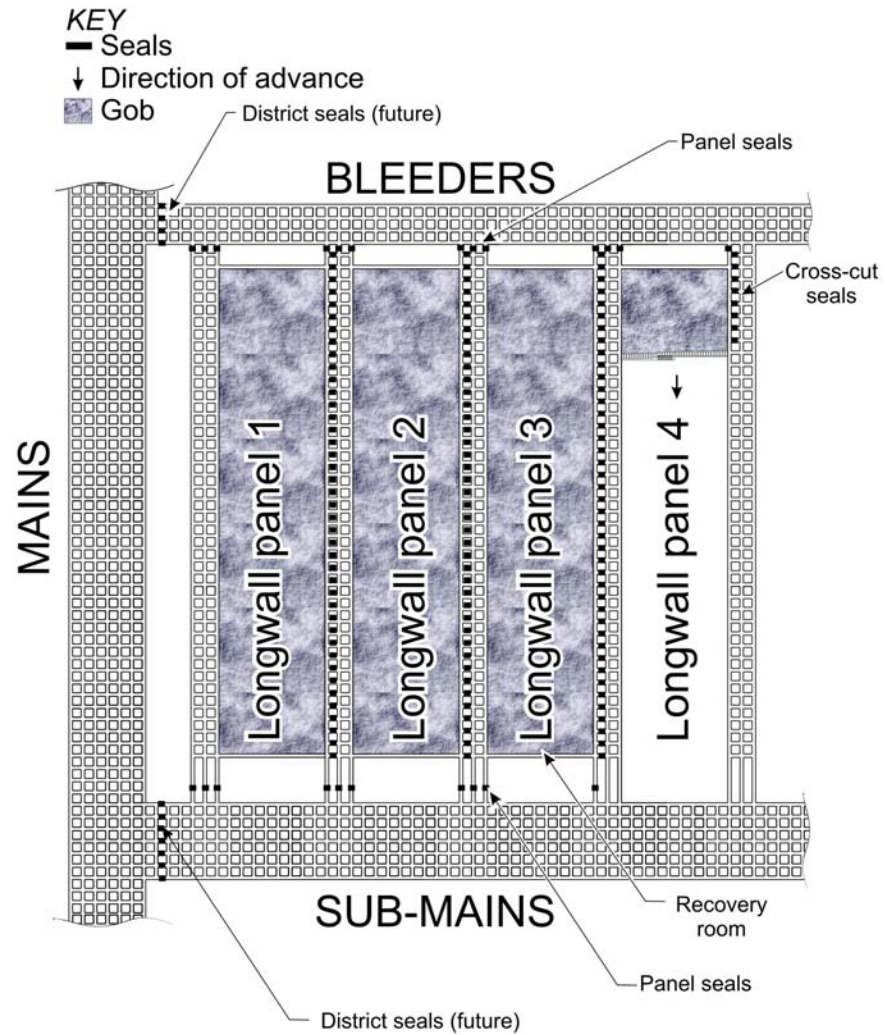
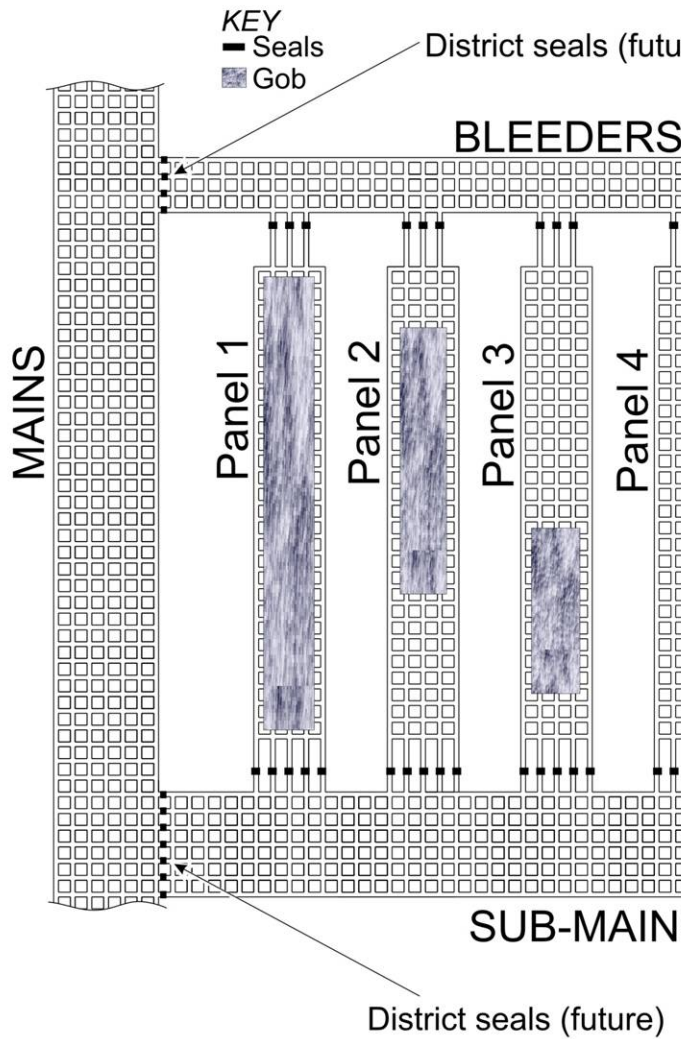






# Known explosions in sealed areas from 1993 to 2006

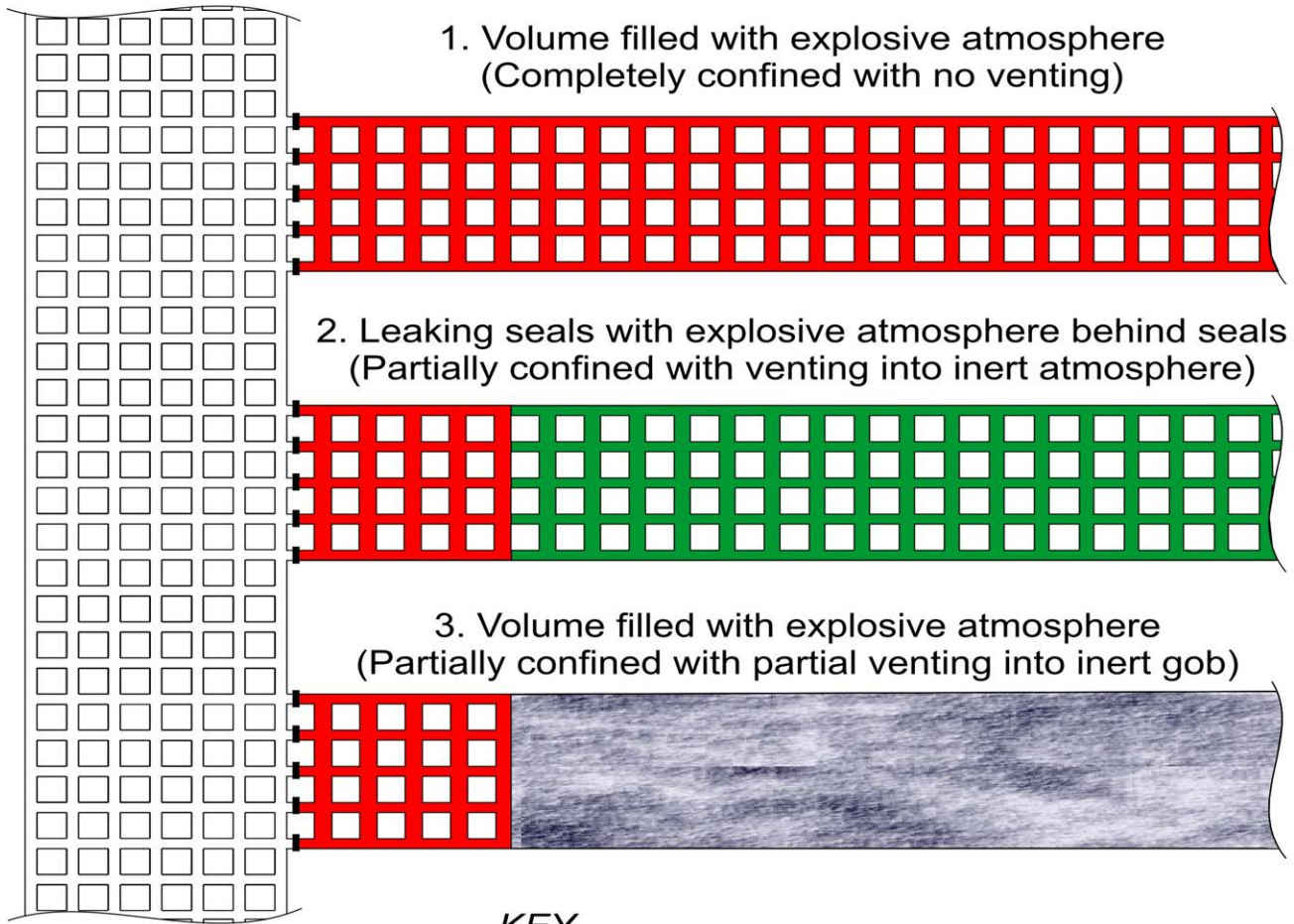
- 1993 – Mary Lee #1 Mine – (2 seals)
- 1994 – Oak Grove #1 Mine – (2 seals)
- 1995 – Gary 50 Mine – (none)
- 1996 – Oak Grove #1 Mine – (6 seals)
- 1996 – Oasis Mine – (3 seals)
- 1996 – Oasis Mine – (more seals)
- 1997 – Oak Grove #1 Mine – (1 seal)
- 2006 – Sago Mine – (10 seals)
- 2006 – Darby Mine
- 2006 – Jones Fork E-3 Mine





# Seal classification and considerations

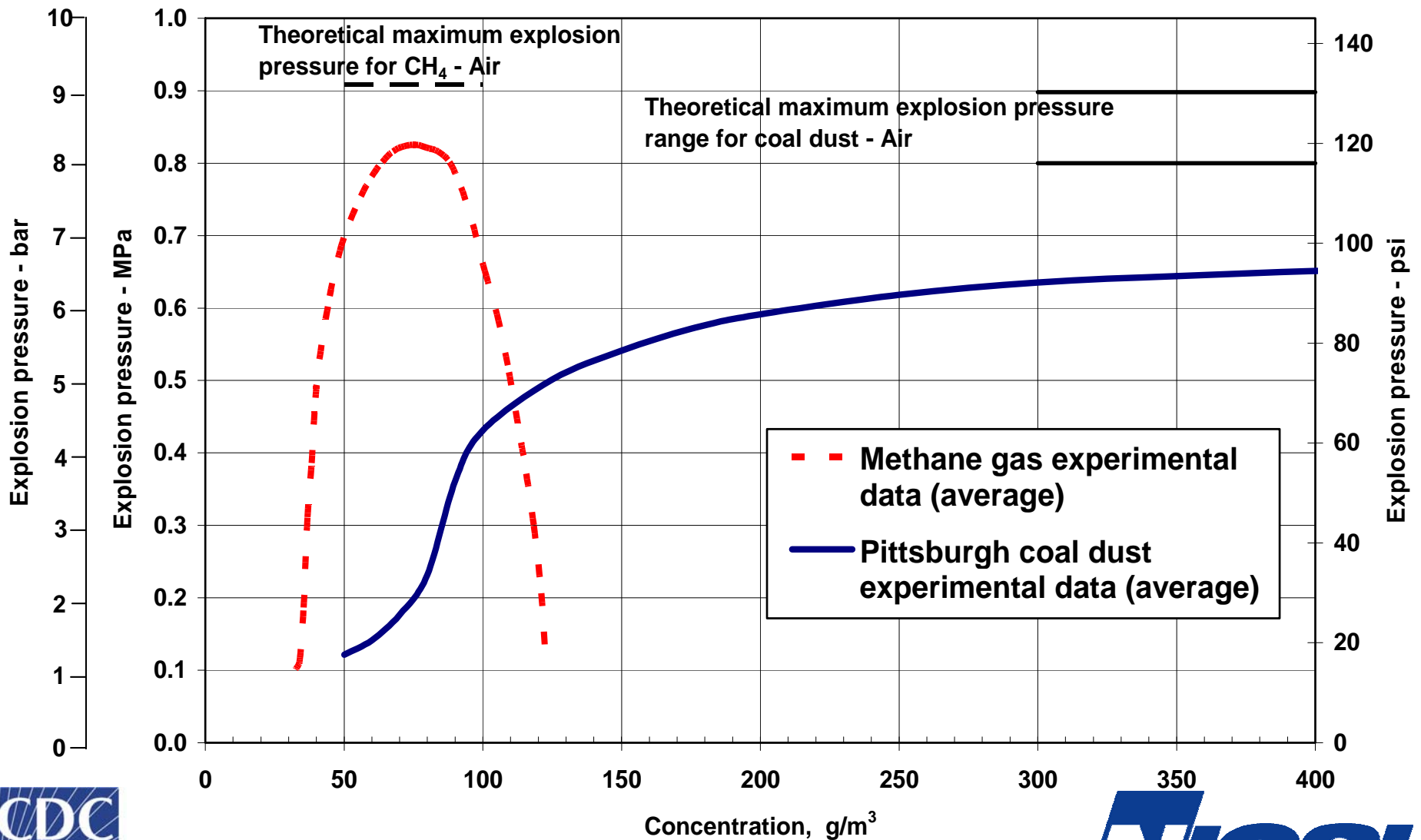
	<b>Explosive volume potential</b>	<b>Convergence loading potential</b>	<b>Leakage potential</b>
<b>District</b>	Very large	Low	Moderate
<b>Panel</b>	Large	Moderate	High
<b>Cross-cut</b>	Small	High	High

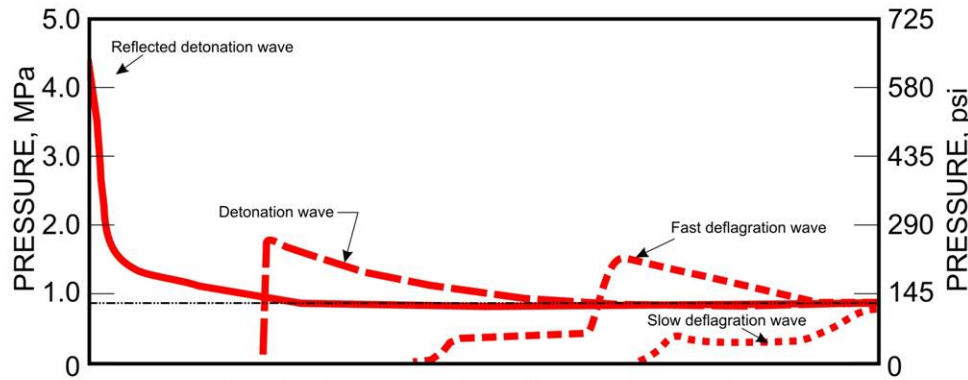


- KEY**
- Seals
  - Explosive atmosphere
  - Inert atmosphere
  - Gob

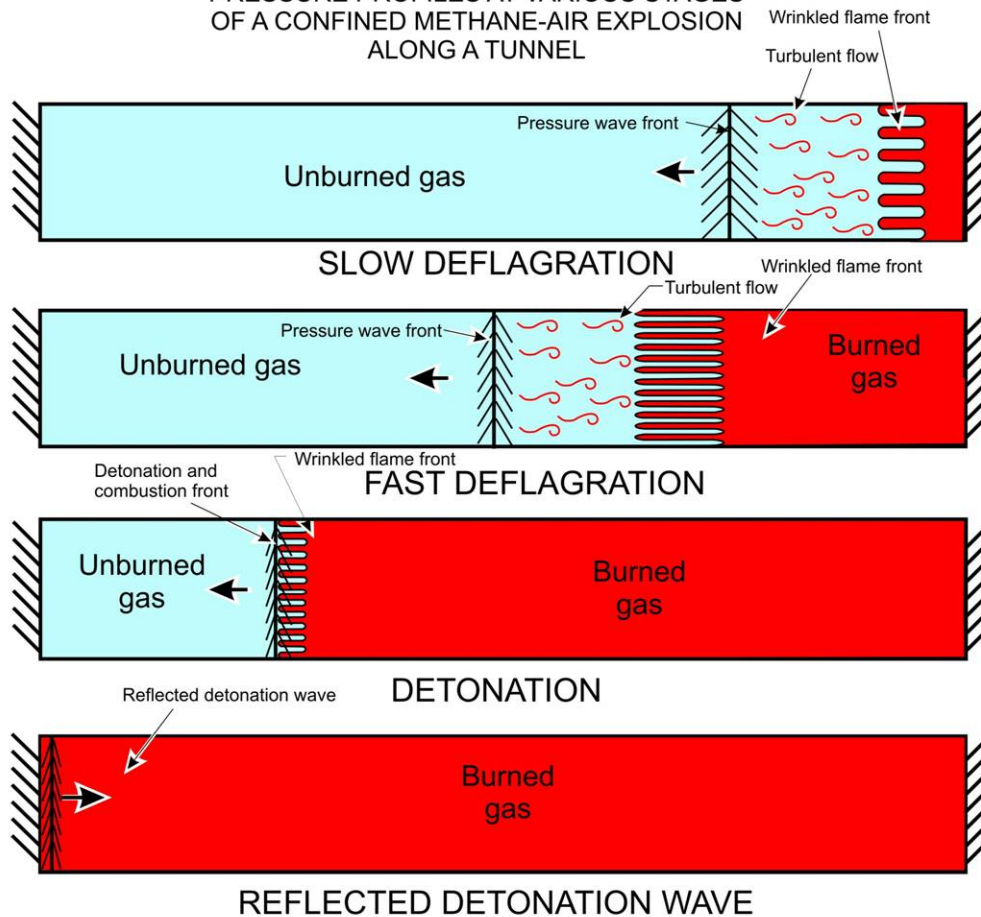
# CV explosion pressure from methane-air and coal dust-air

Comparison of Gas and Dust Flammability  
20-L Chamber data





PRESSURE PROFILES AT VARIOUS STAGES OF A CONFINED METHANE-AIR EXPLOSION ALONG A TUNNEL



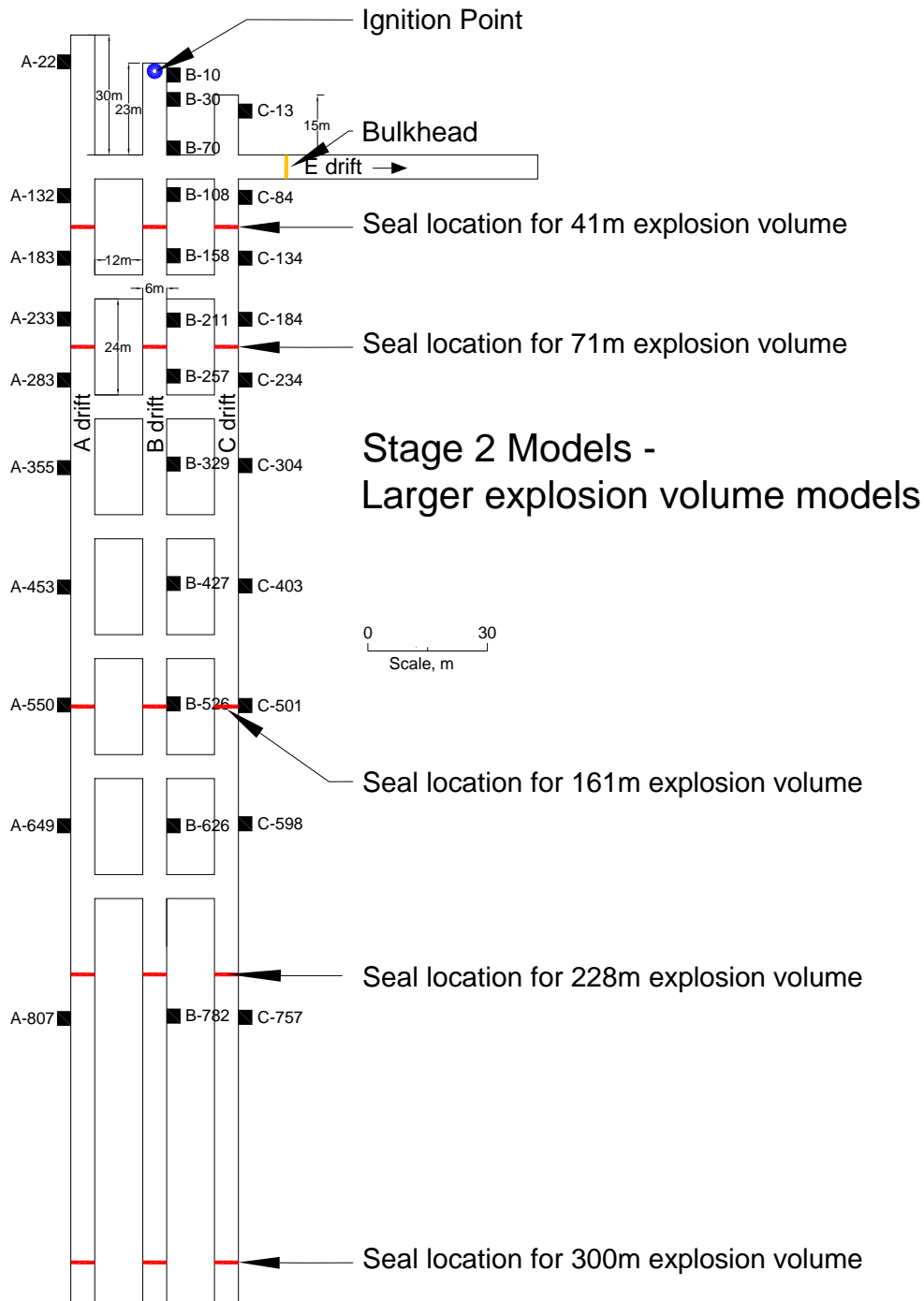
Explosions in tunnels

deflagration to detonation

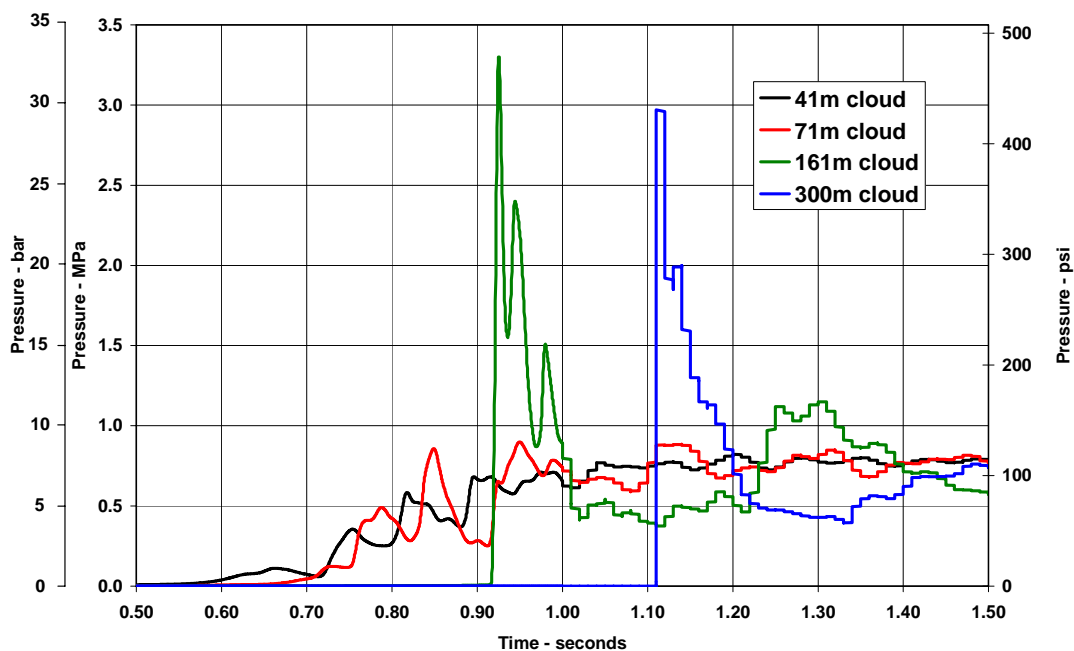
# Explosion Chemistry and Physics for Ideal Mix of 10% Methane and Air

- **Fact 1** – 908 kPa (132 psi) constant volume (CV) explosion pressure for CH<sub>4</sub> and air
- **Fact 2** – 790 to 890 kPa (115 to 129 psi) CV explosion pressure for coal dust and air
- **Fact 3** – 1.76 MPa (256 psi) Chapman-Jouguet (CJ) detonation wave pressure
- **Fact 4** – 4.50 MPa (653 psi) reflected detonation wave pressure

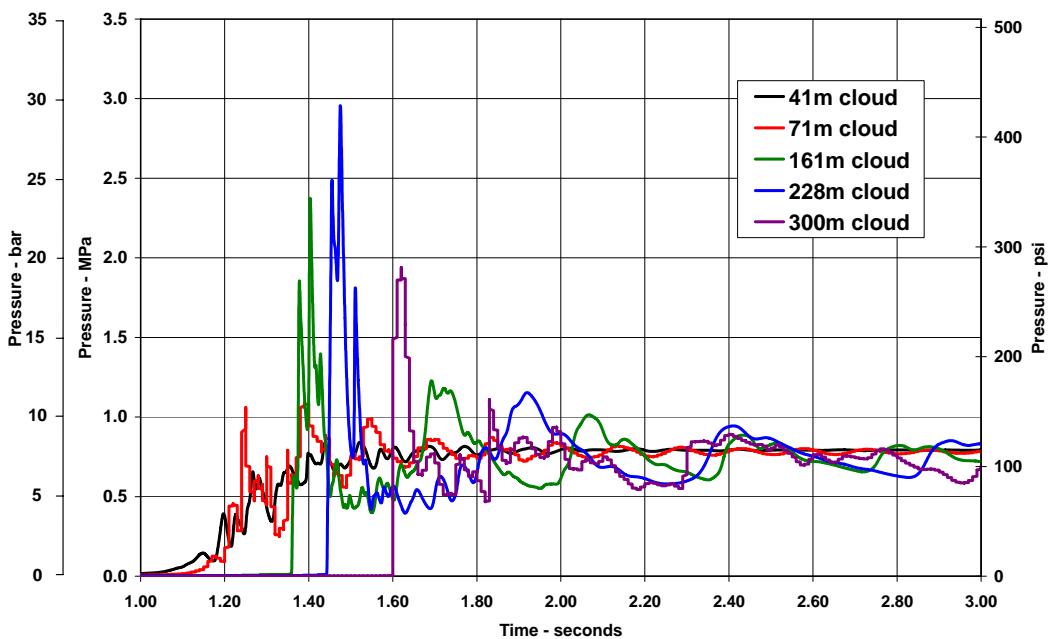
# Stage 2 Models Large volume, confined explosions



Pressure vs Time History at Seal B - Various Cloud Sizes (AutoReaGas)



Pressure vs Time at Seal B - Various Cloud Sizes (FLACS)



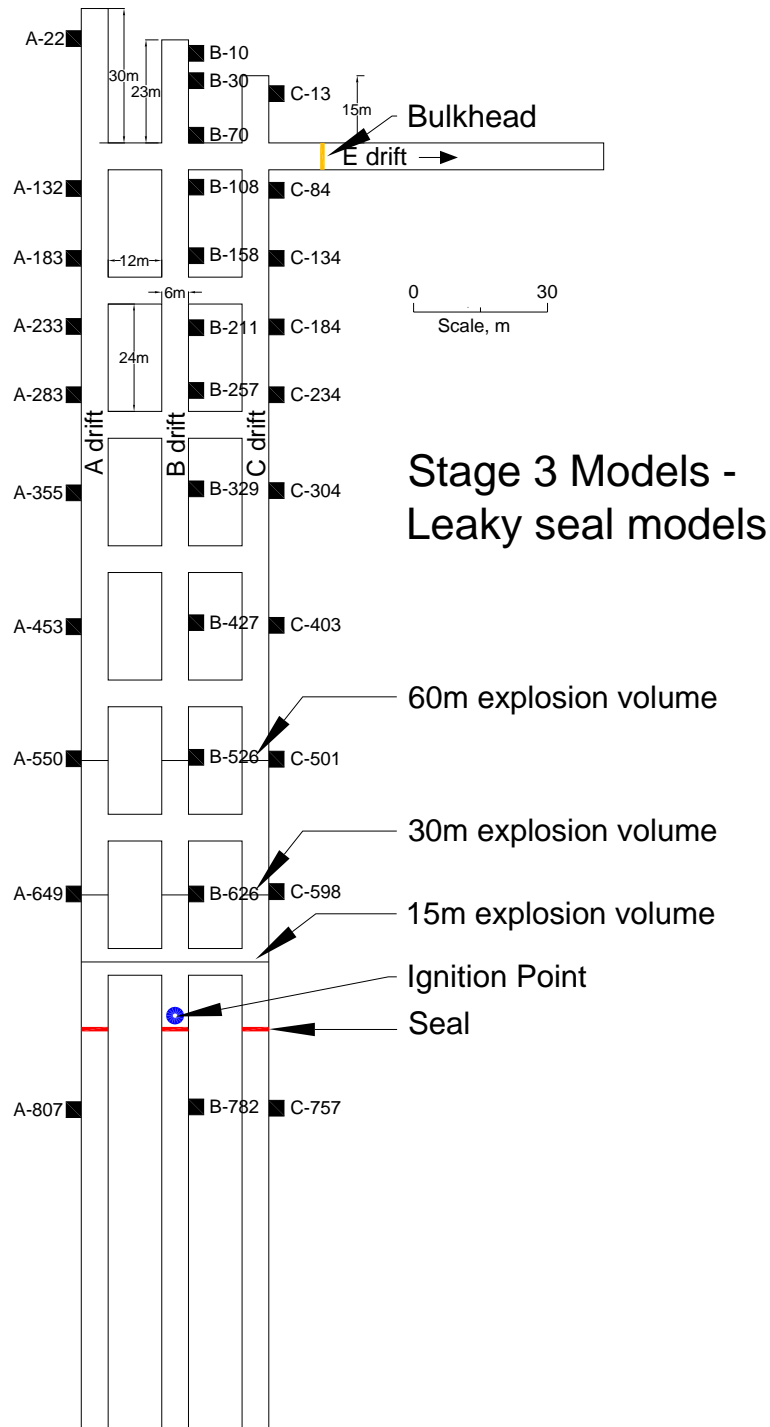
Calculated Pressure-time history at Seal B for large volume confined explosions

AutoReaGas (top)

FLACS (bottom)



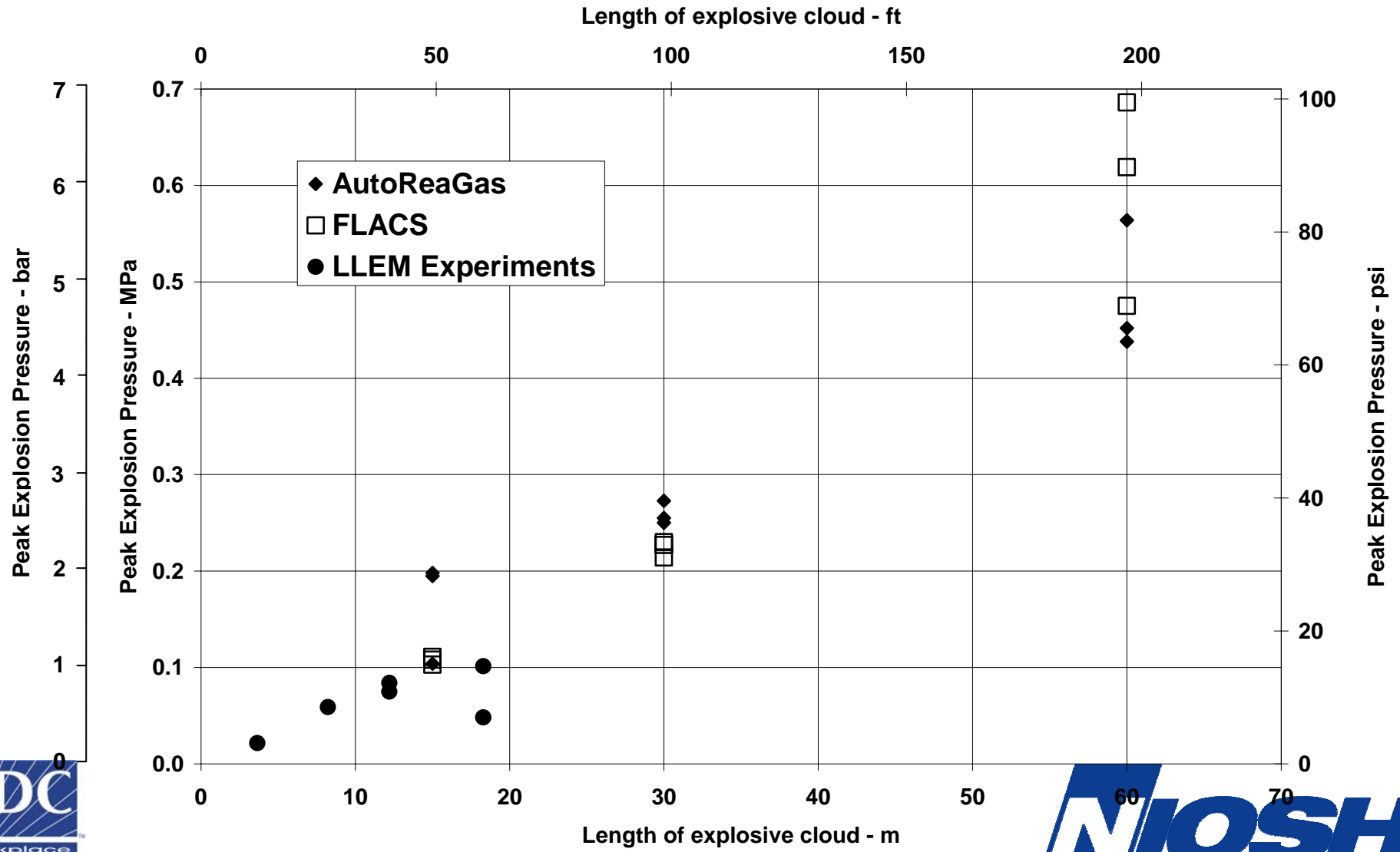
Stage 3  
Models  
partially  
confined,  
partially filled,  
volume  
behind  
leaking seal





# Peak explosion pressure versus length of explosive cloud behind leaking seal

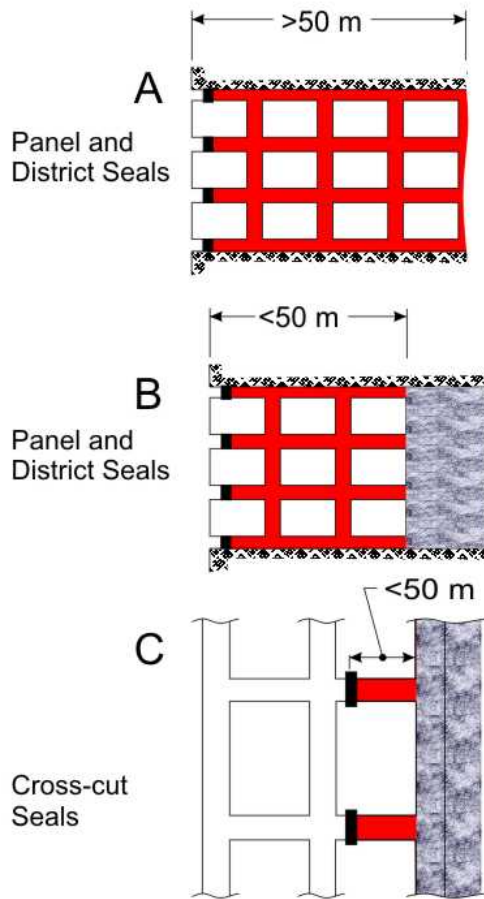
Peak Explosion Pressure versus Length of Explosive Cloud Behind Seal



## SCENARIO 1

Unmonitored seals

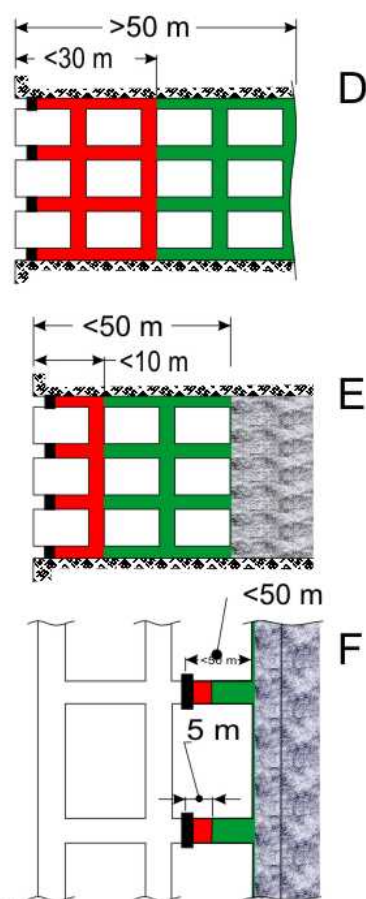
- No monitoring
- No inertization



## SCENARIO 2

Monitored seals

- Managed atmosphere behind seals
- Inertization as necessary

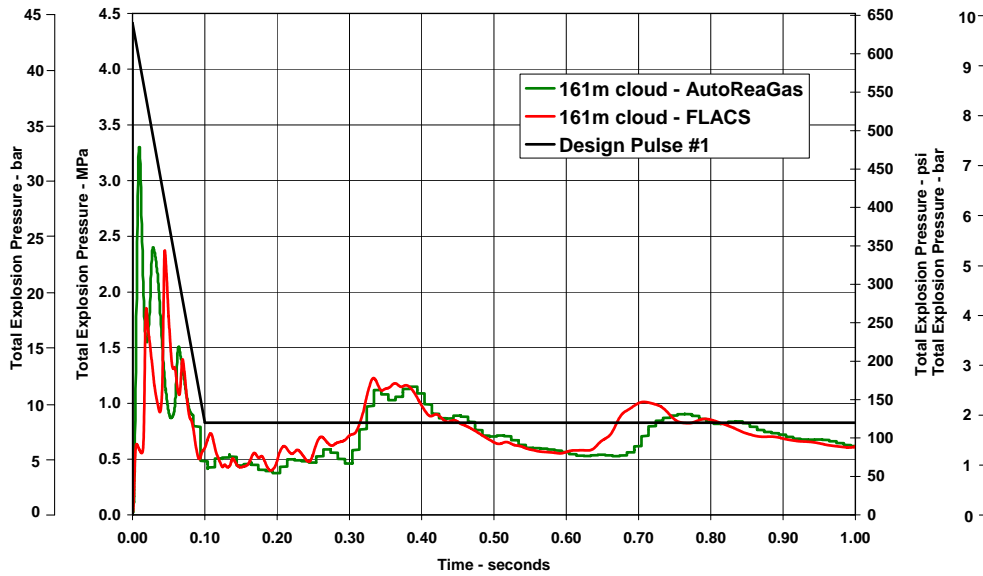


**KEY**

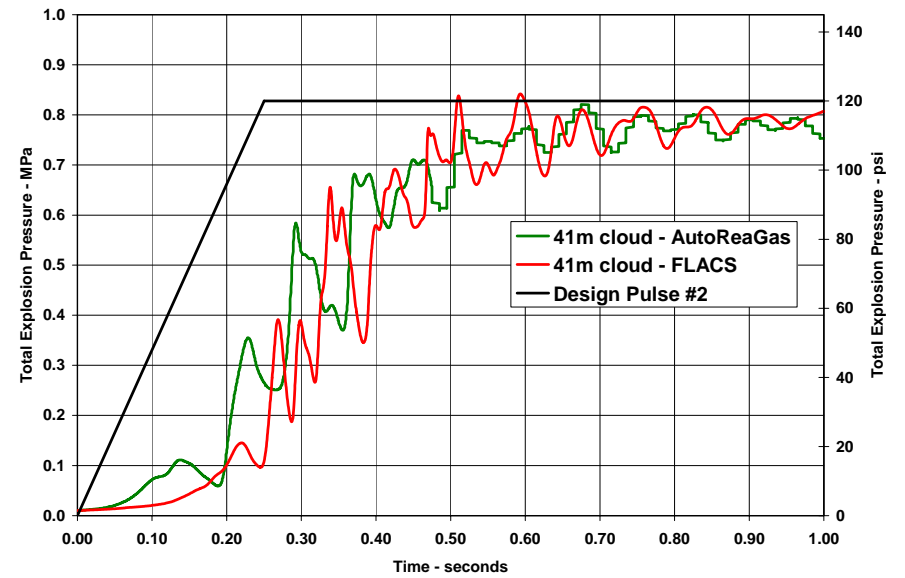
- Seals
- Explosive atmosphere
- Inert atmosphere
- Gob

# 3-tiered explosion pressure design criteria

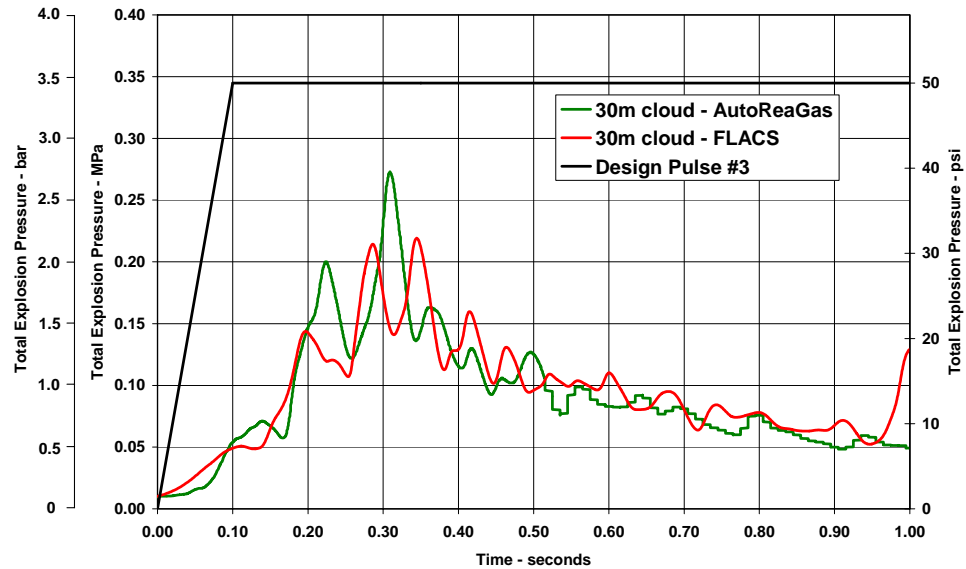
NIOSH Design Pulse #1 - Unlimited, Confined Volume  
Pressures are Overpressure



NIOSH Design Pulse #2 - Limited, Confined Volume  
Pressures are Overpressure



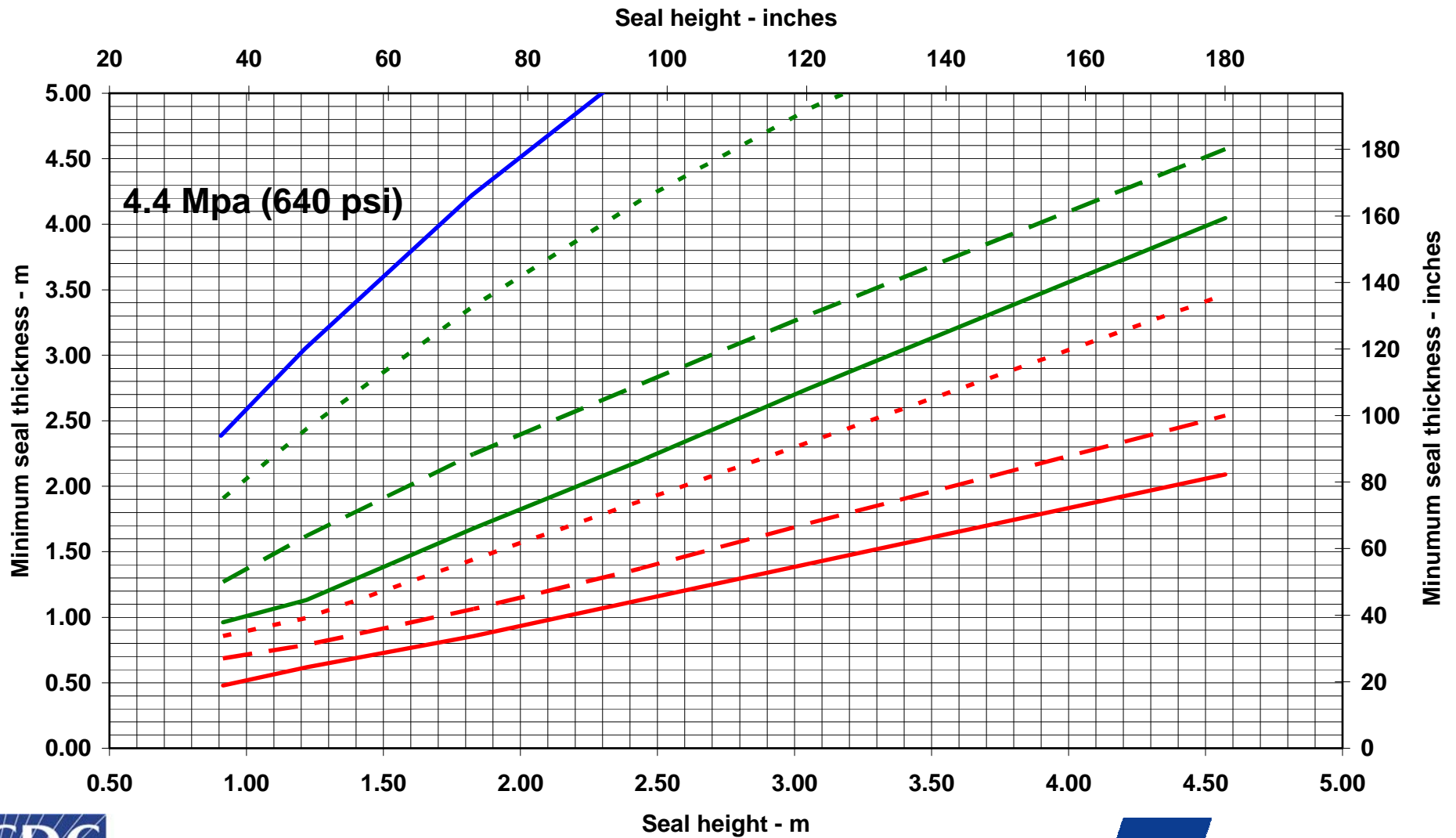
NIOSH Design Pulse #3 - Limited Volume, Unconfined  
Pressures are Overpressure



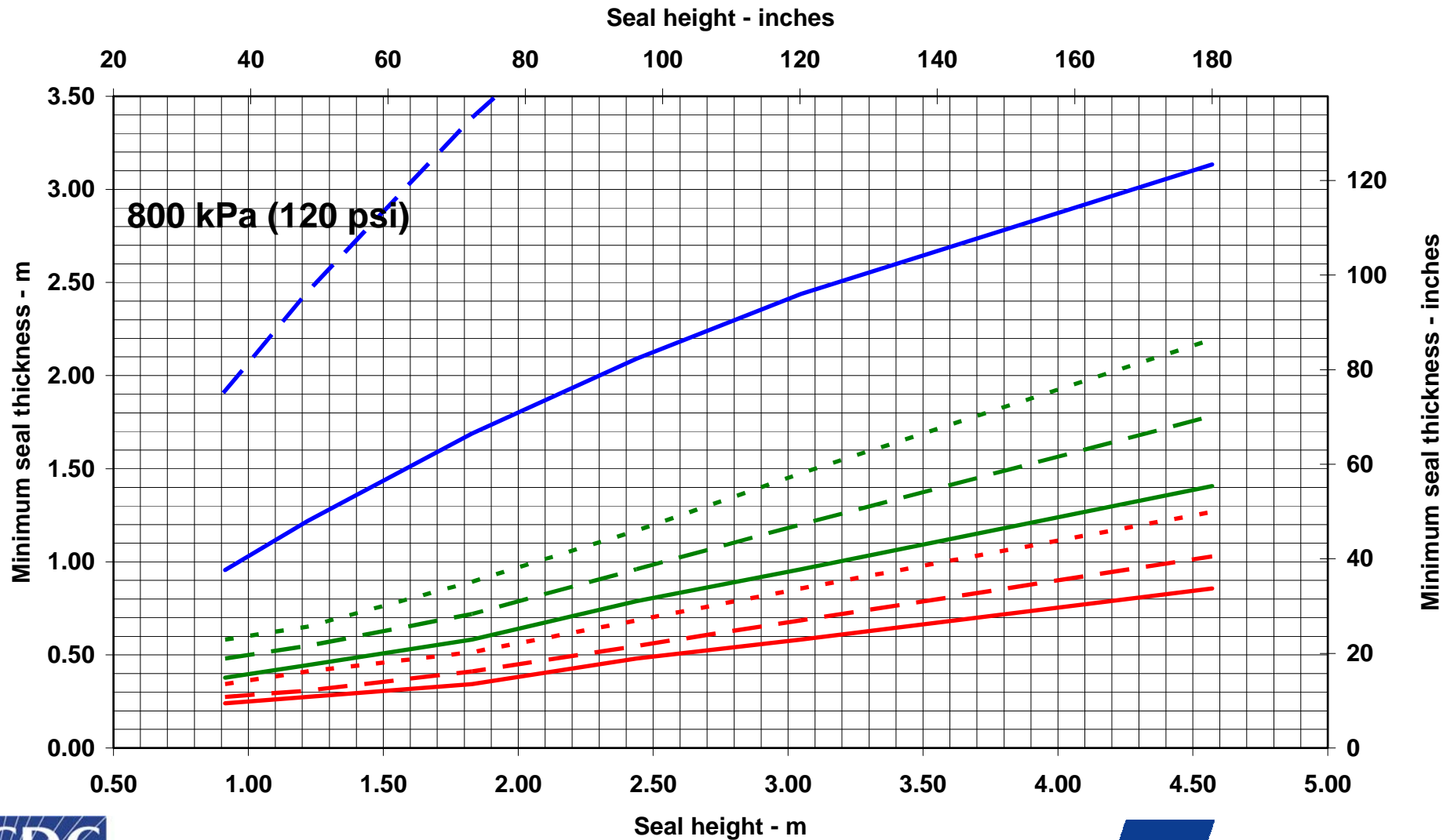
# Three Analysis Methods

- Wall Analysis Code – dynamic & arching
  - Simple plug analysis - static
  - Anderson's arching analysis - static (check)
- 
- Convergent analyses, similar results
  - Sensible comparison to limited LLEM tests

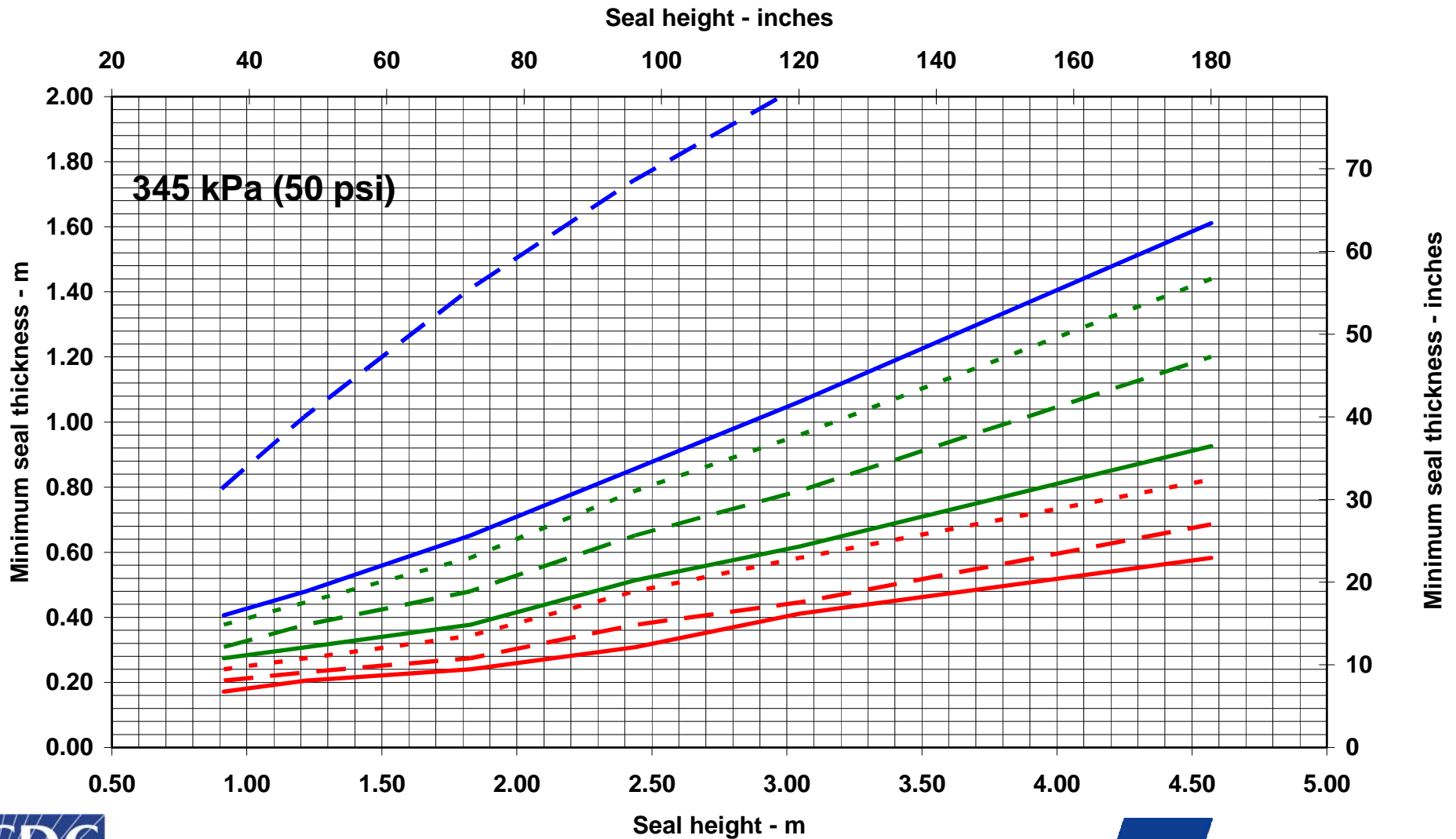
- WAC - 24 MPa (3500 psi) 2.40 S.G. (150 pcf) - 28 day regular concrete
- - - WAC - 10 MPa (1500 psi) 2.40 S.G. (150 pcf) - 1 day HES concrete
- Plug - 5 MPa (750 psi) 1.60 S.G. (100 pcf) - 1 day fly ash / cement
- Plug - 2.8 MPa (400 psi) 0.80 S.G. (50 pcf) - lightweight foam cement
- - - WAC - 17 MPa (2500 psi) 1.92 S.G. (120 pcf) - concrete blocks & mortar
- WAC - 8 MPa (1200 psi) 1.76 S.G. (110 pcf) - 1 day gypsum
- - - Plug - 3.5 MPa (500 psi) 1.60 S.G. (100 pcf) - sprayed gypsum



- WAC - 24 MPa (3500 psi) 2.40 S.G. (150 pcf) - 28 day regular concrete
- - - WAC - 10 MPa (1500 psi) 2.40 S.G. (150 pcf) - 1 day HES concrete
- - - WAC - 5 MPa (750 psi) 1.60 S.G. (100 pcf) - 1 day fly ash / cement
- Plug - 2.8 MPa (400 psi) 0.80 S.G. (50 pcf) - lightweight foam cement
- - - WAC - 17 MPa (2500 psi) 1.92 S.G. (120 pcf) - concrete blocks & mortar
- WAC - 8 MPa (1200 psi) 1.76 S.G. (110 pcf) - 1 day gypsum
- - - WAC - 3.5 MPa (500 psi) 1.60 S.G. (100 pcf) - sprayed gypsum
- - - Plug - 1.4 MPa (200 psi) 0.18 S.G. (11 pcf) - lightweight foam cement

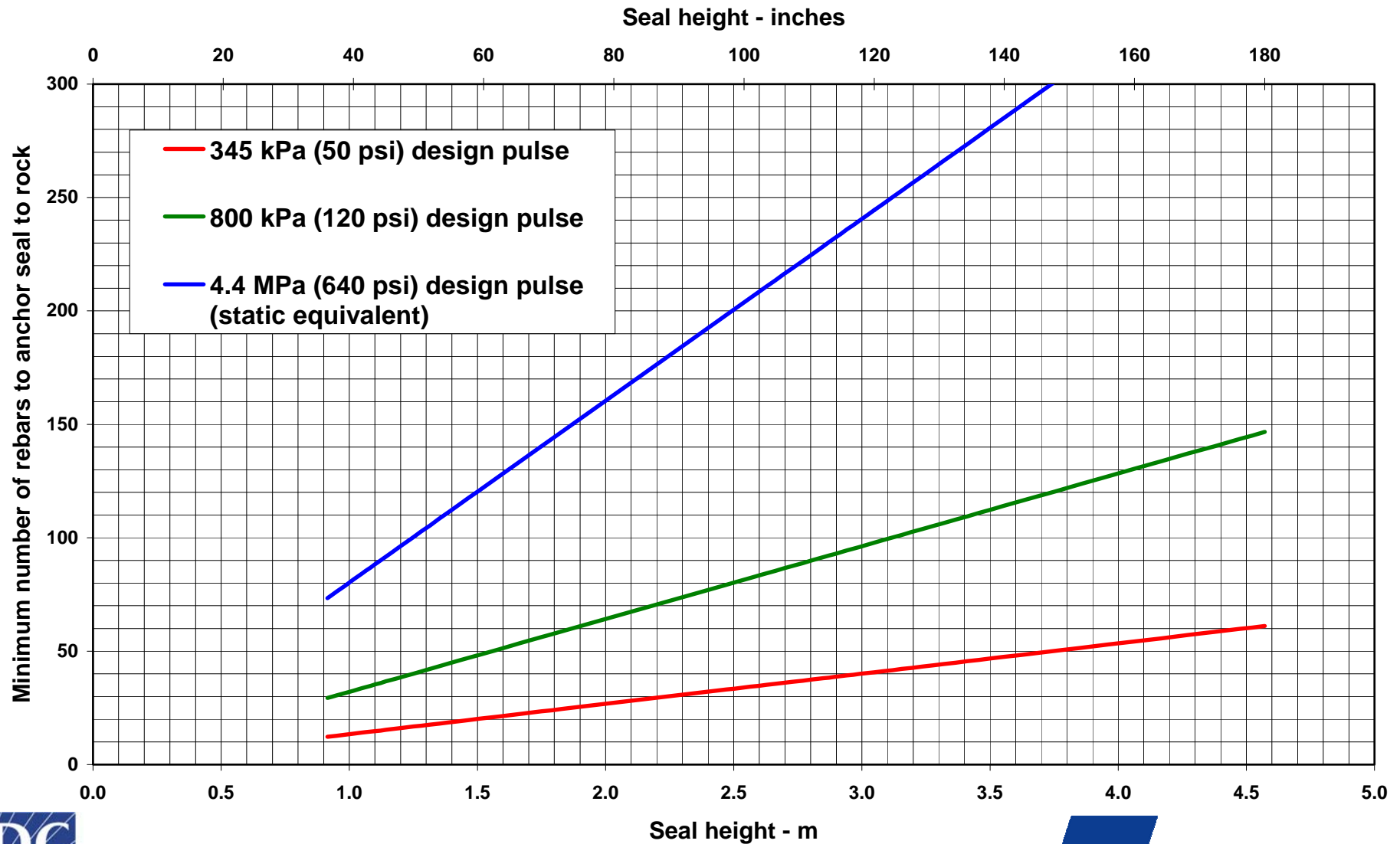


- WAC - 24 MPa (3500 psi) 2.40 S.G. (150 pcf) - 28 day regular concrete
- - - WAC - 10 MPa (1500 psi) 2.40 S.G. (150 pcf) - 1 day HES concrete
- - - WAC - 5 MPa (750 psi) 1.60 S.G. (100 pcf) - 1 day fly ash / cement
- WAC - 2.8 MPa (400 psi) 0.80 S.G. (50 pcf) - lightweight foam cement
- - - WAC - 17 MPa (2500 psi) 1.92 S.G. (120 pcf) - concrete blocks & mortar
- WAC - 8 MPa (1200 psi) 1.76 S.G. (110 pcf) - 1 day gypsum
- - - WAC - 3.5 MPa (500 psi) 1.60 S.G. (100 pcf) - sprayed gypsum
- - - Plug - 1.4 MPa (200 psi) 0.18 S.G. (11 pcf) - lightweight foam cement



# Design chart for number of rebar

Minimum number of reinforcement bars to raise design safety factor by 0.5  
(assuming 6.1 m (20-ft) wide entry, No. 6 bar, Grade 40 steel)





# Recommended procedure for seal design (outline for new seal rules)

1. Information gathering by licensed, professional engineer
2. Seal engineering by licensed, professional engineer
3. Seal construction monitoring by licensed, professional engineer
4. Regular, post-sealing inspection

# 3 Tiered Explosion Pressure Design Criteria

- Monitored seals with limited volume CH<sub>4</sub>-air mix – 345 kPa (50 ksi) pulse
  - Monitoring assures < 5 m explosive mix at seals
  - Explosive volume < 40% of sealed volume
  - Detonation unlikely
- Unmonitored seals without possible detonation – 830 kPa (120 psi) pulse
  - Sealed volume < 50 m (165 ft) long
  - Run-up length < 50 m (165 ft)
  - Detonation less likely
- Unmonitored seals with possible detonation – 4.40 MPa (640 psi) pulse
  - Sealed volume > 50 m (165 ft) long
  - Run-up length > 50 m (165 ft)
  - Detonation possible

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

**R. Karl Zipf, Jr., Ph.D., P.E.**

**Michael J. Sapko, M.Sc.**

**Jurgen F. Brune, Ph.D.**

[www.cdc.gov/niosh/mining](http://www.cdc.gov/niosh/mining)

Review comments welcome

