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CSX Curtis Bay Terminal North Reclaim Tunnel Explosion Modeling Results

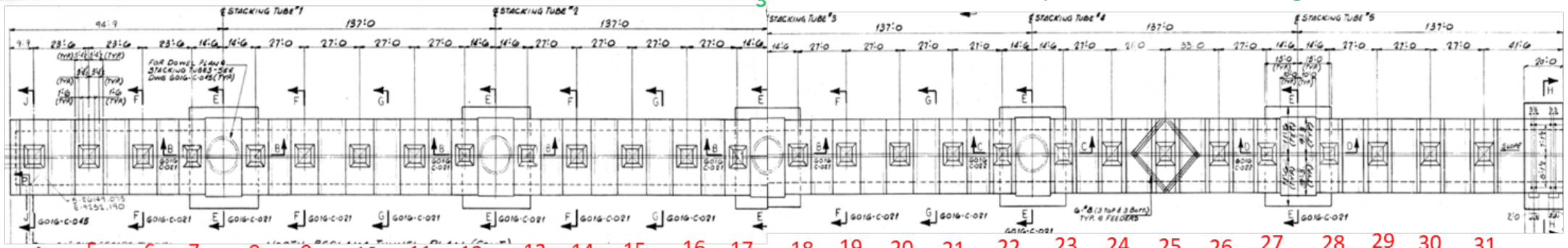
April 4, 2022

Presentation Overview

- Andrew Staszak, SciRisq
- Subconsultant to EFI Global
- Provide a review of computational (CFD) blast modeling
- Share relevant coal dust explosion research
- Structural blast damage indicators
- EFI Global provided blast load estimates to SciRisq
- Modeling efforts focus
- Expand our understanding of the event
- Provide technical explanations of critical elements of the event
- Generate feedback that may aid the facility in future design and operational decision making
- Help delineate plausible scenarios

North Coal Reclaim Tunnel Configuration

tower No. 1 2 3 4 5

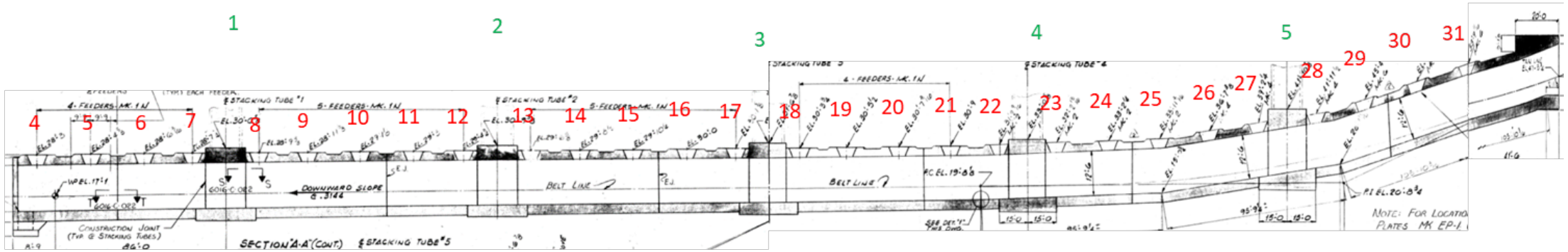


4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

hole/vibrator No.

NORTH RECLAIM TUNNEL PLAN

1 2 3 4 5



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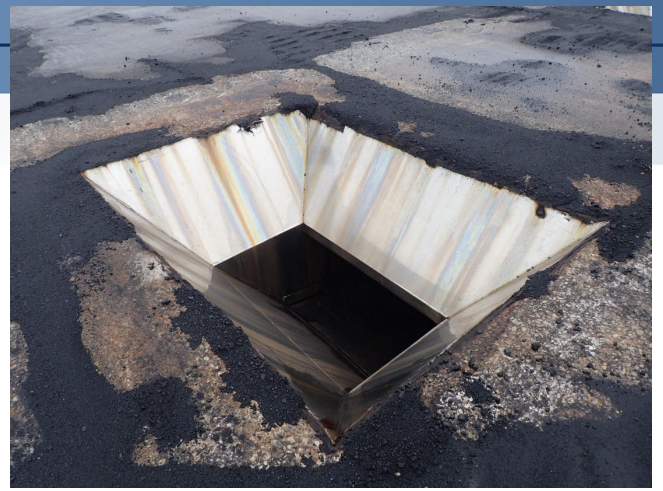
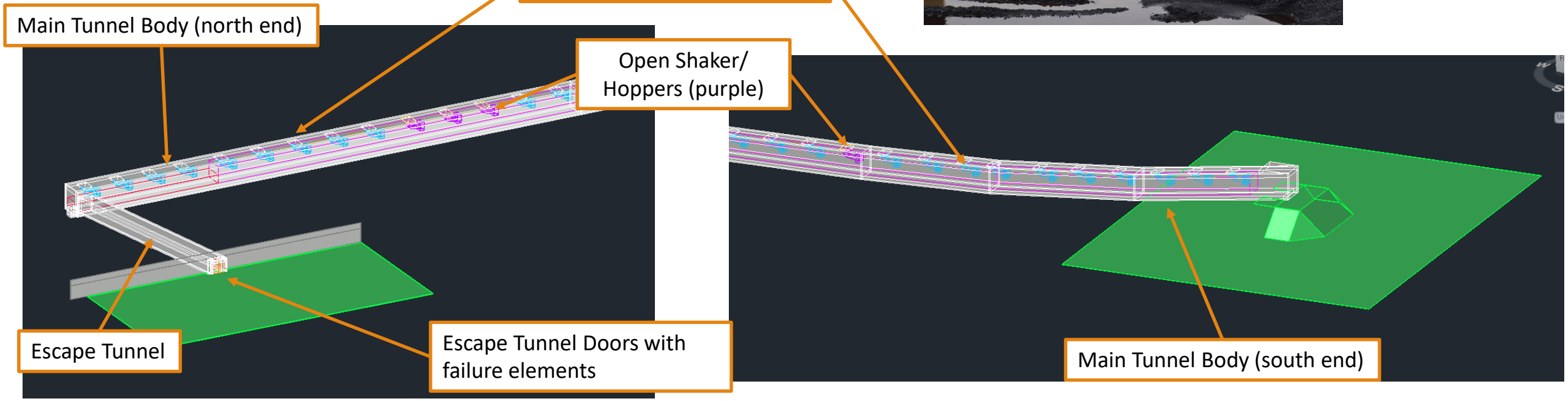
North Reclaim Tunnel Elevation

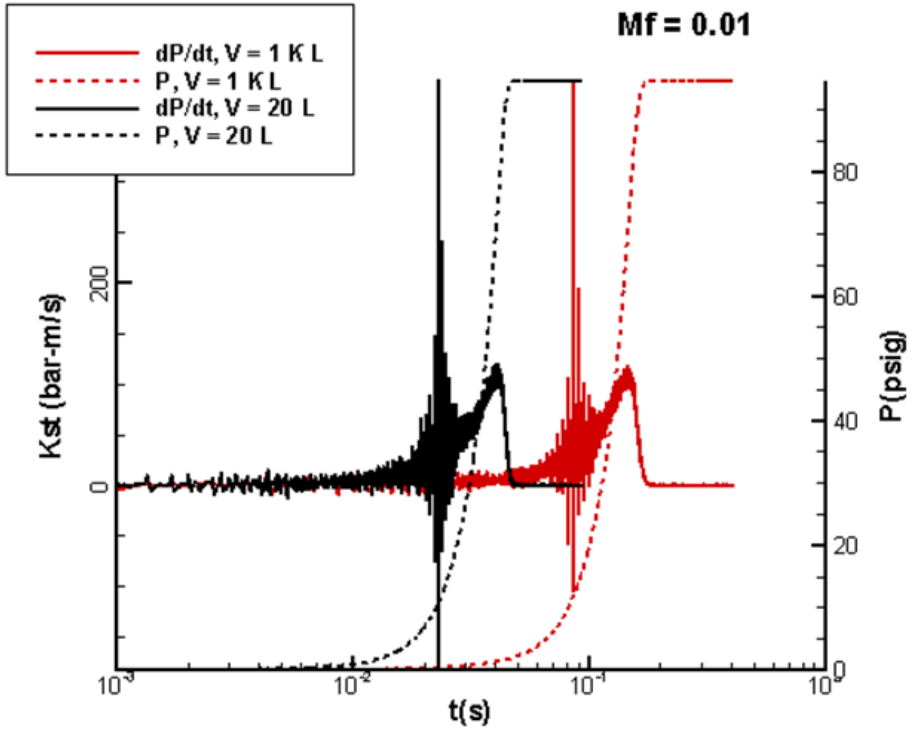
CFD Model Overview





northern half view – looking ESE

southern half view – looking ENE



- Coal Dust
- ASTM sample tests showed K_{st} = 126 bar m/s & P_{max} = 7.8 bar; performed in 20L vessel
- Assessments have shown this is produced if dust/air volume is burned at a rate of ~3.5 m/s (M_f=0.01); same rate seen in 1D environment with no obstacles; similar to laminar burning velocity of a gas/air mixture
- Past studies have shown that dust explosions in 1D environments with obstacles - increases flame speed on the order of 10 times
- Propane
- Confinement of propane/air clouds are well known to accelerate burn rate
- Flame speeds in 1D with obstacles can approach M_f=1 or higher for stochiometric mixtures; will be less if cloud is lean or rich
- Methane
- Confinement of methane/air clouds are also well known to accelerate burn rate
- Flame speeds in 1D with obstacles can approach M_f=0.5 or higher for stochiometric mixtures; will be less if cloud is lean or rich

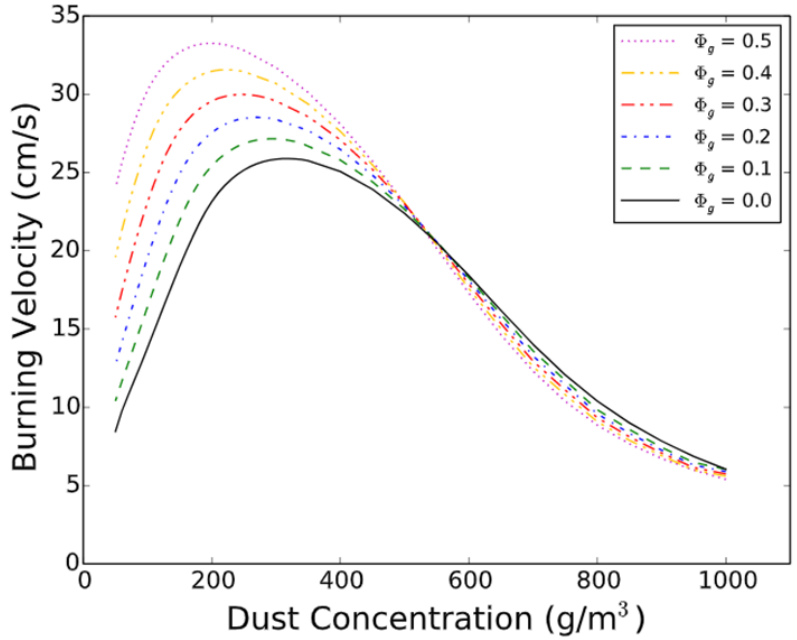


Fig. 5. Burning velocity of coal dust/methane gas mixtures in air with different initial gas equivalence ratios using the MP1 reaction mechanism.

- Bulk coal can contain entrained methane
  - Methane can be released naturally
  - Methane release can be increased during the agitation (i.e., friction, grinding, breaking) of transfer systems
  - Methane release in 1D environments such as a transfer tunnel with limited ventilation could develop pockets of detectible methane clouds
- Mixed Dust-Gas-Air Combustion
  - Introduction of gas (i.e., methane, propane) within a combustible dust cloud is know to “boost” flame speeds that result in higher energy release explosions
- NFPA 68
  - Presence of ignitable gas within combustible dust-air mixtures reduces both LFL and the amount of energy required to ignite cloud and results in both increased maximum pressures and rate of pressure rise

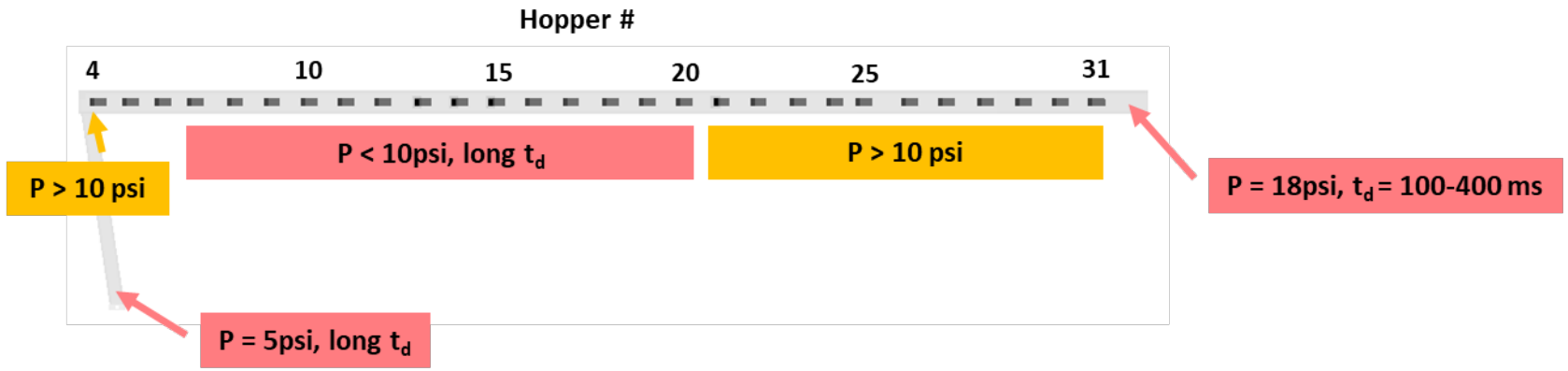
- Qualitative information collected from video that captures dynamics of event at tunnel openings
  - South portal opening, escape tunnel egress, and at uncovered hoppers (13, 14, 15 and 21)
- Relevant background
  - Pressure front will lead the combustion reaction front for dust and gas cloud explosions that occur with a burn rate of M_f=1, which represents deflagration events
  - Pressure front induces velocity resulting in fuel-air cloud ahead of moving combustion reaction front which would result in unburned cloud being discharged from the tunnel openings listed above
  - If a fuel-air cloud discharges to an ambient environment there is the potential of combustion external to the tunnel which is dependent on mixture with the introduction of a new oxidizer (air) and potential ignition sources
  - The long tunnel's aspect ratio (i.e., 1-dimentional) and limited venting will result in generation of quasi-static pressure within the tunnel due to heating the air in the tunnel




Approximate Blast Estimates from Structural Damage Indicators

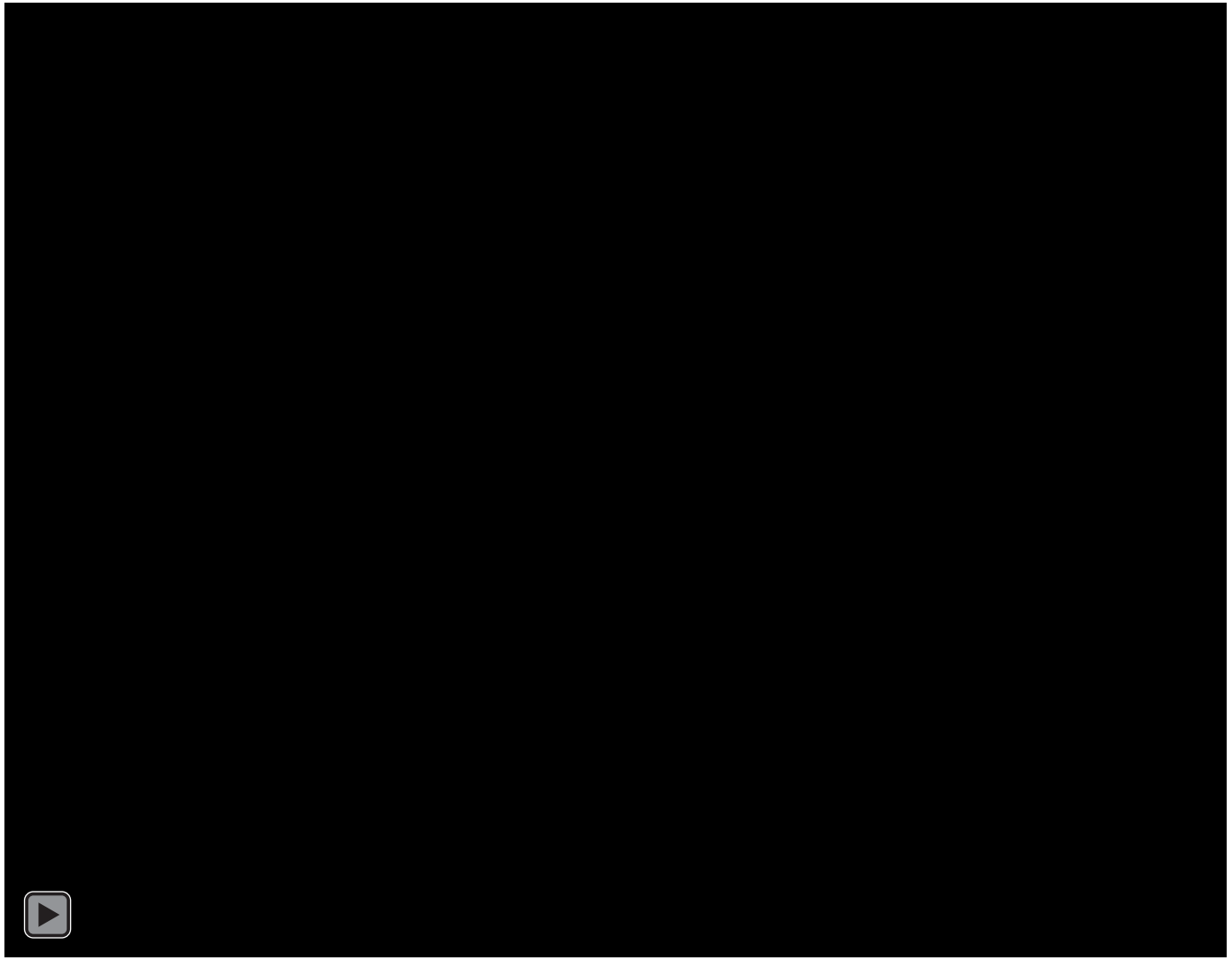
- Based on nonlinear dynamic single-degree-of-freedom analysis
- Using simplified pressure waveforms

Incident Pressure and Durations – Approximate from field observations

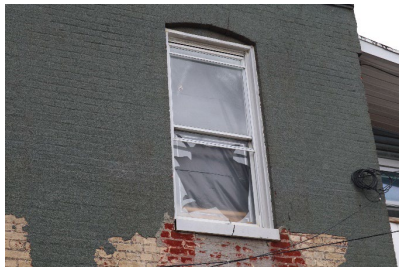


Coal Dust Explosion Simulation with Ignition near Shaker 10

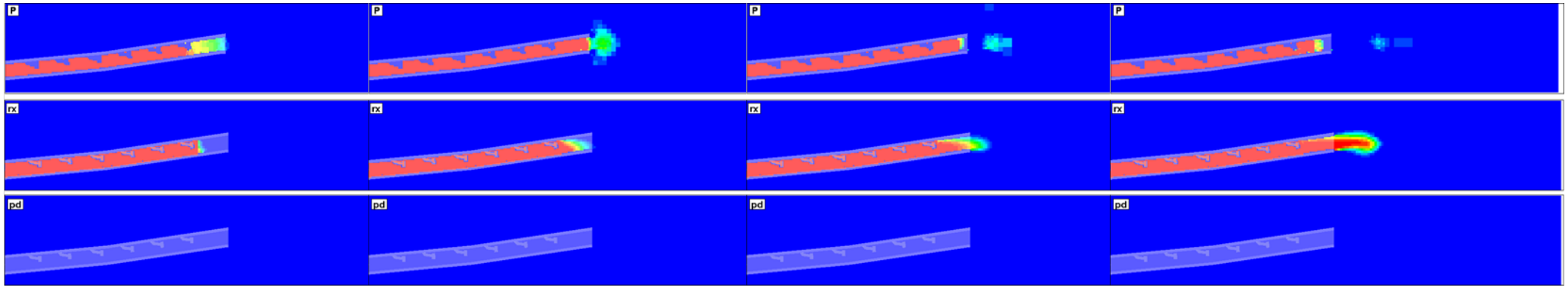
- Coal dust cloud uniformly distributed along most of tunnel length
- 3m/s burn velocity
- Simulation observations
- Pressure wave (P) ahead of combustion reaction front (rx)
- Unburnt coal (rx) driven out of south portal opening
- Unburnt coal (rx) dispersed from south portal opening has large fireball potential
- The south portal plume effect will be similar in other simulations since the effect is geometry driven
- Other ignition locations along tunnel
- Other explosive sources/mixtures
  - Coal dust, methane, propane



Coal Dust Explosion Simulation with Ignition near Shaker 10

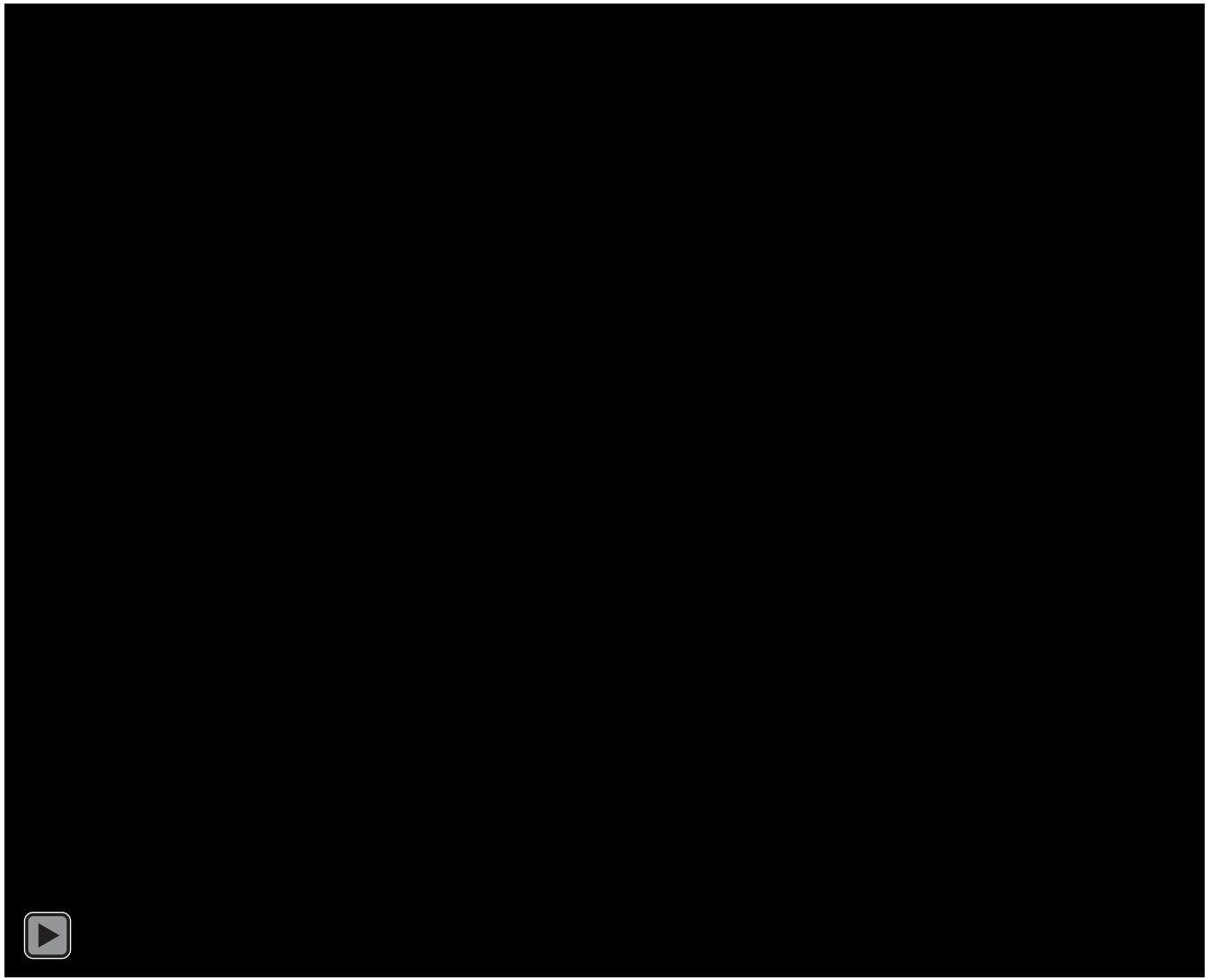


- Dynamics similar to gun blast/flash event
- Pressure front from internal deflagration forces coal-air mixture out the south end of the long tunnel
- Coal-air cloud further mixes with ambient air affecting flammability limits
- Due to under expanded release, flow accelerates and pressure drops just before exiting portal
- A compression front forms with a high-pressure “bubble” further downstream of the portal that can represent an ignition source
- This can happen long before any product from the internal explosion reaches the exit and is most likely the source of the observed fire ball
- Expected south fireball could extend 50-75ft out of the end of the south portal



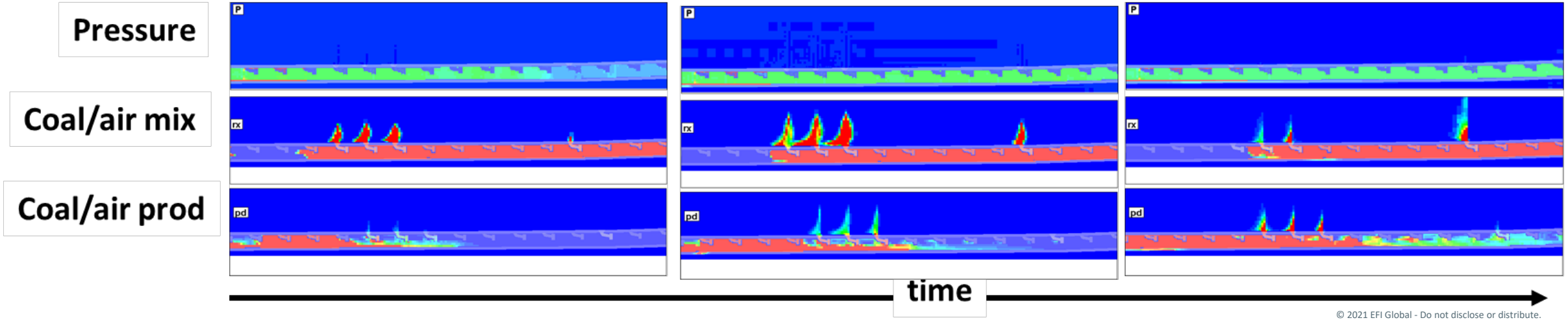
Coal Dust Explosion Simulation with Ignition near Shaker 10

- Additional simulation observations
- Ramp up of quasi-static pressure within tunnel
- Due to small openings in system compared to total tunnel volume
  - Analogous to putting your thumb over the top of a shaken soda bottle and leaving a small opening with your thumb
- Results in long duration pressure loading
  - High impulse
- Drive unburnt coal (rx) out of the open loading holes at grade
  - Dust geysers



Coal Dust Explosion Simulation with Ignition near Shaker 10

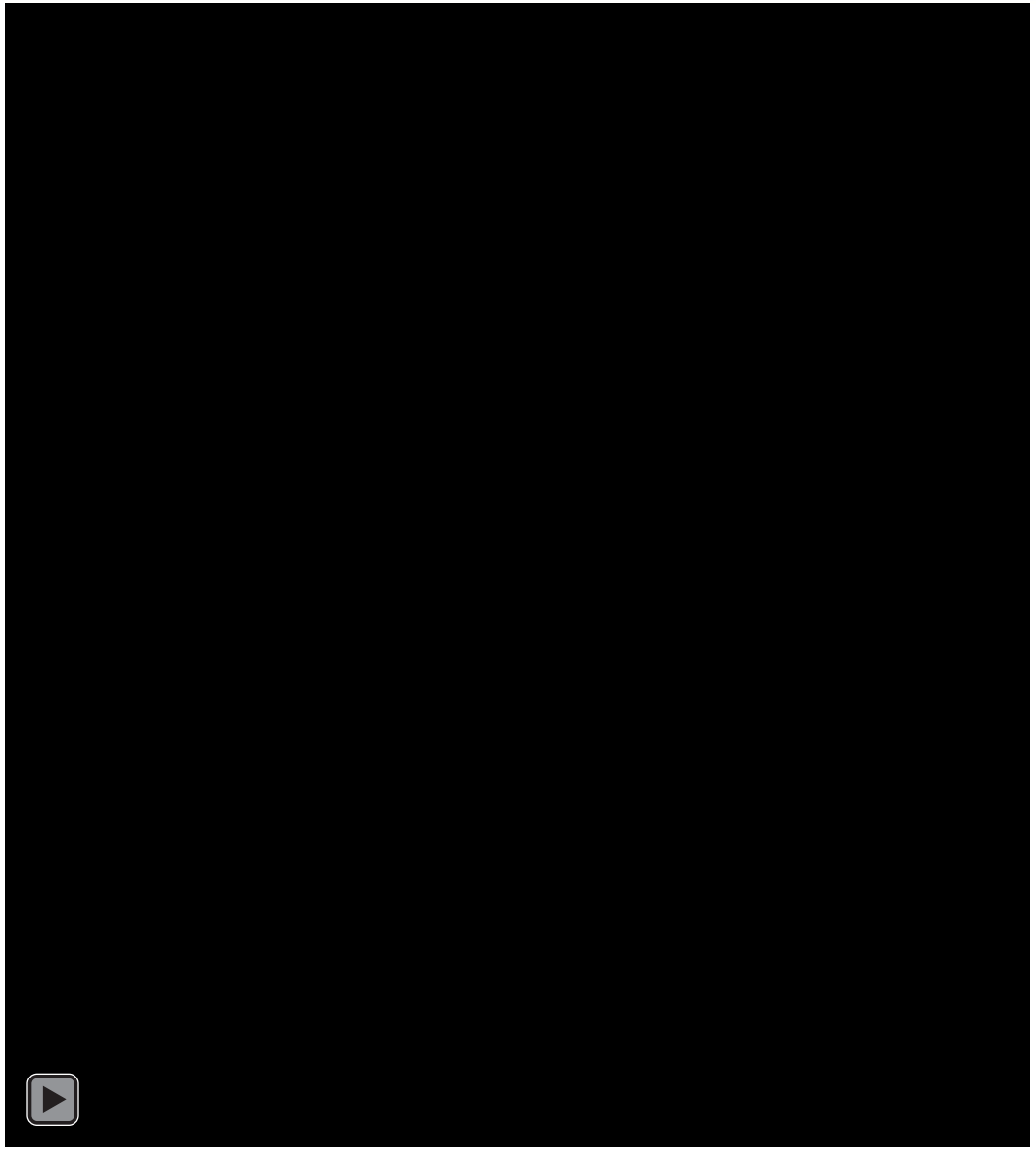
- Geyser observations
- Pressure front from internal deflagration forces coal-air mixture out the open loading holes at grade
- No external high-pressure “bubbles” forming above openings external to tunnel
  - Therefore, external ignition of coal-air cloud not likely
- Product of combustion from internal deflagration eventually vents from loading openings but would not be expected to accompanied with a fire ball
- Discharge plumes could extend 75ft or more vertically



Coal Dust Explosion Simulation with Ignition near Shaker 10

Simulation observations at escape tunnel

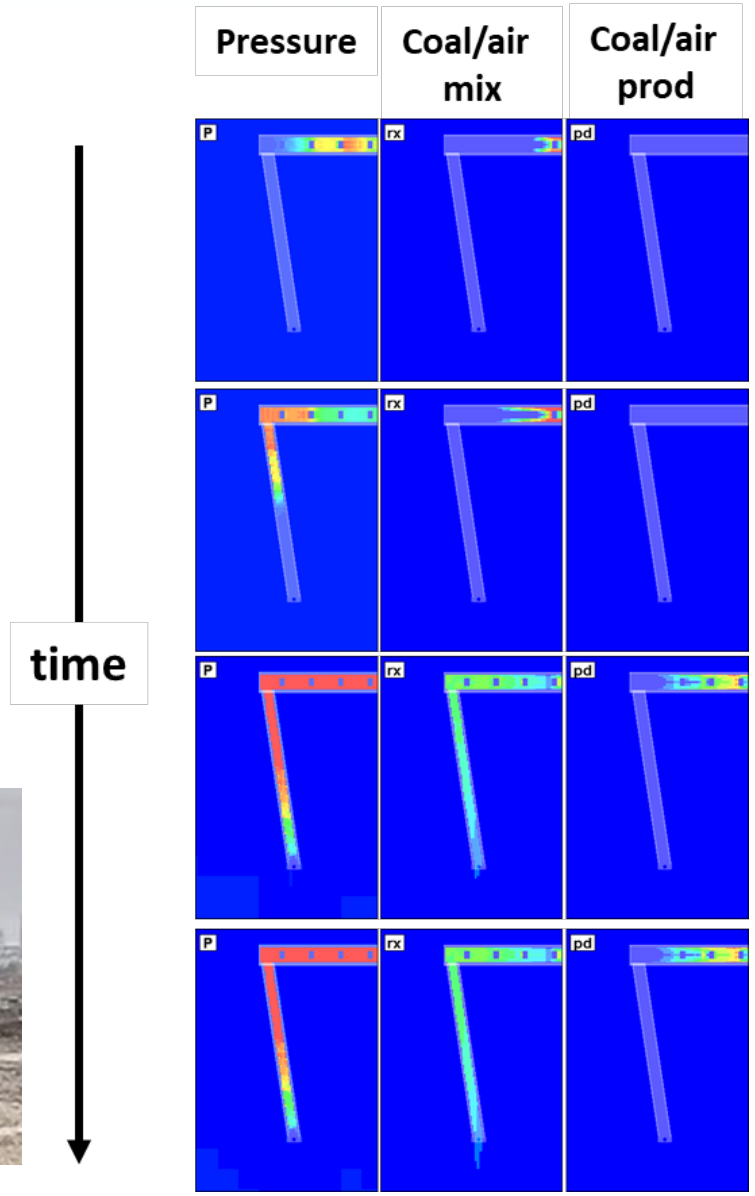
- Ramp up of quasi-static pressure within escape tunnel
- Due to small openings in system compared to total tunnel volume
  - Analogous to putting your thumb over the top of a shaken soda bottle and leaving a small opening with your thumb
- Results in long duration pressure loading
  - Bottle cart in escape tunnel launched due to long duration loading
- Unburnt coal (rx) driven towards north end of tunnel
  - Unburnt coal is diluted as it makes a 100deg turn to move down the escape tunnel
  - Unburnt coal observed on north half of escape tunnel walls



Coal Dust Explosion Simulation with Ignition near Shaker 10

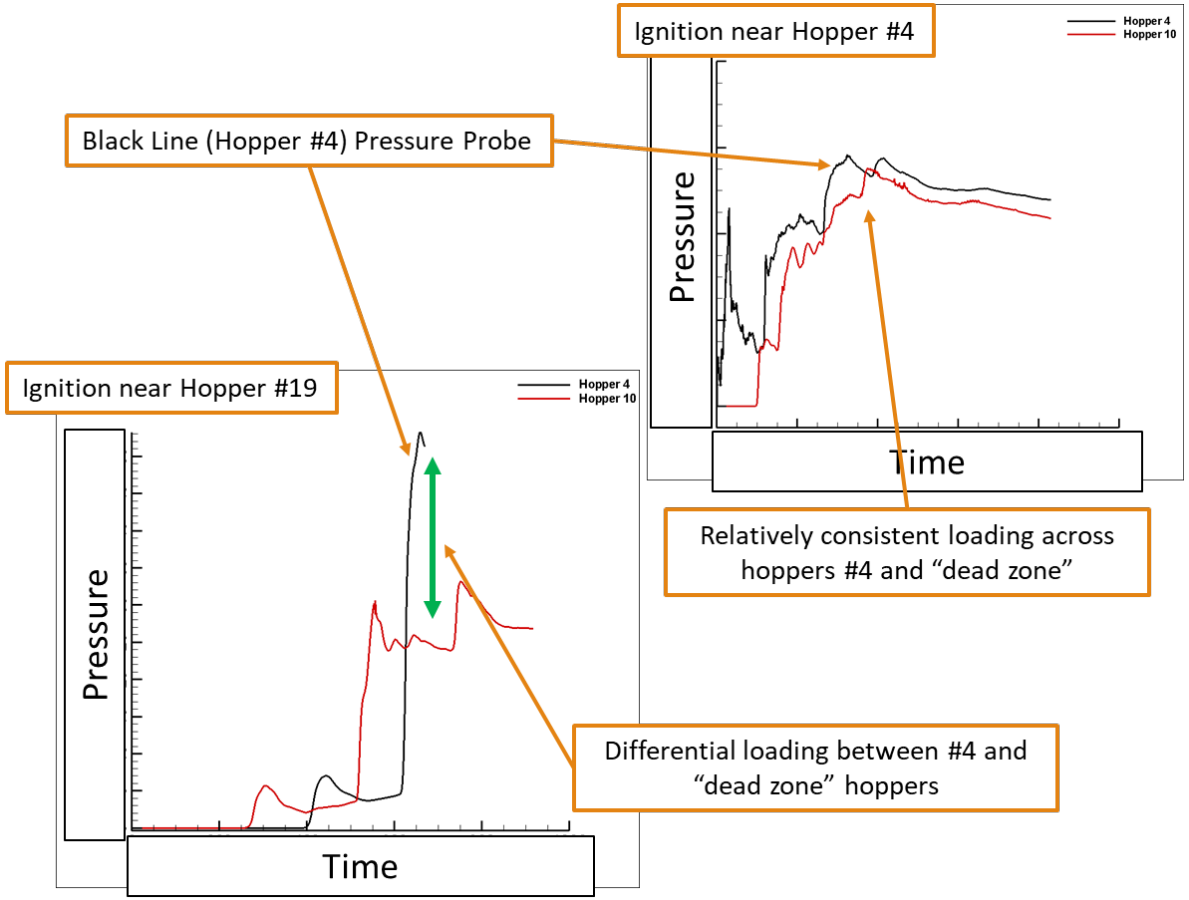
Escape tunnel observations

- Pressure front from internal deflagration forces coal-air mixture down and out of escape tunnel
- Coal-air mixture thins out (diluted non-flammable condition) at escape tunnel exit that reduces probability of ignition
- No external high-pressure “bubble” forms external to escape tunnel opening
  - Therefore, external ignition of coal-air cloud not likely
- Combustion front becomes unstable
- Unlikely to experience a fire ball at escape tunnel exit



Shaker 4 Damage versus Dead Zone Damage Ignition Scenarios

- Damage indicators show that blast loading near Shaker 4 was more significant than at adjacent shakers and dead zone
- Blast pressure loads most plausible from an ignition not at Shaker 4 but further south down the tunnel
- This scenario results in a pressure wave moving north and interacting with the north end wall and creating a reflected blast load that approximately doubles the incident pressure blast load



Summary of Modeling Findings

- A number of simulations were run with various ignition locations
  - Coal-only: both full-height and half-height tunnel clouds with normal and “boosted” flame speeds
  - Gas-only: 40lb cloud at north end near Shaker 4 and 10lb cloud near Shaker 16
  - Mixed Coal-gas: coal with propane or methane
- Modeling goals
  - Inform investigation team and support communication of physical observations (i.e., link observations with physics based model)
  - Support refinement of origin & cause scenarios
  - Support decisions regarding future operations
- From these simulations, a number of conclusions about the event are drawn with varying degrees of confidence
  - Ignition likely occurred south of Shaker 4, likely within the “dead zone”, or before Shaker 20
  - Coal dust contributed substantially to the explosion event in order to produce the large impulse (long blast duration) and large fireball observed at the south portal
  - Fuel source configurations (i.e., coal and gas) were plausible to develop the necessary blast loading, either from a coal dust only cloud or a hybrid coal dust-gas cloud
  - A small flammable gas cloud or less-than-flammable gas cloud could have “boosted” the blast event
  - Simulations could be improved to better match damage indicators by varying coal dust and/or gas concentrations along the length of the tunnel

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Thank you.

Questions?