Development of Gas Explosion Testing of Pressure Relief Valves for Refuge Alternatives

Contract # 75D30118C01230

2021 Refuge Alternative Partnership Meeting

JHON SILVA
JOSH CALNAN
TODOR PETROV

Nov 17, 2021

Agenda

1. Project background
2. Objectives
3. Experimental setup
    3.1 PRVs tested in this project.
    3.2 Attempts to replicate the recommended pressure-time curve.
    3.3 Final experimental Setup
4. Valves Testing
5. Results/Conclusions
6. Numerical Modeling

1. Project Background

- Limited testing has been conducted to evaluate the performance of RAs when they are subjected to the NIOSH's recommended explosion pressure-time curve (triangular impulse overpressure of 103 kPa (15 psi) peak and 200 ms duration).

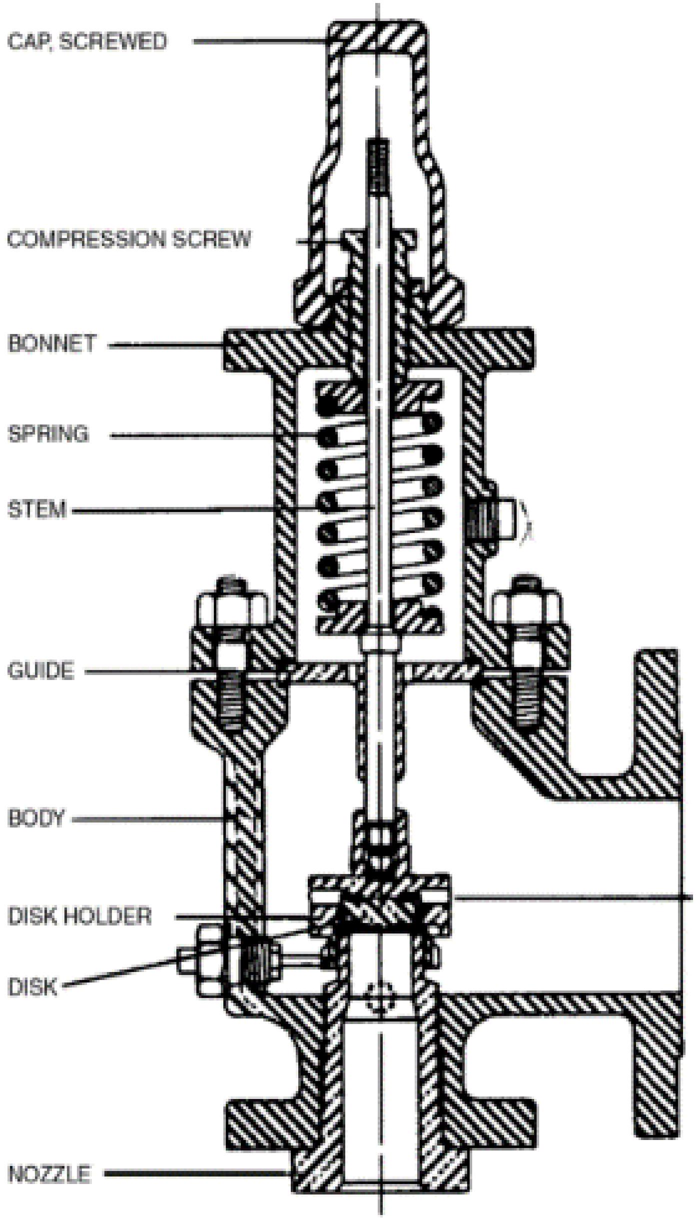
- **A key component of the RAs are the pressure relief valves (PRVs).** The PRVs are installed to exhaust the used air, keeping the internal pressure of the RA below a maximum recommended value 1.25 kPa (0.18 psi).

2. Objectives

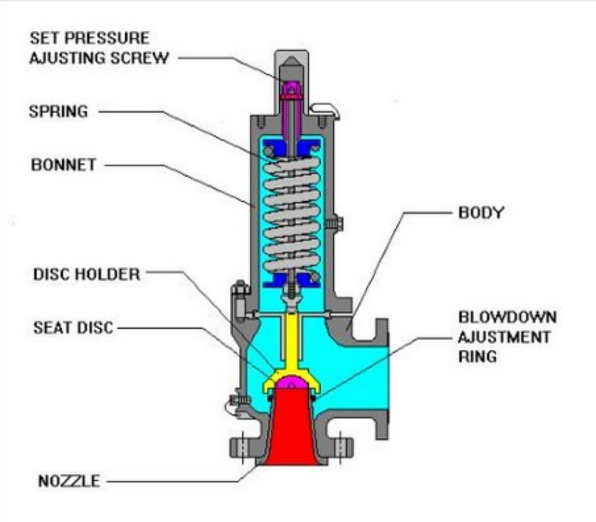
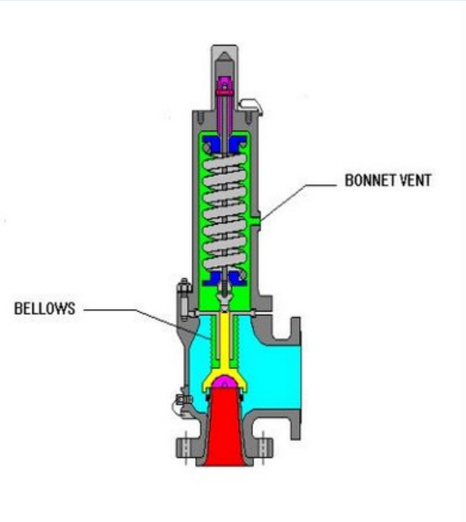
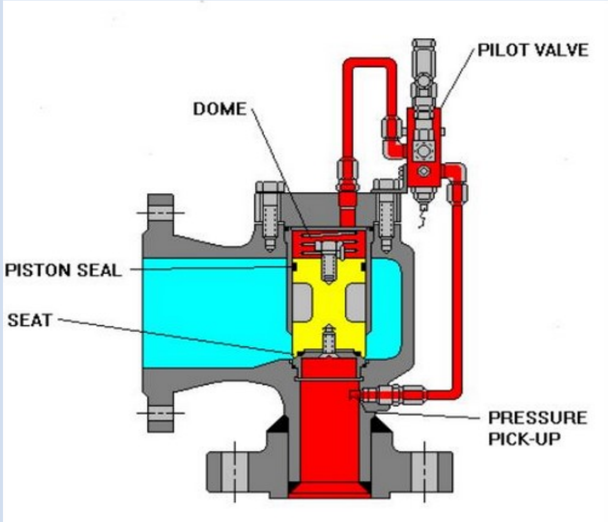
- Address the survivability of PRVs commonly used in Built-In-Place (BIP) and self-contained mobile unit RAs through physical testing and numerical modeling.
- Review the use of other commercially available valves such as blast valves (used in reinforced underground civil shelters) and their applicability to RAs when subjected to overpressure waveforms typical of methane/coal dust explosions.

Pressure relief valves (PRV) - Principles

- PRV- is a safety valve that relieves or controls an undesired overpressure within a system.
- The range of uses extends to a multitude of industries.
- **Several types.** Spring forces the valve shut until the required pressure is achieved, overcoming the force imparted by the spring and opening the valve.
- Others, the spring is replaced by a weight, opening the valve when the pressure equates to the weight holding the valve shut.



Pressure relief valves (PRV) Other Types

Conventional valve	Balanced spring-loaded valve	Pilot-operated apparatus valve
		
Within this system, the bonnet, spring, and guide are exposed to the released fluids.	This design attempts to protect the bonnet, guide, and spring from the fluids and effects of overpressure.	Testing of this type of valve was not considered because there is no relation in the mechanism of action to refuge alternative-type overpressure valves.

3. Experimental Setup

The experimental setup was according to:

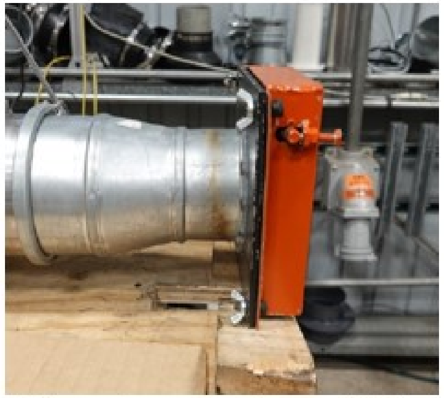
3.1 PRVs tested in this project.

3.2 Attempts to replicate the recommended pressure-time curve.

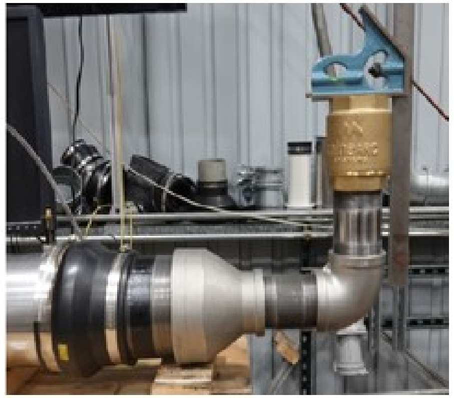
3.3 Final experimental Setup

3.1 Pressure relief valves (PRV) Tested in the project

- Four valves were selected for testing:
  - Chamber enveloped,
  - MineArc,
  - American Safe Room (ASR),
  - Temet YV1



Chamber enveloped Valve (Jack Kennedy Metals)



MineArc overpressure valve

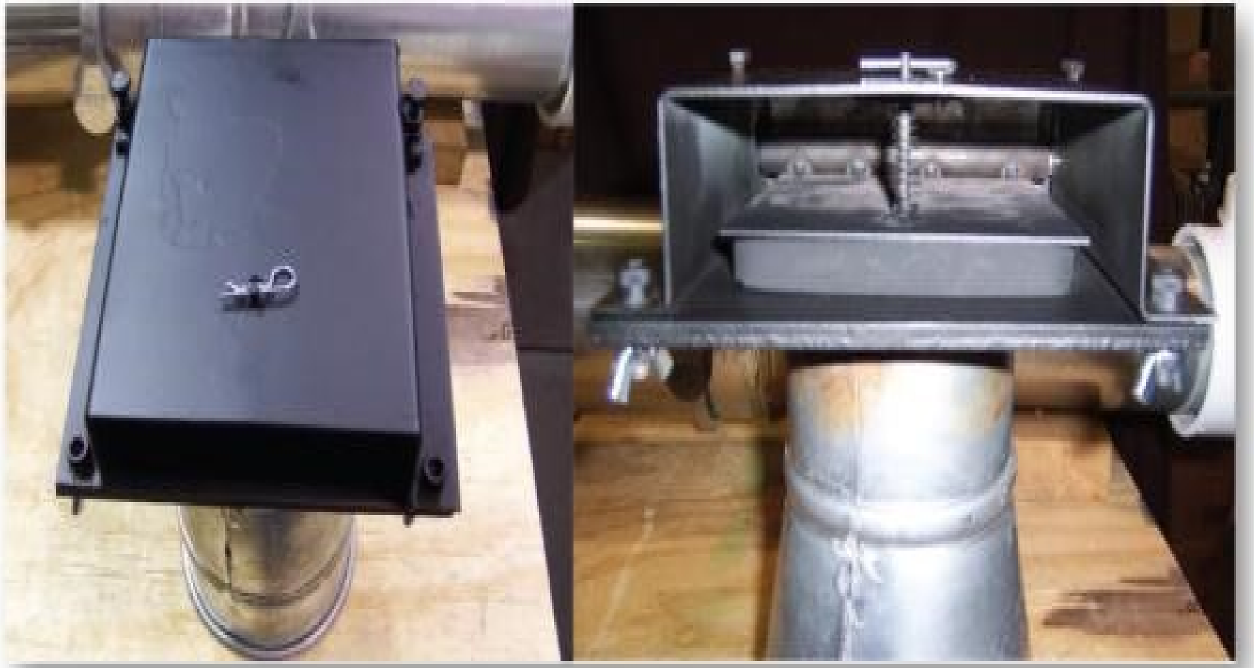
ASR overpressure valve

Temet overpressure valve

Chamber envelope overpressure relief valve

- The chamber envelope overpressure relief valve is commonplace among refuge alternatives seen within US coal mines.

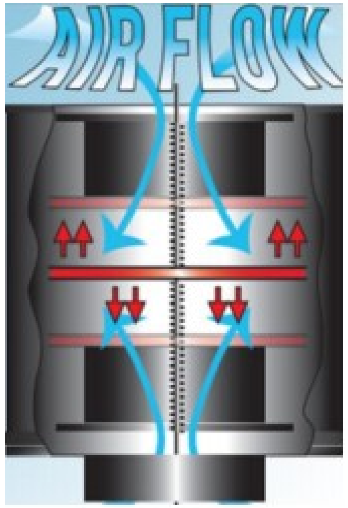
- A spring holding a metal panel against an outlet that leads out of the refuge alternative. Once the pressure within the RA reaches the set pressure, 1.25 kPa (by US mining standards), the spring is compressed, and the air is allowed to be released, lowering the pressure.



MineARC

- The MineARC check valve uses a simple gravity closing mechanism to prevent backflow during a blast overpressure event. These one-way valves allow internal pressure to be released by forcing a small steel disk upward to vent the over pressurization. The opening recloses automatically once the chamber pressure equalizes to the environment.

American Safe Room (ASR)



- The ASR 7-bar blast valve utilizes a membrane suspended between two outlets by opposing spring forces. These springs keep this membrane centered for airflow until an event causing overpressure occurs, which then causes the membrane slam shut. This valve will also protect against the negative phase of an explosion as the membrane is pulled towards the external environment to limit the negative pressure.

Temet YV1

- Used in S1 class shelters according to the Finland regulations, to prevent the overpressure from a blast wave inside the shelter. The YV-1 valve is designed for external installation on an exterior wall or roof. During UKERT testing, the valve was connected to an exterior wall of the RAA. Through bolts were used to attach the valve to the steel side of the simulated RAA.

3.2 Attempts to replicate the recommended pressure-time curve.

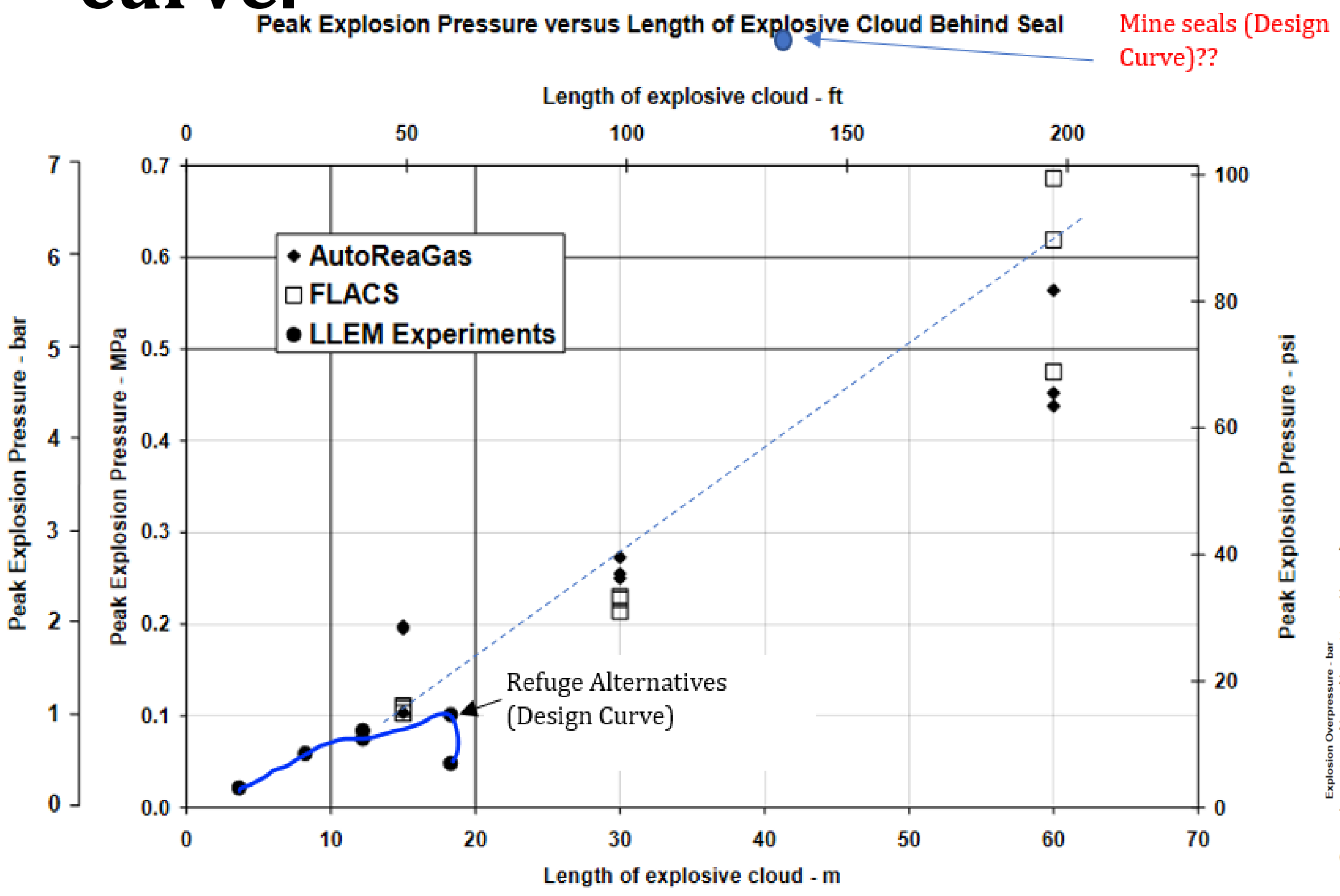


Figure 22.—Peak explosion pressure versus volume size behind leaking seal: calculations and experimental measurements.

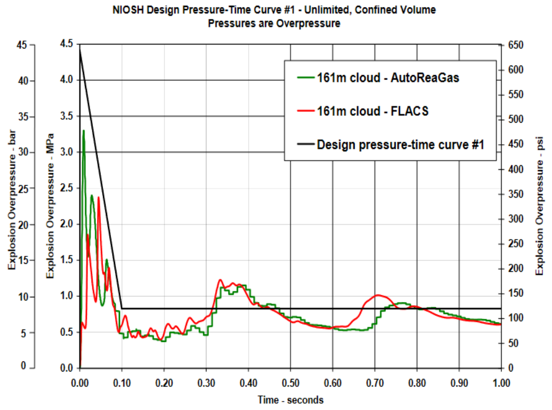


Figure 23.—4.4-MPa (640-psig) design pressure-time curve and typical model calculations.

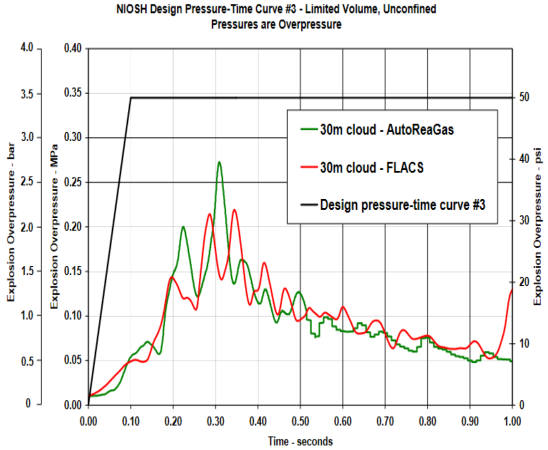


Figure 25.—345-kPa (50-psig) design pressure-time curve and typical model calculations.

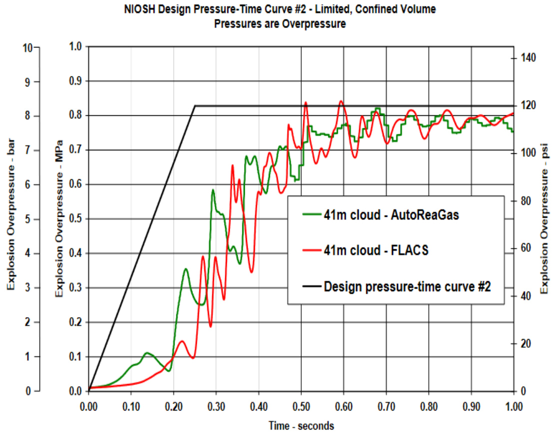
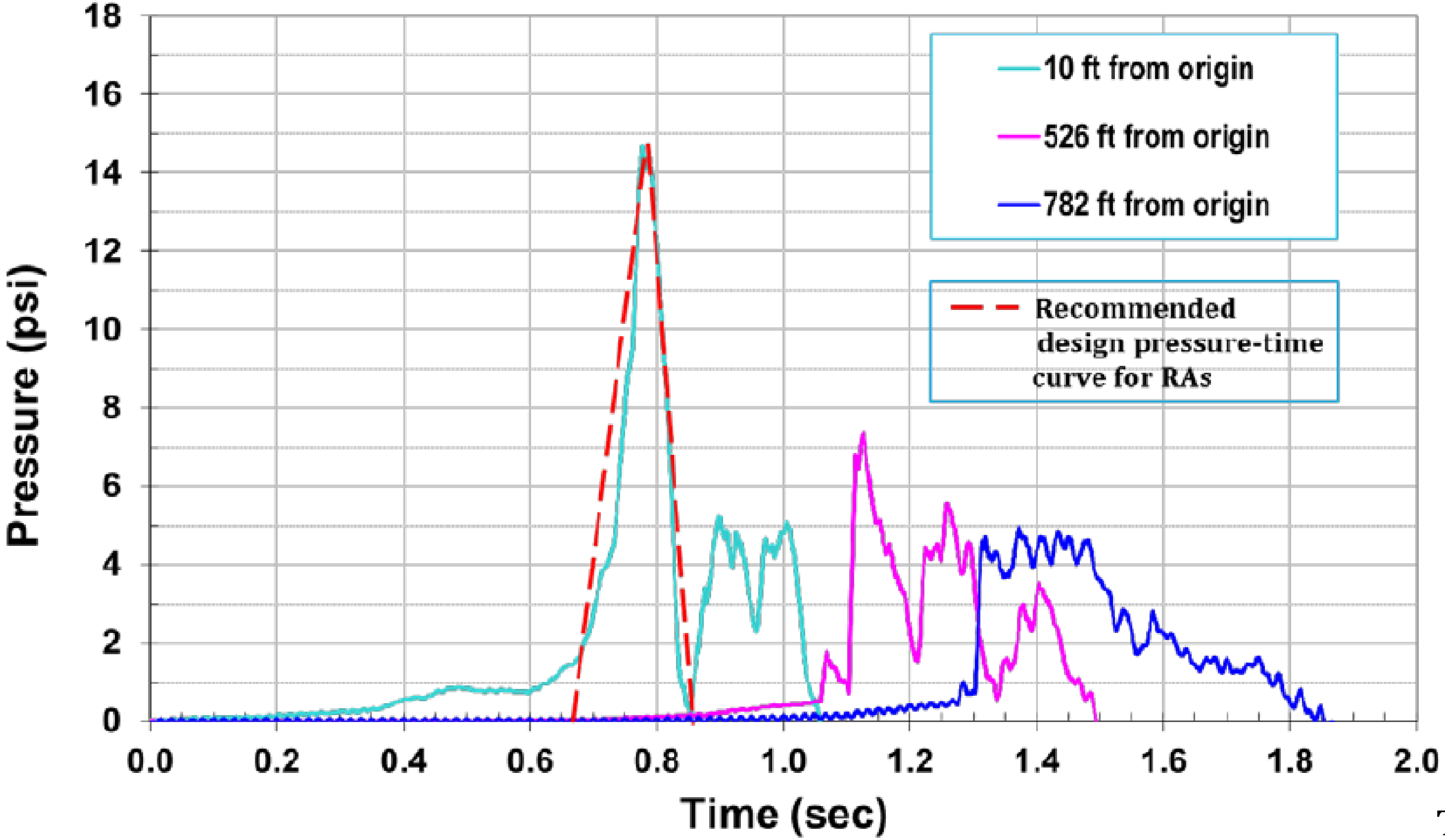


Figure 24.—800-kPa (120-psig) design pressure-time curve and typical model calculations.

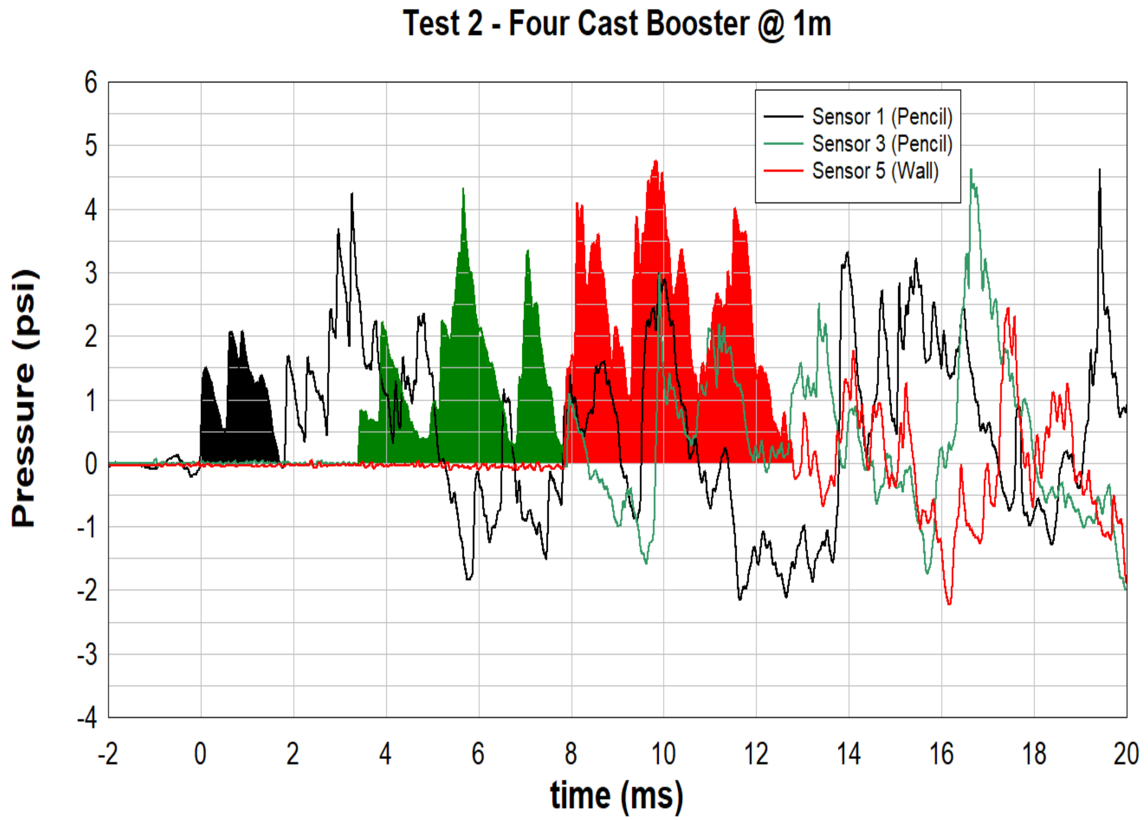


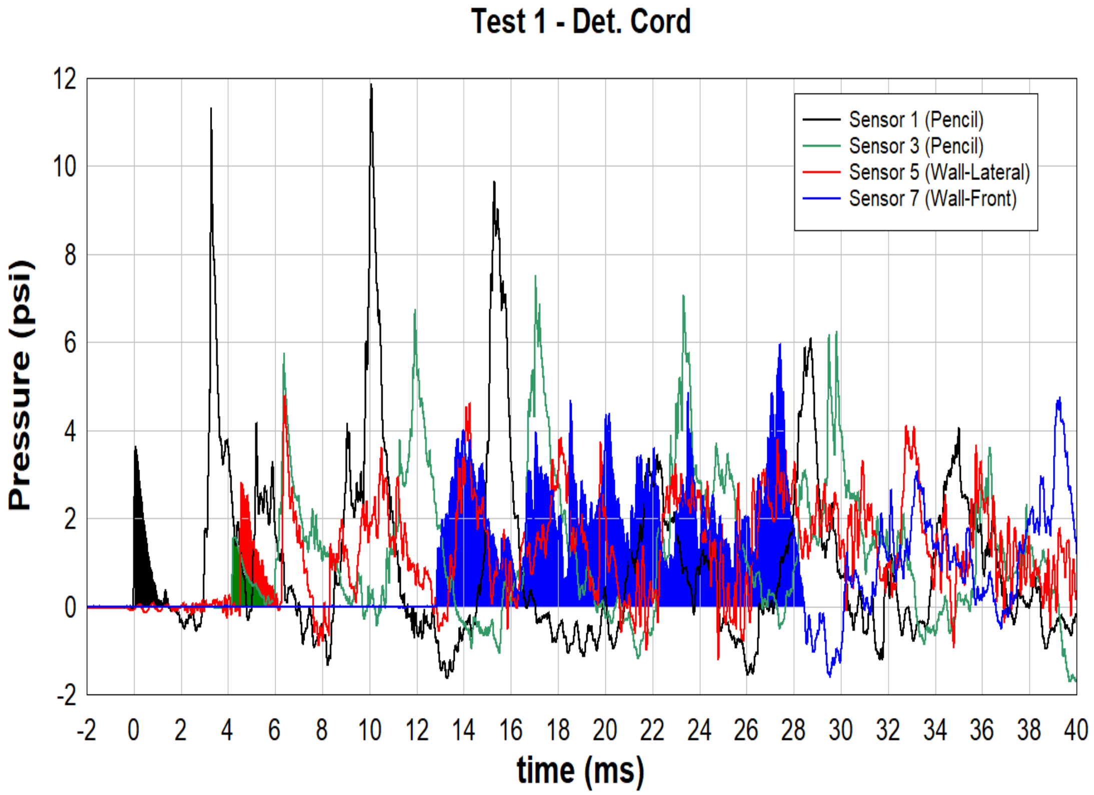
18
16
14
12
10
8
6
4
2
0
Pressure (psi)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
Time (sec)
10 ft from origin
526 ft from origin
782 ft from origin
Recommended design pressure-time curve for RAs

Test #485

High Explosives (Det. Cord, Cast Boosters)

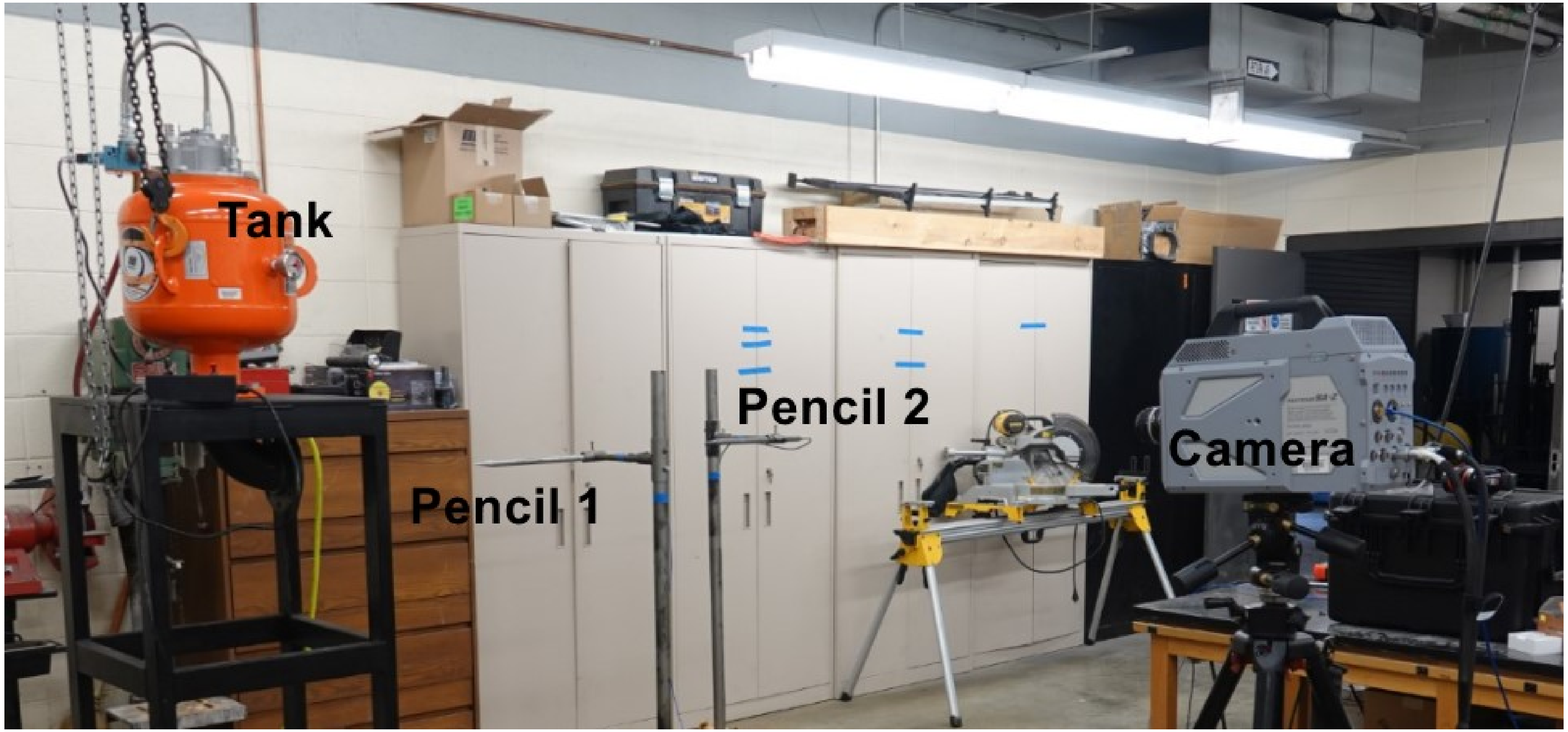
High Explosives (Det. Cord, Cast Boosters)



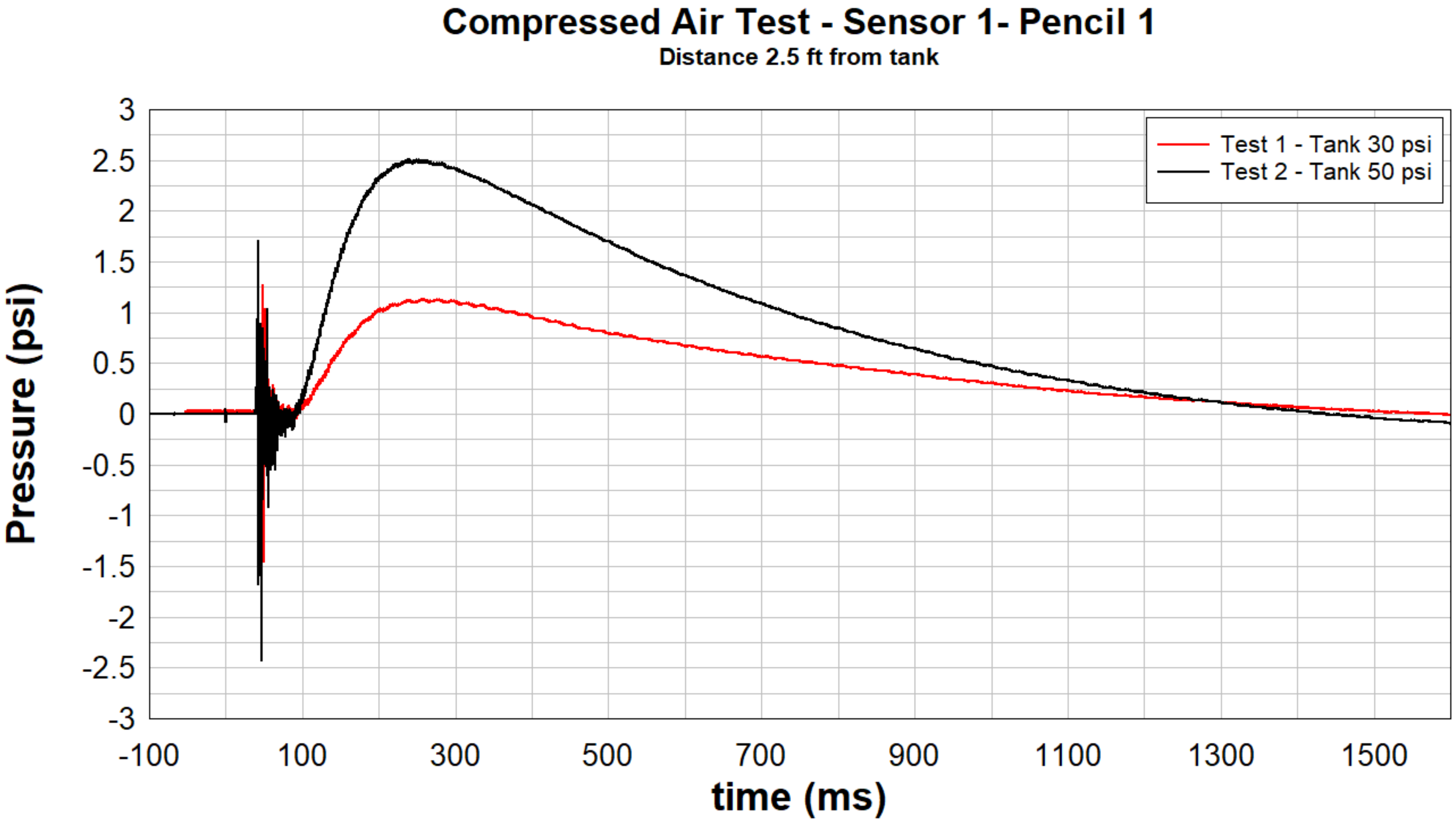


Numerical modeling and analyses indicated that it was needed 50 charges detonated at 1 ms to achieve the target duration (200 ms)

Compressed Air

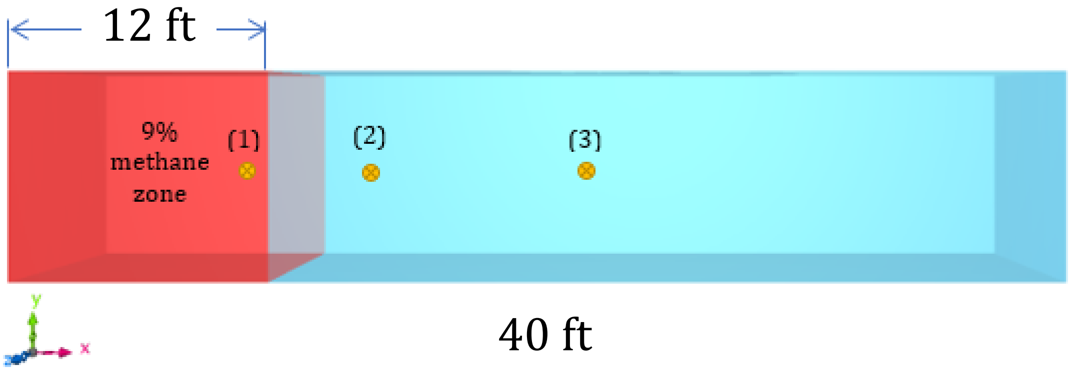


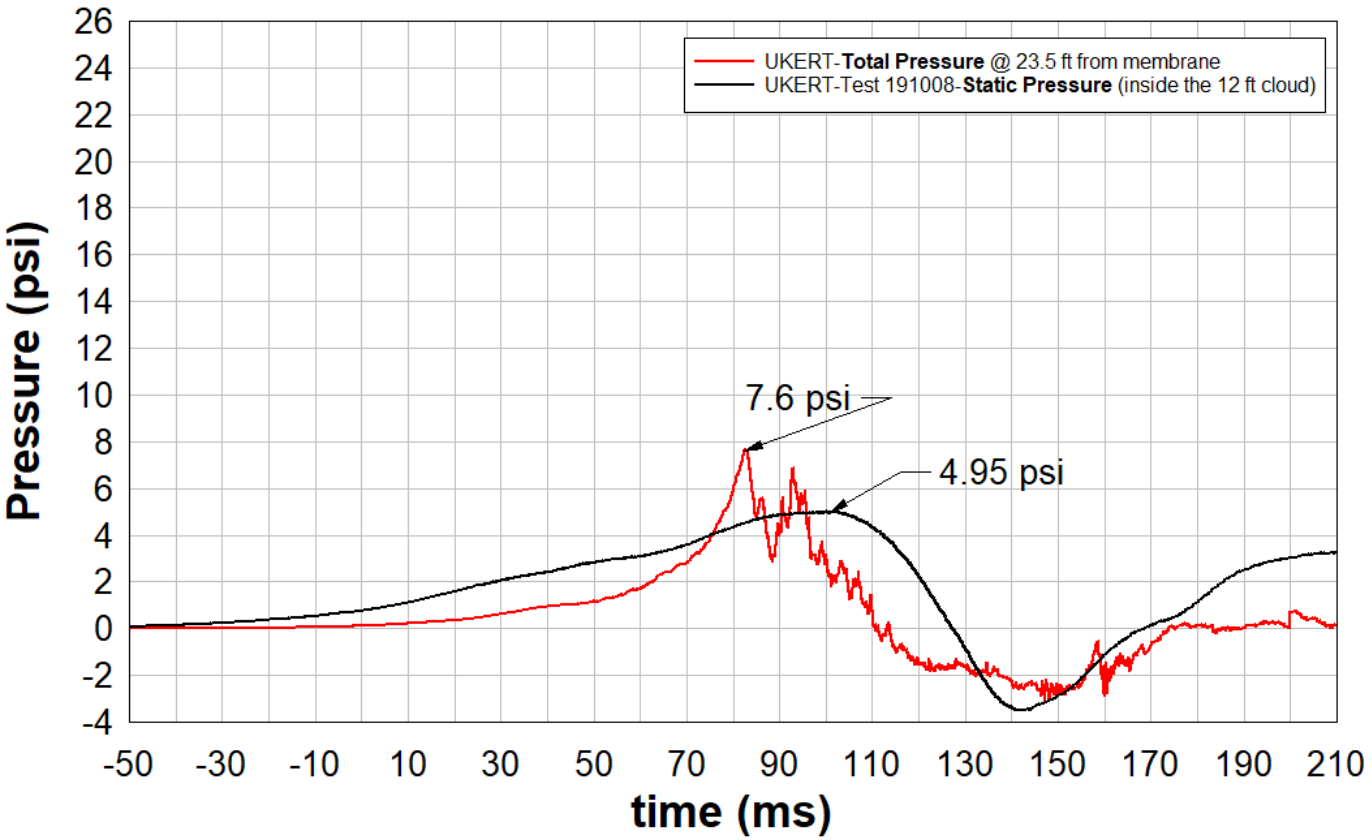
Compressed Air



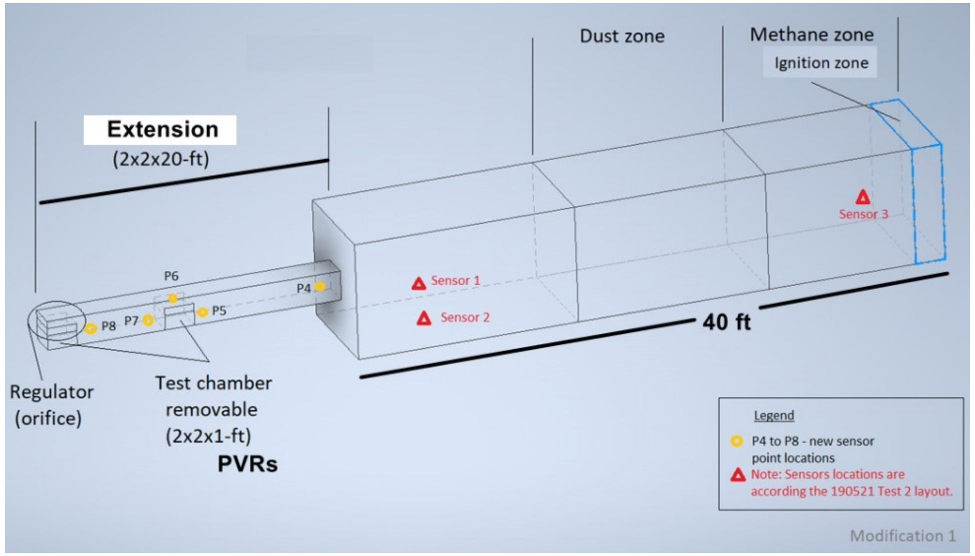
Considerable duration, “low” peak pressure. It can be used, more research required.

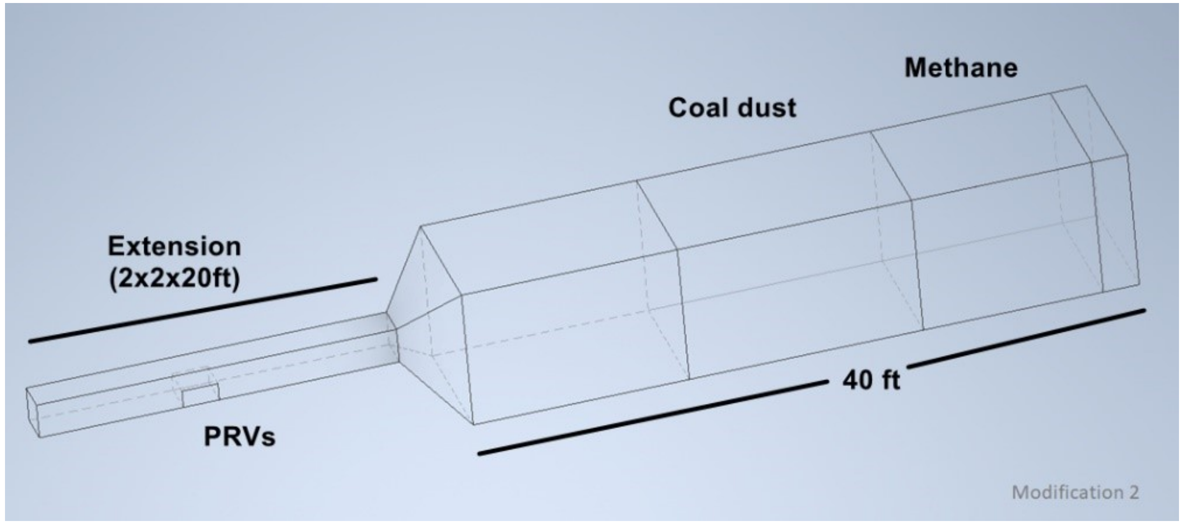
3.3 Final experimental setup.

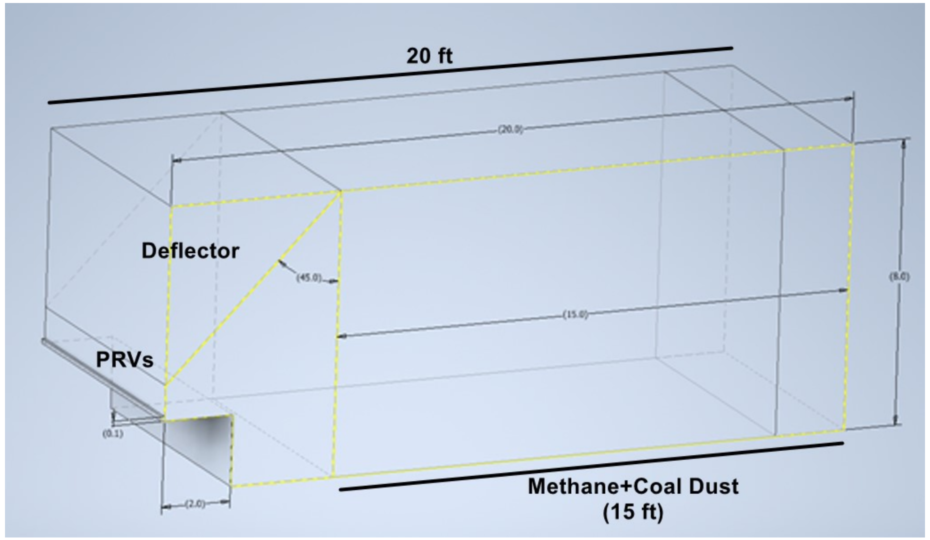




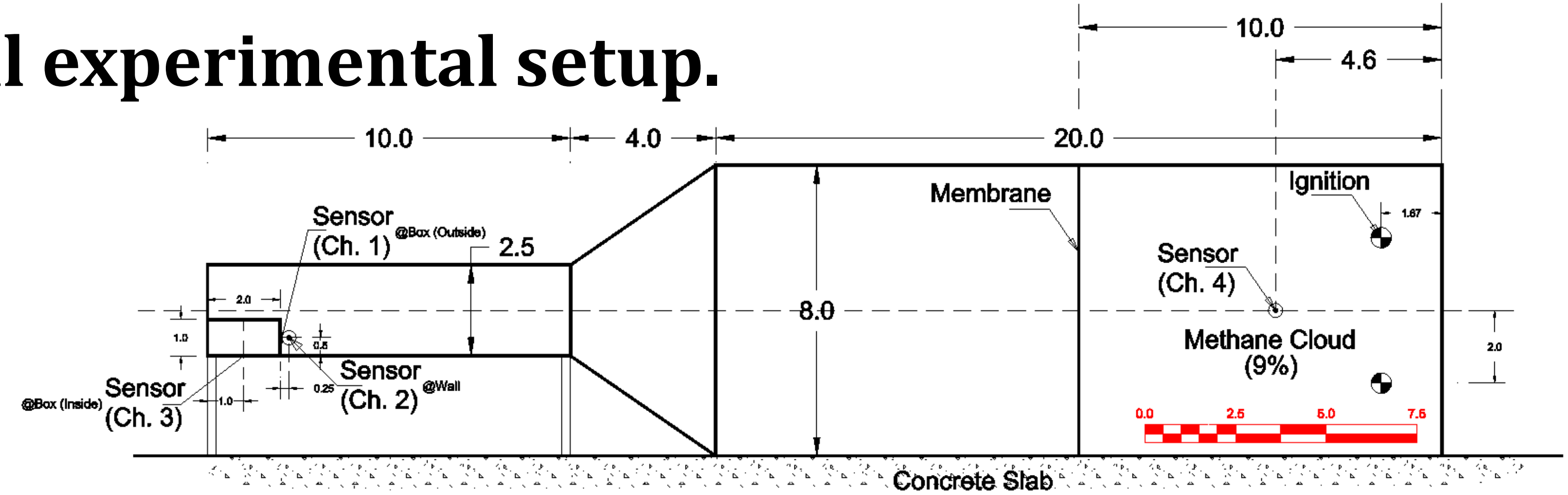
Analysis of alternatives

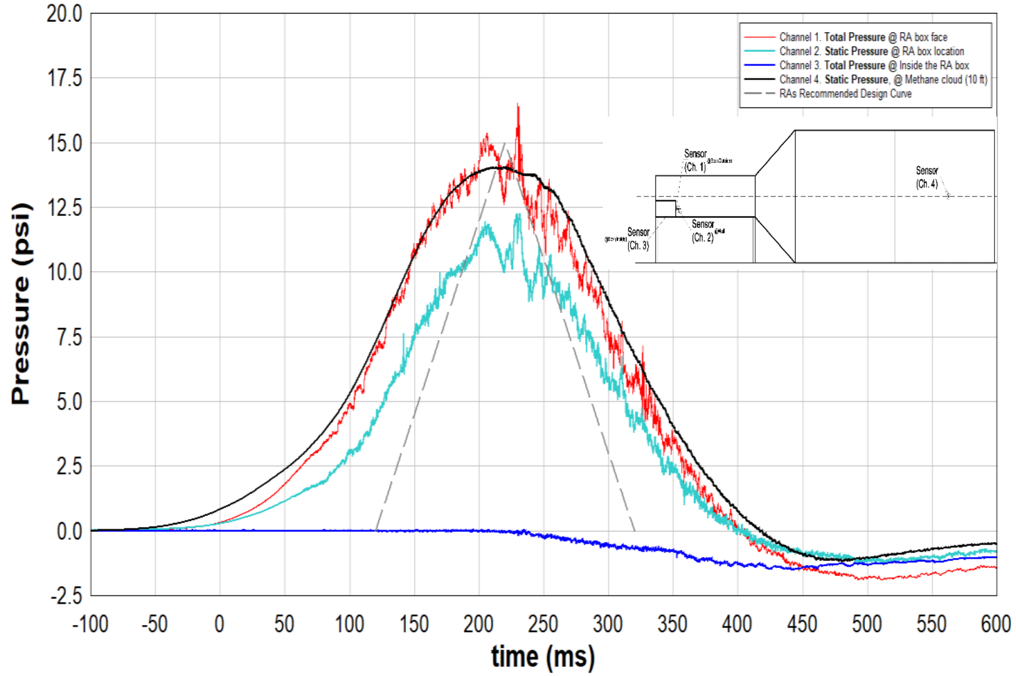






Final experimental setup.

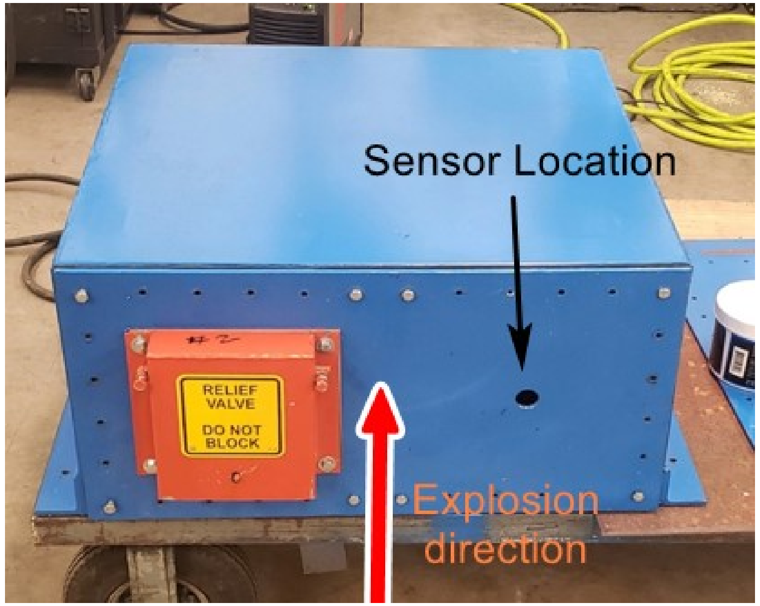


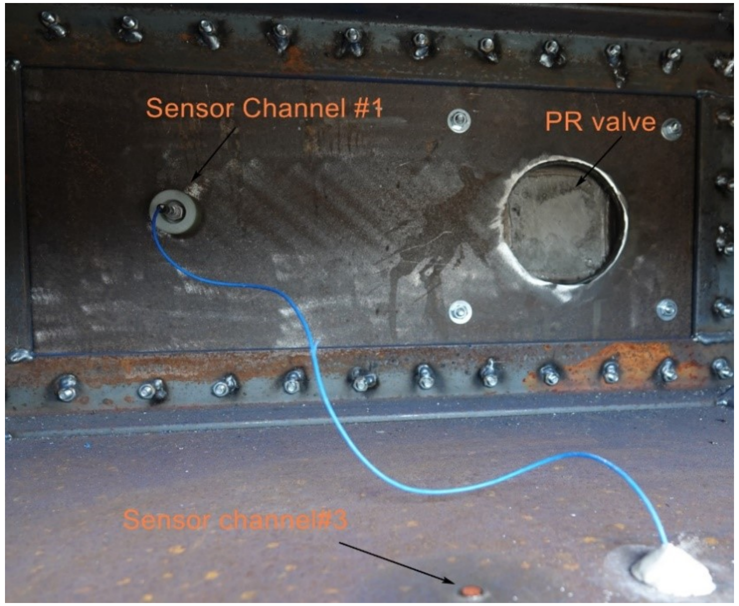


4. Valves Testing

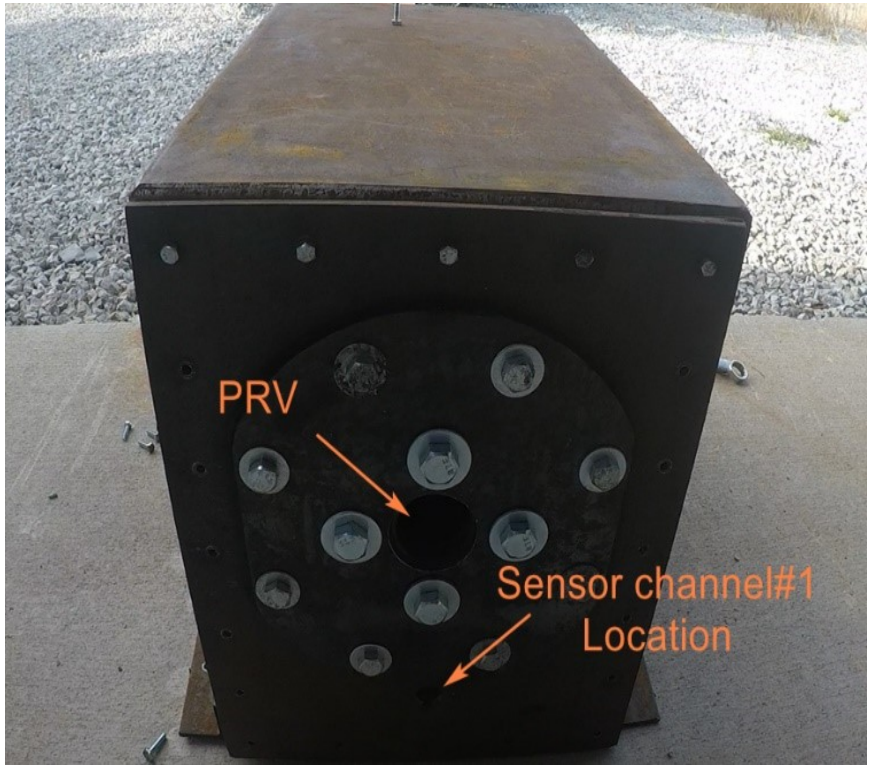
Once the pressure-time curve was replicate, the PRVs where installed on simulated RAs.

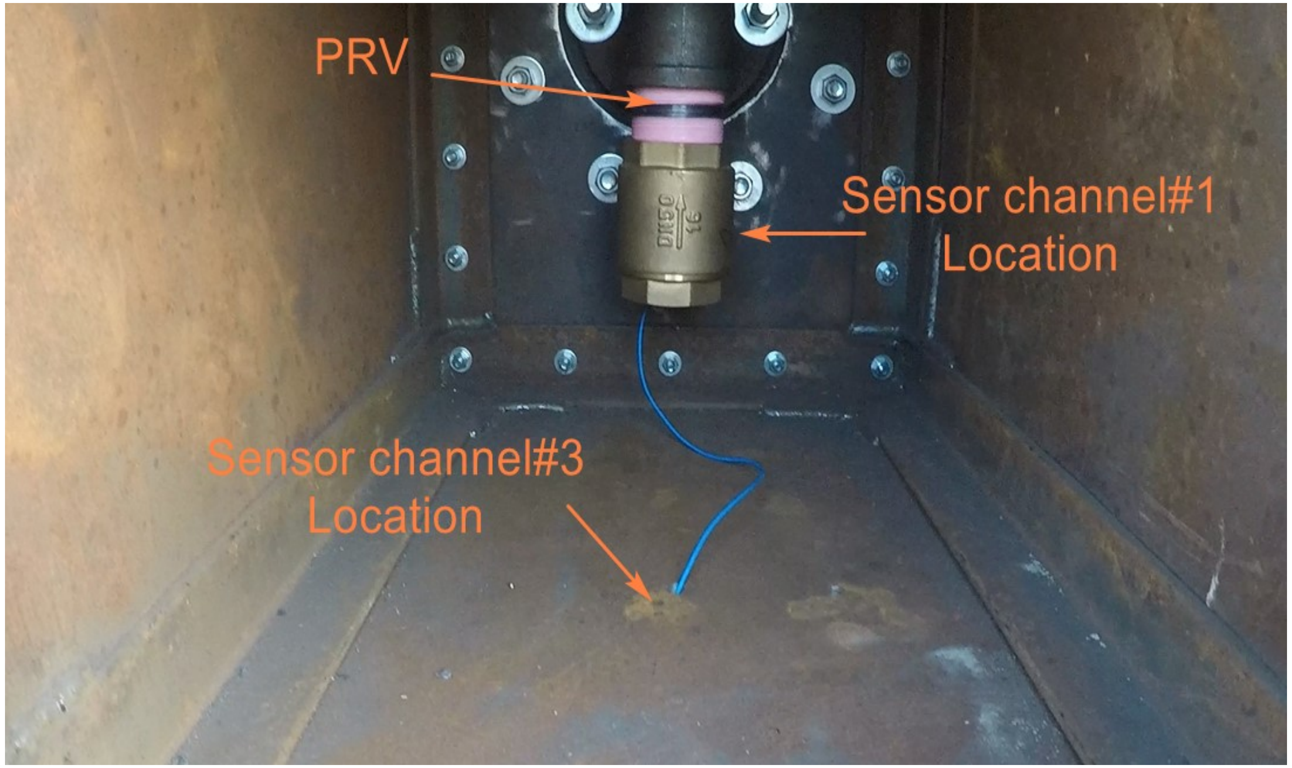
Chamber envelope overpressure relief valve



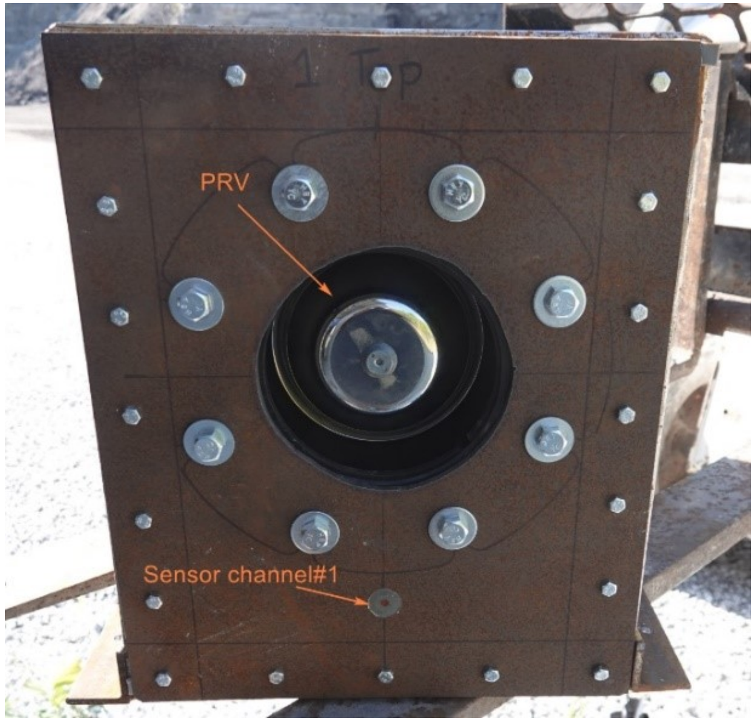


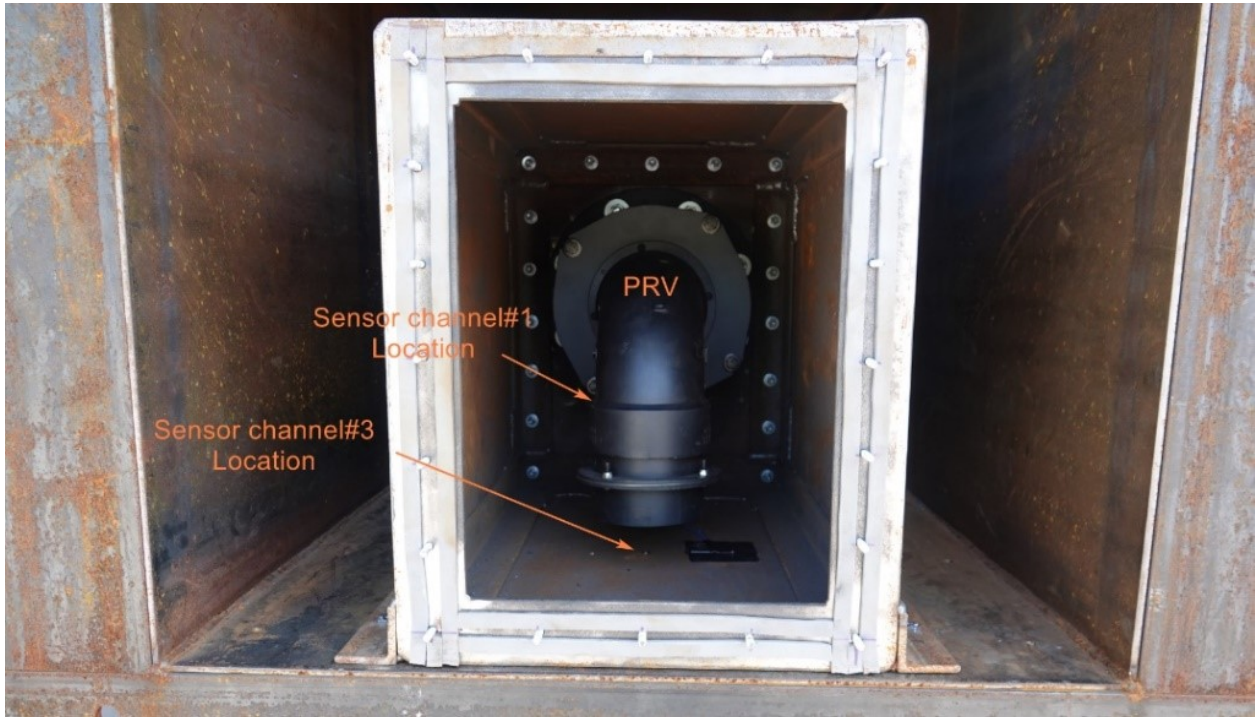
MineARC


PRV
Sensor channel#1
Location

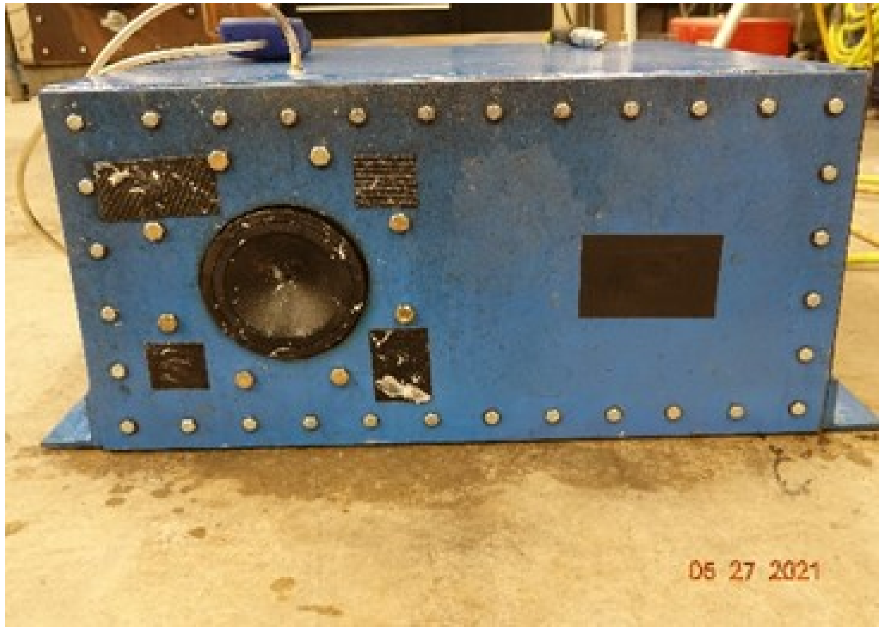

PRV
Sensor channel#1
Location
Sensor channel#3
Location

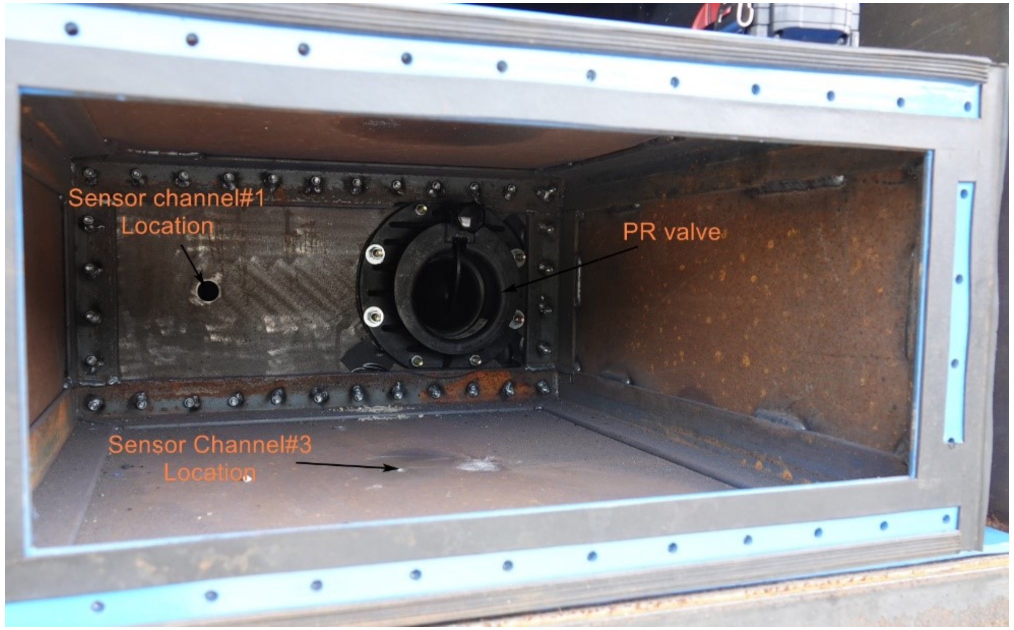
American Safe Room (ASR)





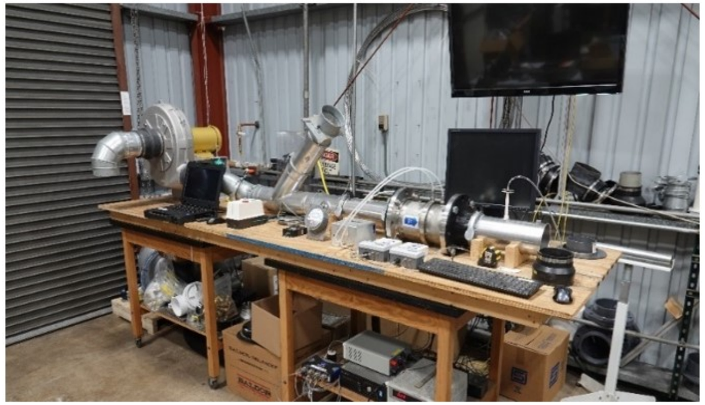
Temet YV1


05 27 2021


Sensor channel#1
Location
PR valve
Sensor Channel#3
Location

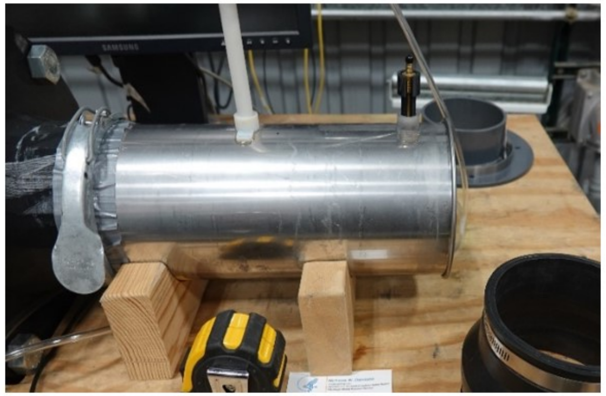
5. Valves Testing Results/Conclusions

Pre-Explosion test

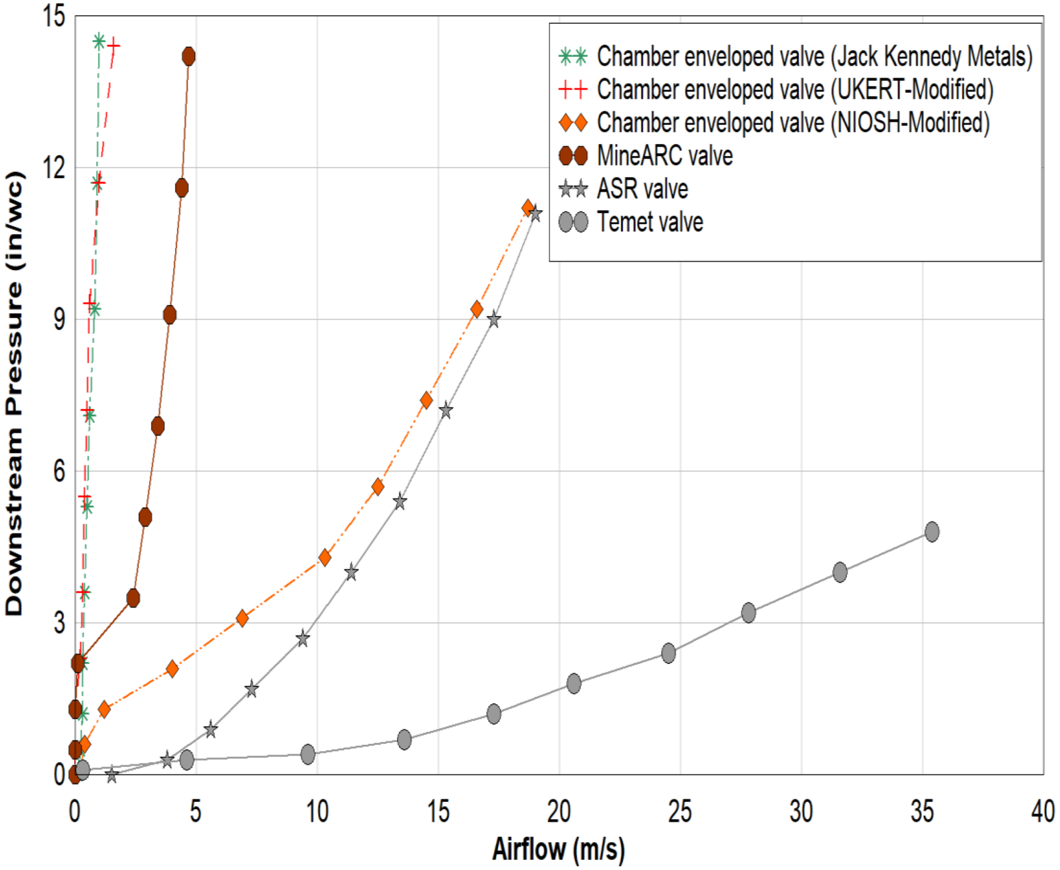


b) Flow Bench

a) Fan



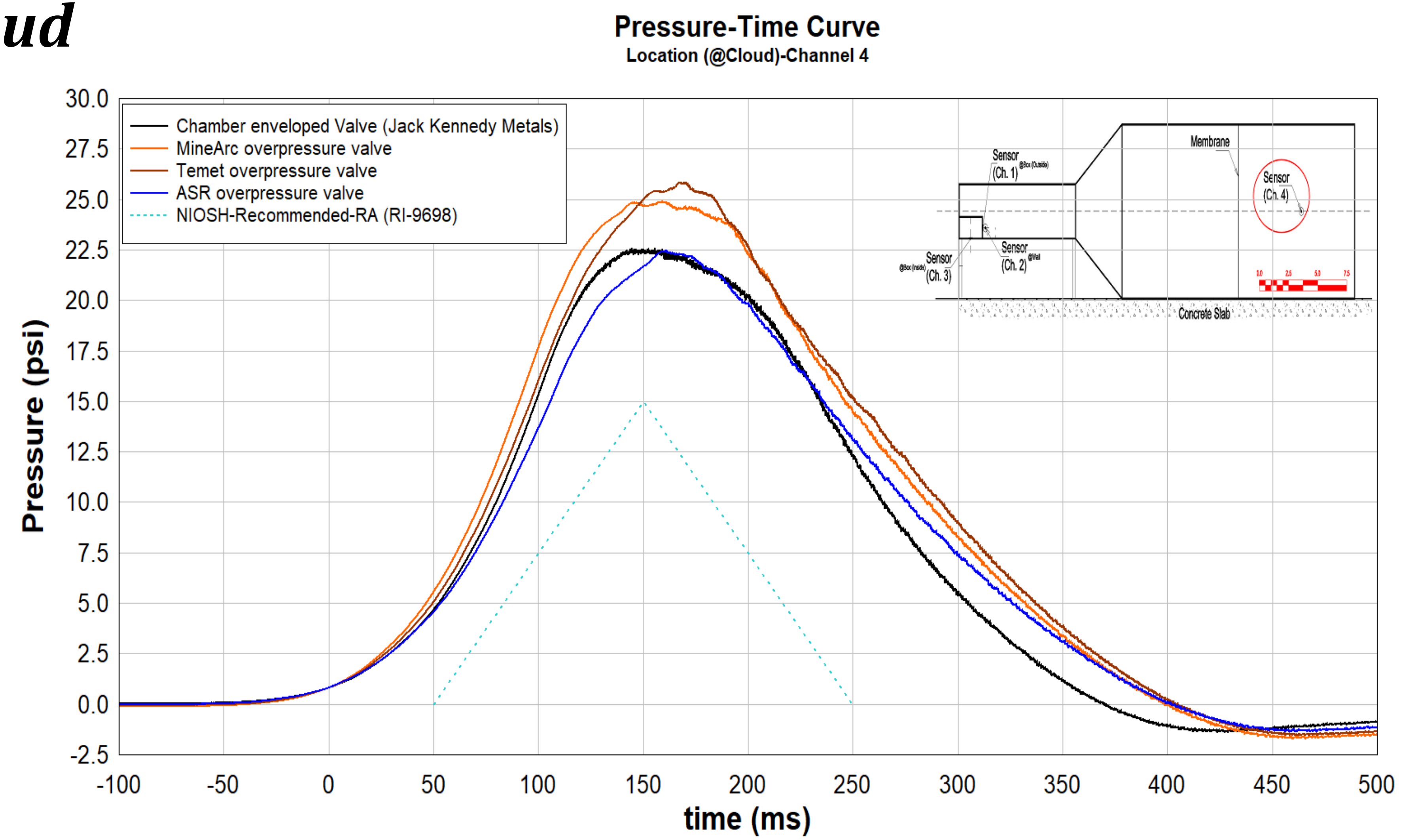
c) Open end



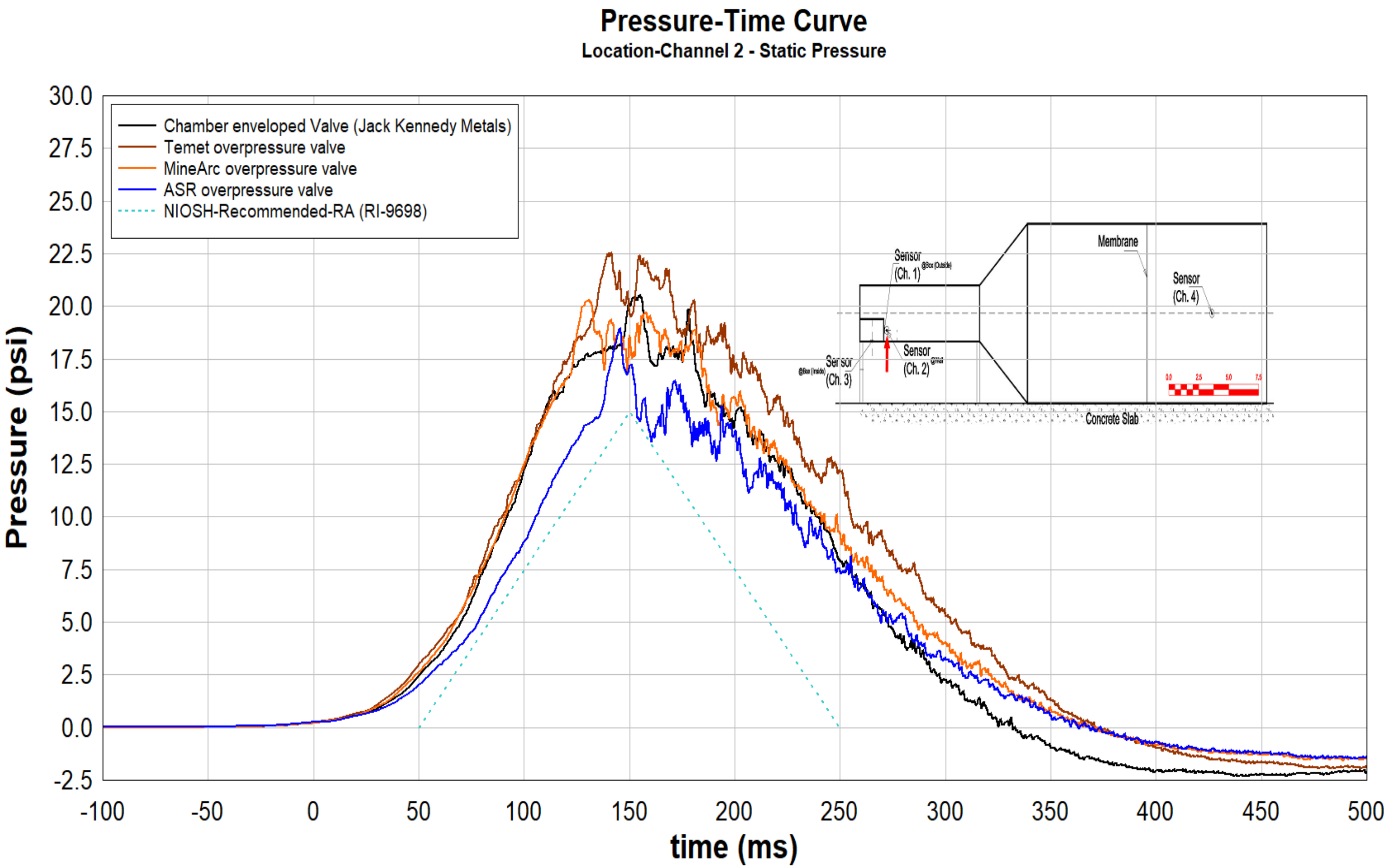
5. Valves Testing Results/Conclusions

Explosion test

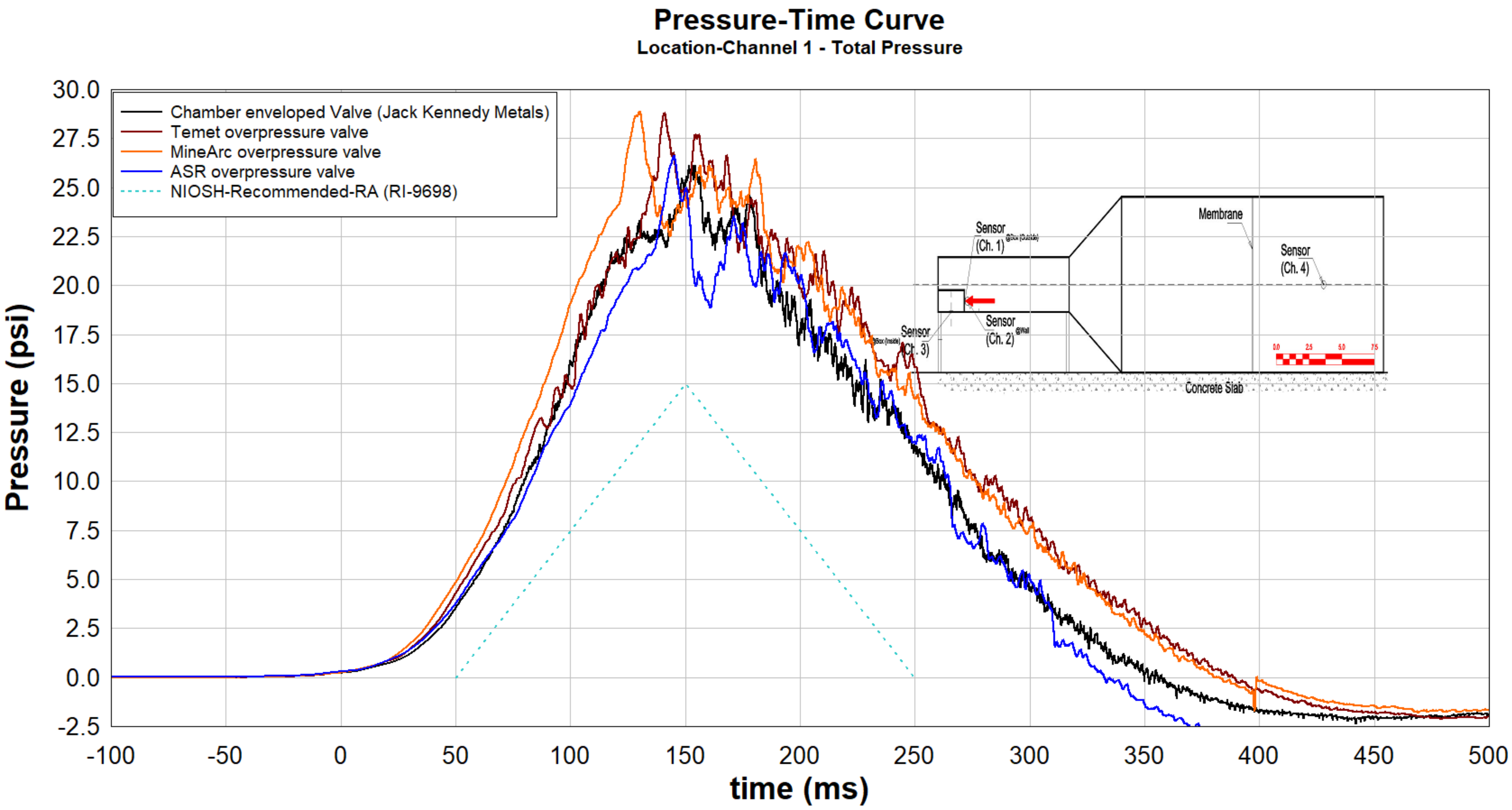
Cloud



Tunnel-Sensor

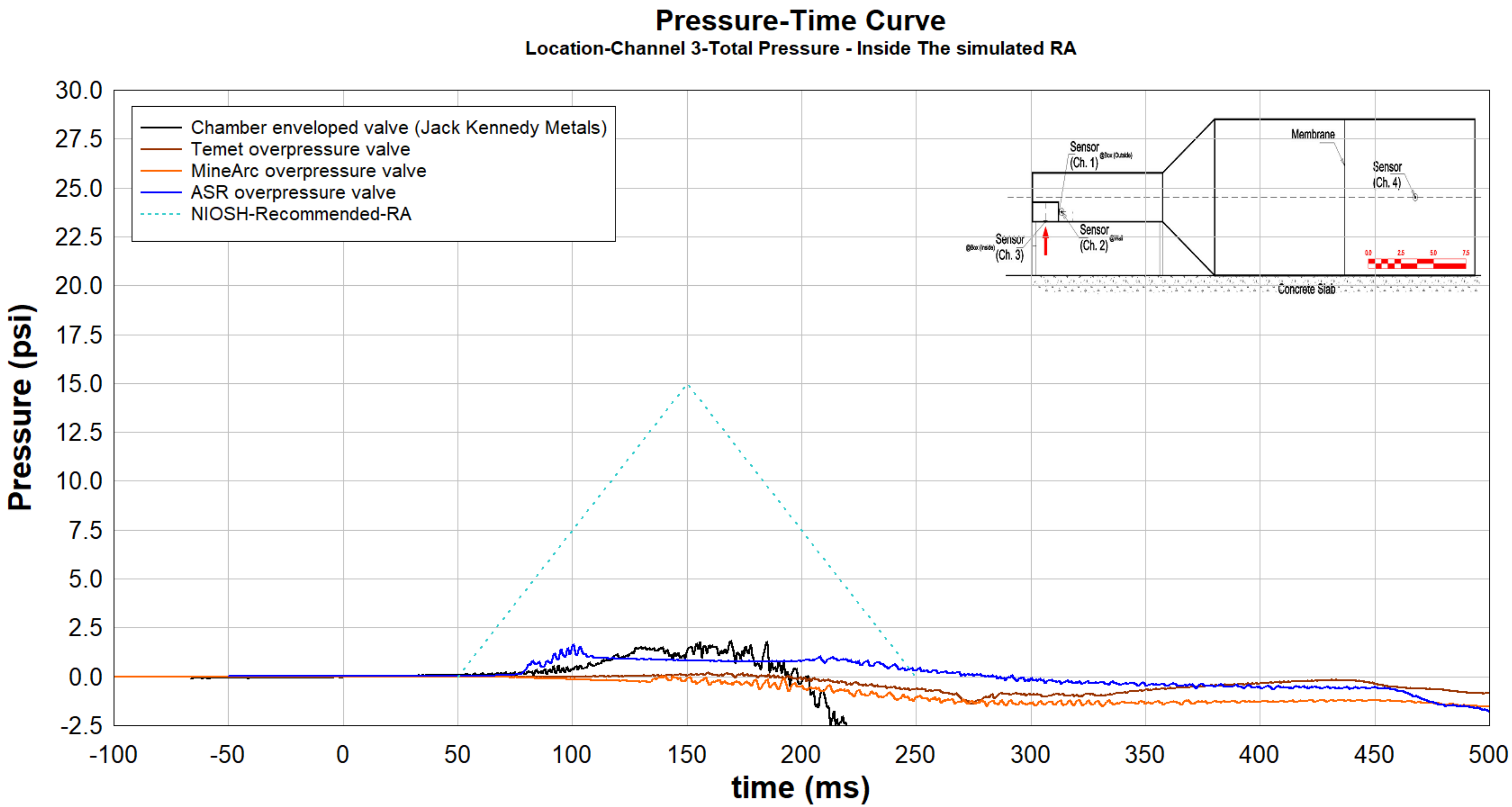


RA-Face



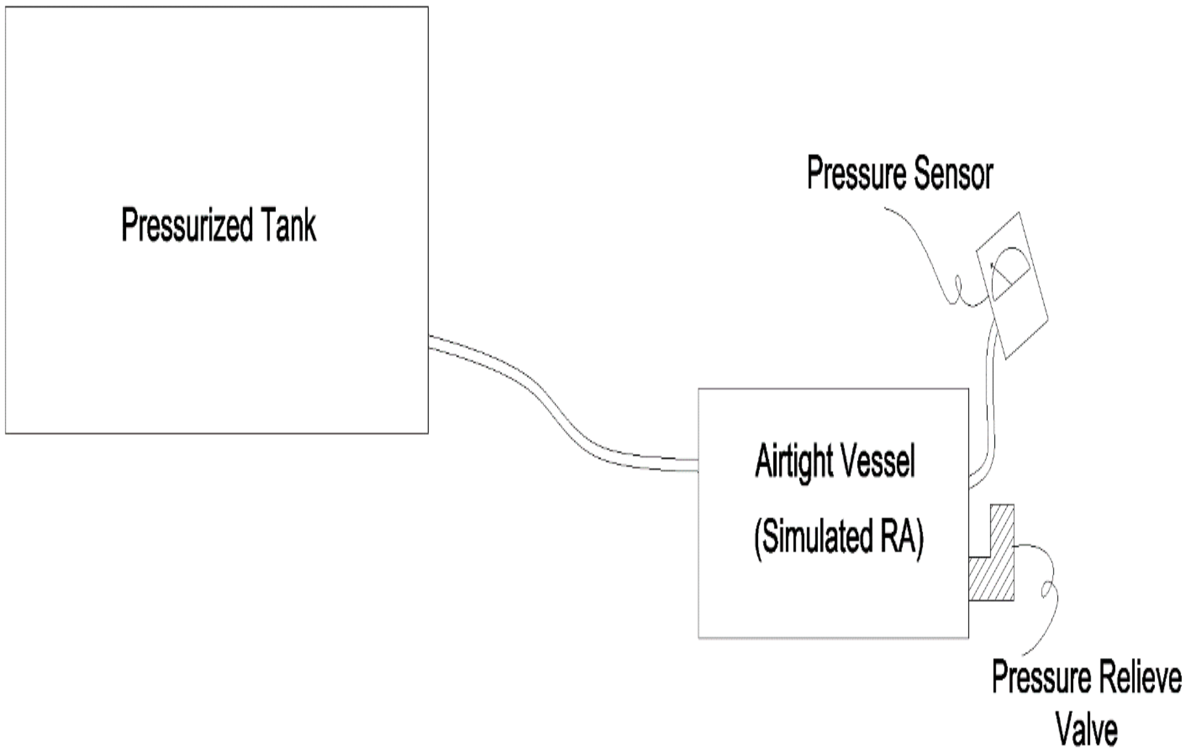
Pressure-Time Curve
Location-Channel 1 - Total Pressure
Chamber enveloped Valve (Jack Kennedy Metals)
Temet overpressure valve
MineArc overpressure valve
ASR overpressure valve
NIOSH-Recommended-RA (RI-9698)
Pressure (psi)
time (ms)
30.0
27.5
25.0
22.5
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
-2.5
-100
-50
0
50
100
150
200
250
300
350
400
450
500
Sensor (Ch. 1)
Sensor (Ch. 2)
Sensor (Ch. 3)
Sensor (Ch. 4)
Membrane
Concrete Slab

RA-Interior


Pressure-Time Curve
Location-Channel 3-Total Pressure - Inside The simulated RA
Chamber enveloped valve (Jack Kennedy Metals)
Temet overpressure valve
MineArc overpressure valve
ASR overpressure valve
NIOSH-Recommended-RA
Pressure (psi)
time (ms)
30.0
27.5
25.0
22.5
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
-2.5
-100
-50
0
50
100
150
200
250
300
350
400
450
500
Sensor (Ch. 1)
Sensor (Ch. 2)
Sensor (Ch. 3)
Sensor (Ch. 4)
Membrane
Concrete Slab

5. Valves Testing Results/Conclusions

Post-Explosion test



b. MineArc

a. ASR

d. Temet

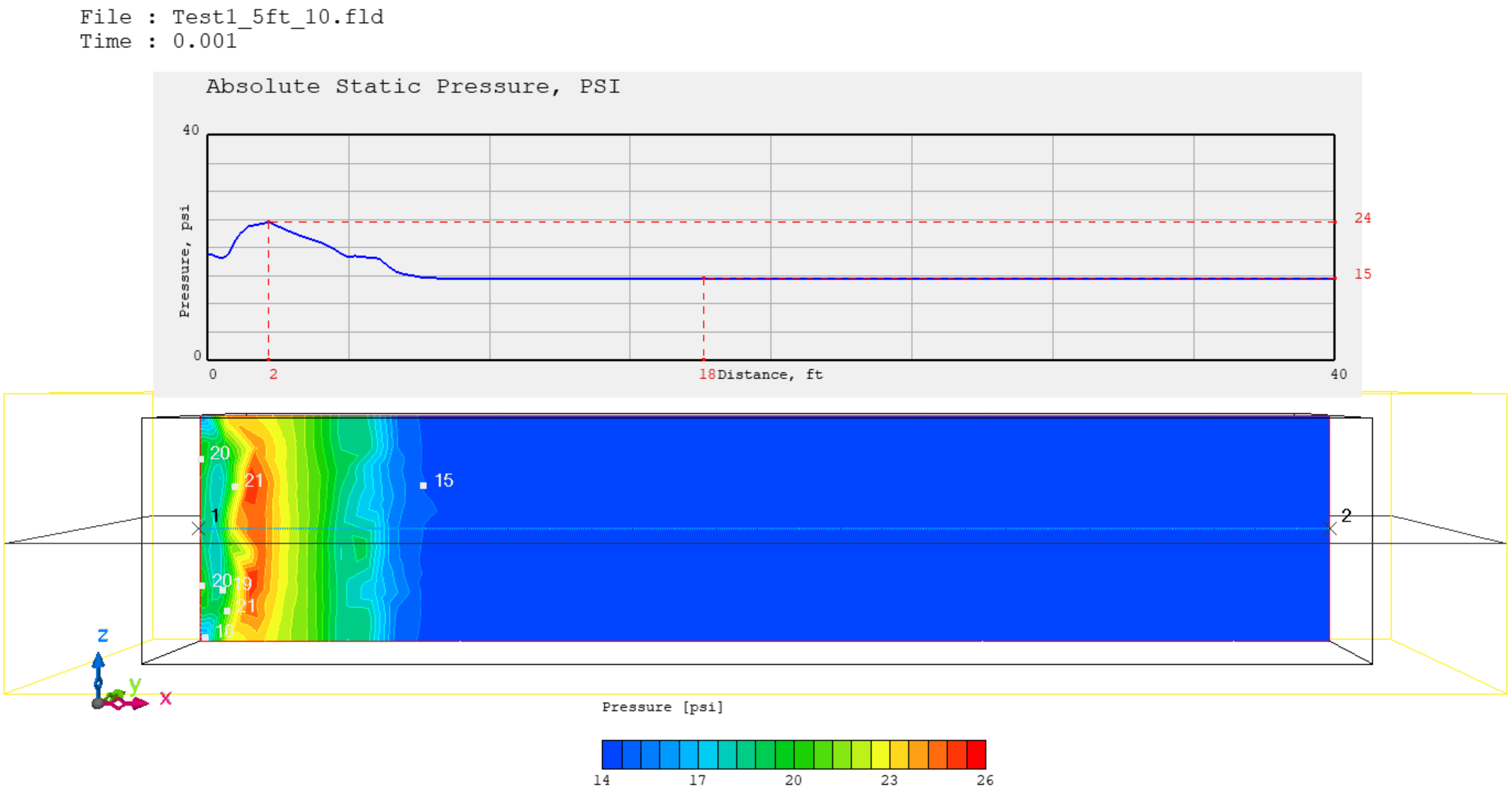
c. Chamber envelop

5. Valves Testing Results-Post-Explosion Test

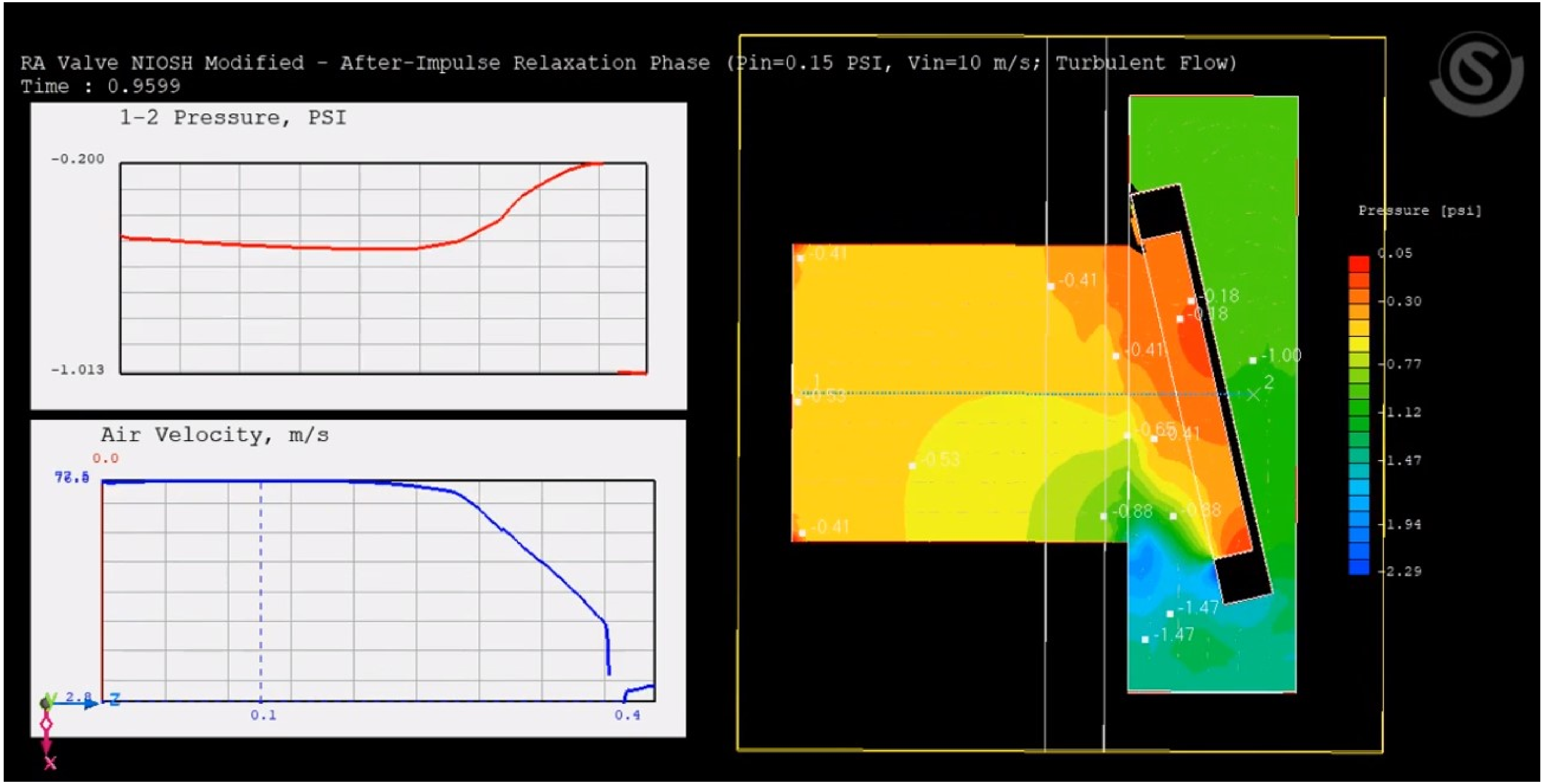
	Steady State pressure in kPa (psi)			
Tank Pressure, kPa. (psi)	**MineArc**	**ASR**	**Temet**	**Chamber envelope NIOSH-modified**
172.37 (25)	0.62 (0.090)	0.140 (0.00072)	0.040 (0.0059)	0.172 (0.0249)
344.73 (50)	0.59 (0.086)	0.145 (0.00076)	0.039 (0.0057)	0.643 (0.0933)
517.10 (75)	0.58 (0.085)	0.165 (0.00087)	0.035 (0.0051)	0.877 (0.1272)

The maximum differential pressure in all the PRVs was 0.877 kPa. This value is below the recommended 1.25 kPa or 1.72 kPa. This is an indication that the PRVs still are functioning after being subjected to the explosion test.

6. Numerical Modeling



6. Numerical Modeling



The University of Kentucky Explosives Research Team UKERT will like to acknowledge the participation of many individuals to make this project possible. John Meuth, Nate Schaefer, Josh Calnan were working in summer welding and cutting steel to made the required shock tube modification.