Vapor Intrusion: Regulatory Update and Advances in Assessment Tools

January 14, 2016

SERDP DOD • EPA • DOE | ESTCP

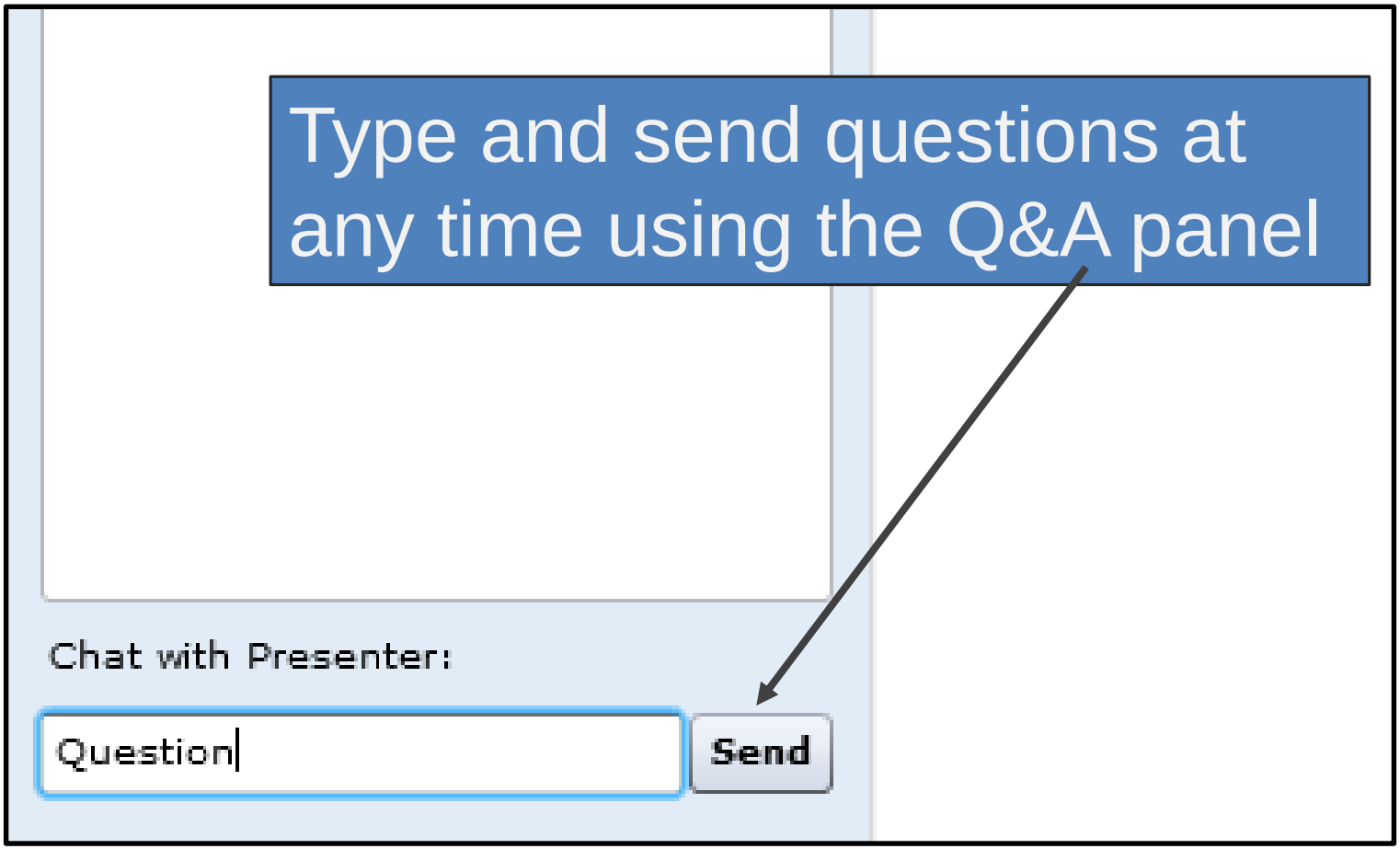
Welcome and Introductions

Rula A. Deeb, Ph.D.
Webinar Coordinator

Agenda

- **Webinar Logistics**
  Dr. Rula Deeb, Geosyntec Consultants (5 minutes)
- **Overview of SERDP and ESTCP**
  Dr. Andrea Leeson, SERDP and ESTCP (5 minutes)
- **Mass Flux Characterization for Vapor Intrusion Assessment**
  Dr. Helen Dawson, Geosyntec Consultants (25 minutes + Q&A)
- **Passive Sampling for Vapor Intrusion**
  Dr. Todd McAlary, Geosyntec Consultants (25 minutes + Q&A)
- **Final Q&A session**

How to Ask Questions



In Case of Technical Difficulties

- Delays in the broadcast audio
  - Click the mute/connect button
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    - U.S./Canada: 1-877-776-3503
    - International: 330-871-6014
    - Required conference ID: 96507774
- Submit a question using the chat box

SERDP and ESTCP Overview

Andrea Leeson, Ph.D.
Environmental Restoration Program Manager

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SERDP

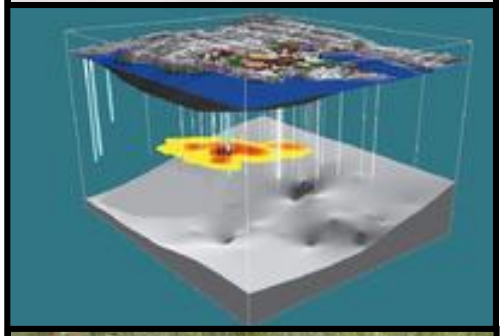
- Strategic Environmental Research and Development Program
- Established by Congress in FY 1991
  - DoD, DOE and EPA partnership
- SERDP is a requirements driven program which identifies high-priority environmental science and technology investment opportunities that address DoD requirements
  - Advanced technology development to address near term needs
  - Fundamental research to impact real world environmental management

ESTCP

- Environmental Security Technology Certification Program
- Demonstrate innovative cost-effective environmental and energy technologies
  - Capitalize on past investments
  - Transition technology out of the lab
- Promote implementation
  - Facilitate regulatory acceptance

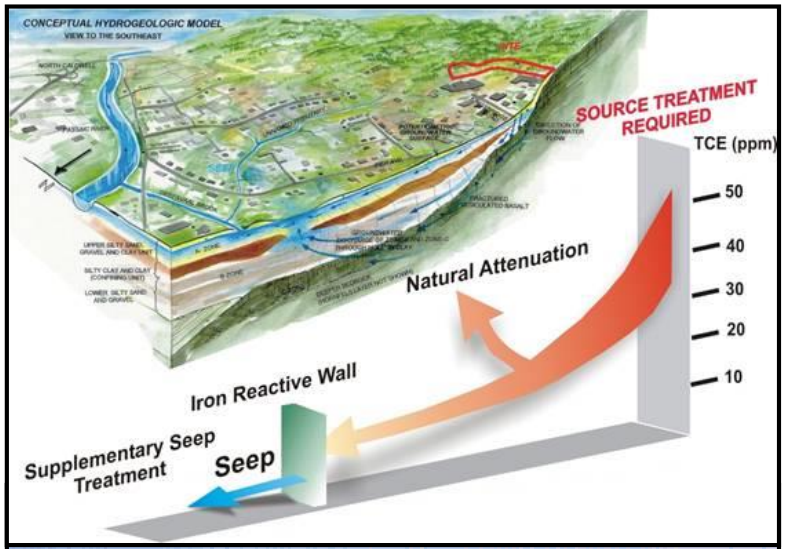
Program Areas

1. Energy and Water
2. Environmental Restoration
3. Munitions Response
4. Resource Conservation and Climate Change
5. Weapons Systems and Platforms



Environmental Restoration

- Major focus areas
  - Contaminated groundwater
  - Contaminants on ranges
  - Contaminated sediments
  - Wastewater treatment
  - Risk assessment



SERDP and ESTCP Webinar Series

DATE	Topics
January 28, 2016	Per- and Polyfluoroalkyl Substances (PFAS): Analytical and Characterization Frontiers
February 11, 2016	Chromate/Hazardous Material Free Coating Systems for Military Aircraft and Ground Support Equipment
February 25, 2016	Munitions Response
March 10, 2016	Fate, Transport and Effects of Insensitive Munitions
March 24, 2016	Cadmium and Chromate Elimination Efforts: Implementation Plans and Strategic Roadmaps for Three DoD Depots
April 7, 2016	Resource Conservation and Climate Change
April 21, 2016	Long Term Monitoring Issues at Chlorinated Solvent Sites

http://serdp-estcp.org/Tools-and-Training/Webinar-Series

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Mass Flux Characterization for Vapor Intrusion Assessment

Helen Dawson, Ph.D.
Geosyntec Consultants

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Agenda

- Vapor intrusion (VI) assessment challenges
- Recent US EPA VI guidance
- Key impacts on VI assessment
- Mass flux characterization ER-201503
- Risk management

VI Assessment Challenges

- Technical
  - Temporal and spatial variability
  - Background sources
  - Preferential pathways
- Regulatory
  - Non-residential settings
  - Short-term exposures

US EPA Vapor Intrusion Guidance

June 2015

OSWER Publication 9200.2-154

OSWER TECHNICAL GUIDE FOR ASSESSING AND MITIGATING THE VAPOR INTRUSION PATHWAY FROM SUBSURFACE VAPOR SOURCES TO INDOOR AIR

U.S. Environmental Protection Agency

Office of Solid Waste and Emergency Response

June 2015

EPA VI Guide's Key Recommendations

- Use multiple lines of evidence
- Increase VI pathway sampling
- Evaluate non-residential settings
- Consider influence of preferential pathways
- Consider background sources
- Consider short-term exposures and effects

Use Multiple Lines of Evidence

2002 Draft VI Guidance

BOTTOM-UP

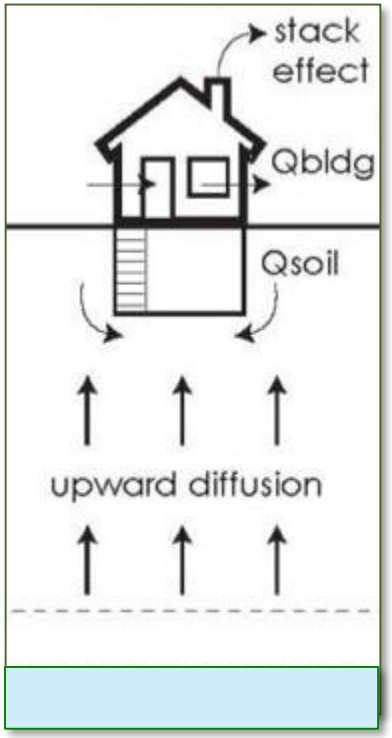
Indoor air

Subslab

Soil gas

Groundwater

Generic Concept



2015 Final VI Guidance

VI More Likely

VI Less Likely

Conc.	Geology	Hydrology	Weather	Building
High Source Conc., Highly Volatile Compounds	Coarse-Grained, Vertically Uniform Media	Low Moisture Content, Shallow Water Table	Heating Season, Falling Barometric Pressure, Strong Winds	Cracked Slab, Sumps, Partial Slabs, Low Air Exchange Rate
Low Source Conc., Less Volatile Compounds	Horizontal and Laterally Extensive Fine-Grained Layers	Deep Water Table, High Moisture Content	Increasing Barometric Pressure, Minimal Wind, Moderate Temperature	High Air Exchange Rate, Intact Slab

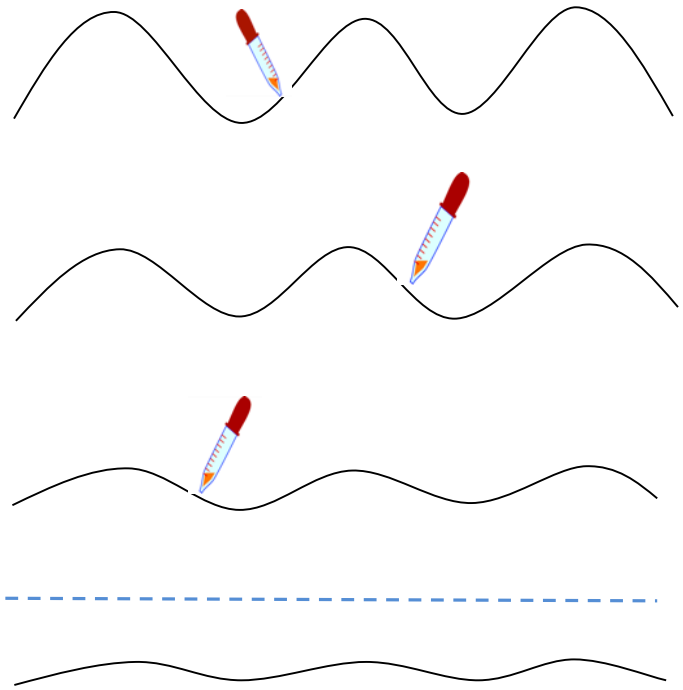
Multiple Lines of Evidence

Comprehensive Conceptual Site Model

Increase VI Pathway Sampling

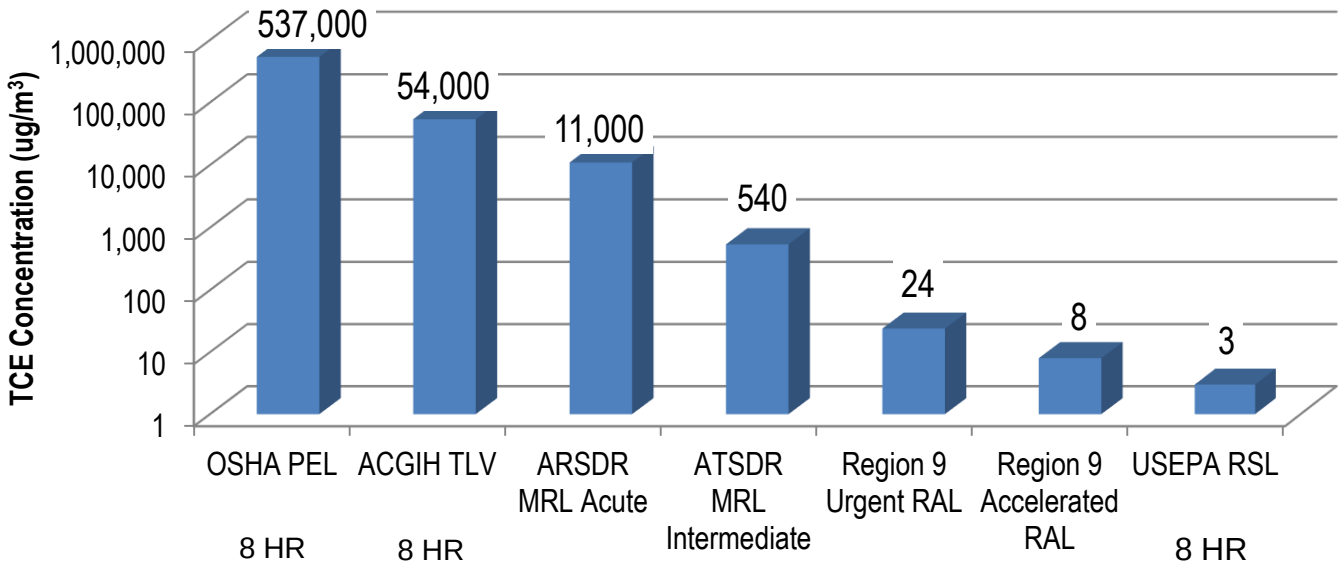
- EPA recommends increasing number and frequency of samples
- Indoor air
  - Multiple sampling rounds
- Sub-slab
  - Multiple samples per building
- Soil vapor
  - Multiple locations and depths

Temporal Variability



Evaluate Non-Residential Settings

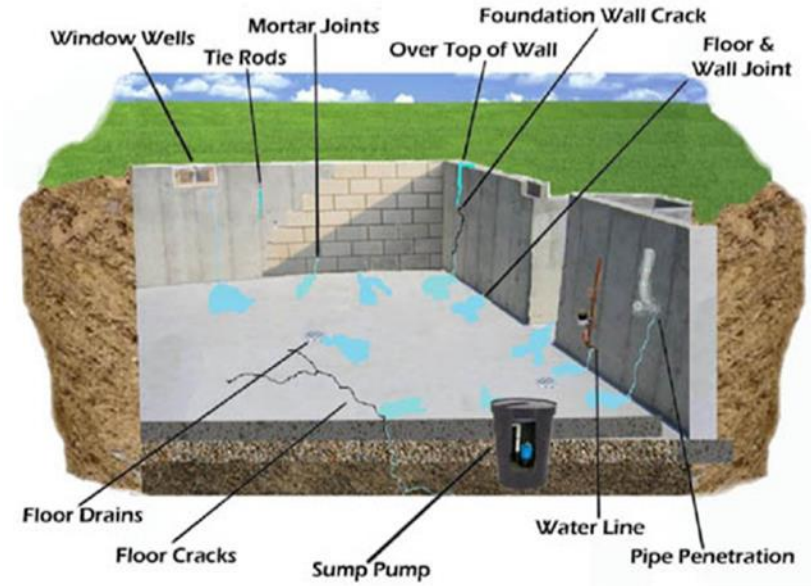
- EPA has authority to assess and mitigate VI in non-residential settings
- Wide range of promulgated/recommended indoor air target concentrations



TCE Regulatory Levels for Commercial/Industrial Scenarios

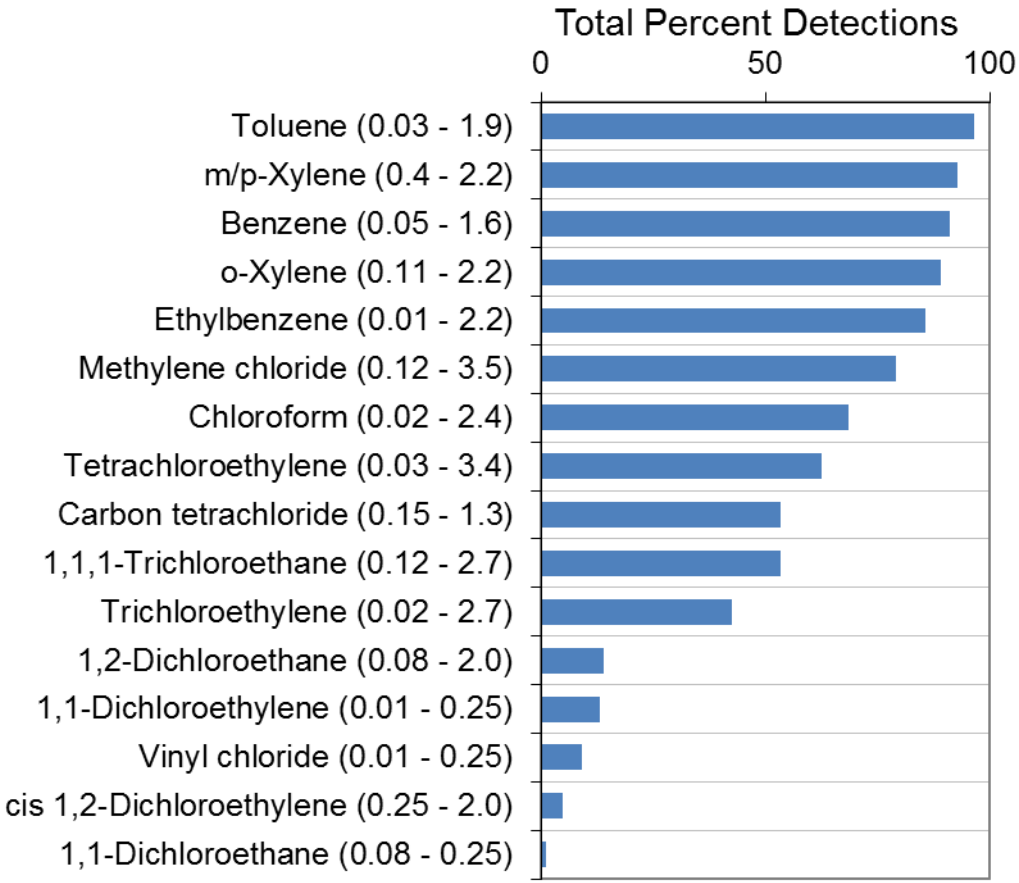
Consider Preferential Pathways

- "Significant" preferential pathways may impact overlying or nearby buildings
- Regulator requests vapor sampling of sewer or storm drain conduits and bedding



Consider Background Sources

- Ambient background
  - VOCs in urban air
- Indoor sources
  - VOCs emitted from consumer products and building materials
- Difficult to assess with conventional sampling methods
- Often ignored



Values in parentheses are reporting limits in µg/m³

***Source**: Dawson and McAlary, 2009*

Consider Short-Term Exposures

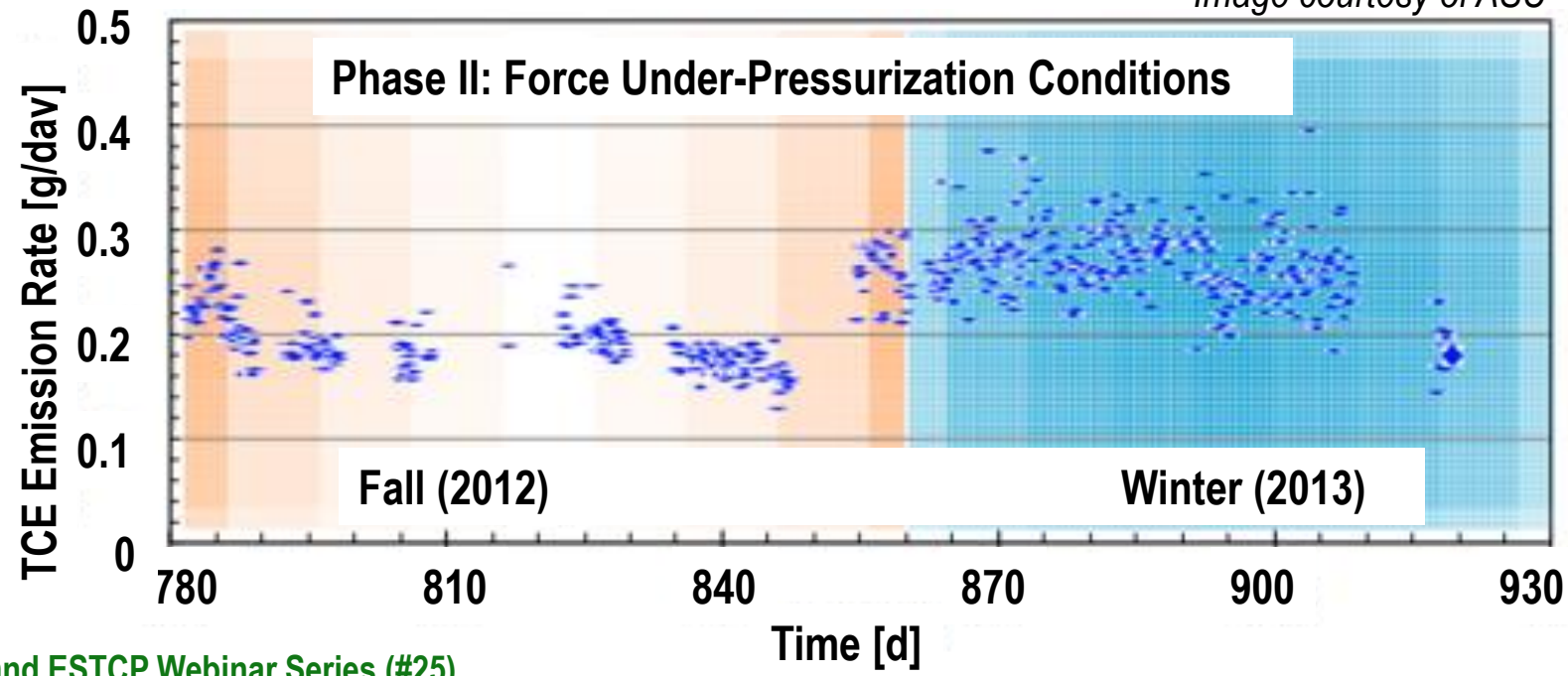
- Very low target levels for TCE
- Difficult to assess short-term exposures with conventional sampling methods

Region or State	Residential ($\mu g/m^3$)	Commercial ($\mu g/m^3$)
US EPA Region 9 (Accelerated / Urgent Response Levels	2 / 6	8 / 24
US EPA Region 10 (Removal Action Level)	2	8.8
Massachusetts (Imminent Hazard)	6	24
New Hampshire (Action Level)	2	8.8
New Jersey (Rapid Action Level)	4	18
California DTSC (Accelerated Response Action Level)	2	8

Mass Flux as an Alternative?

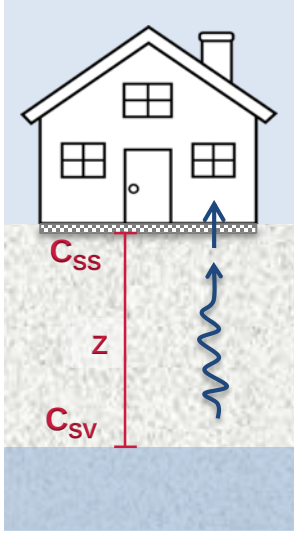
- MUCH less variability (3x, not 1000x)
- Potential to provide RME indoor air concentrations

Image courtesy of ASU



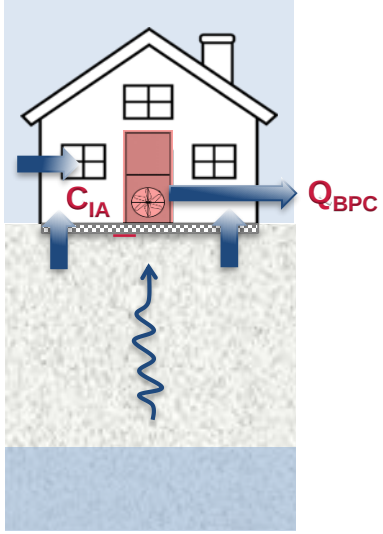
Mass Flux Characterization (ESTCP ER 201503)

Diffusive Flux
MF1



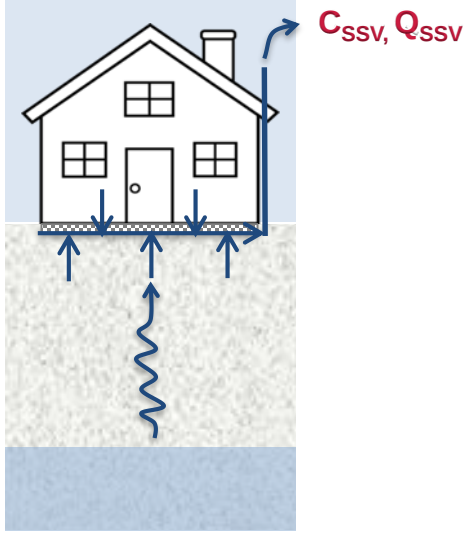
$$MF = - D^{eff} A_B \Delta C_{SV} / \Delta Z$$

Building Flux
MF2



$$MF2 = C_{IA} Q_{BPC}$$

Sub-Slab Flux
MF3



$$MF3 = C_{SSV}\ Q_{SSV}$$

Demonstration/Validation Needed

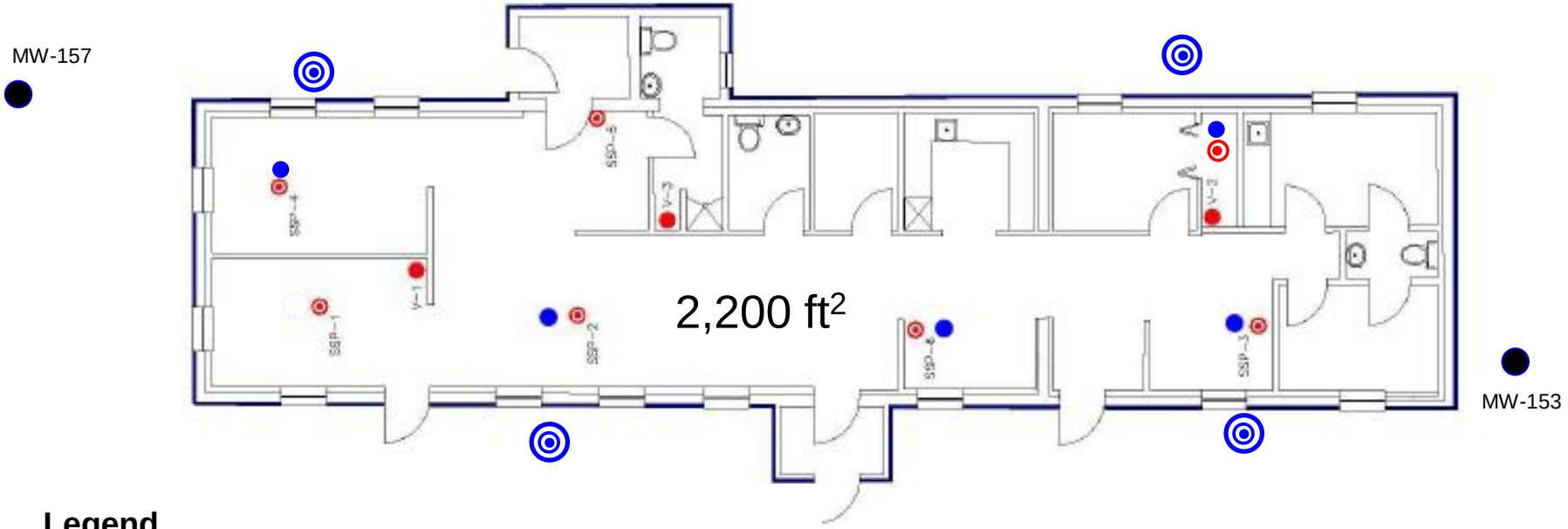
- Develop and compare alternative methods
- Provide data to support regulatory acceptance
- Transfer technology to DOD and contractors

Demonstration Site 1

- Site selected
- TCE concentrations
  - Groundwater 6.6 to 120 µg/L
  - Indoor air 20 to 59 µg/m^3 (pre-mitigation)
  - Sub-slab 86 to 29,019 µg/m^3
- Measured sub-slab mass flux (ER-201322)
- Planning field work for 2016/2017

Building 200, Raritan Arsenal, Edison, NJ

Demonstration Site 1



Legend

- SSV extraction point (existing)
- Sub-slab probe (existing)
- Proposed soil vapor probe (5 ft deep)
- Proposed multi-level soil vapor probe (12 ft, 19 ft)
- Groundwater monitoring well (location approximate)

Building 200, Raritan Arsenal, Edison, NJ

Sub-Slab TCE Mass Flux (MF3)

- Building 200 – August 2015 mass flux measurements from ESTCP ER-201322
- Trichloroethene

	Stack Concentration ($\mu g/m^3$)	Stack Velocity (ft/min)	Stack Area (ft^2)	Flow Rate (cfm)	Mass Removal Rate (g/day)
Vent Pipe V-1	290	37	0.049	1.8	0.02
Vent Pipe V-2	190	35	0.049	1.7	0.01
Vent Pipe V-3	1000	31	0.049	1.5	0.06
			Total	5.1	**0.10**

Indoor Air Concentrations

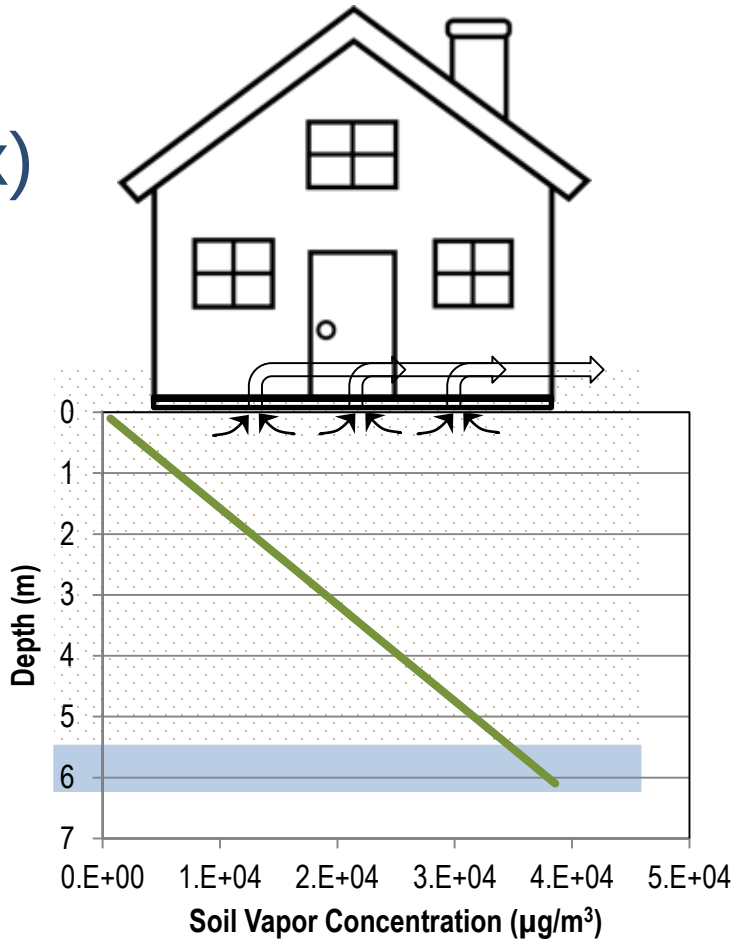
- Indoor air concentrations estimated from MF3 similar to pre-mitigation (2005) indoor air concentrations (20 to 60 µg/m^3)
- Trichloroethene

Building Footprint (ft^2)	Building Height (ft)	Air Exchange Rate (/hr)	Q_{build} (scm/d)	Indoor Air (µg/m^3)
2200	10	0.18	2690	**36**
2200	10	0.45	6724	**14**
2200	10	1.26	18827	**5**

Source: *ESTCP ER-201322*

Vadose Zone Mass Flux (MF1)
Estimated from Groundwater Concentration

- Conditions
  - Groundwater 120 µg/L (max)
  - Depth to water 20 ft
  - Vadose zone soil sand
- Calculated mass flux
  - Mass transport rate ~0.13 g/day
- Similar to measured MF3



Application to VI Risk Management

- Calculate indoor air RME concentration from mass flux

  $IA\text{-}RME = MF / (V_{bldg}\ AER)$

- Calculate mass flux threshold from target indoor air concentration

  $MF_{threshold} = IA_{target}\ V_{bldg}\ AER$

Abbreviations

RME: *Reasonable maximum exposure*
MF: *Mass flux*
AER: *Air exchange rate*
IA: *Indoor air*
V_{bldg}: *Building volume*

Conclusions

- Mass flux characterization has potential to improve VI assessment
  - Provide an alternative line of evidence
  - Address challenges due to temporal variability and preferential pathways
  - Reduce timeframe for and increase confidence in risk management decisions
  - Reduce VI assessment costs

Related Efforts

- ESTCP Project ER-201322
  - Demonstration/validation project
  - High volume sampling and vacuum testing of the sub-slab (MF3) to optimize design and operation of mitigation systems
- Raritan Arsenal
  - Mass flux measurements in vent-pipes (MF3) at the former Raritan Arsenal for about 6 years (Bertrand and McAlary, 2010)

Acknowledgments

- Collaborators
  - Bill Wertz, Todd McAlary, and Paul Nicholson, Geosyntec Consultants, Inc.
  - Dan Carr, Sanborn Head and Associates
  - Kyle Gorder, Air Force
  - Kyle Kirchner, Navy
  - Paul Johnson, Colorado School of Mines

For additional information, please visit
www.serdp-estcp.org/Program-Areas/Environmental-Restoration/Contaminated-Groundwater/Emerging-Issues/ER-201503

Speaker Contact Information

hdawson@geosyntec.com; 202-753-5006

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Q&A Session 1

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Passive Sampling for Vapor Intrusion

Todd McAlary, Ph.D.
Geosyntec Consultants

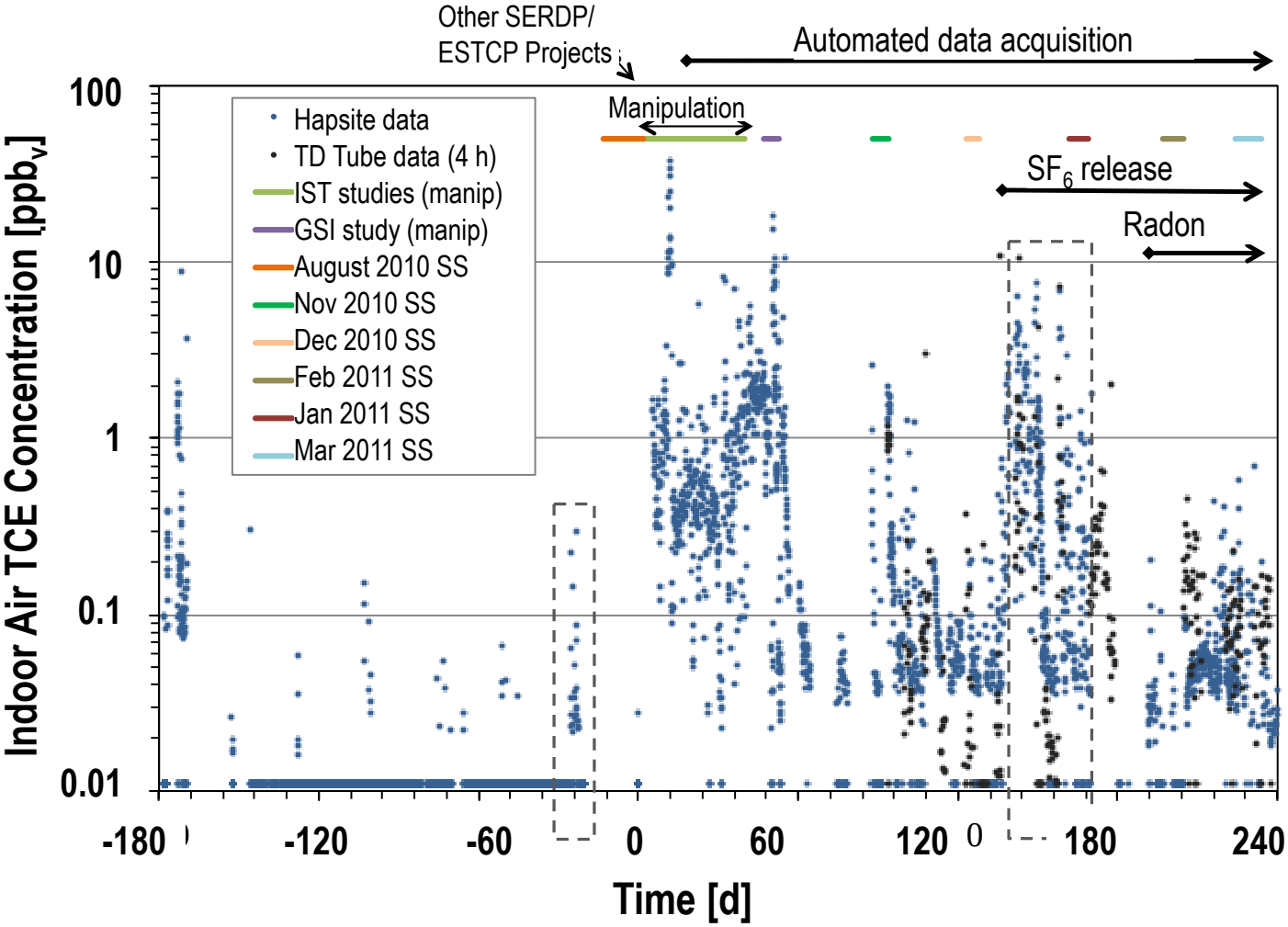
Agenda

- Rationale for demonstration/validation
- Lab and field testing
- Performance data
- Regulatory acceptance
- Applications

Motivation and Objectives

- Address temporal variability
  - Short duration time-weighted average samples are more likely to result in false-positive or false negative conclusions
- Assess conditions specific to vapor intrusion
  - Low target concentrations
  - Multiple media (indoor air, outdoor air, soil gas)
- Support regulatory acceptance
  - Rigorous comparison to established methods

Temporal Variability



"temporal variability is easy to manage, just collect enough samples for a statistical analysis" - EPA

Radon analogy: a 90-day sample is a "short-term" sample

Data courtesy of Paul Johnson, ASU

Passive Samplers Tested

- Differences
  - Size, uptake rates, sorbents, medium of uptake, method of analysis
- Mass (M) and time (t) are measured accurately. Key is to know the uptake rate (UR)

3M OVM 3500

SKC Ultra II

Radiello™

ATD Tubes

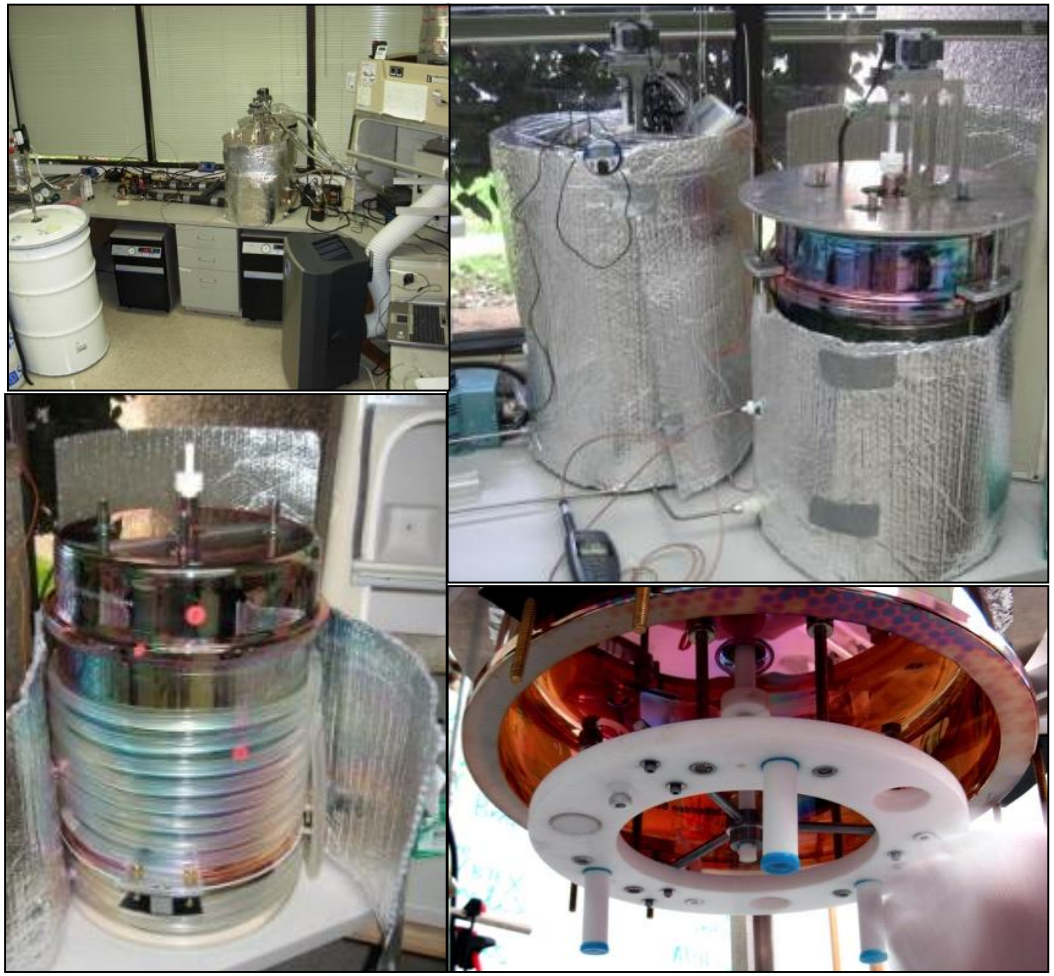
Waterloo Membrane Sampler™

$$C_0 = \frac{M}{UR\ t}$$

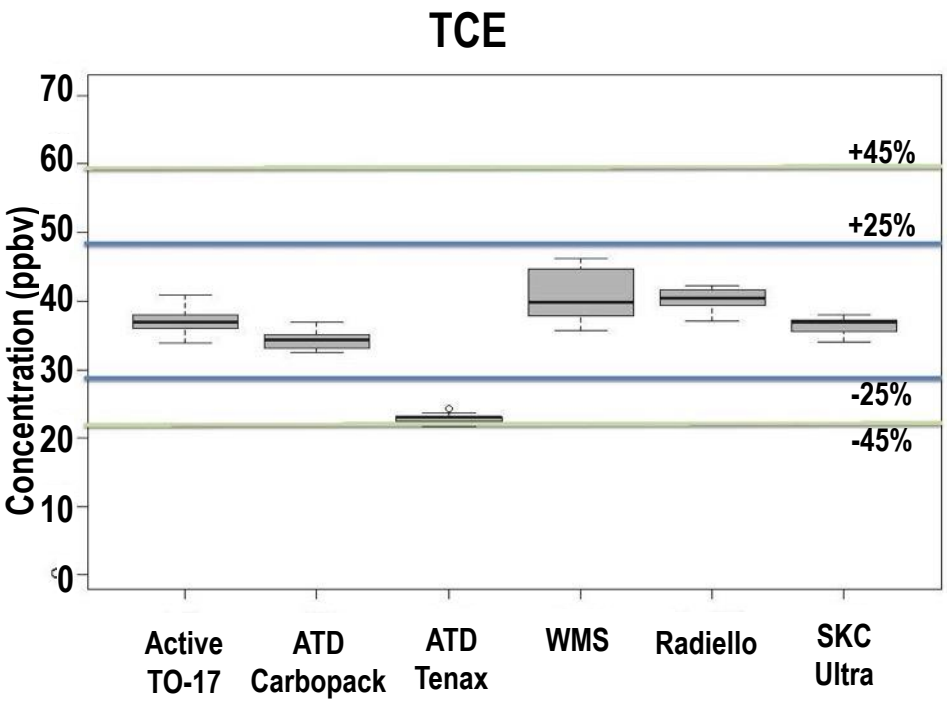
Equivalent Sample Volume

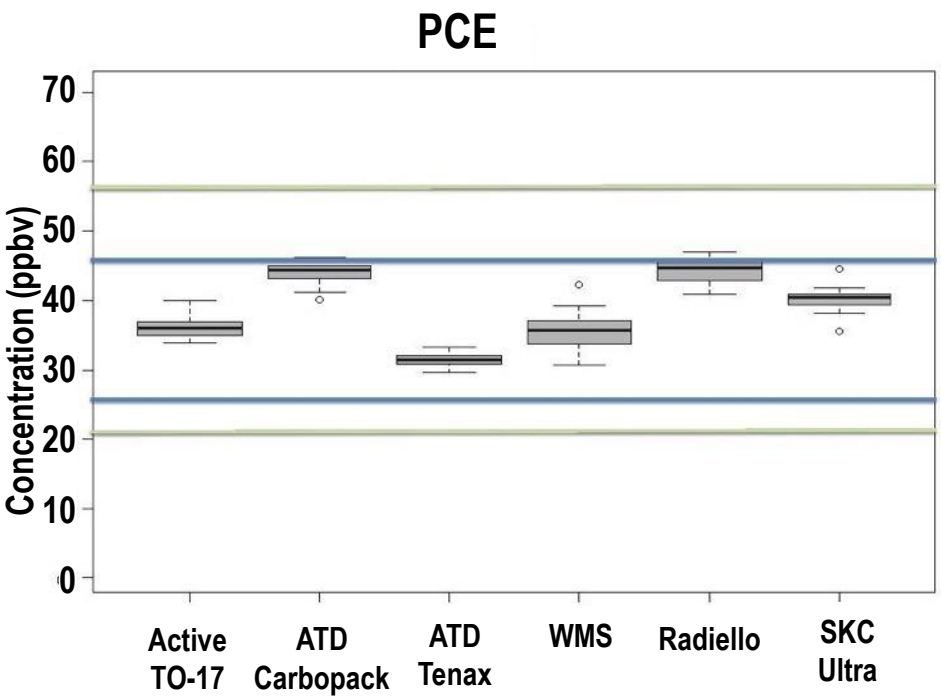
Passive Sampler Calibration

- Tested 5 samplers in triplicate and 10 compounds
- High, medium and low
  - Concentration
  - Face velocity
  - Temperature
  - Relative humidity
  - Duration
- 24 chambers x 5 samplers x 3 replicates x 10 chemicals = 3600 data points



Center-Point Results





***Note**: Scales are linear*

Conditions

Duration = 4 days
Velocity = 0.23 m/s
Temperature = 22 °C
Concentration = 50 ppb
Humidity = 63%

Accuracy

Mostly met the performance criteria

Mean C/Co (passive/active)	ATD: Carbopack B	ATD: Tenax	WMS	Radiello	SKC	Active/ Calculated
1,1,1-trichloroethane	**0.72**	**0.67**	**1.15**	**0.95**	**0.8**	0.79
1,2,4-trimethylbenzene	**0.73**	**0.69**	0.54	**1.13**	**0.69**	0.89
1,2-dichloroethane	0.6	**0.67**	**0.86**	**0.83**	**0.75**	0.87
Benzene	1.71	**1.07**	**0.99**	**0.9**	**0.95**	0.72
Carbon tetrachloride	**0.82**	**0.67**	**1.18**	**0.81**	0.55	0.98
Hexane	**1.12**	0.55	**1.15**	**0.8**	**0.7**	0.86
2-butanone (MEK)	0.21	**1**	**1.12**	0.62	0.46	1.33
Naphthalene	**0.9**	**0.98**	0.17	2.26	0.36	0.82
Tetrachloroethene	**1.15**	**0.85**	**0.72**	**1.02**	**0.98**	0.94
Trichloroethene	**0.91**	0.62	**0.8**	**0.91**	**0.87**	0.91

Mean C/Co is the mean of 24 passive/active concentration ratios (one for each chamber

Bold: average C/Co values of 0.63 to 1.58, which meet the success criterion: RPD < +/-

Active ATD tube data were compared to concentrations calculated from mass flow

Inter-Chamber Precision

Almost all met the performance criteria

Mean intra-chamber COV	ATD: Carbopack B	ATD: Tenax	WMS	Radiello	SKC	Active ATD/ Calculated
1,1,1-trichloroethane	**7%**	**3%**	**7%**	**5%**	**14%**	13%
1,2,4-trimethylbenzene	**5%**	**5%**	**7%**	**4%**	**22%**	7%
1,2-dichloroethane	**8%**	**3%**	**6%**	**4%**	**12%**	9%
Benzene	**5%**	**6%**	**12%**	**3%**	**10%**	6%
Carbon tetrachloride	**4%**	**6%**	**8%**	**4%**	**8%**	12%
Hexane	**7%**	**2%**	**7%**	**7%**	**16%**	7%
2-butanone (MEK)	47%	**5%**	**13%**	**11%**	**23%**	15%
Naphthalene	**6%**	**12%**	**7%**	**6%**	**16%**	7%
Tetrachloroethene	**2%**	**3%**	**6%**	**3%**	**6%**	5%
Trichloroethene	**3%**	**2%**	**5%**	**3%**	**16%**	5%

Mean intra-chamber COV is the average of 24 COV values, from three replicates in each

Bold: COV value meets the success criterion: < 30%

Intra-Chamber Precision

Variability increased for varied conditions

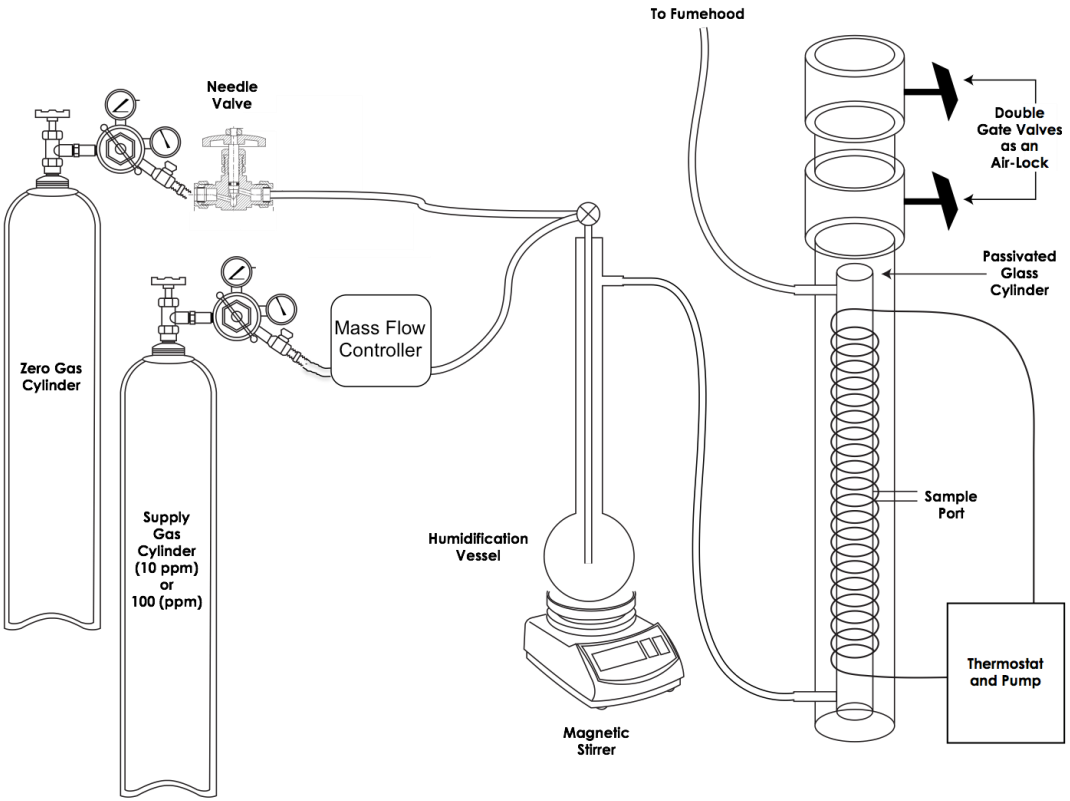
Mean inter-chamber COV	ATD: Carbopack B	ATD: Tenax	WMS	Radiello	SKC	Active ATD/ Calculated
1,1,1-trichloroethane	**24%**	**27%**	**26%**	35%	51%	18%
1,2,4-trimethylbenzene	**12%**	**16%**	42%	**25%**	55%	17%
1,2-dichloroethane	31%	32%	35%	**28%**	61%	23%
Benzene	88%	69%	116%	70%	65%	19%
Carbon tetrachloride	**25%**	**26%**	31%	**28%**	59%	19%
Hexane	37%	45%	56%	**28%**	39%	27%
2-butanone (MEK)	**25%**	31%	**26%**	**16%**	40%	19%
Naphthalene	**18%**	**25%**	128%	46%	58%	17%
Tetrachloroethene	**13%**	**14%**	34%	**27%**	**26%**	18%
Trichloroethene	**11%**	**17%**	34%	**30%**	51%	16%

Inter-chamber COV is the COV of 24 average C/Co values, one from each chamber test

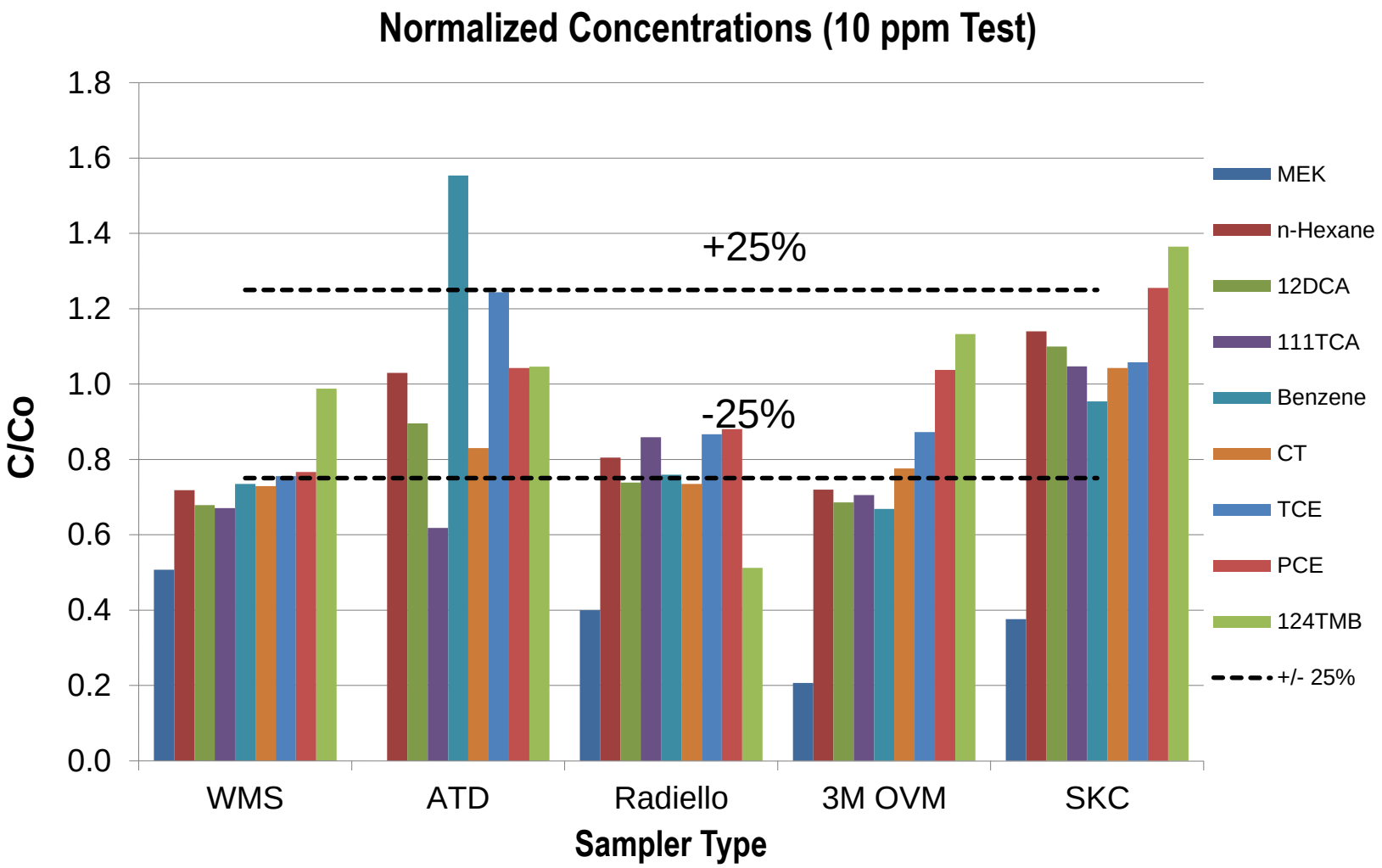
Bold: COV value meets the success criterion: < 30%

High Concentration Lab Tests

- 1, 10 and 100 ppmv
- 80% humidity, 20°C
- 30 minute samples
- Very low velocity (100 mL/min)
- “Zero” velocity



High Concentration Test Results



Field Testing

Soil gas sampling

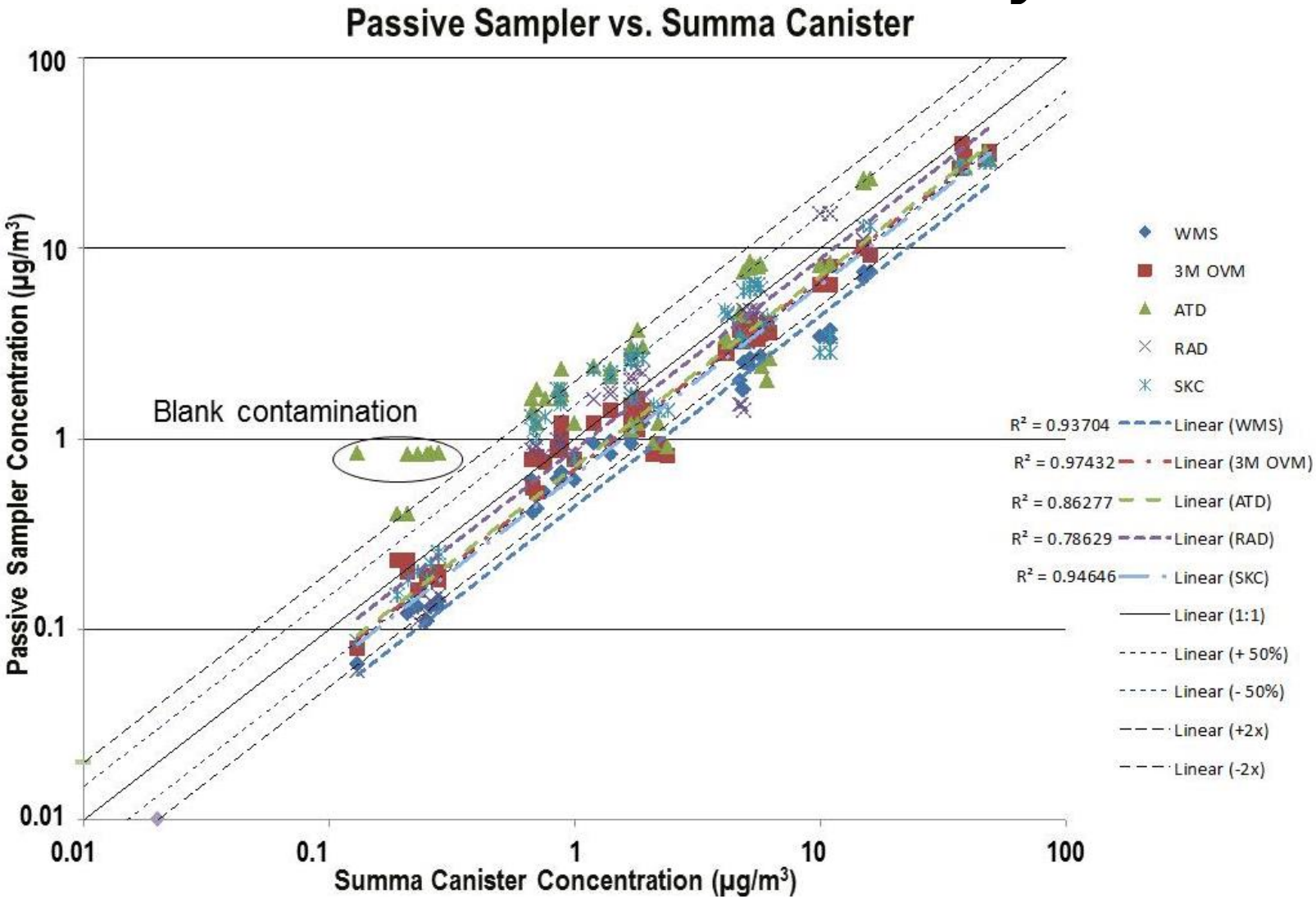
Indoor air sampling

Sub-slab sampling

Outdoor air sampling

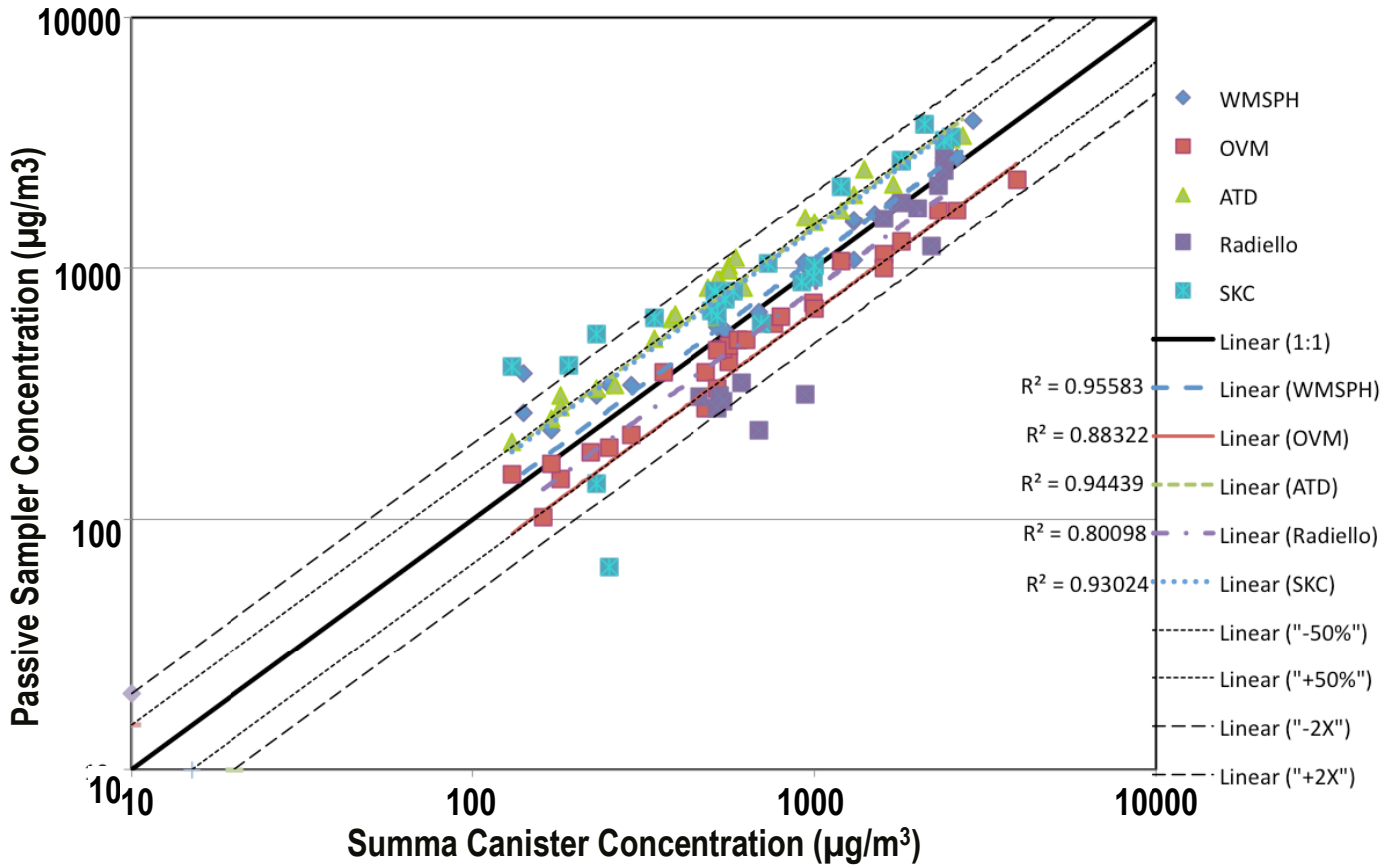
Support by Ignacio Rivera and Bart Chadwick of SPAWAR

Indoor Air VOCs at Cherry Point



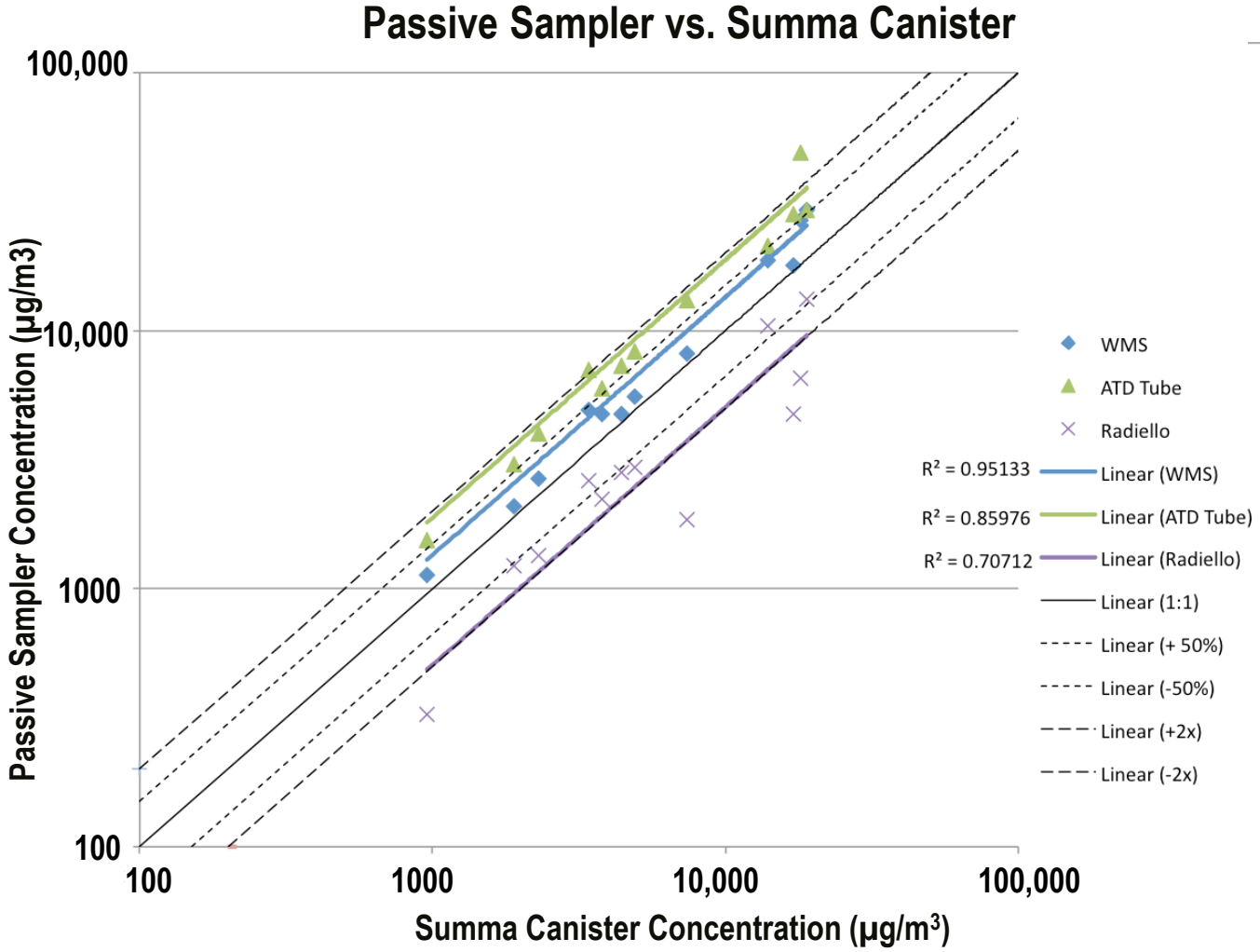
***Note**: Excludes compounds for which equivalent sample volume was greater than Safe Sample Volume*

Soil Vapor Sampling, NAS JAX



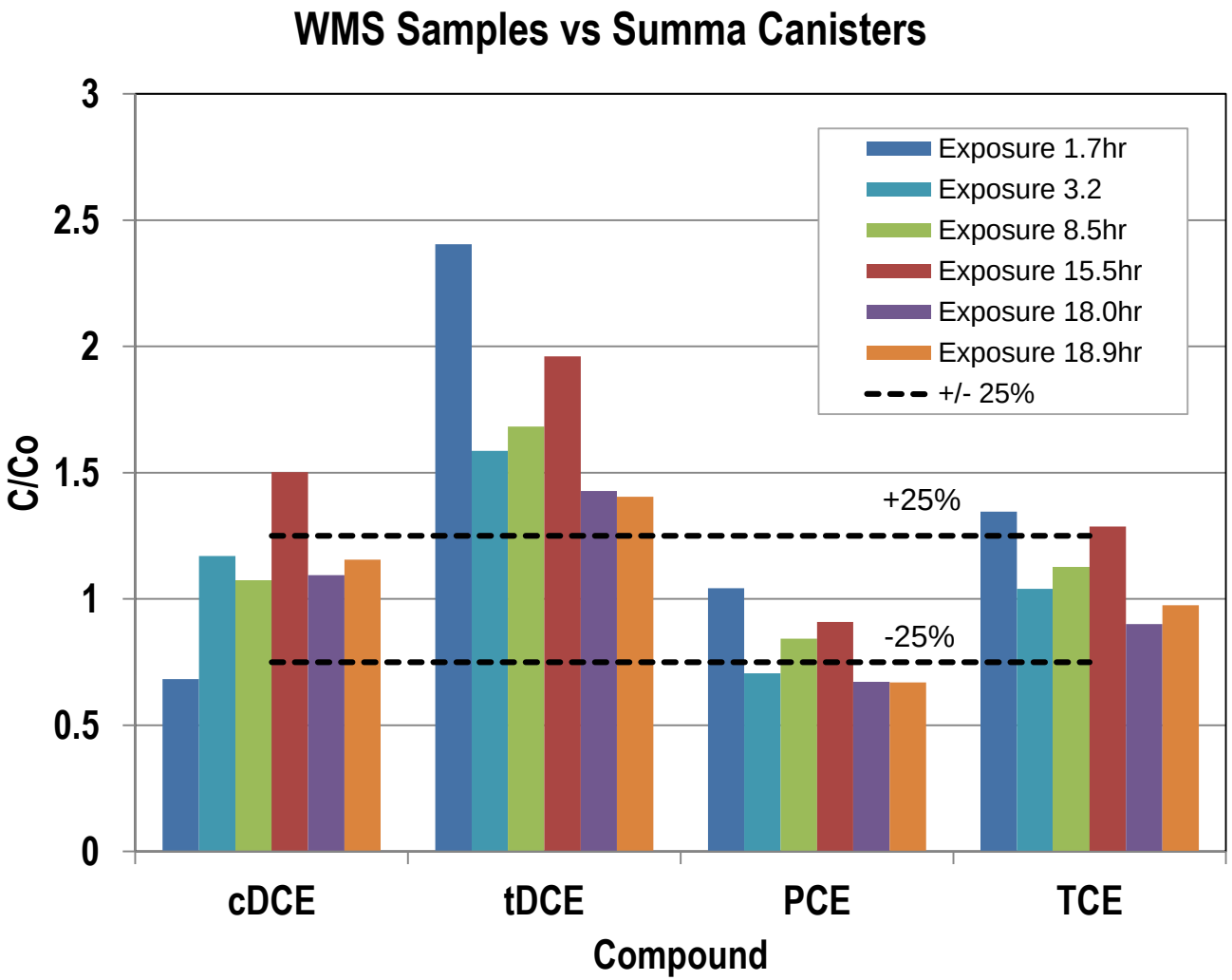
Notes:
Probes to 3-4 feet deep, exposure durations of 20, 40 and 60 minutes
Strong correlations, regression slopes all near 1.0

Passive Sub-Slab, NAS JAX



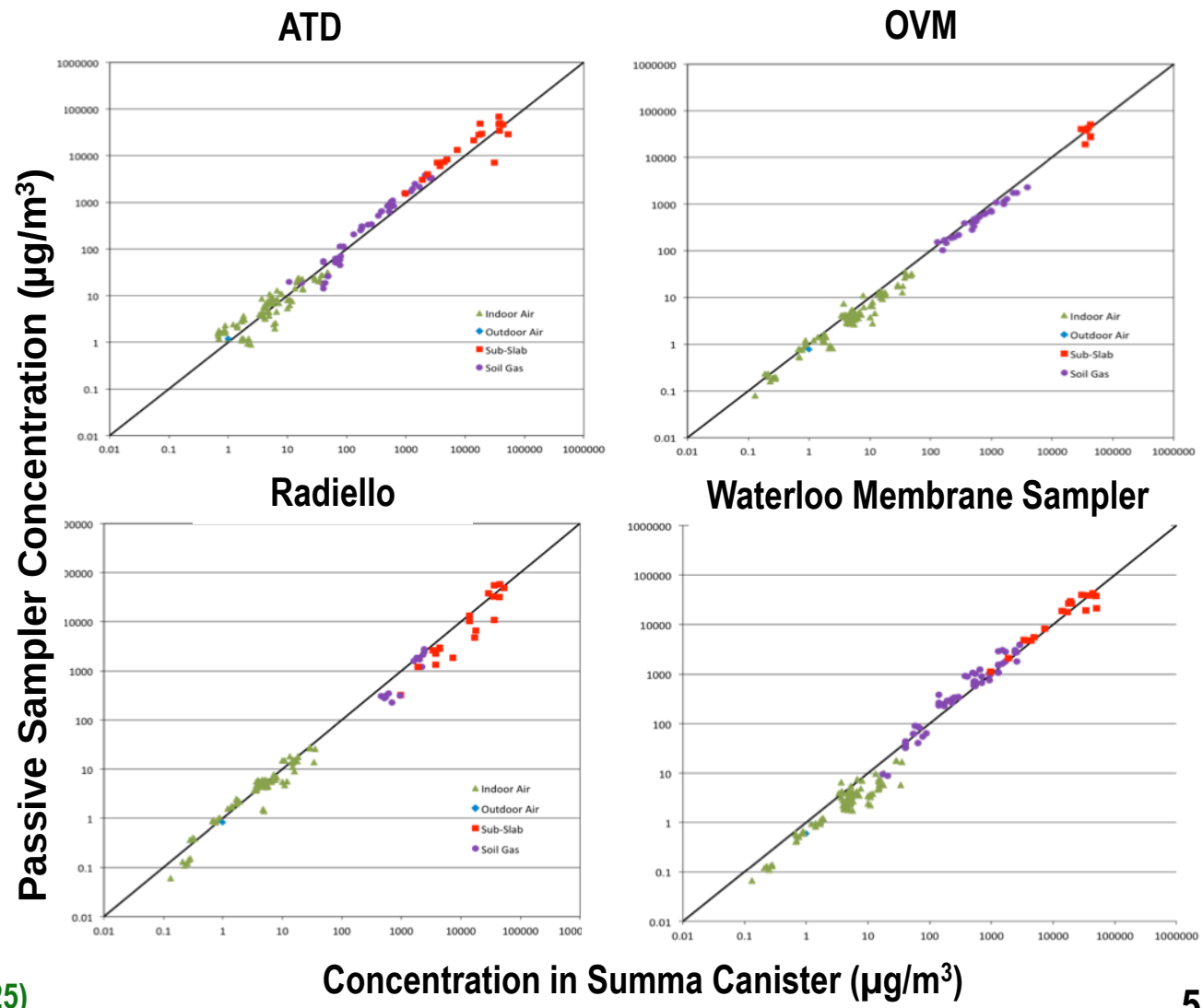
***Note**: Limited to 1-inch diameter or less – Low-uptake rate samplers*

Temporary Passive – NAS JAX



Passive and Active Sampler Correlation

- Strong correlation to conventional samples over 6+ orders of magnitude
- Quantitative results for soil vapor (a breakthrough)



Applications

Indoor air

Soil gas

Flux chambers

Sub-slab soil gas

Vent-pipes

Outdoor air

Quality Considerations

- Routine QA/QC, trip blanks and media blanks
- Select sorbent for to match target compounds
  - Retention (safe sample volume > product of uptake rate and sample duration)
  - Recovery (same as EPA Method TO-17)
- Select sample duration to achieve reporting limits lower than screening level
- Select a sampler with an uptake rate low enough to avoid starvation, but high enough to achieve reporting limits below screening levels
- Field calibration is always an option

Shoebox or Cargo Van?

Conclusions

- Benefits
  - Simpler protocols – less operator error
  - Easier to ship, handle and use – lower overall cost
  - Integrate over time to manage temporal variability
  - Lower reporting limits with no premium cost
  - Precision and accuracy mostly comparable to active samplers
  - 30-year history in industrial hygiene
- Limitations
  - Retention, starvation, calibration, contamination
  - All avoidable through careful sampler/sorbent selection, QA/QC
- Well-documented to support regulatory acceptance

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For additional information, please visit
www.serdp-estcp.org/Program-Areas/Environmental-Restoration/Contaminated-Groundwater/Emerging-Issues/ER-200830

Speaker Contact Information

tmcalary@geosyntec.com; 905-339-7066

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Q&A Session 2

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“Per- and Polyfluoroalkyl Substances (PFAS): Analytical and Characterization Frontiers”

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Survey Reminder

Please take a moment to complete the survey that will pop up on your screen when the webinar ends

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