Survivability of Mine Communication Systems after a Catastrophic Event

Kentucky Professional Engineers in Mining Seminar

Project sponsored by: ALPHA FOUNDATION FOR THE IMPROVEMENT OF MINE SAFETY AND HEALTH
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University of Kentucky

Terminology:

Survivability:

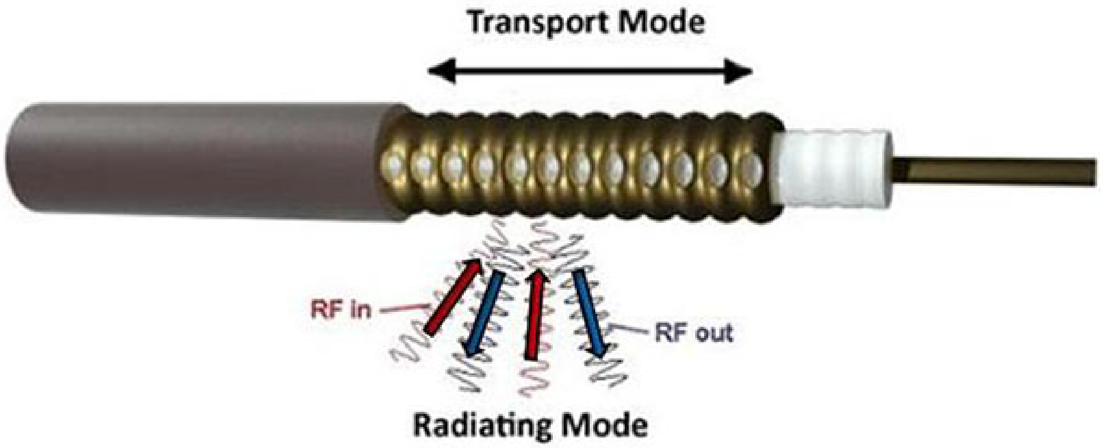
1. able to be survived
2. capable of withstanding attack or countermeasures

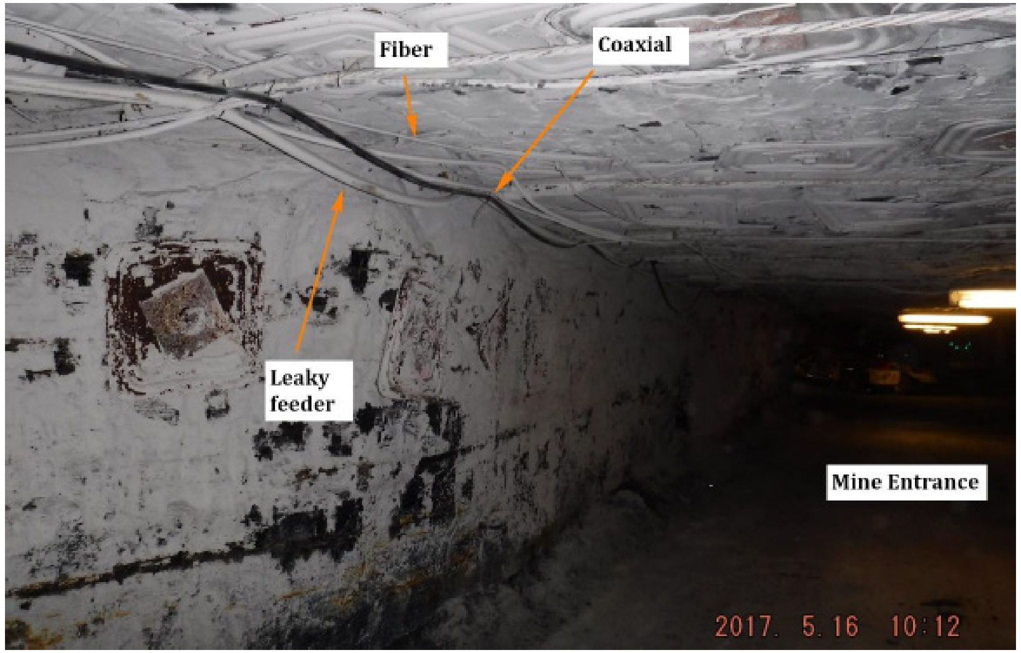
The ability of a system to continue to provide essential and operations-critical services following an emergency event ***(DG Firesmith 2003)*** such as an explosion, fire, roof fall, or water inundation (for mining).

Communication Systems

Leaky Feeder (LF)

Primarily a voice communication system. Leaky feeder cable is run throughout the mine and acts as an antenna along its entire length. Standard VHF/UHF handheld radios are used to communicate.



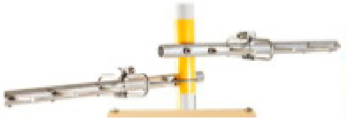


Communication Systems

Partial/Full Wireless Mesh

A wireless system consist of networks of wireless access points (WAPs), also known as nodes. These nodes communicate via standard wireless communications protocols such as IEEE 802.11 (WiFi) or IEEE 802.15.4 (Zigbee). The nodes are organized into a grid.

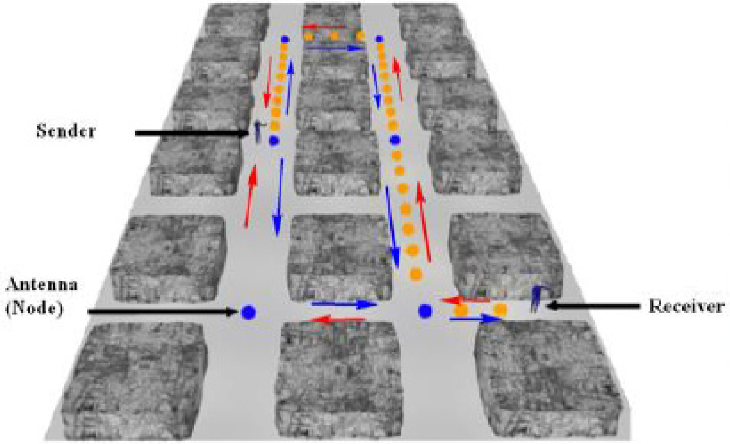
node – System B



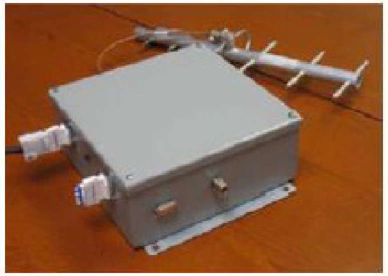
Antenna
System B

Battery backup Case
– System A

Node – System C



a) Basic Layout



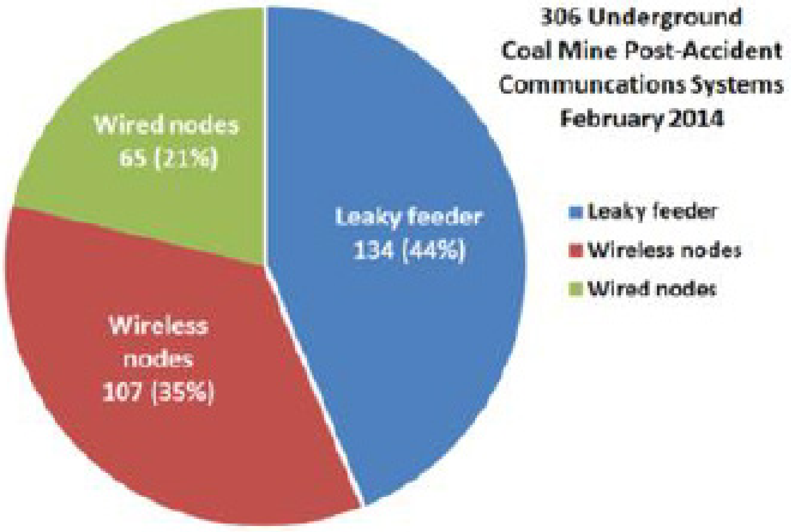
b) Wireless node with external antenna

Communication Systems

Through the Earth

Uses ultra-low frequencies (ULF) to communicate from the surface trough the ground to miners underground. The system uses a large antenna installed on the surface to transmit to the mine.

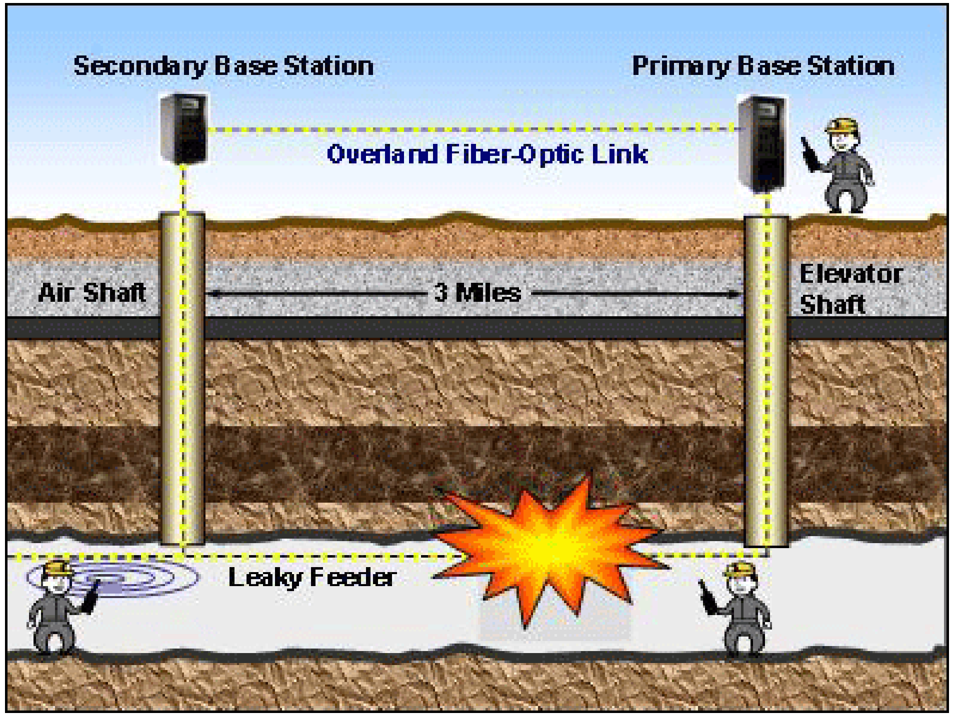
Communication Systems



(Damiano, 2014)

Figure only includes C&T systems installed underground that are used for emergency purposes, and does not include any C&T system installed or used for non-emergency situations, such as communications for everyday operations.

Communication Systems



NIOSH/CDC-MSHA

Currently the systems are designed and implemented based on redundancy principles following an emergency event.

Alternative Communication Path (ACP)

Survivability Analysis

Assessment of the ability of the system to perform critical functions and provide coverage in key locations following an adverse event such as an explosion.

But How?

Basic steps:

1. Define the event (Explosions, rock falls)
2. Define critical emergency operations and determine pre-event operations reliability and coverage
3. Determine system survivability
4. Determine hardening techniques

Event Definition (Pressures)

Event definition is challenging:

- Coal Dust explosions
- Methane explosions
- Mixture → Coal dust/methane explosions

Most of the information, if not all, regarding the pressures and effects have been assessed form past accidents:

a) Sago Mine disaster (2006)
b) Upper Big Branch (2010)
c) Darby Mine (2006)

Event Definition (Pressures)

Event definition from past disasters:

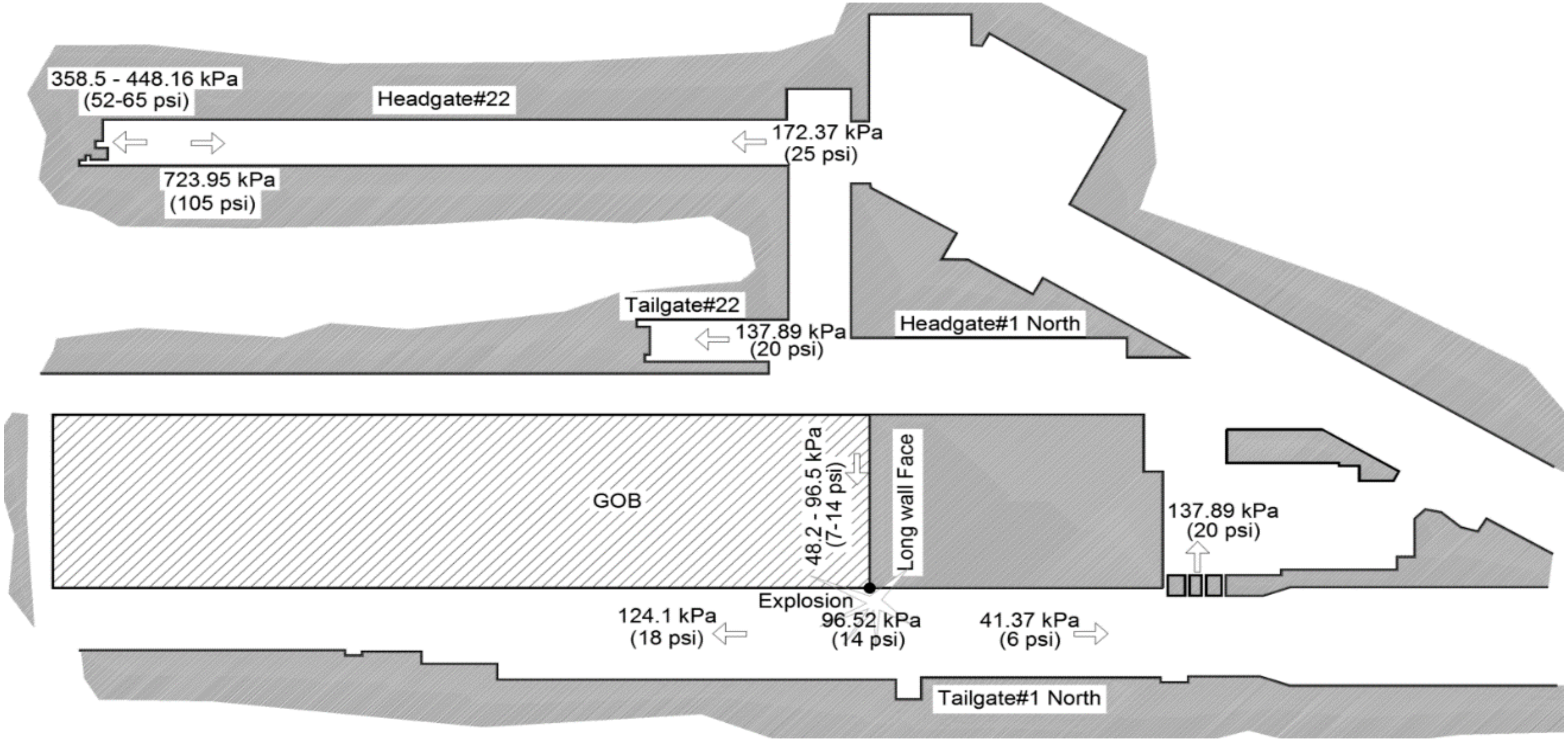
Assessment of pressure, temperature, etc. has been based on secondary information of the effects (distance of flying objects, bending of elements, etc.) and for their calculation, assumptions had been made.

Sago Mine

Upper Big Branch

Event Definition (Pressures)

Event definition from past disasters:

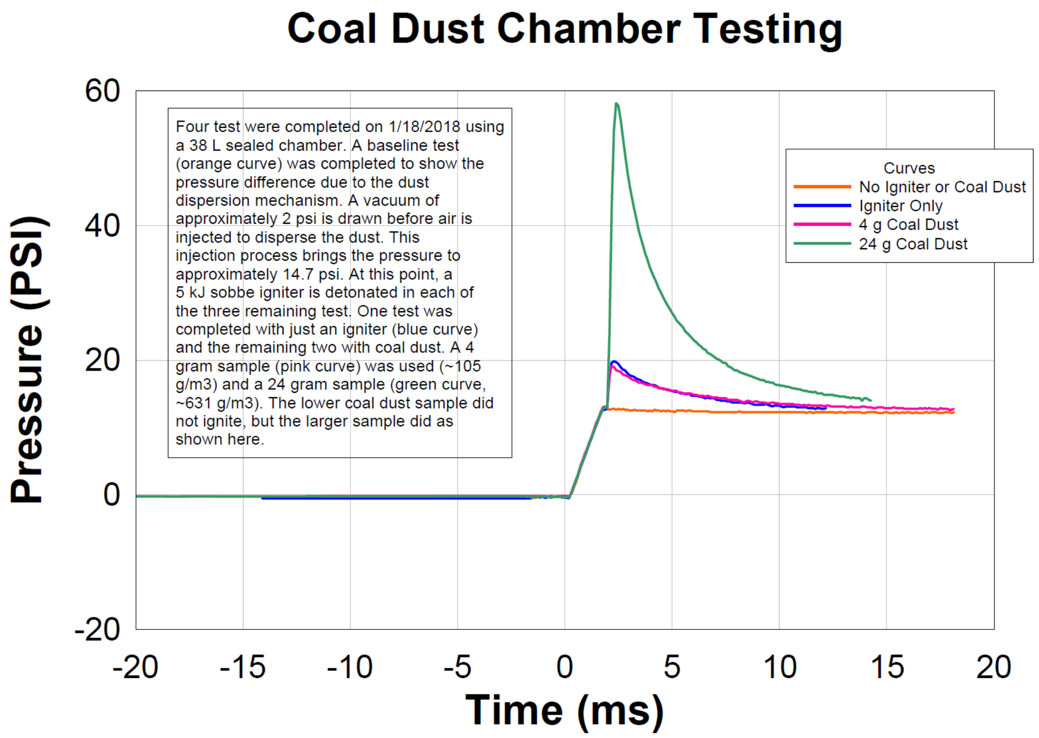


Upper Big Branch: Interpretation

Event Definition (Pressures)

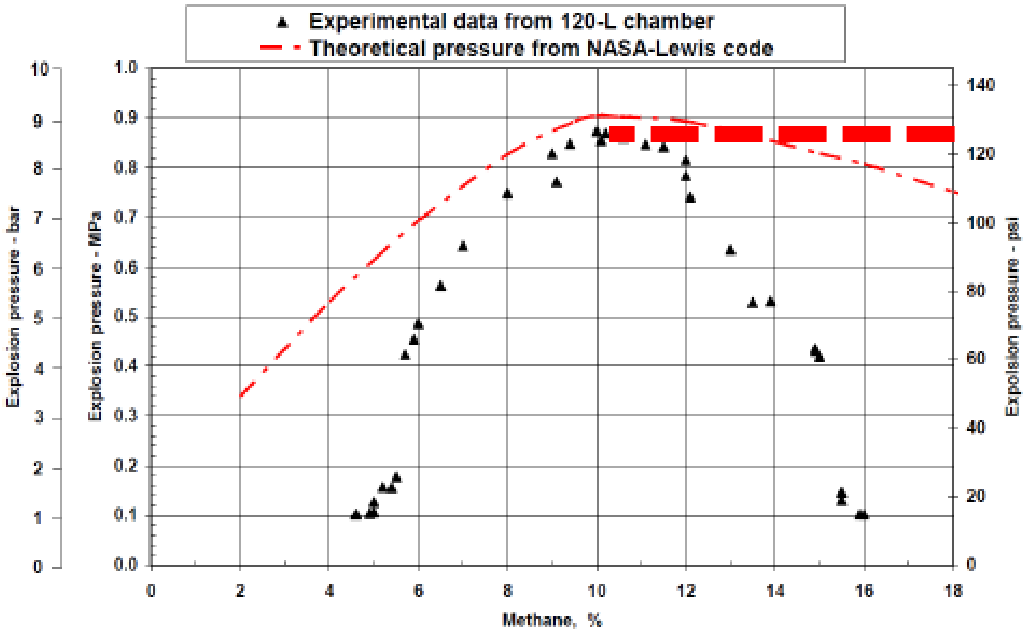
Event definition form Lab tests:

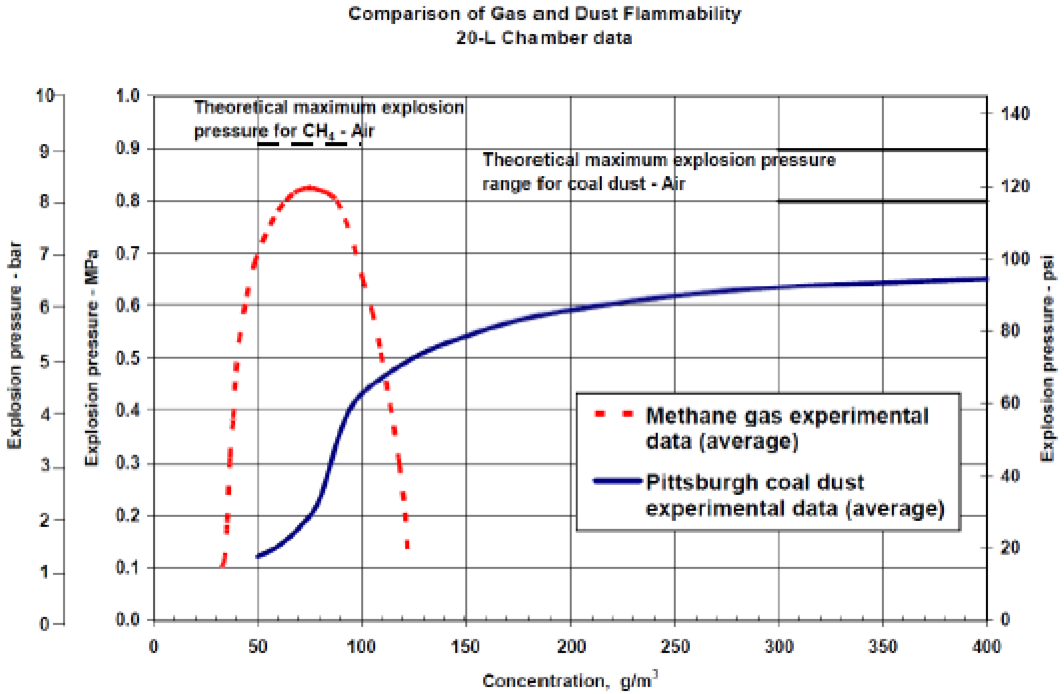
There is uncountable information and data of coal dust/methane and mixtures explosions for small containers. 20 liters, 38 liters etc.



Event Definition (Pressures)

Event definition from Lab tests:

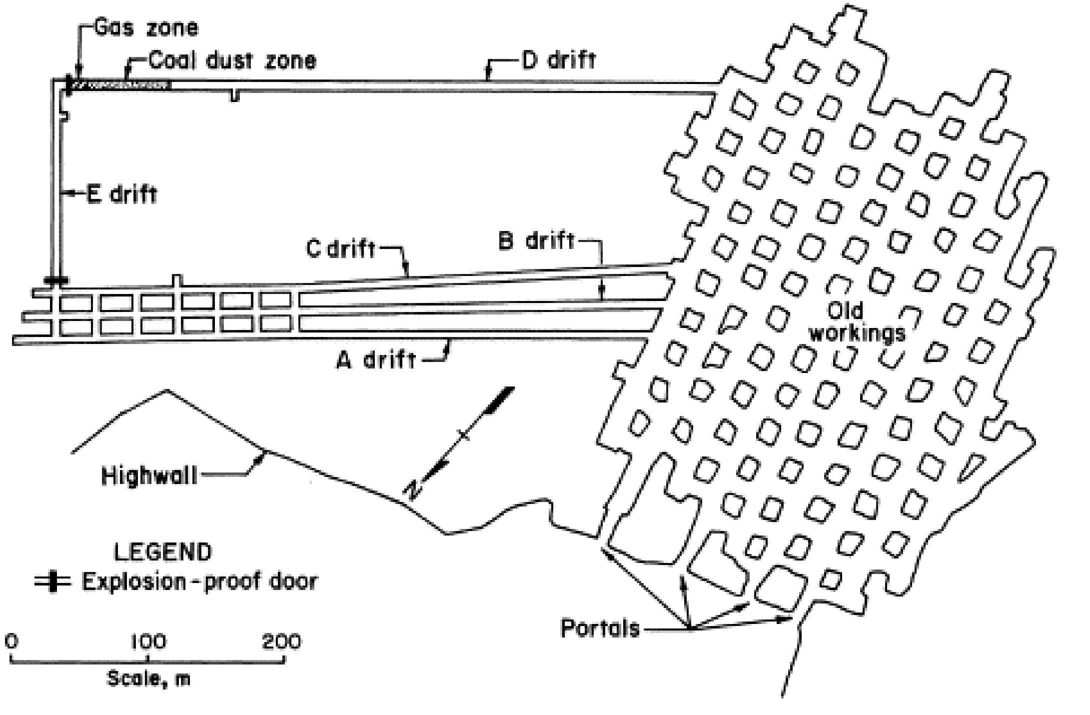




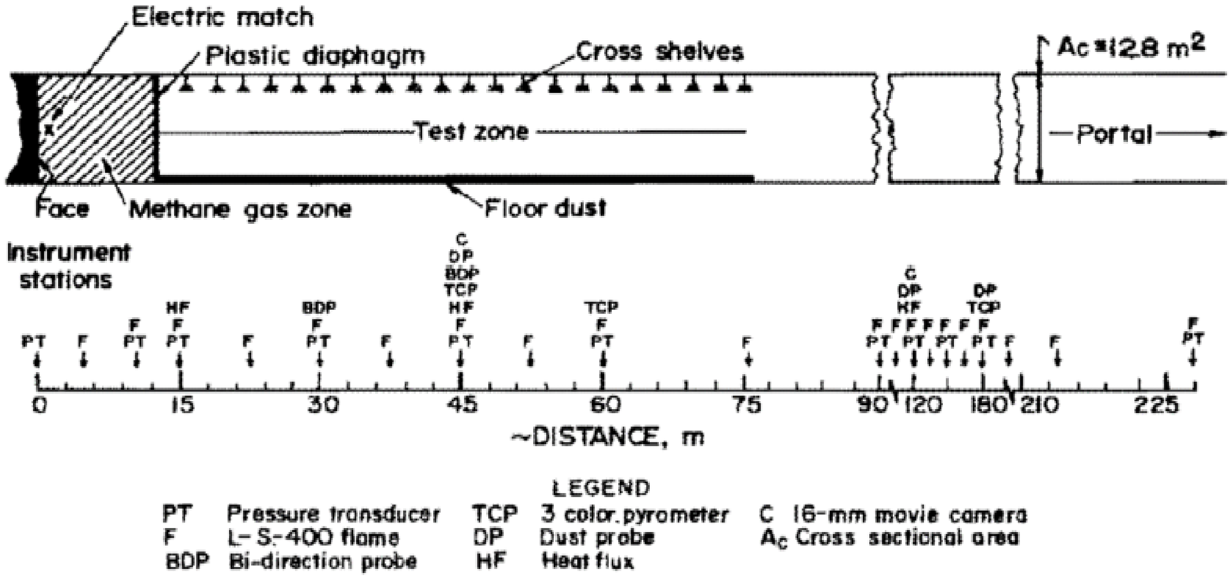
Event Definition (Pressures)

Event definition from Lab tests → Lake Lynn Experimental Mine (LLEM)

NIOSH did a series of full-scale experiments to measure the effects of various methane gas clouds extensions in underground layouts of one and three entries.

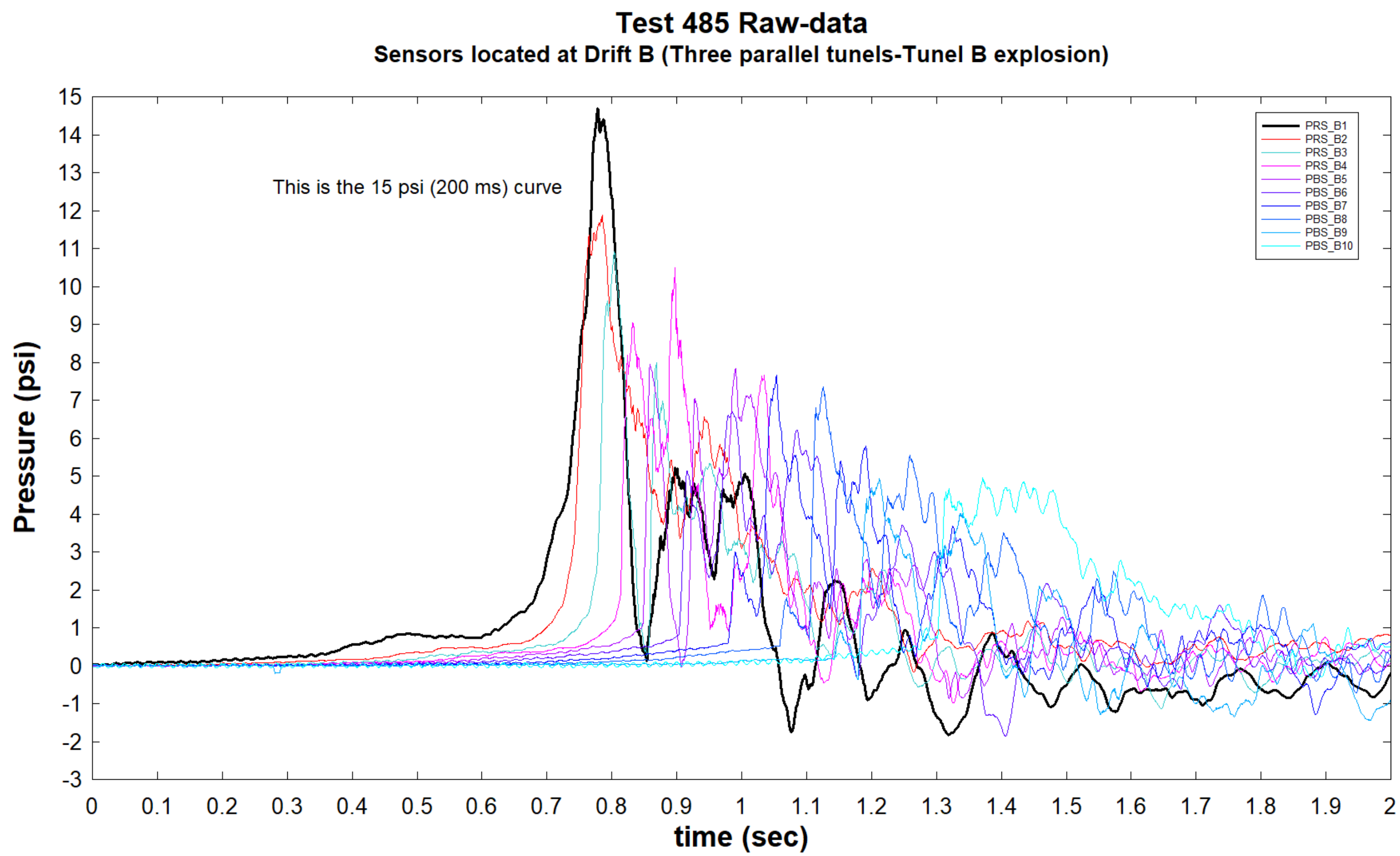


PLAN VIEW OF LAKE LYNN



Event Definition (Pressures)

Event definition from Lab tests → Lake Lynn Experimental Mine (LLEM)

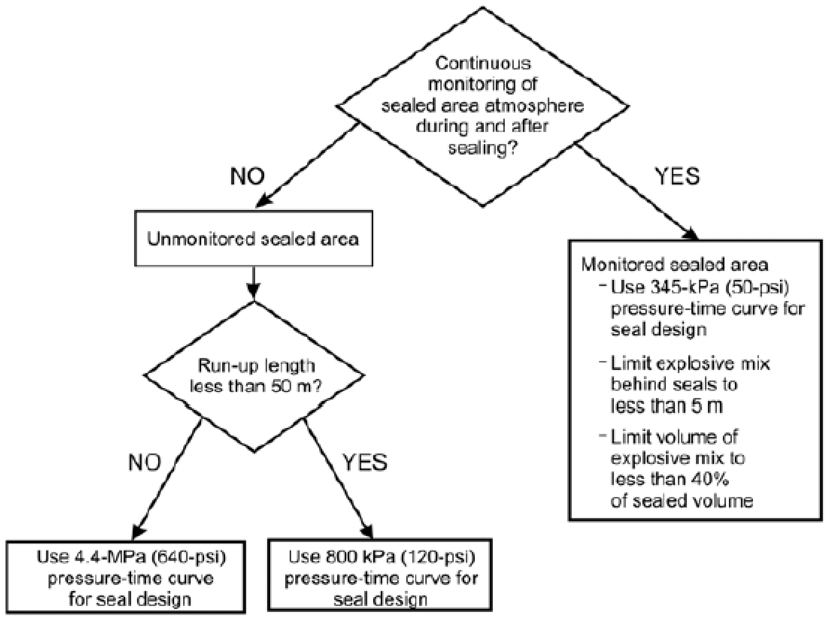


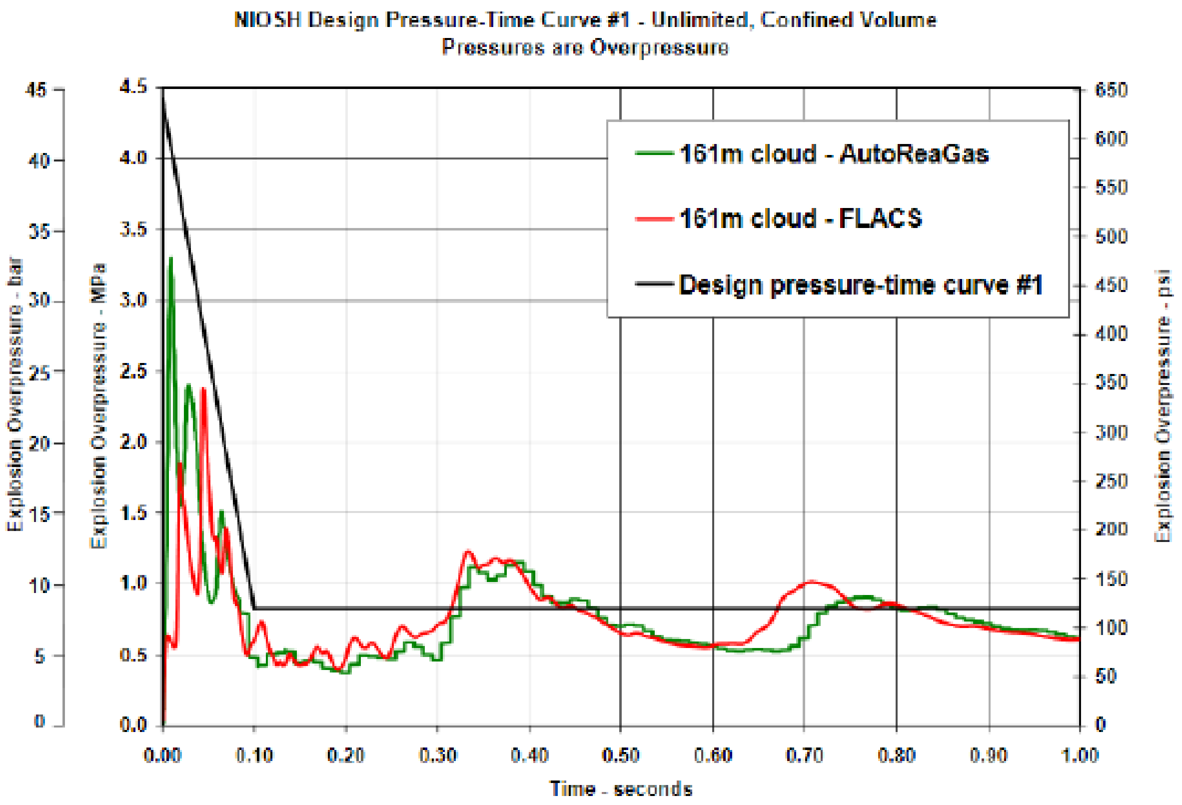
IGNITION ZONE:
Use **~10% gas** up to **B-60** (**835 cubic ft natural gas**).
Ignite 1 ft off the floor near the face using **single point ignition** (2 matches twisted together and located at the center point of the face near the floor with a similar backup on shot fire #2). Leave the **mixing fan OFF** during shot fire.

Load dust onto the pans located ~10 ft outby the PRL probes at B-135 and B-331; **coal dust tray (one pan with PPC, one pan with Pgh coarse dust) will be placed within the gas zone on this test.**

Event Definition (Pressures)

NIOSH-Event definition from Numerical Analysis (CFD Software)





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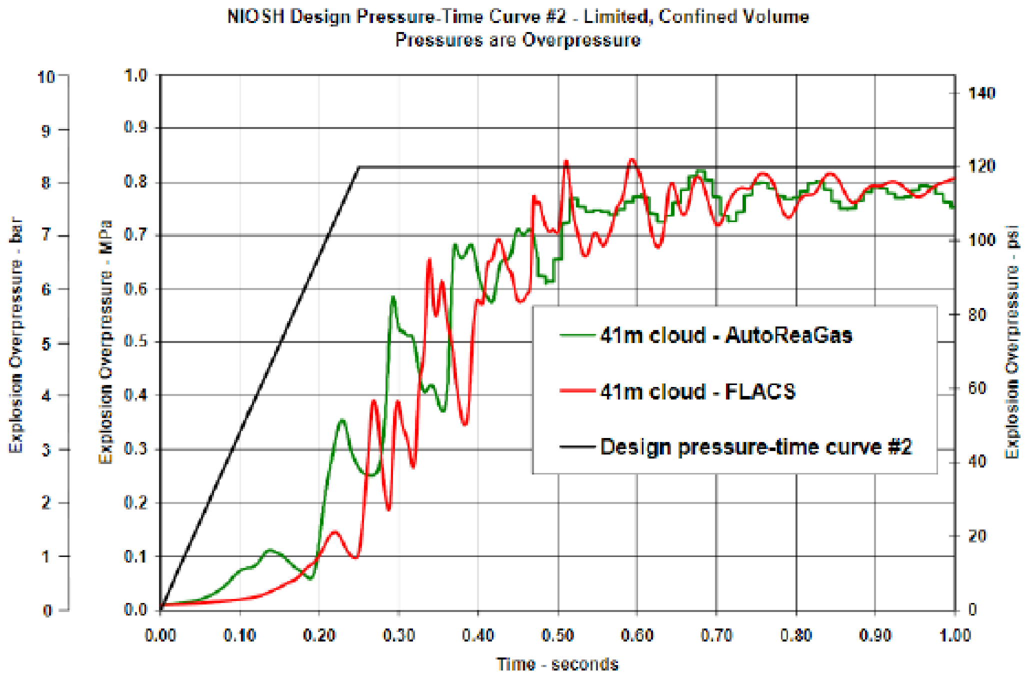
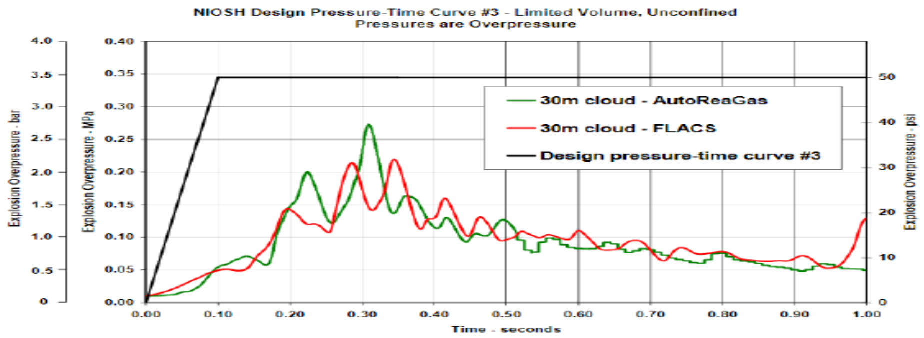




Event Definition (Pressures??)

Several sources of information. Peak values ?

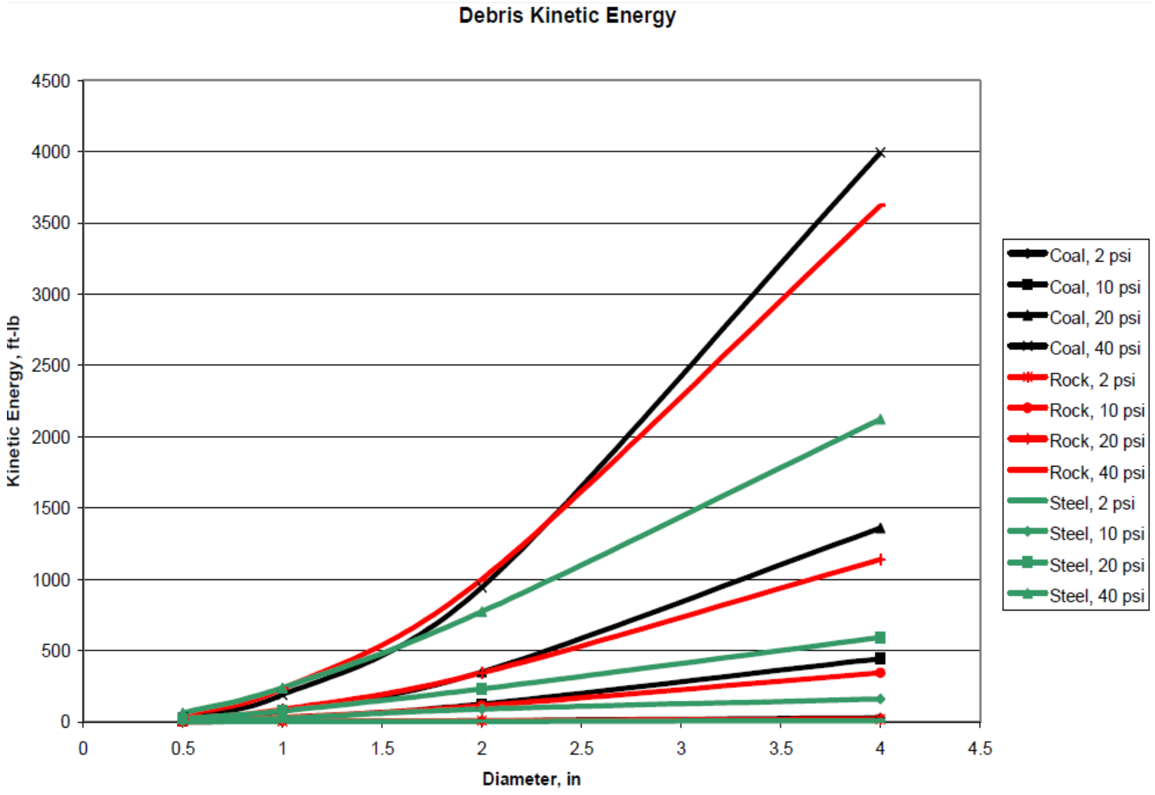
- 15 psi → LLEM test 60 ft gas/coal dust cloud and 3 entries
- 50 psi → Scenario #3; 5 meters methane cloud
- 120 psi → Scenario #2; 41 meters cloud
- 120 psi → 20 L chamber only methane
- 130 psi → 120 L chamber? Only methane
- 130 psi → Theoretical
- 650 psi → Scenario #1; 161 meters cloud?

This Project adopted 150 psi as peak pressure:

Methane and coal dust explosion research conducted in open-ended conditions in galleries with a gas zone length ***lower than 50 m*** (165 ft). In these tests, a cloud of the explosive mixture was partially confined and able to vent. In experimental explosions (Genthe, 1968) with subsonic flame speeds less than 330 m/s (1,100 ft/s), explosion pressures of less than 1.0 MPa (145 psig) were measured. In other testing, peak pressures of 1.04 MPa (150 psig) were developed indicating that some pressure piling occurred as the explosion propagated (Nagy, 1981; Schultze-Rhonhof, 1968; Zipf et al. 2007).

Event Definition (Rock falls - Debris)

Again, event definition is challenging: Practically, no information is available



Foster-Miller report, gives estimations for what kinetic energies could be expected from various types of material at different overpressure values.

A mining research contract final report
DECEMBER 2009

System Reliability and Environmental Survivability - Volume 2

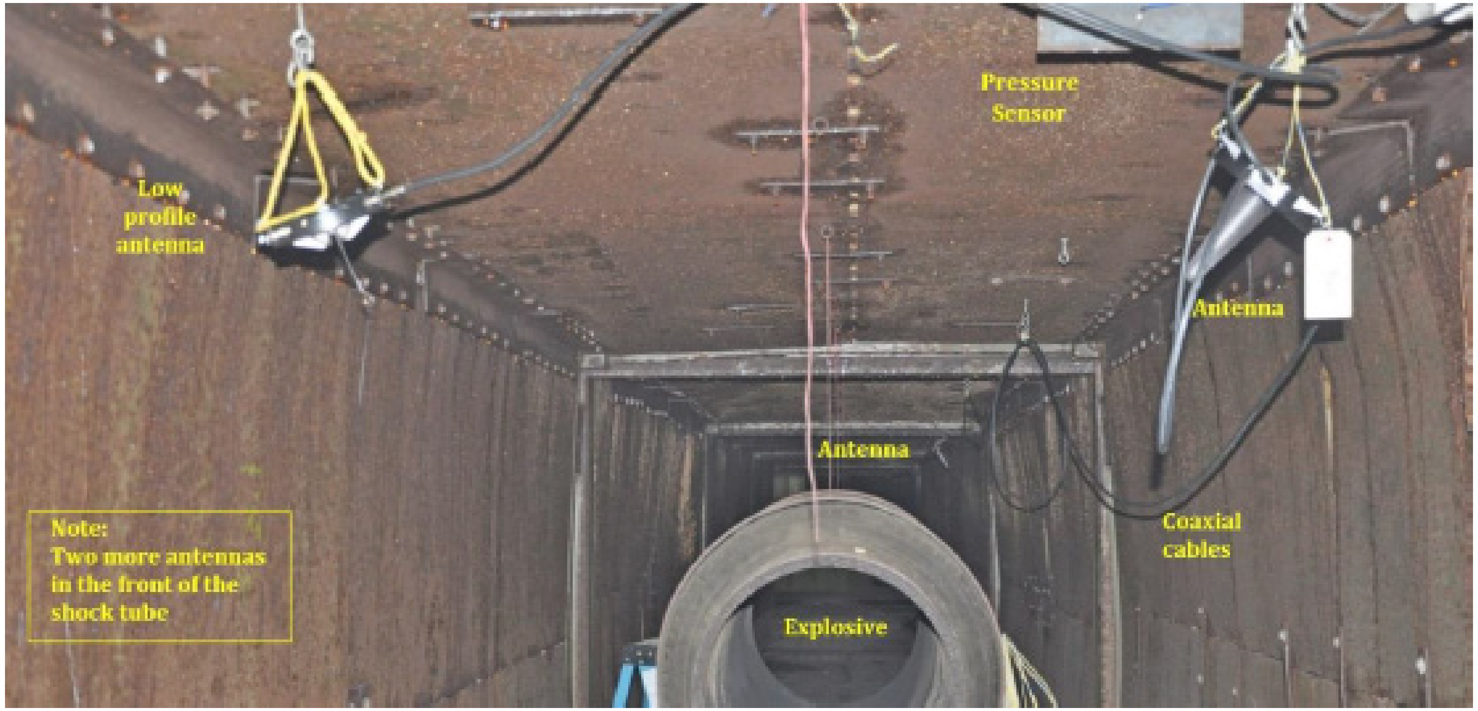
Contract No. 200-2008-26864
QinetiQ North America/Foster-Miller Inc.
Technology Solutions Group
350 Second Avenue
Waltham, MA 02451-1196

TESTING
Peak - Pressure

UKERT – Lab-Underground

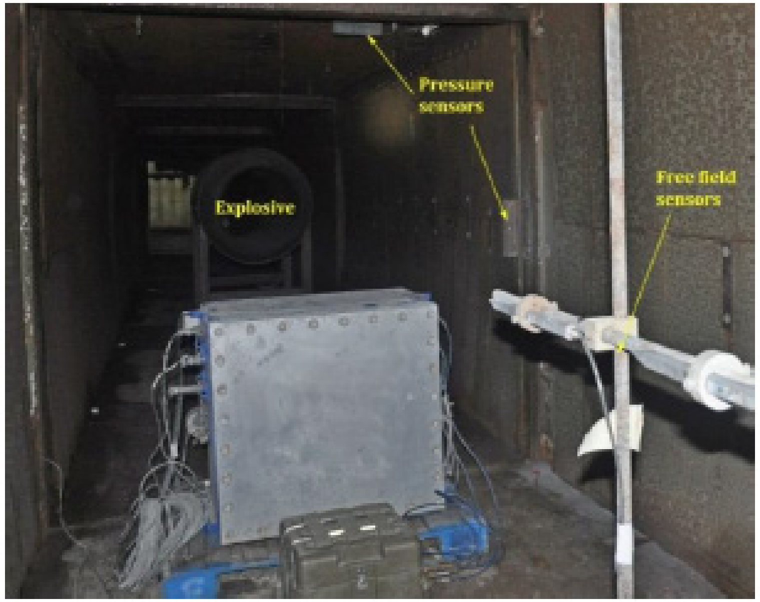
TESTING
Peak - Pressure

UKERT - Lab



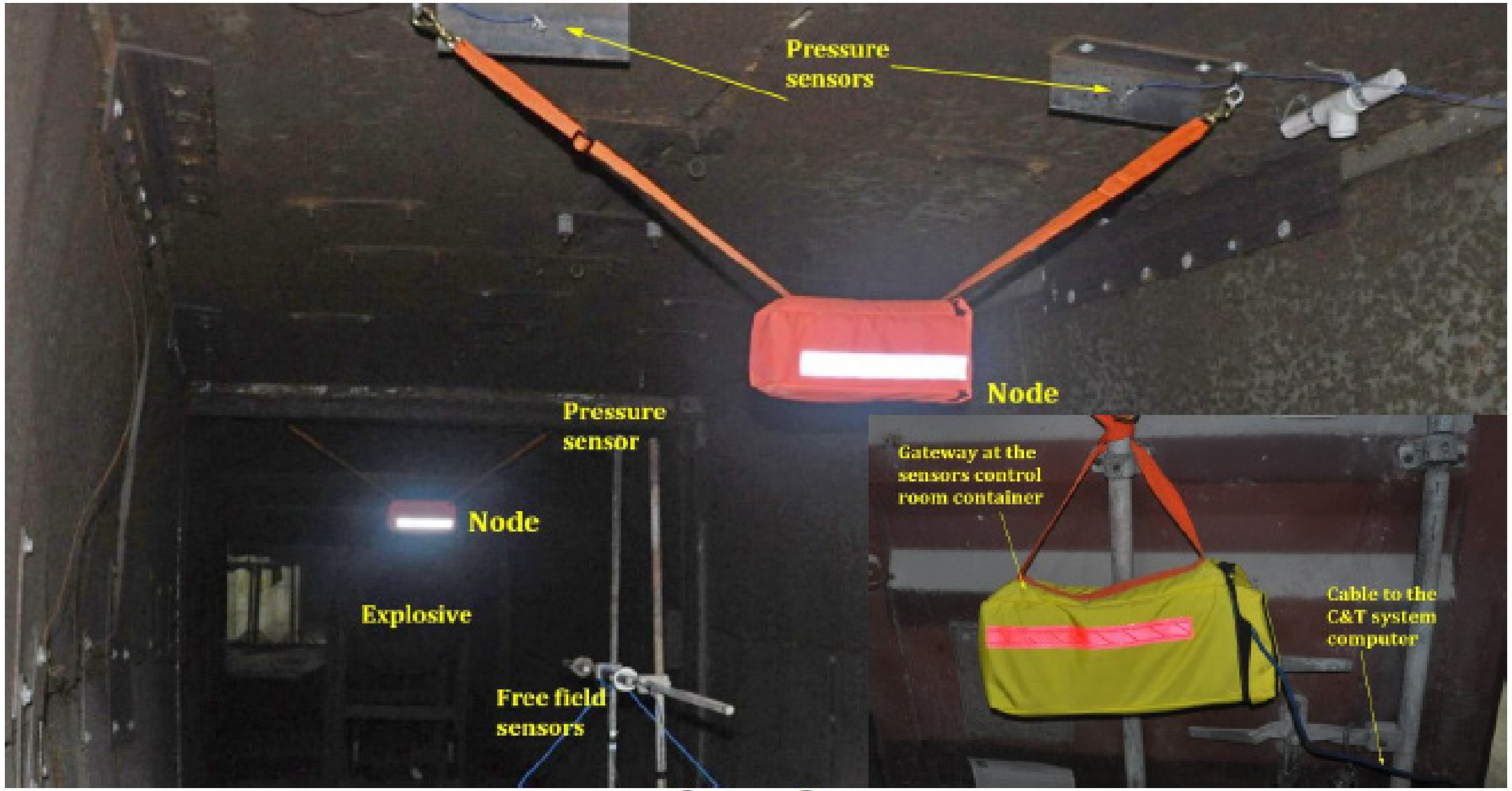
TESTING
Peak - Pressure

UKERT - Lab

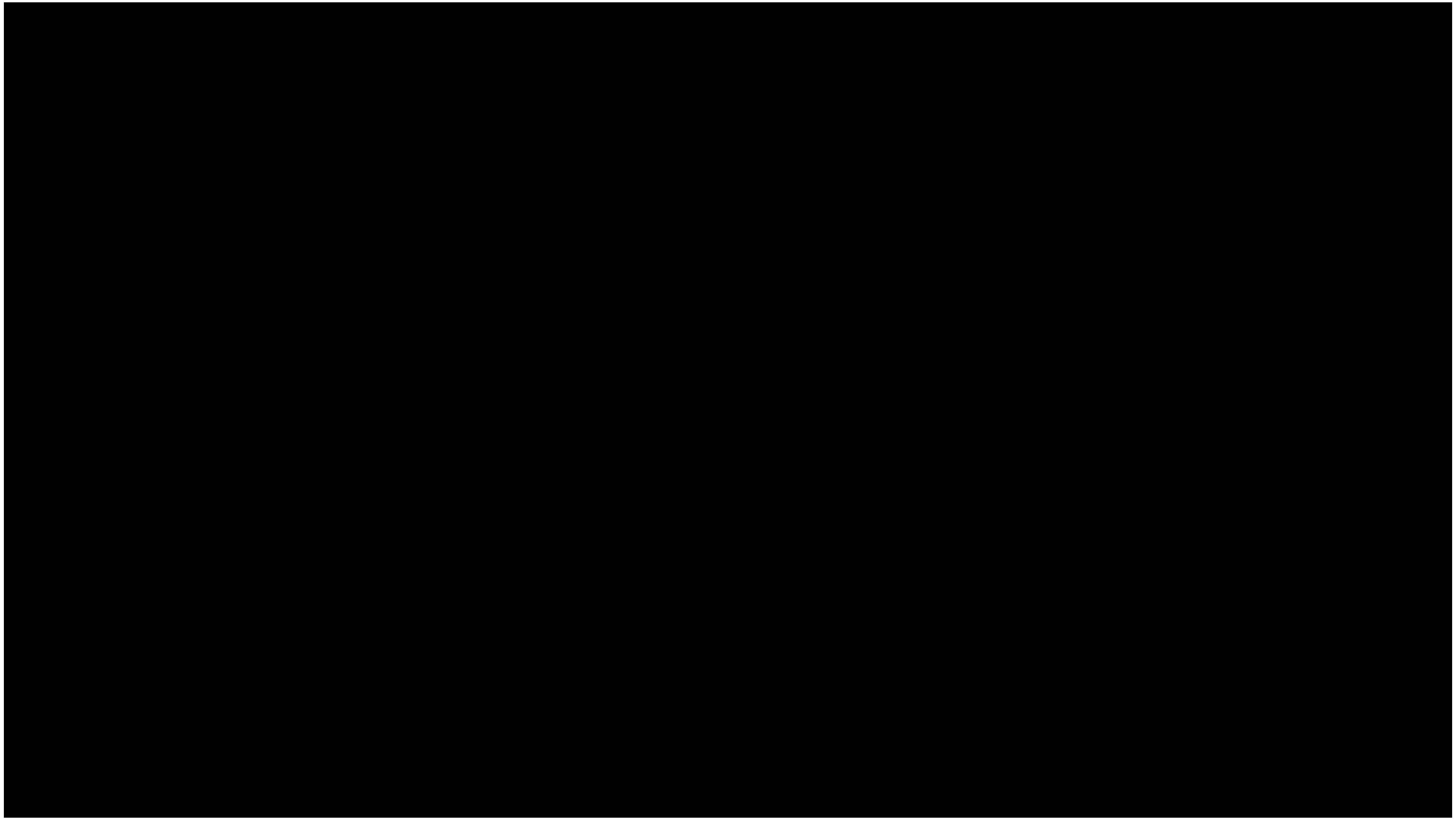


TESTING
Peak - Pressure

UKERT - Lab



TESTING
Peak - Pressure



TESTING
Peak - Pressure

Systems After Third Test

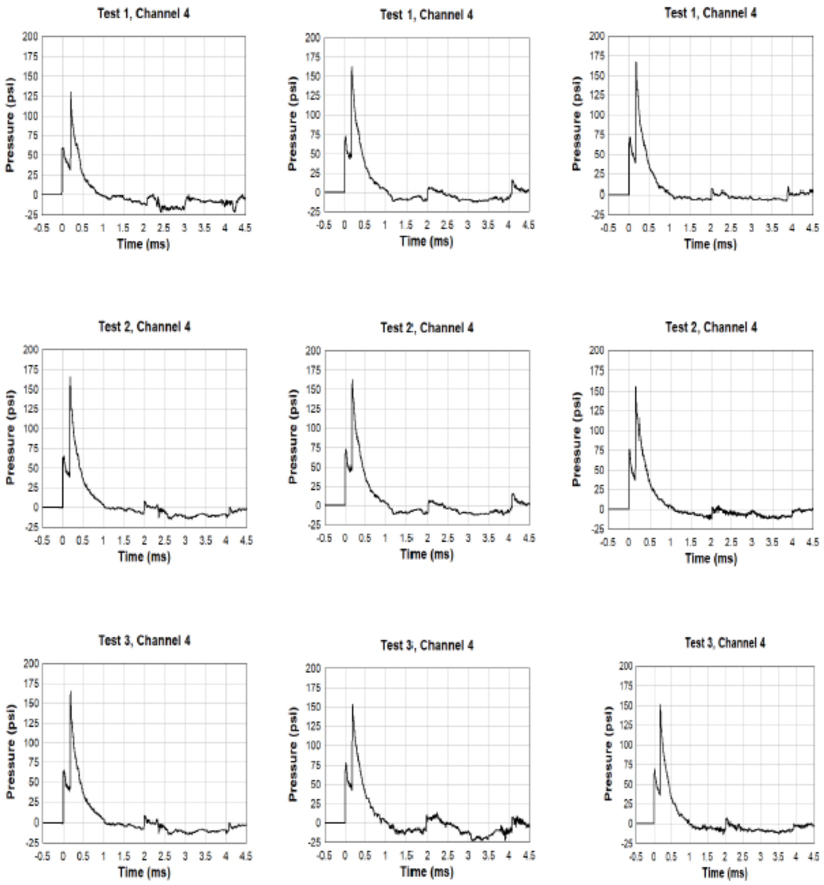


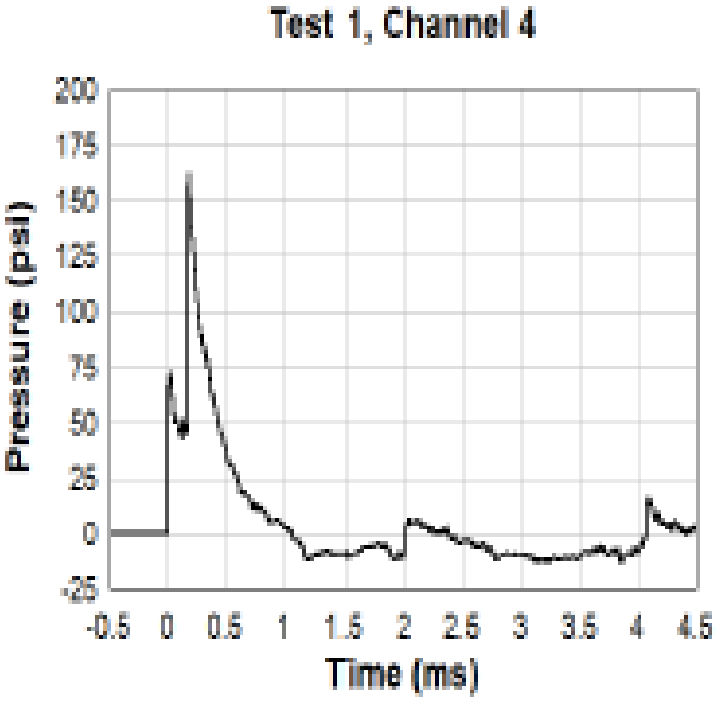





TESTING
Peak - Pressure

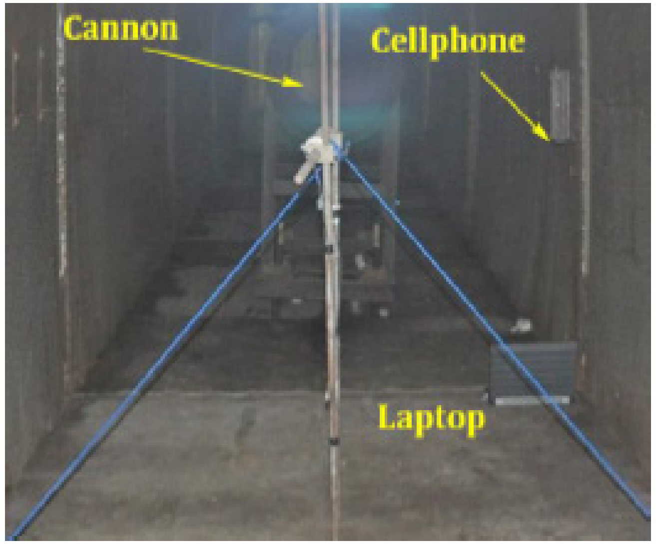
NO- physical damage was observed in any device

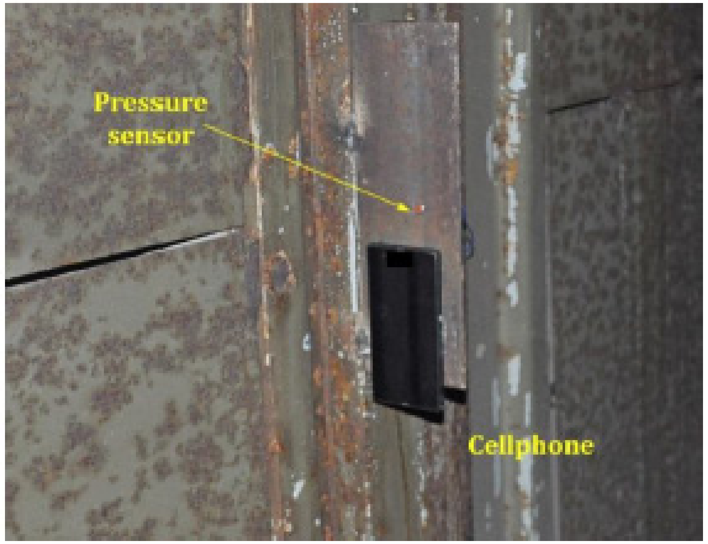




TESTING
Peak - Pressure

How to verify that result???





TESTING
Peak - Pressure

How to verify that result???

TESTING
Peak – Pressure - Results

System A:
It was observed that all nodes included in system A's network were functioning before and after testing. One node lost connection for several seconds following the explosion, but then self-connected. Some nodes were displaced from their initial location onto the floor during the explosion, but this did not stop the system functions.

System B:
It was observed that the above and below ground units that make up System B were able to send both text and voice messages successfully throughout testing. After test three, the system rebooted. Because the system often experiences regular reboots, it cannot be determined if this was caused by the explosion. Regardless, the system was able to successfully reboot and communicate after all testing.

System C:
It was observed that nodes from System C were able to communicate before all tests, and after two tests. However, after one test, a node at section one failed to reconnect to the network after the explosion.
The impact with the floor caused the batteries inside the device to compress and not function properly. After replacing batteries, the unit functioned properly.

TESTING
Peak – Pressure - Results

According to these results, it can be concluded that, devices close to the explosion will be affected by the over-pressure. In some instances, the power supply component can be affected, as a functioning part of the device's safety mechanisms. In other cases, the physical impact of system components can cause interruptions in the power supply.

Despite the interruptions experienced by the systems, the reconnections were temporary and/or easily fixed. If a coal mine explosion produced pressures higher than 150 psi, it is expected that the elements would experience longer interruptions. The redundancy found in C&T systems helps protect against individual node failure.

During this set of tests, it was noted that improving component installation techniques to avoid shortcuts commonly used in mining operations (to speed the installation process), the survivability of the devices could be considerably enhanced.

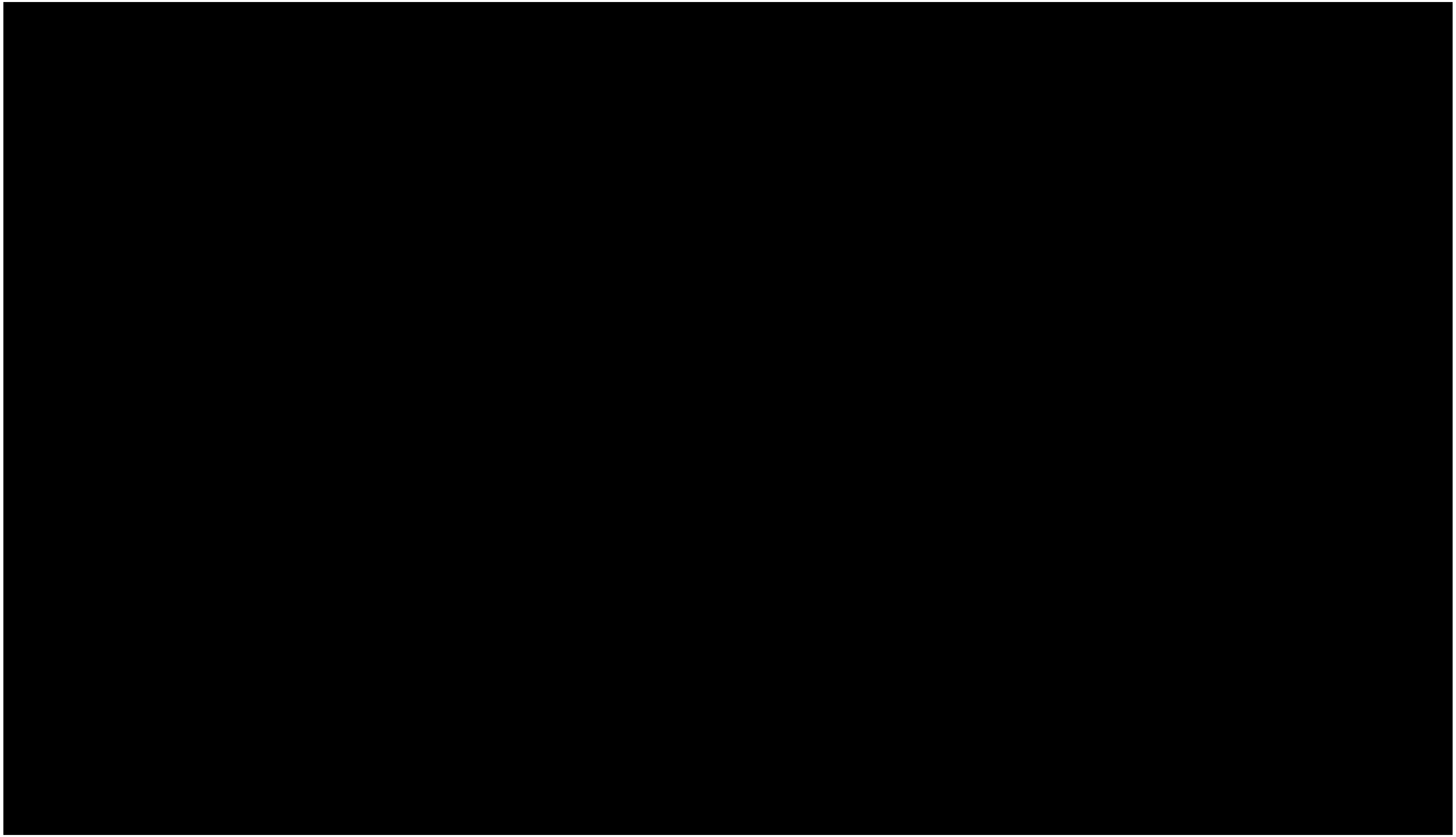
TESTING
Debris - Impacts

ASTM E1886-13a standard

Standard Test Method for Performance of Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Missile(s) and Exposed to Cyclic Pressure Differentials

Test	Velocity (ft/s)	KE (J)
1	245	5593
2*	-	-
3	223	5406
4	245	5454
5	236	5305
6	245	5454
AVG	239	5442

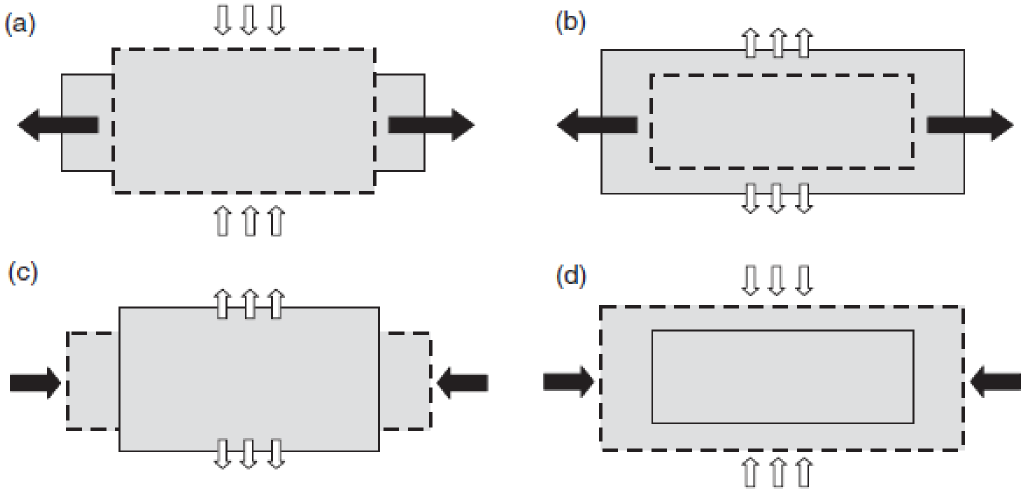
TESTING
Debris - Impacts

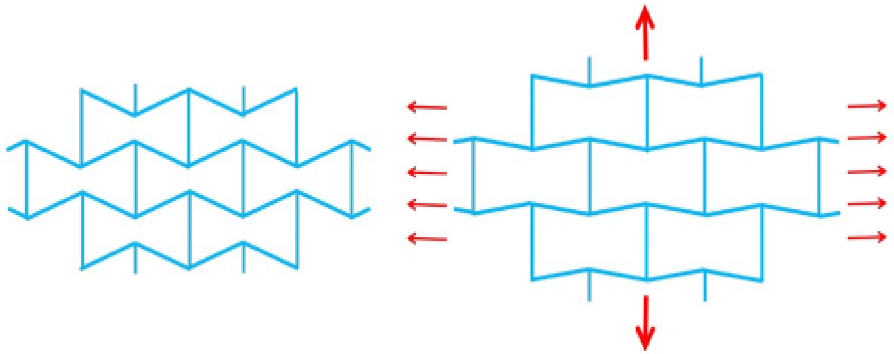


TESTING
Debris - Impacts

TESTING
Debris – Impacts-Hardening

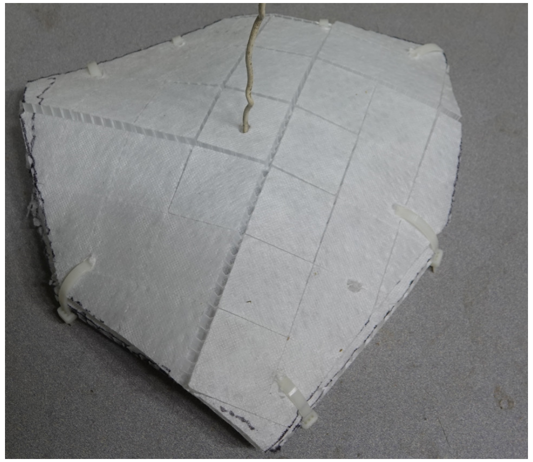
Negative Poison Ratio Materials (Auxetic Materials)

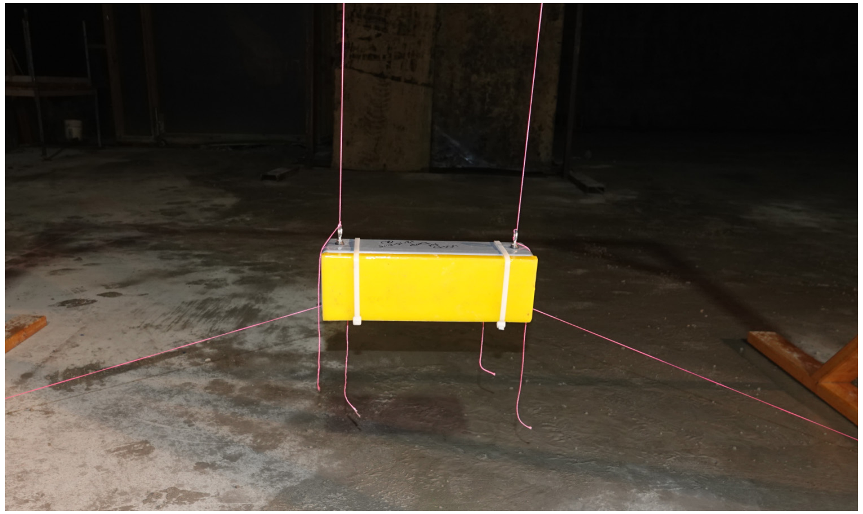


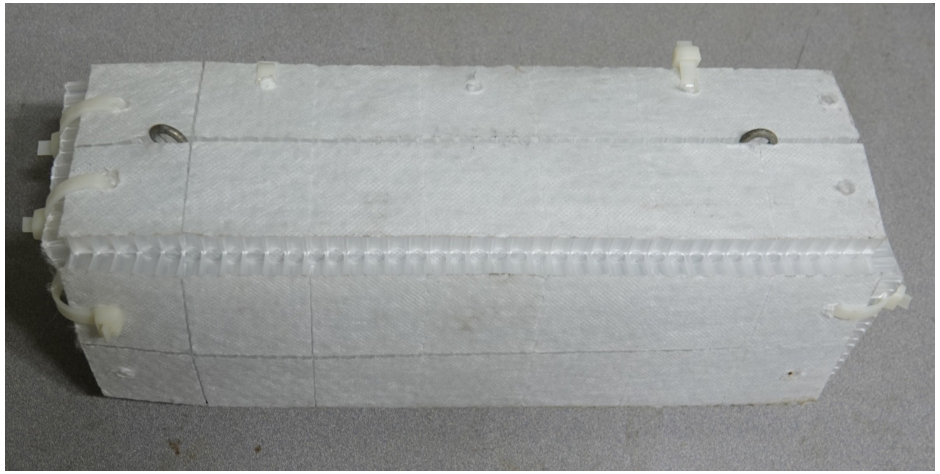


Honeycomb Structure

TESTING
Debris – Impacts-Hardening







TESTING
Debris – Impacts-Hardening-Results

Test	Comments
1	There was a wide dispersion of parts both from the hardening material and from the device. The low-profile antenna was broken in parts and scattered, would not be operational.
2	As in the previous test, wide dispersion of hardening material but the low-profile antenna stayed mostly intact. Circuit board was bent upwards, and upper casing was broken off. Could possibly be in operation, but severely damaged.
3	Polyurethane not damaged, but separated from the box on impact. Box lid was broken in half. Interior components are mostly intact. Mostly likely, not operational.
4	Polyurethane not damaged, but again separated. Lid and box mostly intact. Batteries were inserted before testing and were busted during impact. Not operational.
5	Hardening material widely dispersed. Box lid completely destructed, batteries dispersed and damaged. Would not be operational.
6	Polyurethane cut on the tip of the cone and separated from the device. However, minimal damage to the cone. One corner chipped, no interior damage. Likely operational.

Yellow Polyurethane: Commercially made, this material was very tough and was the only material completely unharmed by testing. The material is heavier than the other polyurethane tested (White polyurethane). Moderately inexpensive, this material is currently only available for flat pieces. However, different shapes could be crafted to fit a wider variety of shapes. Also, a different method of attaching the material could result in better results. The material seemed to provide some protection for devices, but still left components damaged.

To date Conclusions

1. Tests using a large shock tube and explosives (C4) shows that the peak pressure doesn't have a major impact in the survivability of C&T devices and systems. The integrity of the devices and systems was held during testing.

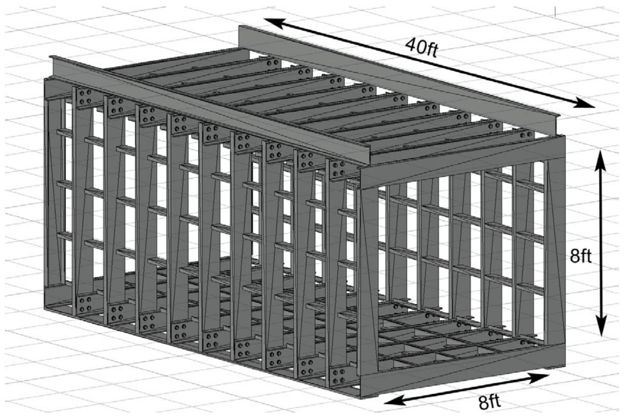
2. The main effect to account for the protection of devices and systems is impact. Impact could be the results of the devices throw against walls and floors or the direct impact of debris generated during the explosion or elements impulse by the air wave.

3. Several materials are being tested to enhance the survivability of C&T devices. Yellow polyurethane is promising.

During the development of the project, the importance of testing using coal dust/methane was becoming evident. A new shock tube is under construction for that propose.

UKERT – Lab-Surface

UKERT – Lab-Surface



Scaled Shocktube Testing: High Speed, full length and two ignition points

Aprox:
1000 frames/second

Acknowledgements

UKERT Team

Acknowledgements

Sponsors:

Project sponsored by: ALPHA FOUNDATION
FOR THE IMPROVEMENT OF MINE SAFETY AND HEALTH
Project ID: AFC316-49

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Dr. Thomas Novak
Dr. Steven Shafrick
Dr. Josh Calnan