METHODS FOR NONDESTRUCTIVE EVALUATION OF UNDERGROUND MINE SEALS

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THE DEPARTMENT OF MINING & MINERALS ENGINEERING

AT VIRGINIA TECH

ASSESSMENT OF TECHNOLOGY FOR NON-DESTRUCTIVE TESTING OF IN-SITU UNDERGROUND MINE SEALS

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OVERVIEW

- Background and Motivation
- Technology identified for assessment
  - Ultrasonic Sensing
  - Ground Penetrating Radar
  - Tracer Gas Methods*
- Experimental Methods
- Findings
- Recommendations

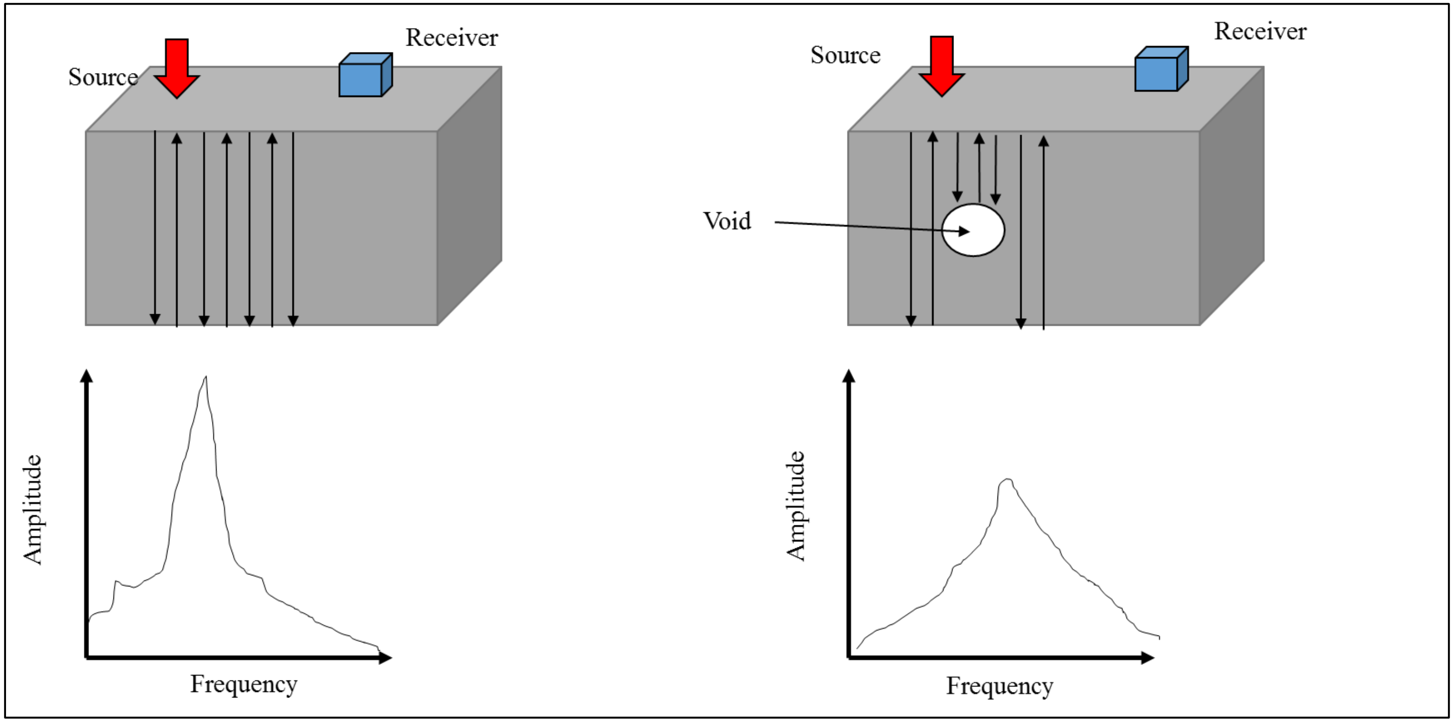
BACKGROUND AND MOTIVATION

- After several major mine accidents in the winter/spring of 2006 the MINER Act was promulgated and signed into law on June 15, 2006
- Among others, there were specific changes to law regarding mine seals:
  - Seals rated at 50 psi must be monitored
  - Or seals rated to 120 psi installed under strictly engineered plans

Getty Images, 2006

- Maintenance and Examination of Seals is limited to:
  - Visual Inspection (outby only) or obvious communication with the sealed area
  - Inspection of seals as they are routinely breached
  - Obvious structural defects that require replacement

ULTRASONIC SENSING



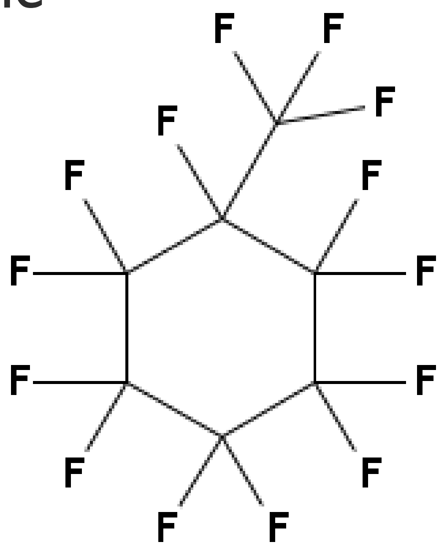
- P-waves reflecting off boundaries in the sample create a resonance frequency that can be measured using FFT analysis
- Developed specifically as concrete strength and flaw detection NDT method

GROUND PENETRATING RADAR (GPR)

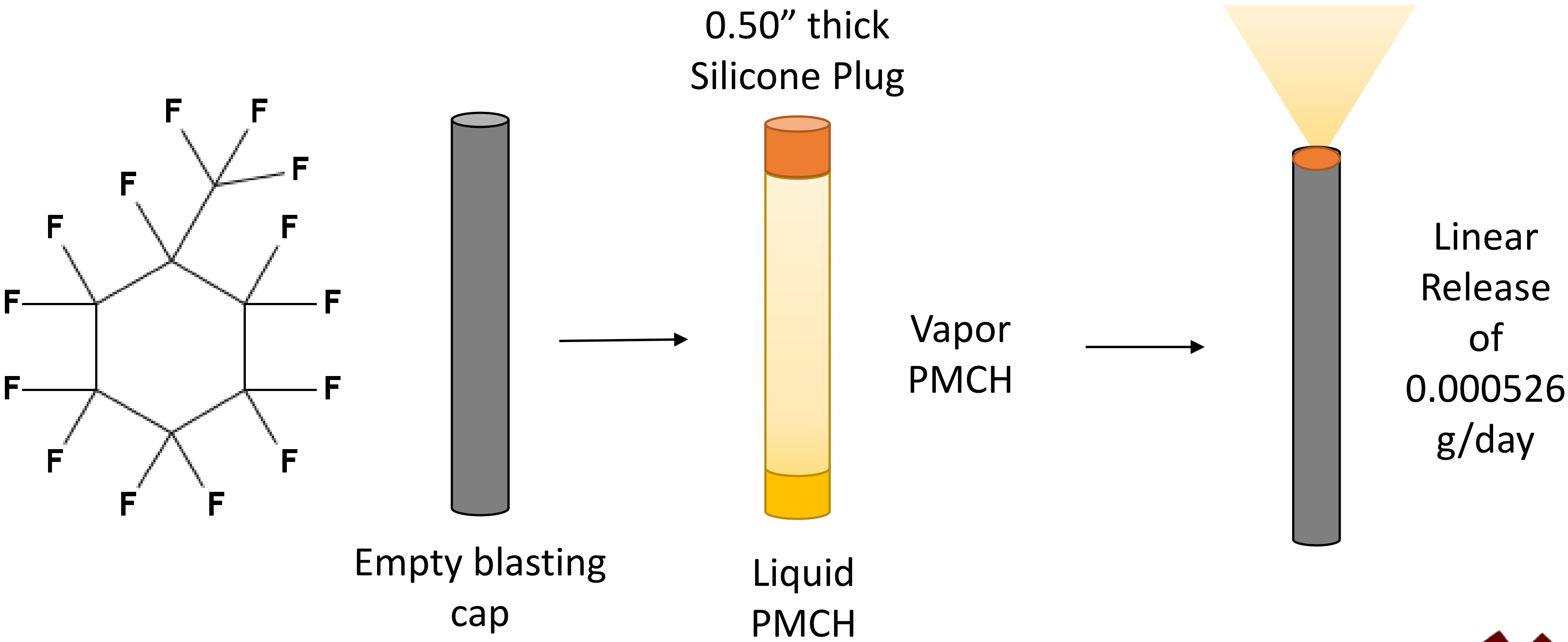
- A geophysical method, similar to ultrasonic, but utilizing high frequency radio waves.
- Widely applied in civil engineering applications, particularly for location of voids and tanks in ground.

TRACER GASES

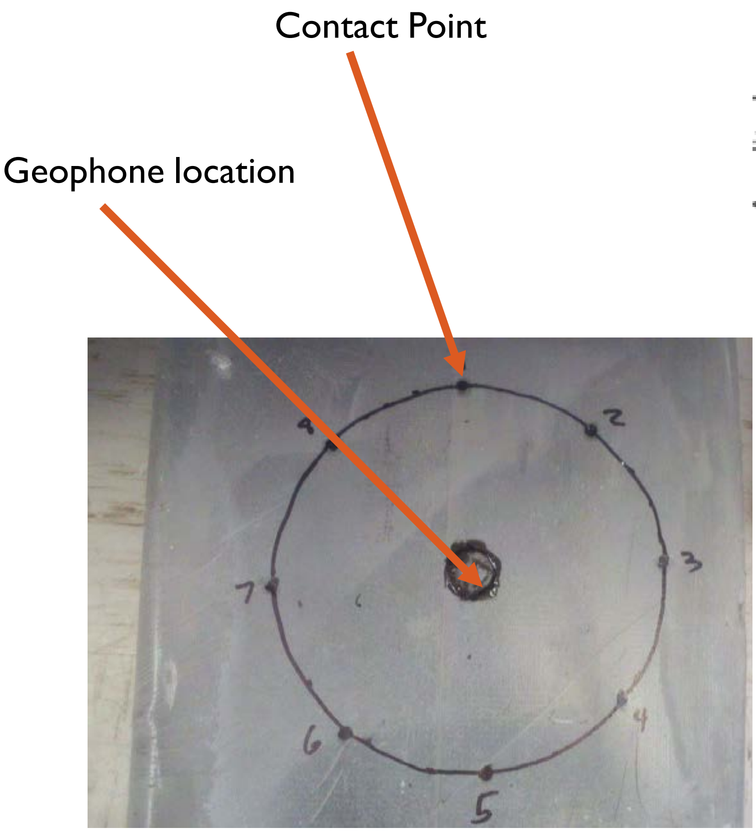
- Utilized a novel gas – has been proven for mine ventilation
- Perfluoromethylcyclohexane (PMCH)
- Tracer used primarily for atmospheric and building ventilation studies
- 250 less abundant in background atmosphere than SF6
- Non-naturally occurring, volatile, inert, nontoxic, heavy molecular weight (350 g/mol)
- Liquid at standard pressure and temperature, but low vaporization pressure (14 kPa)

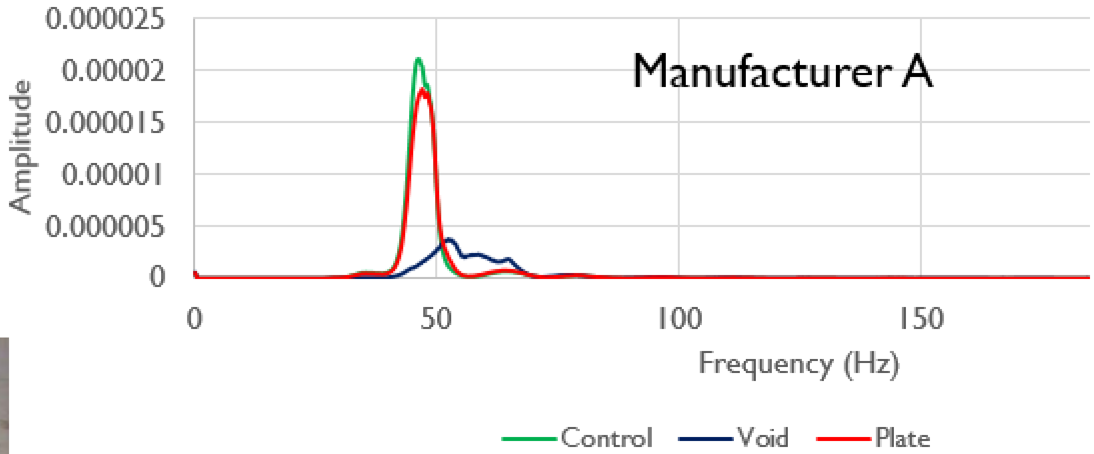


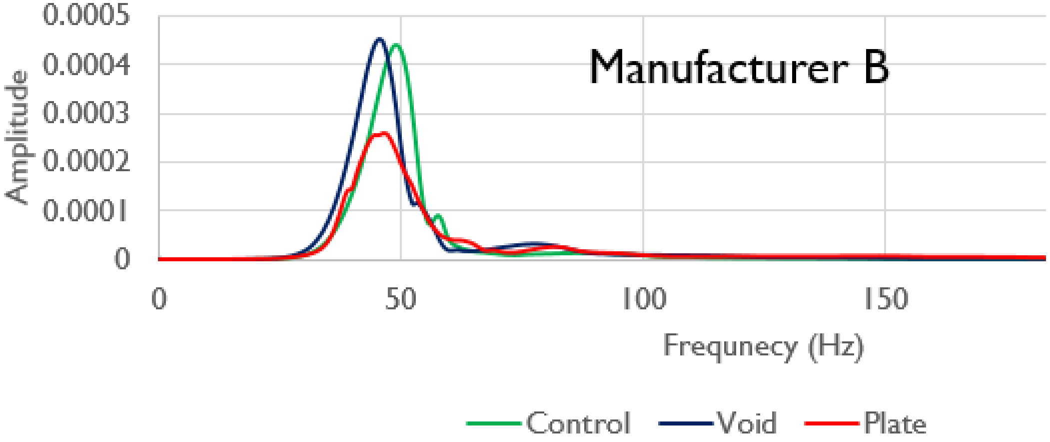
TRACER GASES | PASSIVE RELEASE SOURCES



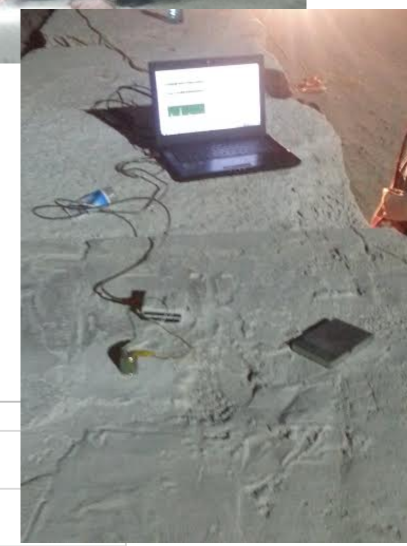
SMALL SCALE EXPERIMENTS



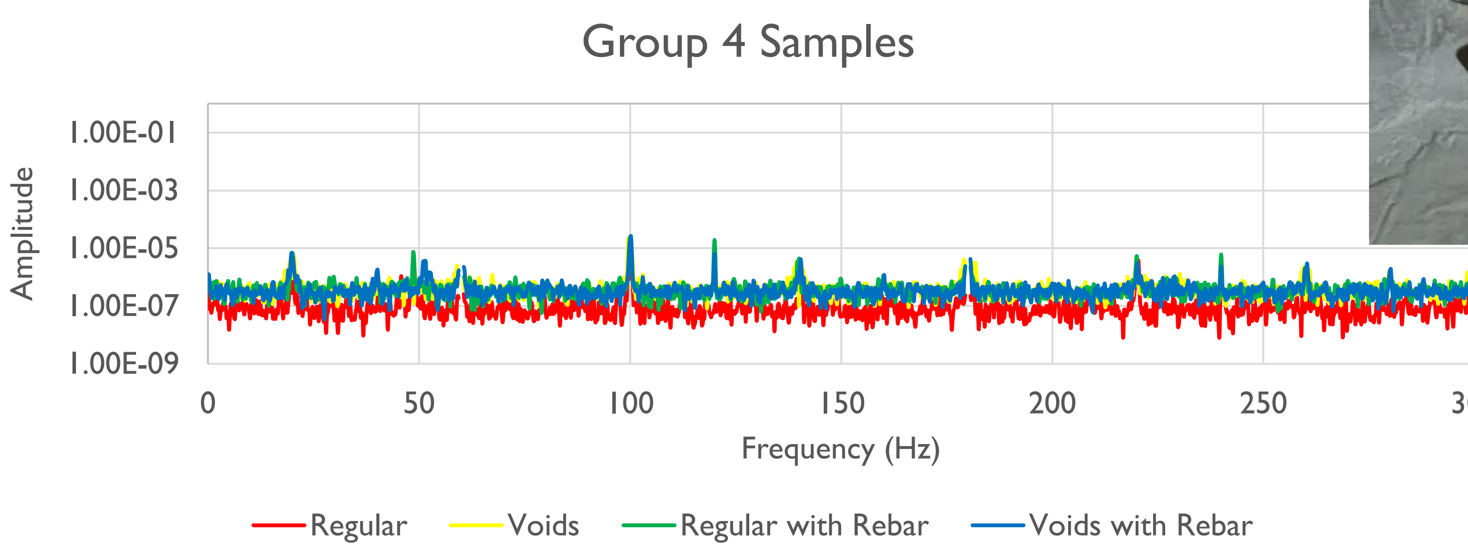




LARGE SCALE EXPERIMENTS



- 12 large samples prepared for analysis:
  - Varied the mix, included small voids, large voids, trash Styrofoam, balls, high density anomalies
  - Samples stored and analyzed in underground limestone mine.



GROUND PENETRATING RADAR EXPERIMENTS

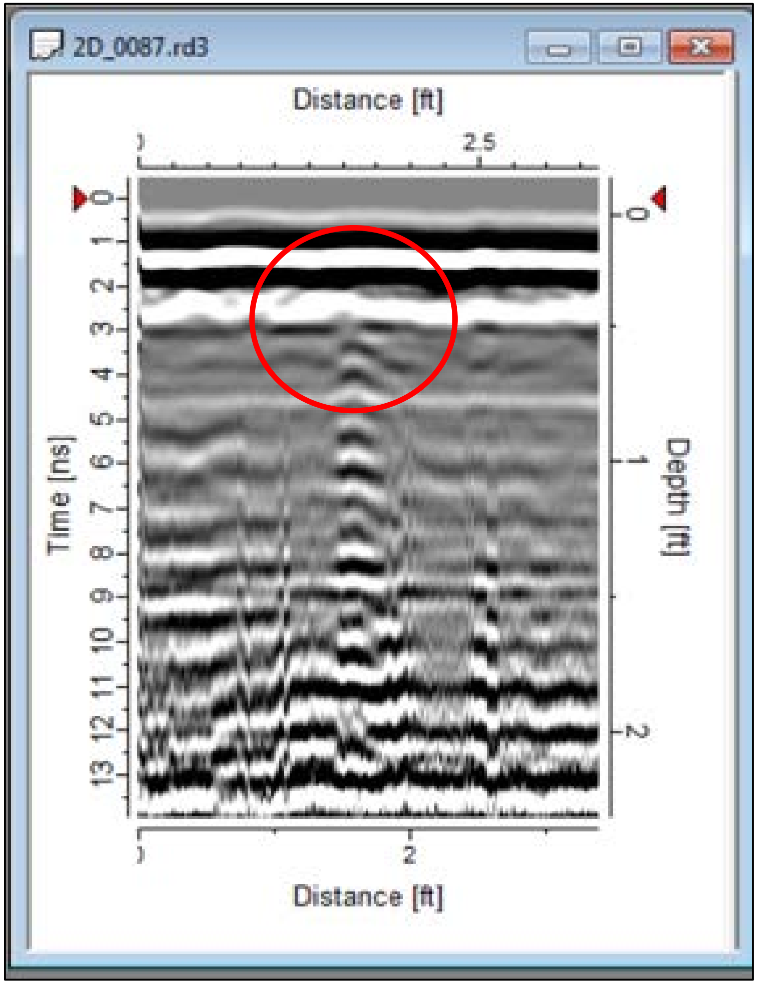
- 5 frequencies (200 to 1600 MHz) and 3 units (2-MALA Geoscience; 1-IDS Detector Duo) were evaluated

GPR SAMPLES POURED AND TESTED

Specimen Identification	Product Manufacturer	Sample Product	Compressive Strength	Feature 1	Feature 2	Feature 3	Feature 4	Feature 5
Unit A	Minova**	Tekseal®	842 psi	Thermocouples	Fractures	Constant UCS	Consistent material	Improper mix ratio
Unit B	Minova	Tekseal®	858 psi	Thermocouples	Regular	Varied UCS	Inconsistent material	Improper mix ratio
Unit C	Minova	Tekseal®	1302 psi	Thermocouples	Fractures	Constant UCS	Desiccated material	Correct mix ratio
Unit D	Minova	Tekseal®	4212 psi	Thermocouples	Regular	Constant UCS	Consistent material	Improper mix ratio
Unit E	Minova	Tekseal®	942 / 792 psi	Thermocouples	Voids on rear	Varied UCS	Desiccated Material	Improper mix ratio
Unit F	Minova	Tekseal®	1439 psi	Thermocouples	Small voids	Constant UCS	Consistent Material	Improper mix ratio
Unit G	Minova	Tekseal®	703 psi	Thermocouples	Regular	Constant UCS	Consistent material	Improper mix ratio
Unit H	Strata	Stratacrete® Medium Strength	N/A	Control	Regular	Constant UCS	Consistent Material	Correct Mix Ratio
Unit I	Strata	Stratacrete® Medium Strength	N/A	N/A	Small Voids/ Styrofoam /	Constant UCS	Consistent Material	Correct Mix Ratio
Unit J	Strata	Stratacrete® High Strength	N/A	Steel Reinforcement	trash & debris	Constant UCS	Consistent Material	Correct Mix Ratio
Unit K	Strata	Stratacrete® High Strength		Steel Reinforcement	Regular	Constant UCS	Consistent Material	Correct Mix Ratio
Unit L	Minova	Tekseal LD®	731 psi	Control	Small Voids/ Styrofoam / trash & debris	Constant UCS	Consistent Material	Correct Mix Ratio
Unit M	Minova	Tekseal LD®	742 psi	N/A	High density anomaly (limestone)	Constant UCS	Consistent Material	Correct Mix Ratio
Unit N	Minova	Tekseal LD®	704 psi	N/A	Small and Large voids	Constant UCS	Consistent Material	Correct Mix Ratio
Number 1	Minova	Tekseal®	975 psi	Control	Regular	Constant UCS	Consistent Material	Correct Mix Ratio
Number 2	Minova	Tekseal LD®	726 psi	Control	Regular	Constant UCS	Consistent Material	Correct Mix Ratio

GPR TESTING

GPR RESULTS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Time [ns]
0
1
2
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6
7
8
9
10
11
12
13
Depth [ft]
0
1
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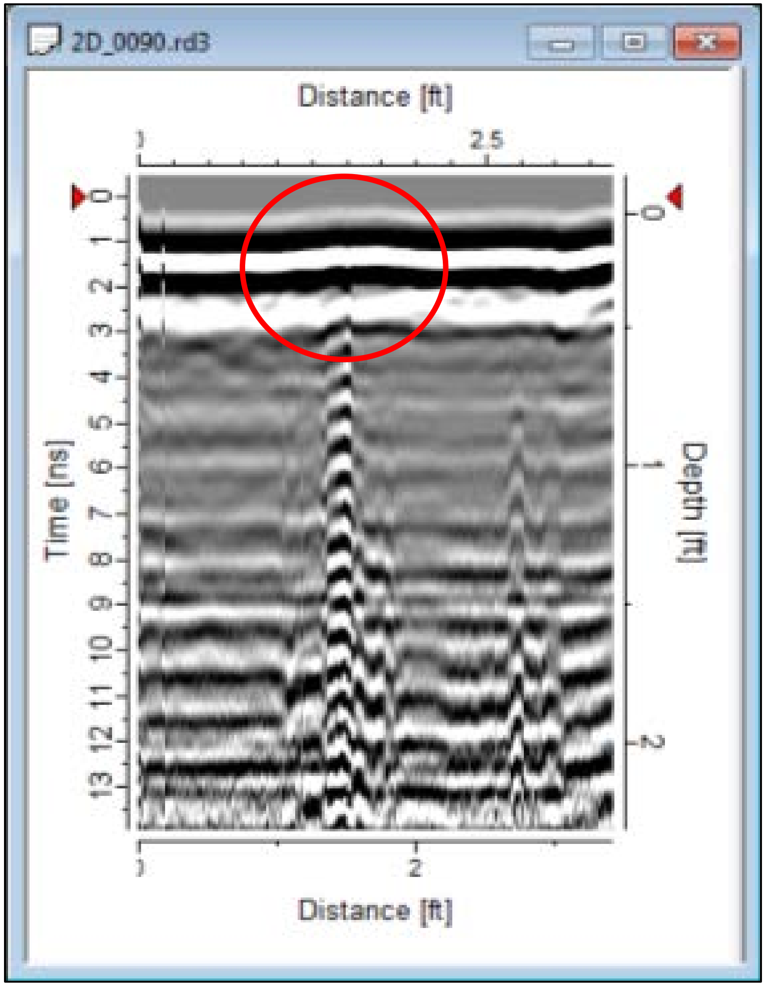
2
Distance [ft]


2D_0090.rd3
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Time [ns]
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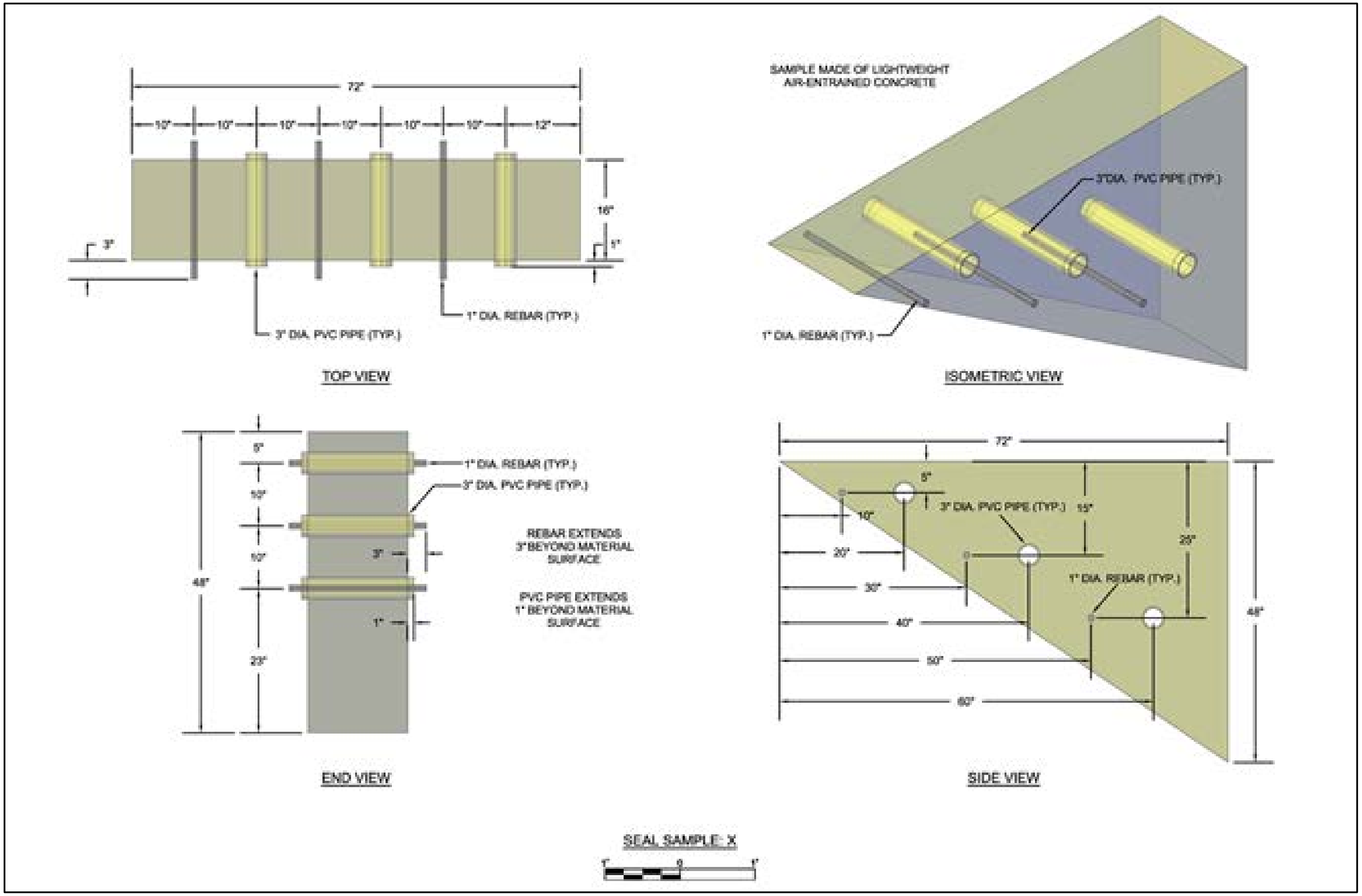
GPR TESTING | WHAT ARE THE DEPTH LIMITATIONS?



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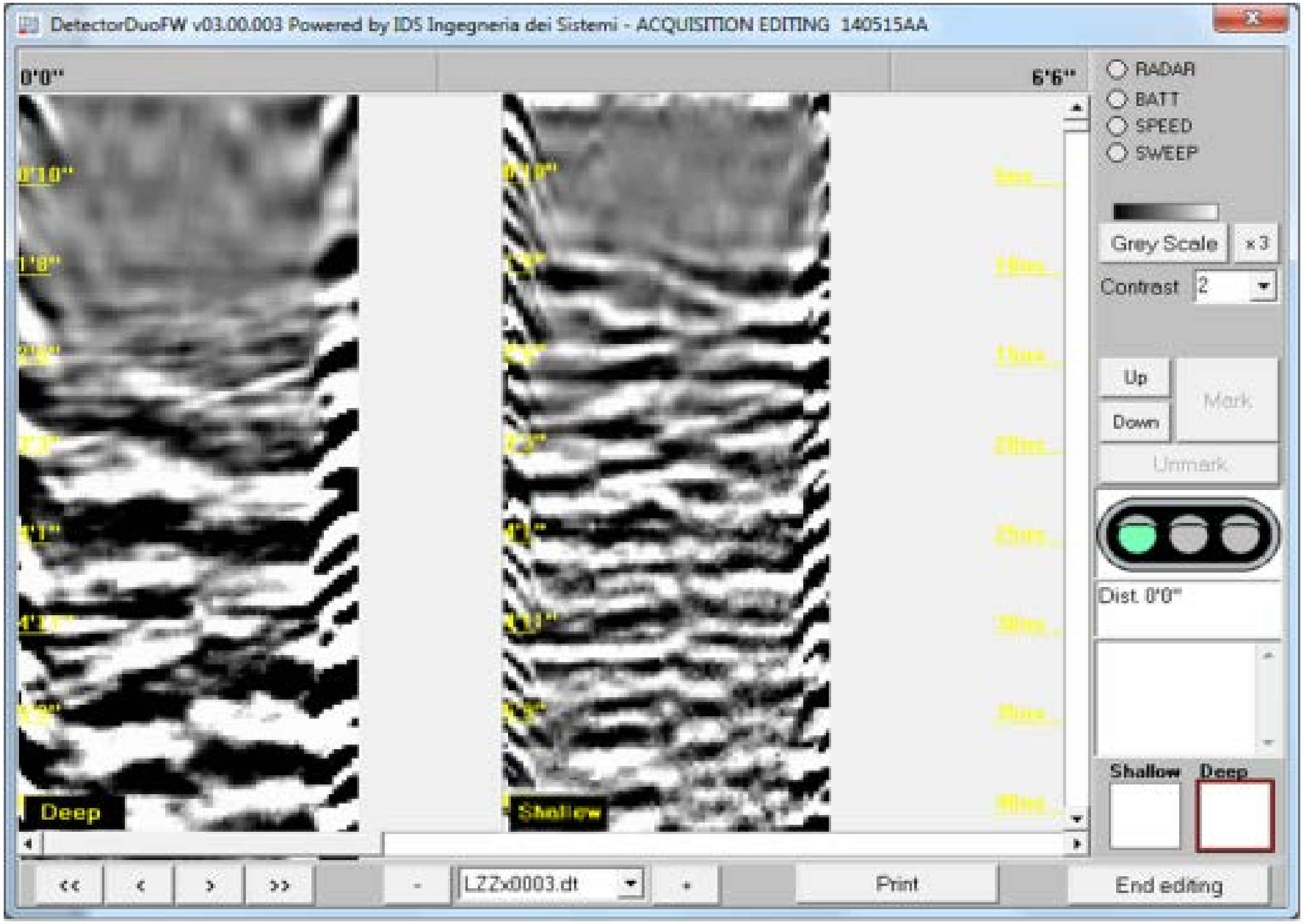
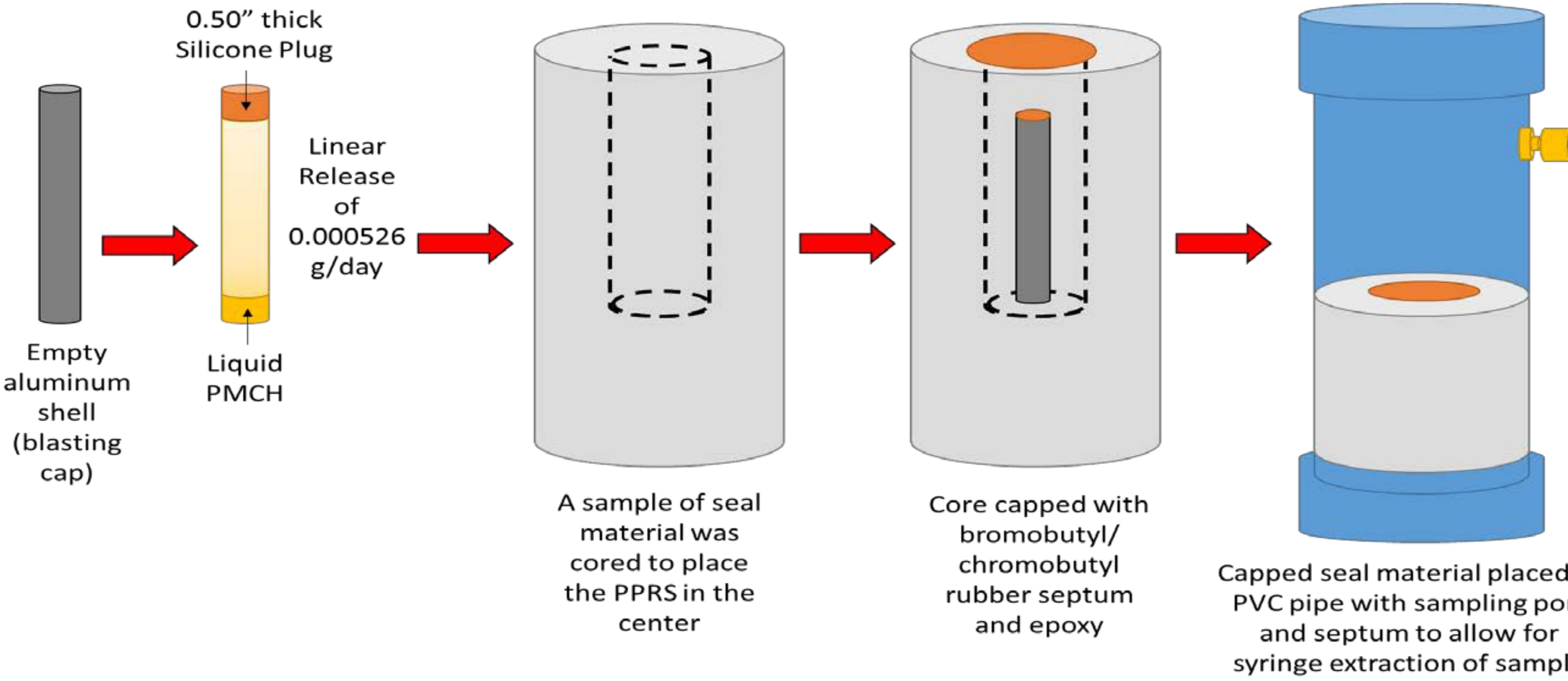


LABORATORY SCALE TRACER GAS EXPERIMENTS



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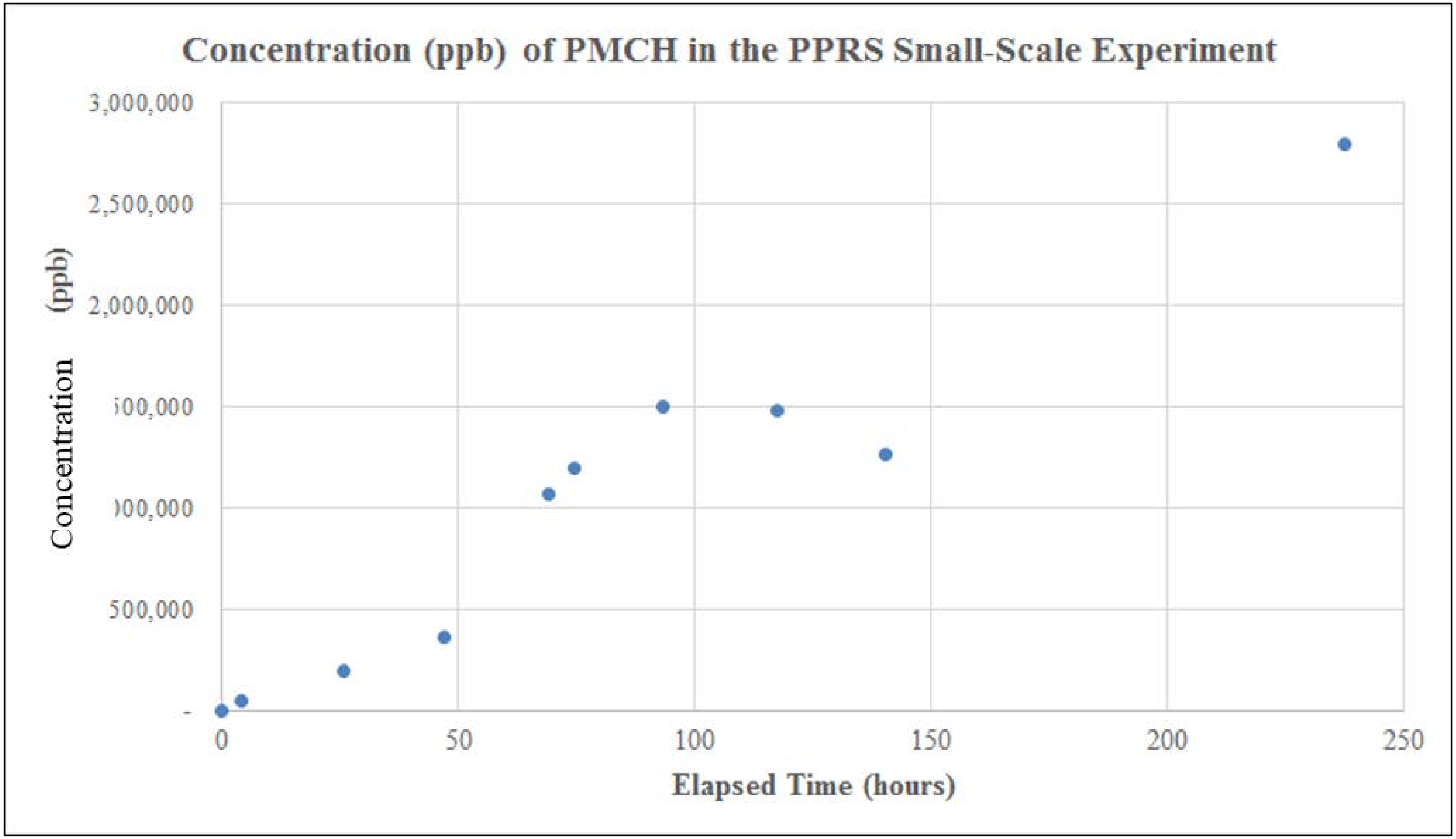
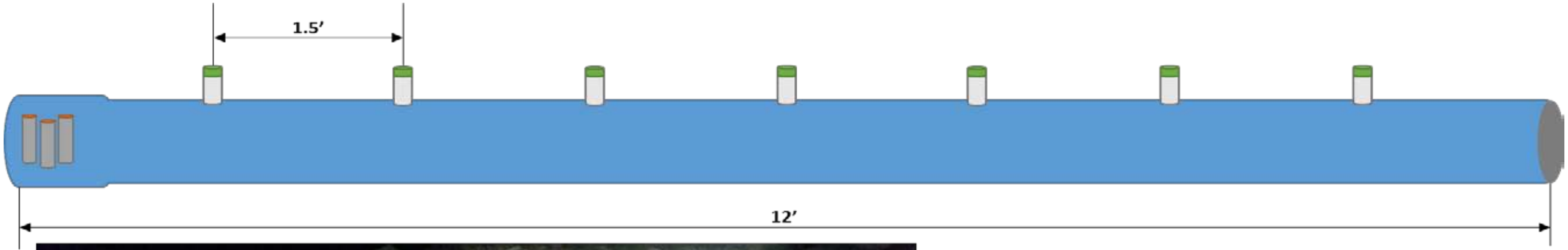
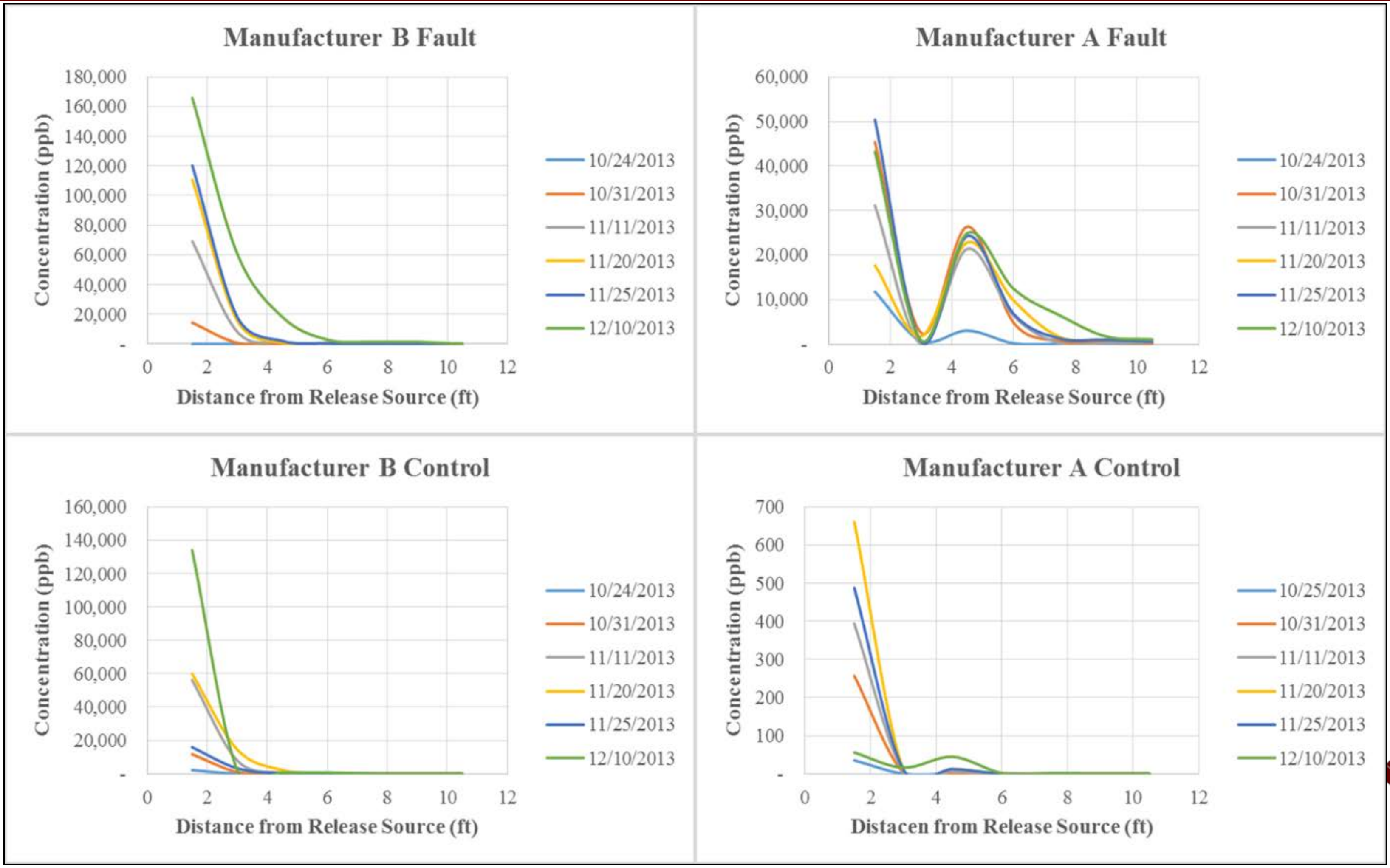


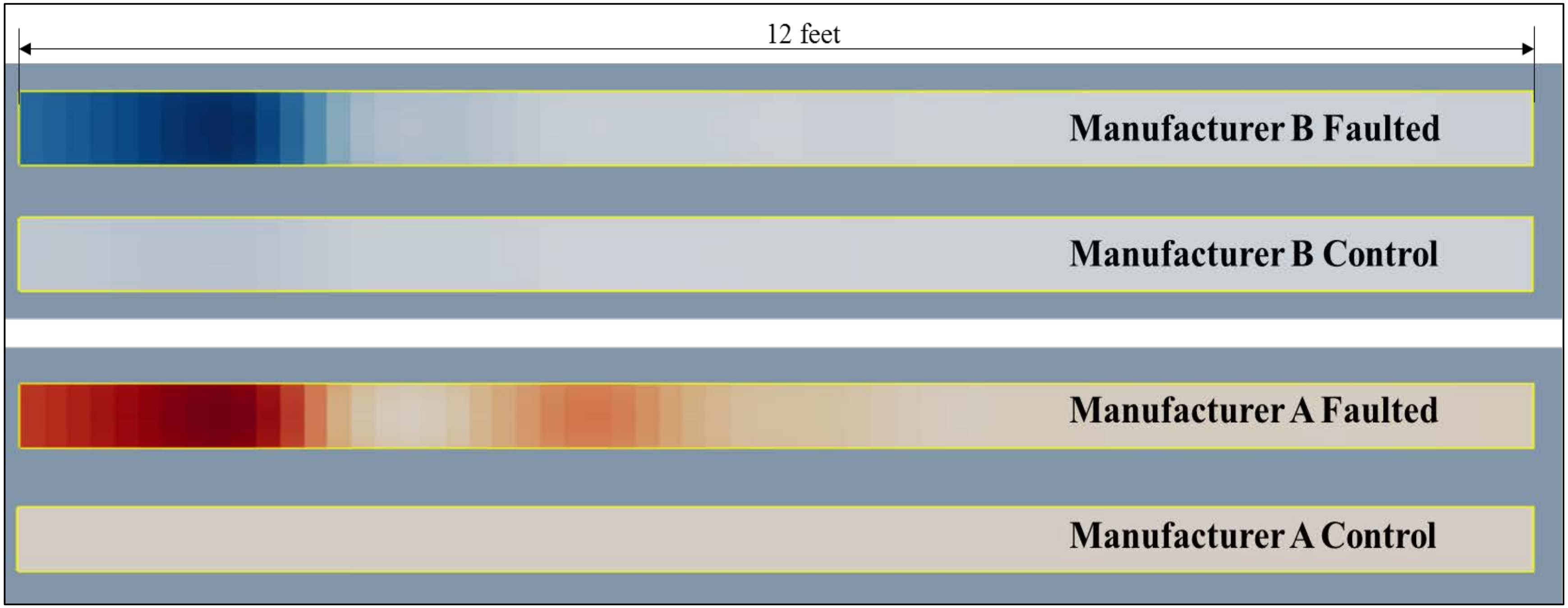
FIELD SCALE TRACER GAS EXPERIMENTS



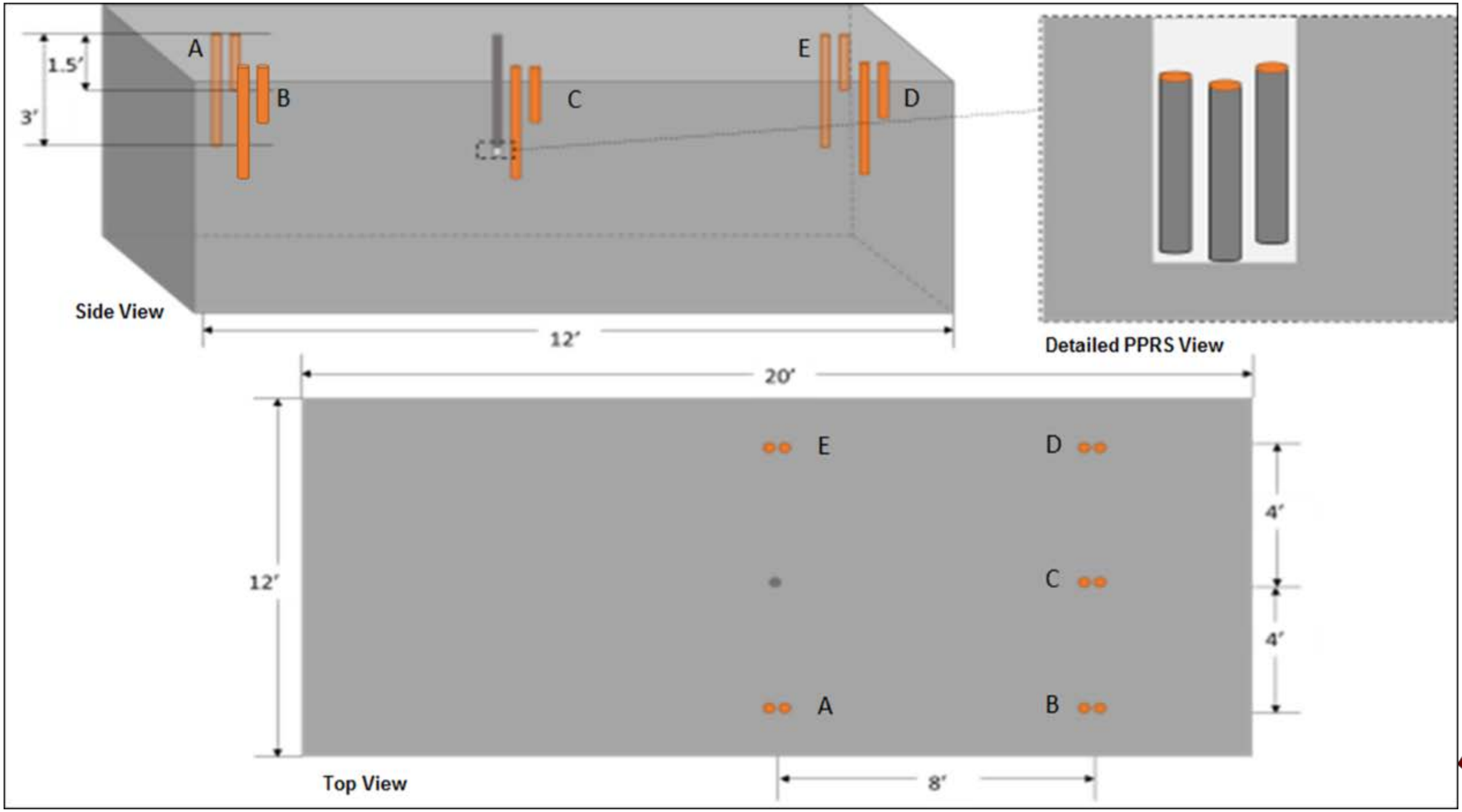
FIELD SCALE TRACER GAS EXPERIMENTS



LARGE SCALE TRACER GAS EXPERIMENTS



FULL SCALE TRACER GAS EXPERIMENTS



FULL SCALE TRACER GAS EXPERIMENTS

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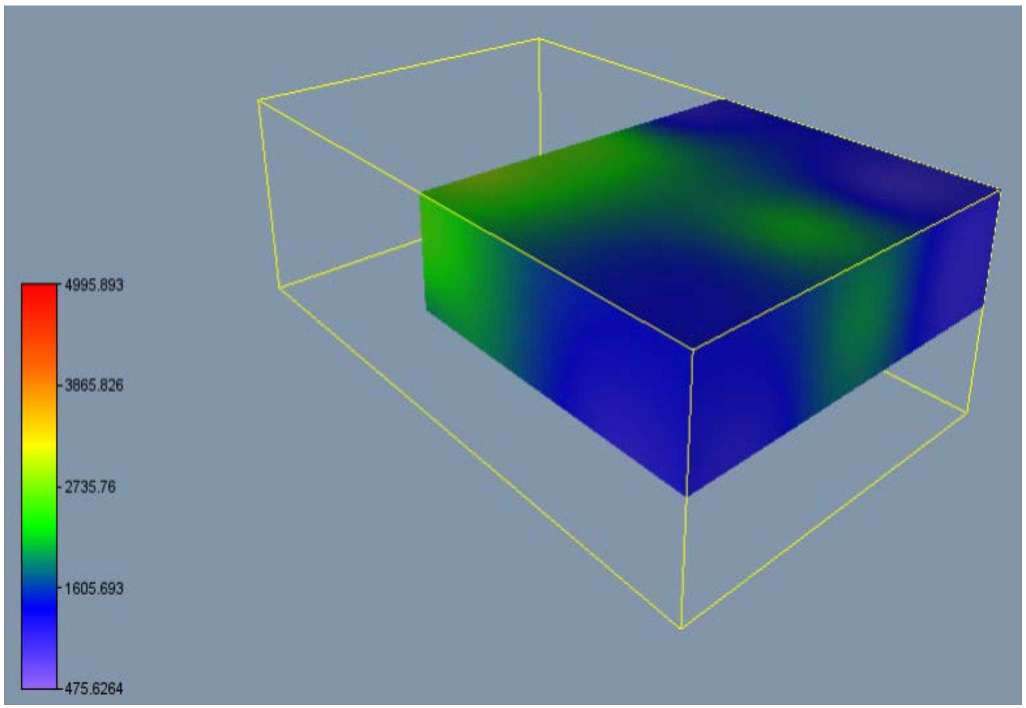
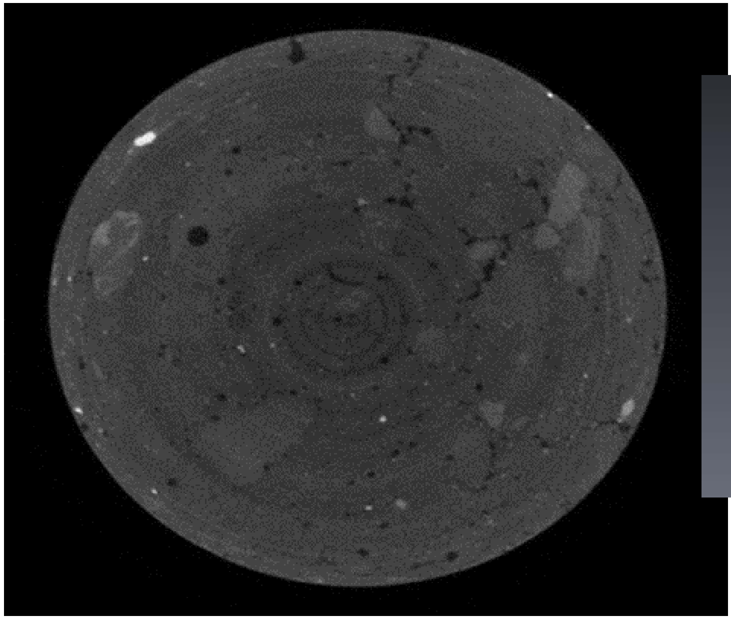
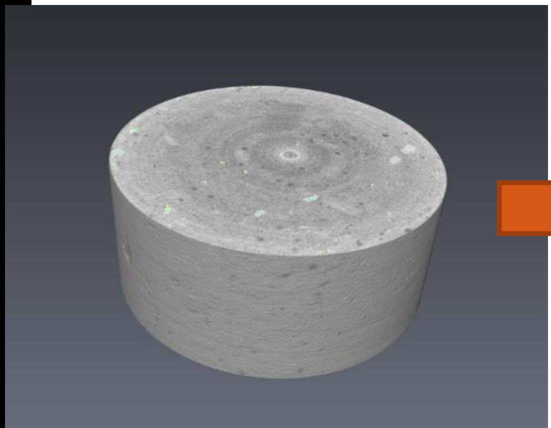


*Note: Samples reported in ppb	Time After Sealing PPRS	
Sampling Location	23 Days	59 Days
A 1.5	6.75	5.87
A 3	5.42	5.77
B 1.5	7.44	6.79
B 3	3.10	4.51
D 1.5	2.93	13.99
D 3	3.34	21.42
E 1.5	27.84	6.55
E 3	8.07	26.95
F 1.5	2.89	3.59
F 3	--	10.26
	N/A	1.31
Air Samples	N/A	1.46
	N/A	--

PRELIMINARY PERMEABILITY STUDIES

- Avizo® permeability simulation
  - 3-D simulation consisting of a constructed 3-D model from CT-scan of seal material sample, with viscosity values for PMCH, and permeability values compared to other geologic structures





4-14 mD

CONCLUSIONS

- GPR allowed for identification of surface/near surface features only
- Ultrasonic methods worked well in the lab environment, but not in the mine environment due to noise
  - The major challenges with wave propagation methods are:
    - Access to only one side of the structure
    - Penetration of 12 feet
    - Resolving small anomalies and structural defects
    - Permissibility
- Tracer Gas use is promising but limited to indicating degree of communication
  - It will not allow for detection of isolated structural defects
  - Placement of passive sources as well as long term behavior must be examined

RECOMMENDATIONS

- More detailed testing of GPR which could include further evaluation of maximum feasible depth of penetration.
- Exploration of background noise cancelling and unique sources might improve viability of ultrasonics, but full penetration of the wave into the seal remains a problem.
- Tracer gases were promising, particularly for gaining an understanding of communication between the sealed area and the active area in a global sense. Placement and reliability of sources must be examined, as well as expected background levels. Isolated structural anomalies cannot be detected with this method.

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NIOSH
Karl Zipf (COTR)

Industrial Collaborators
Strata Worldwide Minova Nally & Gibson Lhoist North America Dyno Nobel

A SHAMELESS PLUG

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