Thank you for signing in early

The webinar will begin promptly at
12:00 pm ET, 9:00 am PT

SERDP DOD • EPA • DOE | ESTCP

SERDP and ESTCP Webinar Series

The webinar will begin promptly at 12:00 pm ET, 9:00 am PT

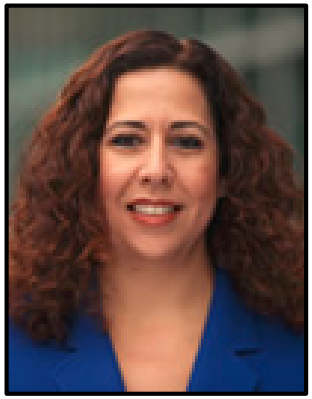
- You have two options for accessing the webinar
  1. Listen to the broadcast audio if your computer is equipped with speakers
  2. Call into the conference line: 303-248-0285
     Required conference ID: 6102000
- For any question or issues, please email serdp-estcp@noblis.org or call 571-372-6565

"Bioavailability of Contaminants of Concern in Soils at DoD-Impacted Sites"

November 3, 2016

SERDP DOD • EPA • DOE | ESTCP

Welcome and Introductions



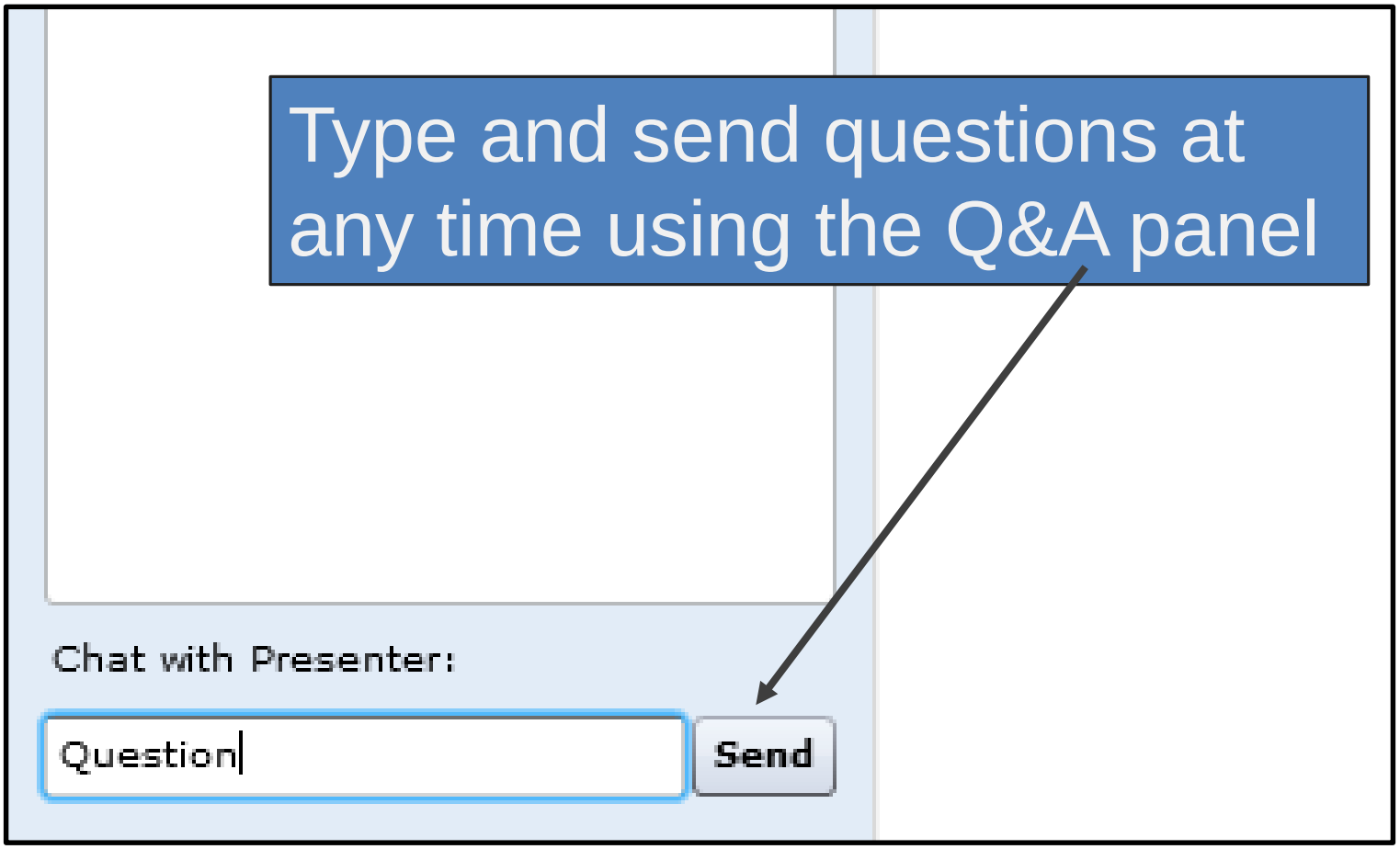
Rula A. Deeb, Ph.D.
Webinar Program Coordinator

SERDP DOD • EPA • DOE | ESTCP

Webinar Agenda

- **Webinar Logistics**
  Dr. Rula Deeb, Geosyntec Consultants (5 minutes)
- **Overview of SERDP and ESTCP**
  Dr. Andrea Leeson, SERDP and ESTCP (5 minutes)
- **Bioavailability of Contaminants in Soils: Overview of SERDP and ESTCP Funded Research and Recommendations**
  Dr. Hans Stroo, SERDP and ESTCP (10 minutes + Q&A)
- **PAH Interactions with Soil and Effects on Bioaccessibility and Bioavailability to Humans**
  Ms. Yvette Lowney, Alloy LLC (20 minutes + Q&A)
- **Mechanisms and Permanence of Sequestered Lead and Arsenic in Soils: Impact on Human Bioavailability**
  Dr. Nicholas Basta, The Ohio State University (20 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
  - Wait 3-5 seconds
  - Click the mute/connect button again
  - If delays continue, call into the conference line
    - Call into the conference line: 303-248-0285
    - Required conference ID: 6102000
- Submit a question using the chat box

SERDP and ESTCP Overview

Andrea Leeson, Ph.D.
SERDP and ESTCP

SERDP

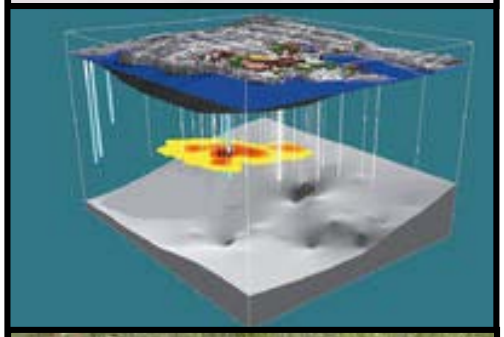
- Strategic Environmental Research and Development Program
- Established by Congress in FY 1991
  - DoD, DOE and EPA partnership
- SERDP is a requirements driven program which identifies high-priority environmental science and technology investment opportunities that address DoD requirements
  - Advanced 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

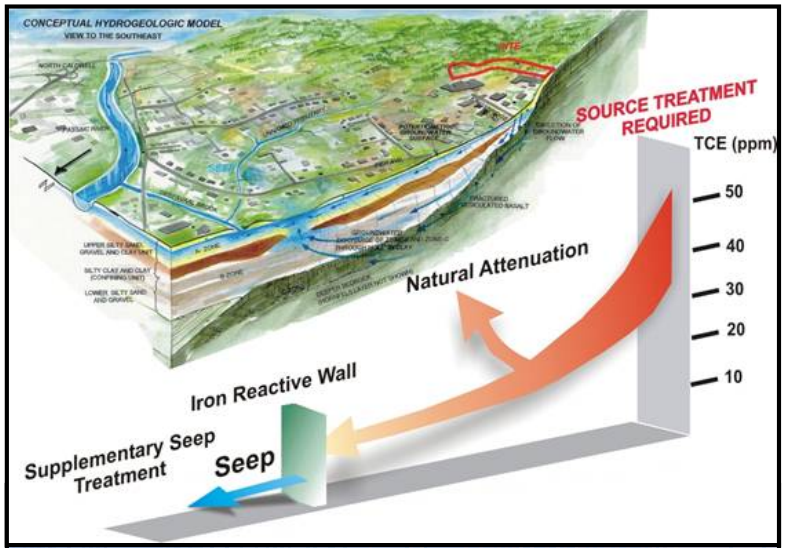
Program Areas

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

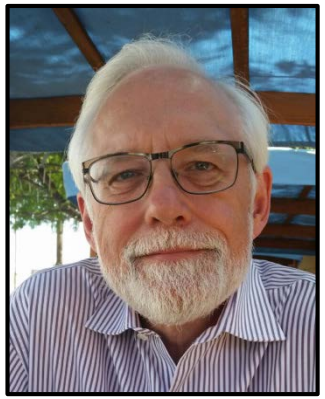
Date	Topic
November 17, 2016	Novel Coatings Systems for Use as High Performance Chemical Resistant Powder Topcoats
December 15, 2016	Advances in the Assessment and In Situ Treatment of Contaminated Sediments
January 12, 2017	**Award Winning Projects**: Energy and Water
January 26, 2017	**Award Winning Projects**: Weapons Systems and Platforms
February 9, 2017	**Award Winning Projects**: Environmental Restoration
February 23, 2017	**Award Winning Projects**: Resource Conservation and Climate Change
March 9, 2017	**Award Winning Projects**: Munitions Response

For upcoming webinars, please visit

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

SERDP DOD • EPA • DOE | ESTCP

Bioavailability of Contaminants in Soils: Overview of SERDP and ESTCP Funded Research and Recommendations

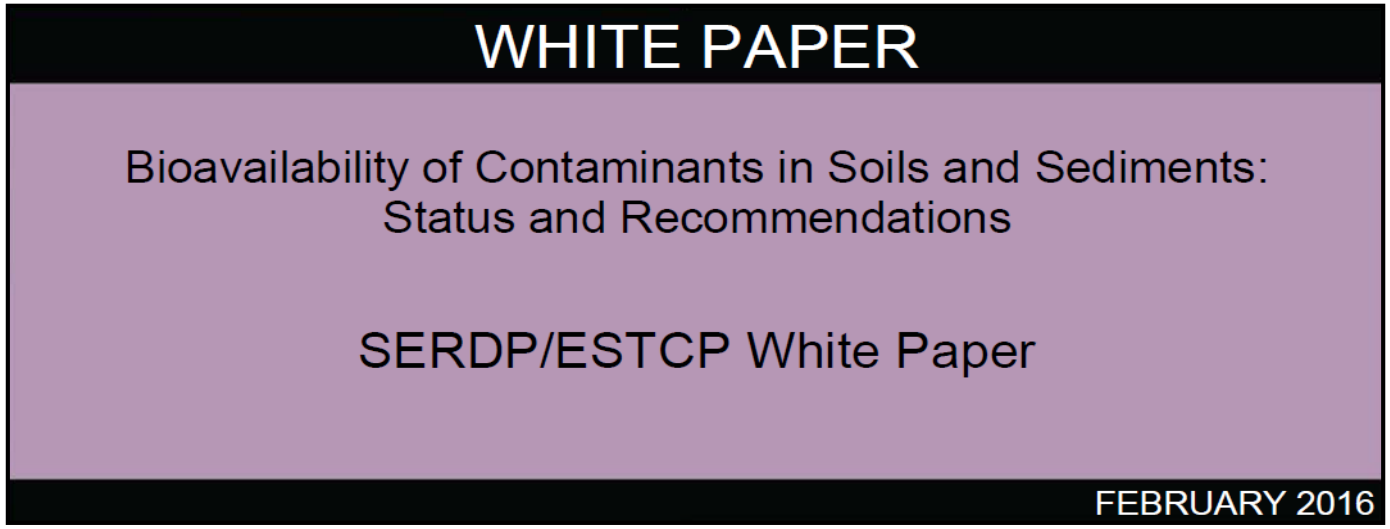


Hans Stroo, Ph.D.
SERDP and ESTCP

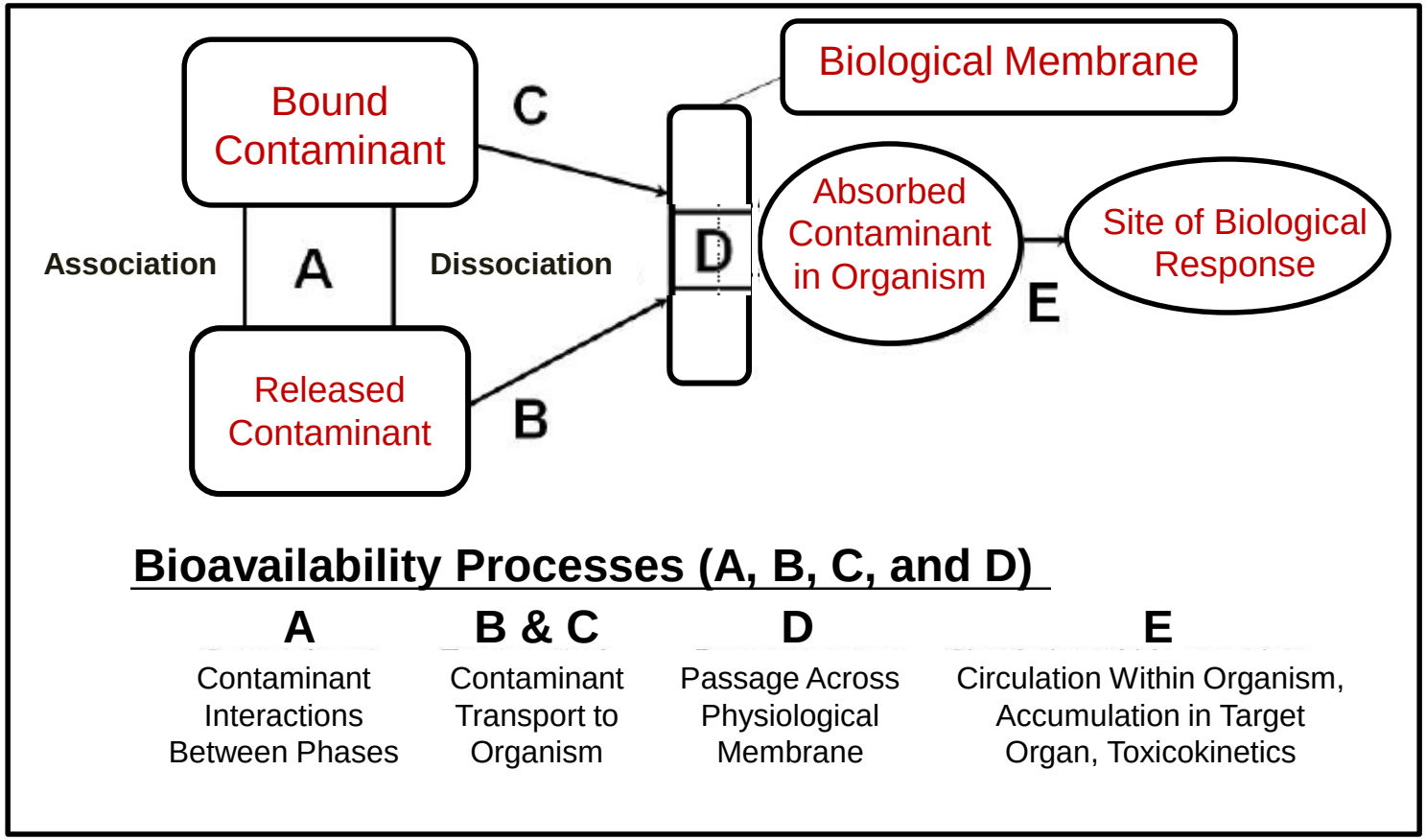
SERDP DOD • EPA • DOE | ESTCP

Presentation Outline

- Introduction and background
- Status of SERDP/ESTCP projects
- Remaining R&D needs



Soil Effects on Bioavailability



NRC, 2003. Bioavailability of Contaminants in Soils and Sediments

Value of Bioavailability in Risk Assessment

Adjusted for Relative Bioavailability (RBA)

$$\text{RBA} = \frac{\text{Absorbed from soil}}{\text{Absorption from medium used in toxicity study}}$$

Direct Relationship of RBA to Risk-Based Criteria

Using Relative Oral Bioavailability in Human Health Risk Assessment

Can be used in **Exposure Assessments**

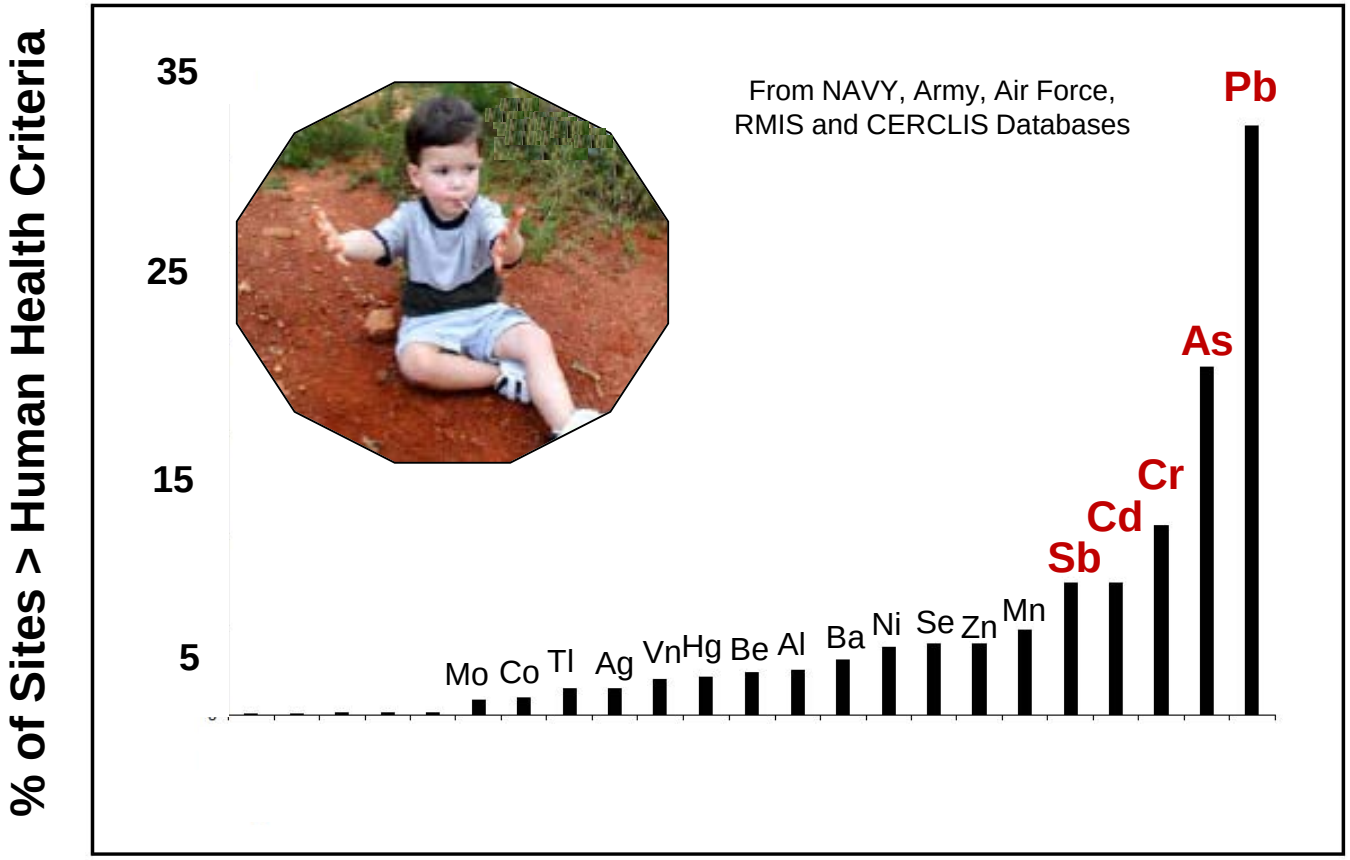
$$\textbf{Exposure}_{\textbf{(RBA-adjusted)}} = \frac{CS \times IR \times EF \times ED \times FI \times \textbf{RBA}}{BW \times AT}$$

…Or in the **Toxicity Assessment**

$$\textbf{Reference Dose}_{\textbf{(RBA-adjusted)}} = \frac{\textbf{RfD}}{\textbf{RBA}}$$

$$\textbf{Cancer Slope Factor}_{\textbf{(RBA-adjusted)}} = \textbf{CSF} \times \textbf{RBA}$$

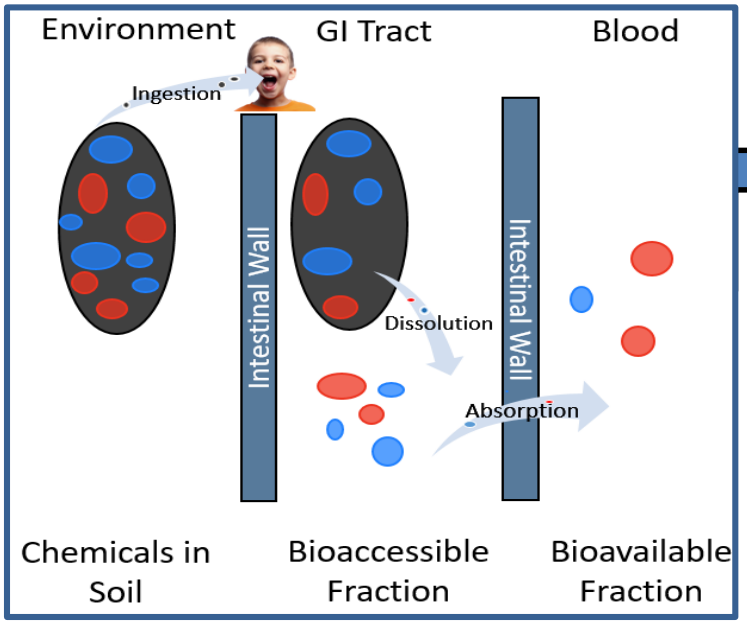
Bioavailability of Inorganics in Soil: Top 5 DoD Targets



Lead (33%) > Arsenic (18%) > Chromium (10%) > Cadmium and Antimony (7%)

Source: Ruby, 2005 (ER-1165)

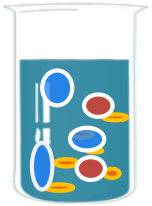
Bioavailability and Bioaccessibility



In Vivo Bioavailability

$3,000-$30,000/Sample

Laboratory



In Vitro Bioaccessibility

$100-$250/Sample

Source: Lowney

Status of SERDP/ESTCP Efforts

Workshop Recommendations

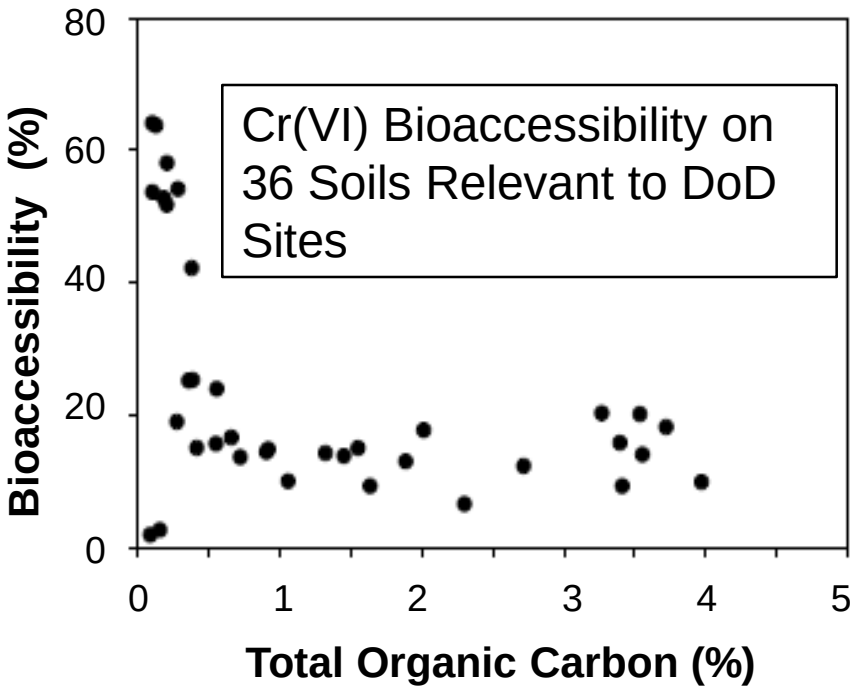
- *In vitro* assays for arsenic
  - ER-1742 (Basta): Sequestration of lead and arsenic
  - ER-200916 (Griffin and Lowney): *In vitro* lead and arsenic assays
  - ER-200517 (Hawkins): Predict metal bioaccesibility
- Cost-effective assays for DoD-relevant organics
  - ER-1743 (Lowney): *In vitro* methods for PAHs
- Bioavailability guidance
  - ITRC: sediments (2015) and soils (2017)
    - http://itrcweb.org/Team/Public?teamID=70

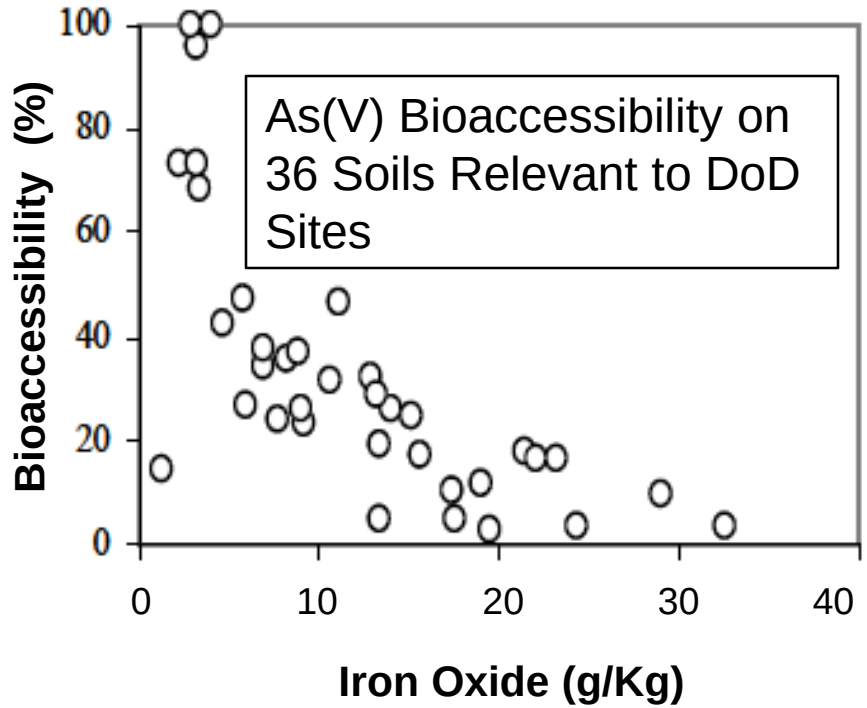
Status of SERDP/ESTCP Efforts

Workshop Recommendations (Cont'd)

- Valid soil limits for DoD contaminants
  - ER-1210 (Lanno): Eco-SSLs for PAHs, TNT, RDX and metals
  - ER-1770 (Trainor): Bioavailability of lead and antimony
- Remediation to reduce bioavailability
  - ER-1351 (Banks): Phosphate mixtures to treat lead and arsenic
  - ER-1350 (Jardine): Novel amendments to treat metals

Predicting Bioaccessibility from Soil Properties





Allows screening level predictions used in Soil Bioaccessibility Tool (SBAT)

Remaining R&D Needs

- Validate *in vitro* models for treated soils
  - Little data on soils treated for lead and arsenic
- Evaluate dermal exposure to cPAHs
  - Methods and dose-response relationships
- Validate the mouse model for metals
  - Less costly than swine, but needs validation

For additional information, please visit

https://serdp-estcp.org/Featured-Initiatives/Cleanup-Initiatives/Bioavailability

Speaker Contact Information

hans@strooconsulting.com; 541-301-3583

SERDP DOD • EPA • DOE | ESTCP

Q&A Session 1

SERDP DOD • EPA • DOE | ESTCP

PAH Interactions with Soil and Effects on Bioaccessibility and Bioavailability to Humans

Yvette W. Lowney
Alloy, LLC

SERDP DOD • EPA • DOE | ESTCP

Presentation Outline

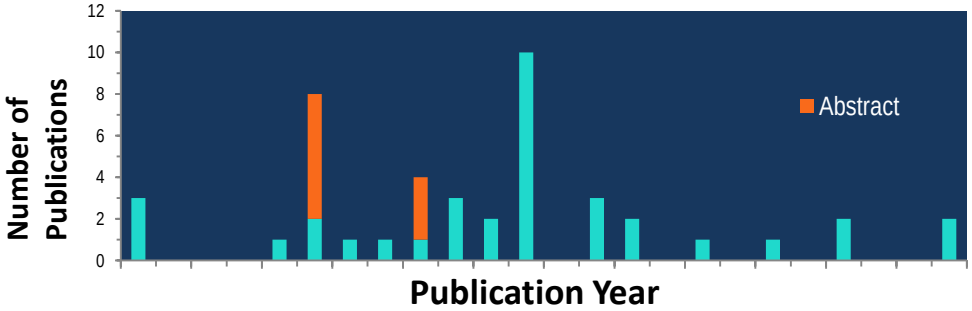
- Impetus for study
- Some of key research components
- Results of the effort
- Implications for risk assessment

Sources of PAHs to Soils

Type	PAH Source	Primary PAH-bearing Materials
Natural	Forest fires	Soot, char
	Grass fires	Soot, char
	Volcanic eruptions	Soot, char
	Oil seeps	Weathered crude oil
Industrial	Manufactured gas plants	Coal tar, pitch, coal, char, soot
	Coking operations	Coal tar, coal, coke, soot
	Aluminum production	Coal tar pitch (making and disposing of anodes)
	Foundries	Coal tar pitch, creosote, fuel oil (used in making sand casts), soot
	Wood treating	Creosote
	Refineries	Soot, various NAPLs (crude oil, fuel oil, diesel, etc.)
	Carbon black manufacture	Soot, oil tar
	Fuel spills and/or disposal	Various NAPLs (crude oil, fuel oil, waste oil, diesel)
Non-Industrial Sources	Skeet	Coal tar pitch or bitumen (used as binder in targets)
	Asphalt sealants	Coal tar
	Landfills	Creosote (treated wood), soot, char
	Incinerators (municipal, hospital)	Soot
	Open burning	Soot, char
	Fire training	Soot
	Fires	Soot, char
	Auto/truck emissions	Soot

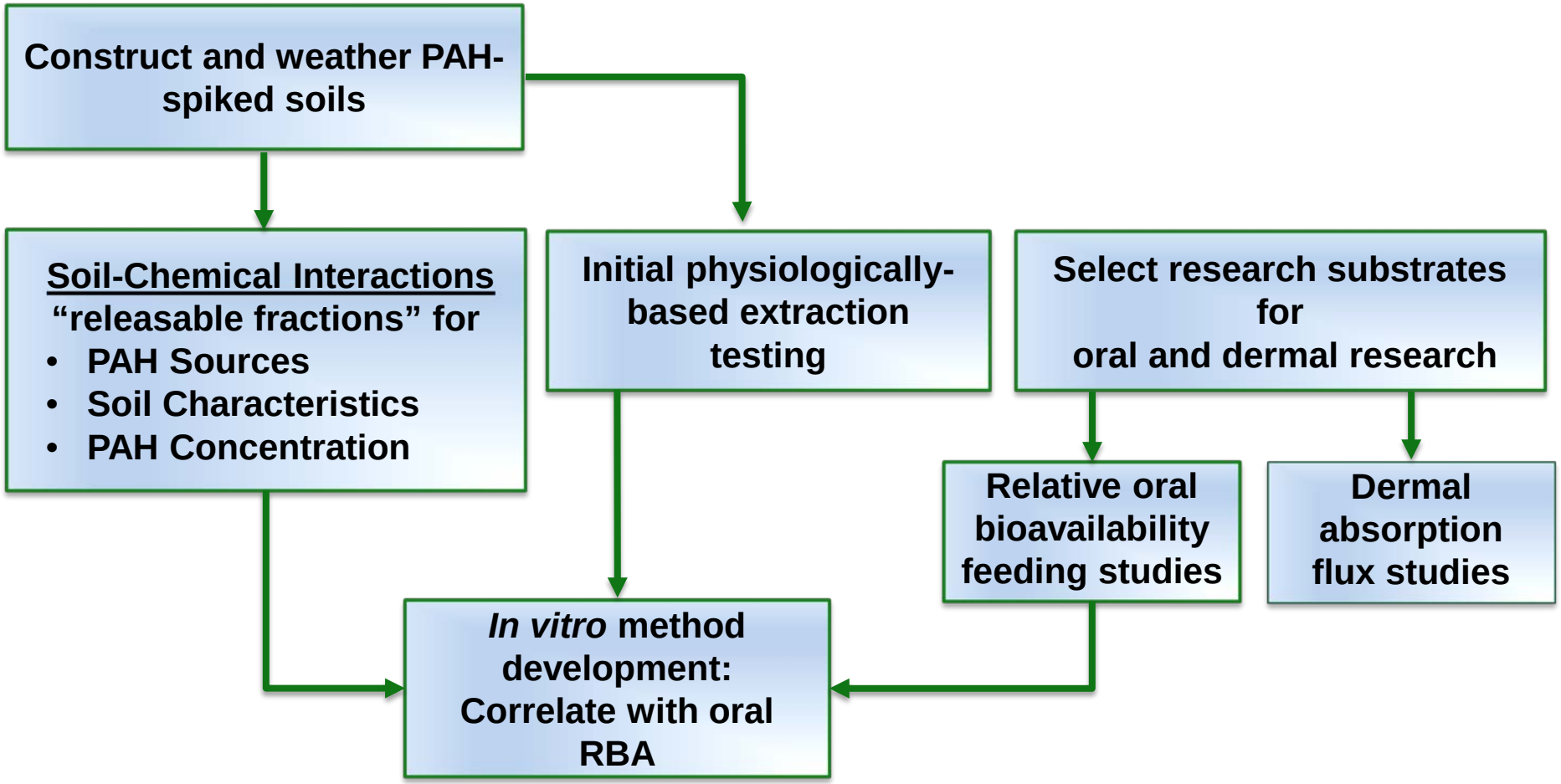
Technical Objective

- EPA default is to assume that the RBA of PAHs in soil is 100%
  - Assumes absorption from soil equivalent to absorption from spiked food
- Existing research supports site-specific adjustments
- Literature still limited
  - Isolated sites
  - Unproven methods
  - High concentrations



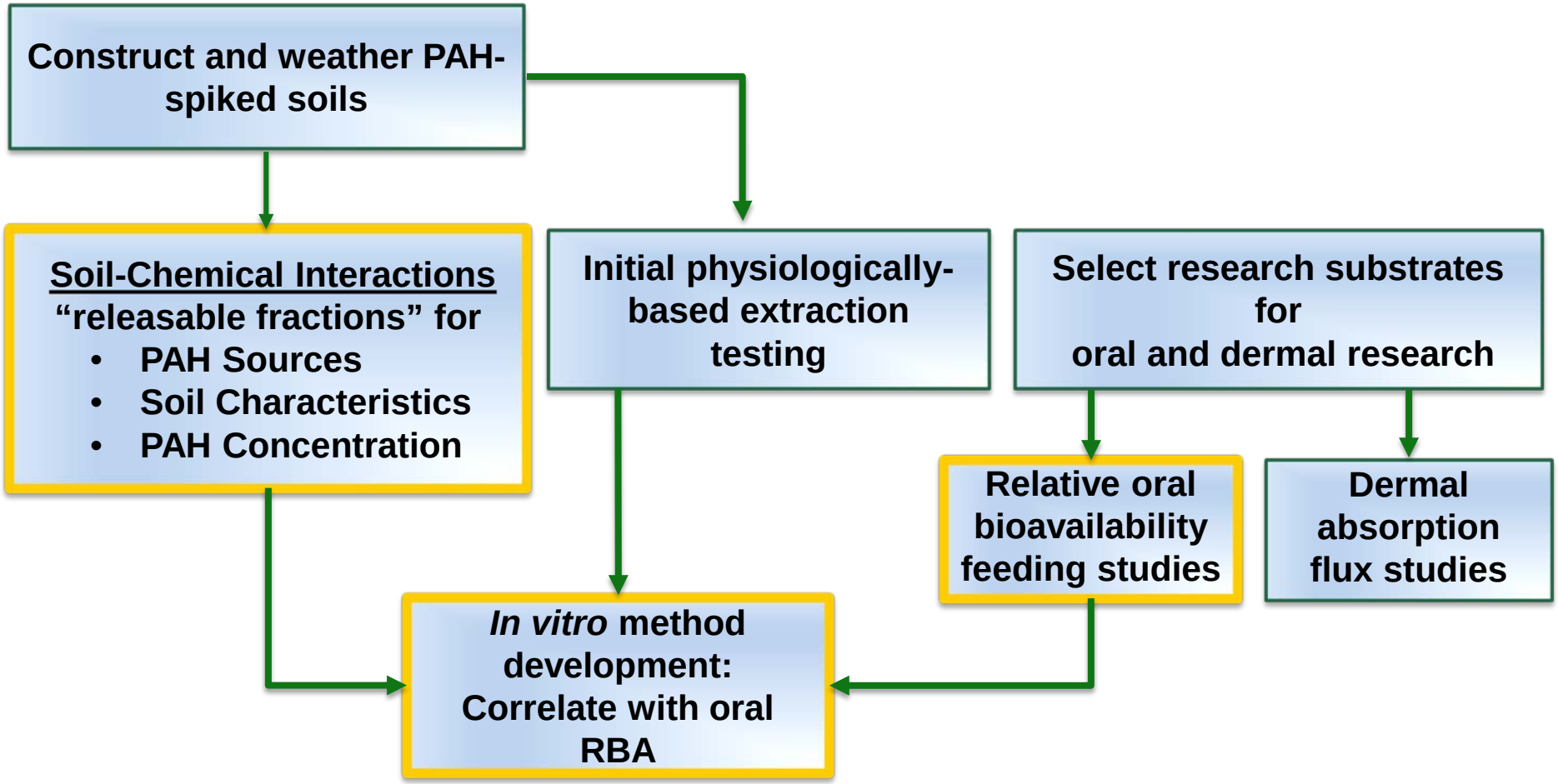
- Our study
  - Provide information on the bioavailability of PAHs from soil
  - Effect of different sources of PAHs
  - Effect of different soil characteristics
  - Effect of different concentrations – within the range of environmental relevance
- This new information and assessment tools will support more accurate HHRA, which may result in higher cleanup goals and more cost-effective, health-protective remediation plans for PAHs in soils

Technical Approach



RBA = relative oral bioavailability

Technical Approach



RBA = relative oral bioavailability

Technical Approach

Construct Soils for Characterization

PAH Sources
Mixture of PAHs in Solvent
Black Carbon Spike Soot
Skeet Spike
NAPL Spike Fuel Oil

Synthetic Spiked Soils

- ASTM Synthetic Soil (70% sand, 20% kaolin, 10% peat moss)

Alter Content of Geosorbents

- 2.0% coal dust
- Reduce peat to 1%
- Reduce clay to 2%

Spike Soils with PAH Sources

Weather Soils for 2 Months

Assess PAH Chemistry and Bioavailability, and Bioaccessibility

Constructed Soils

Sources, Soil Characteristics, PAH Concentrations

Test Soil Matrix (ASTM synthetic soil; 70% sand, 20% kaolinite, 10% peat)

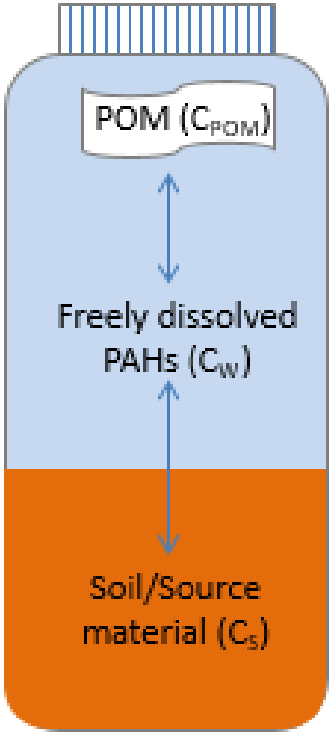
PAH Sources	ASTM soil	ASTM soil plus 2 percent charcoal fines	ASTM soil peat content reduced to 1%	ASTM soil kaolinite content reduced to 2%	ASTM soil kaolinite replaced with montmorillonite	ASTM soil peat replaced with humus
Solvent spike	0.1, 1.0, 10, 100	0.1, 1.0, 10	1.0	1.0	1.0	1.0
Soot	0.1, 1.0, 10, 100	1.0	—	—	—	—
Skeet Particles	0.1, 1.0, 10, 100	1.0	—	—	—	—
Fuel Oil	0.1, 1.0, 10	0.1, 1.0, 10	1.0	1.0	—	—

Values represent target concentration of BaP

Soil-Chemical Interactions

Technical Approach

- Used aqueous equilibrium testing
- Assessed strength of binding between PAHs and soil components
- Full suite of EPA Priority Pollutant PAHs
- Varied
  - PAH source
  - Soil characteristics (NOM, BC, clay)
  - PAH concentration (saturation effects)



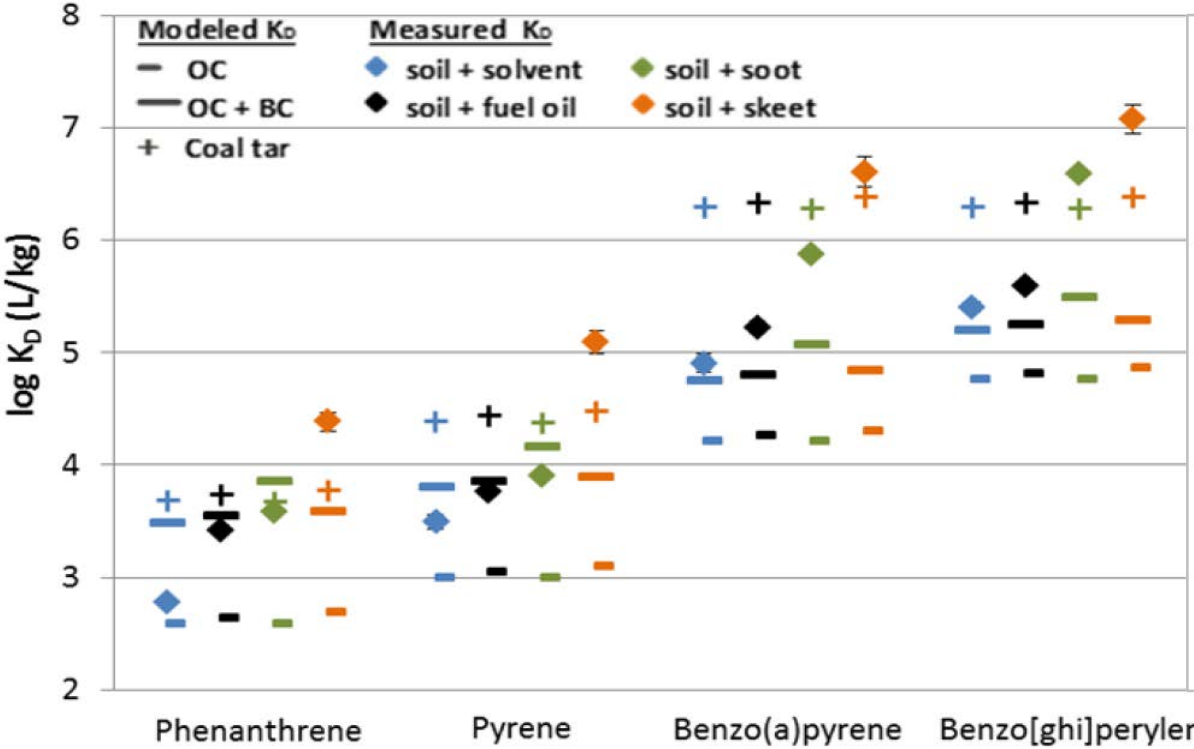
Aqueous Equilibrium Experiments

$$K_D = C_{SOIL} / C_{WATER}$$

$$C_{WATER} = C_{POM} / K_{POM}$$

Soil-Chemical Interactions

Effect of Source Materials on PAH Partitioning

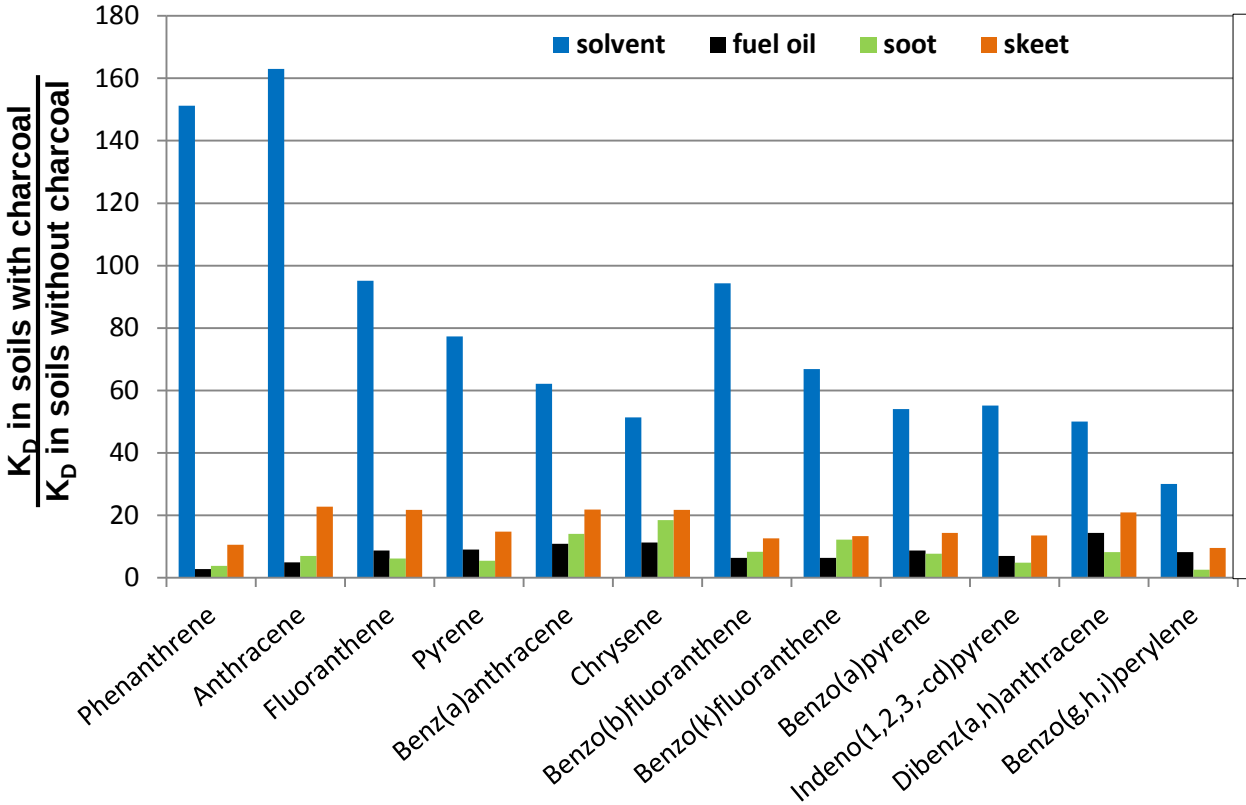


Results demonstrate effect of source material on binding of PAHs to soil: soot or skeet as PAH sources resulted in much stronger binding of PAHs to soil, and lower dissolution

Xia et al., 2016. *Environ. Sci. Technol.* 50: 3444-3452

Soil-Chemical Interactions

Effect of Black Carbon on PAH Partitioning



Results demonstrate effect of adding black carbon (BC) on binding of PAHs to soil: Addition of charcoal resulted in higher binding to soil for every PAH source material

Xia et al., 2016. *Environ. Sci. Technol.* 50: 3444-3452

Soil-Chemical Interactions
Conclusions

- PAH source material governs PAH partitioning
  - Understanding PAH source(s) in contaminated soil can help inform whether a bioavailability investigation would be useful
- Black carbon content can substantially increase soil K_D
  - In situ remediation with black carbon amendments can substantially reduce PAH bioavailability
- Other soil characteristics and PAH concentration had small or no effects on PAH partitioning
- Soil partitioning models and further details on partitioning coefficients of individual soil components and their sorptive interactions are provided in Xia et al. (2016)

Xia et al., 2016. *Environ. Sci. Technol.* 50: 3444-3452

In Vivo Study

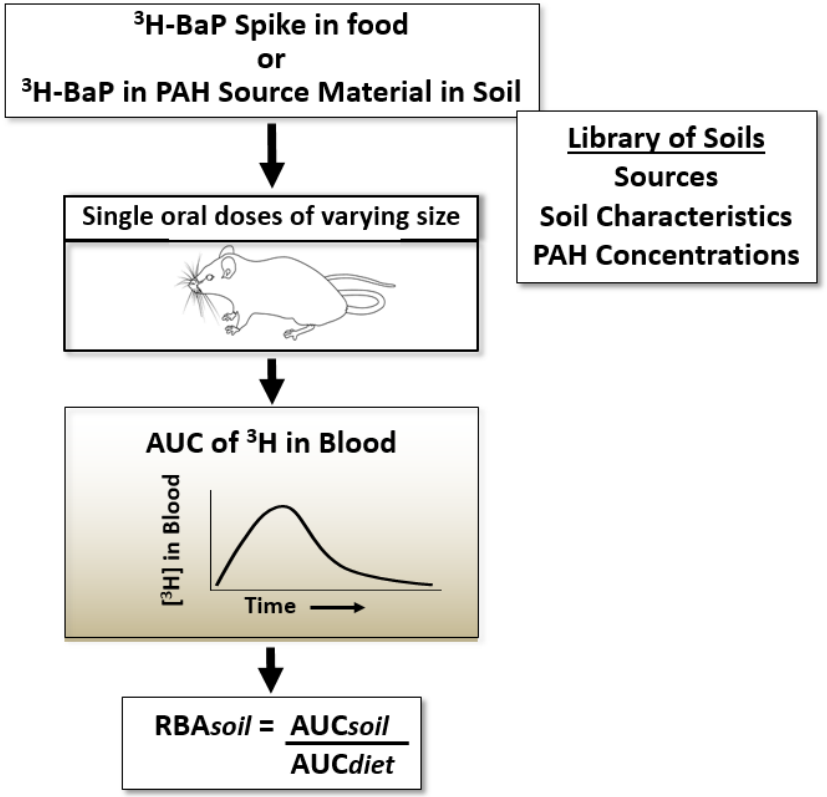
Technical Approach

- Need standardized *in vivo* model for site assessment
- Animal studies required for regulatory acceptance
- Need data for range of soils with diverse characteristics and contaminant sources
- Animal data needed to assess predictive value of *in vitro* method
  - Our focus was to develop methods that can be used to examine bioavailability at environmentally relevant PAH concentrations (low ppm)

In Vivo Study

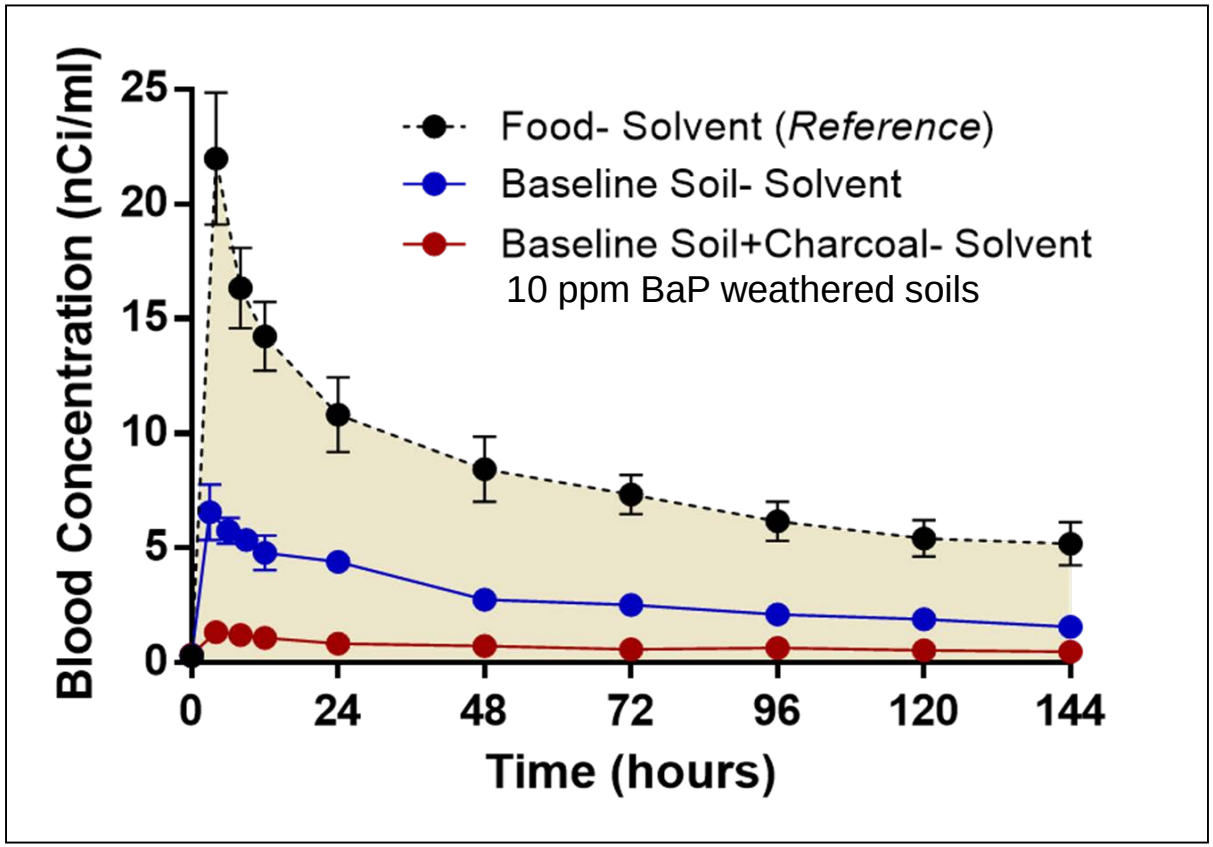
Technical Approach (Cont'd)

- 3H radiolabel allowed for quantitative evaluation in concentration range of environmental relevance
- Use of small animal allowed
  - Higher "n"
  - Lower waste
  - Consistent with animal in critical toxicity study
- Matrix of study soils similar to chemical characterization task
  - PAHs in solvent
  - PAHs in soot
  - PAHs in fuel oil
- AUC in blood is "gold standard" for assessing bioavailability



In Vivo Study

Results



Results demonstrate lower bioavailability of BaP from soils when compared to the same dose in diet. Addition of charcoal to soil further reduced bioavailability

Effect of Soil Characteristics on PAH RBA from Soils

Roberts et al., 2016. *Environ. Sci. Technol. 50* (20): 11274–11281

In Vivo Study

Results (Cont'd)

Summary of Data on RBA of BaP from Soil

PAH Source		Solvent		Soot		Fuel Oil	
Soil Matrix	BaP (ppm)[a]	*AUC (nCi hr/ml)*	*RBA*	*AUC (nCi hr/ml)*	*RBA*	*AUC (nCi hr/ml)*	*RBA*
Baseline Soil	**1**	455 ± 30	**0.56**	442 ± 27	**0.54**	529 ± 3	**0.65**
(BSS)	**10**	413 ± 17	**0.51**	550 ± 26	**0.67**	785 ± 97	**0.96**
	100	426 ± 25	**0.55**	192 ± 13	**0.23**	869 ± 119	**1.06**
Food	[b]	817 ± 28					
BSS +Charcoal	**10**	103 ± 16	**0.13**	171 ± 4	**0.21**	249 ± 24	**0.31**
Reduced Clay	**10**	335 ± 49	**0.41**	—	—	698 ± 40	**0.85**
Reduced Peat	**10**	—[c]	—[c]	—	—	621 ± 70	**0.76**

[a] BaP concentrations correspond to doses of 0.5, 5.0 or 50 µg/dose
[b] BaP in food at concentrations of 1, 10 and 100 ppm
[c] Not evaluated due to evidence of BaP degradation during weathering

Roberts et al. *Environ. Sci. Technol.*, 2016, *50* (20), pp 11274–11281

In Vivo Study

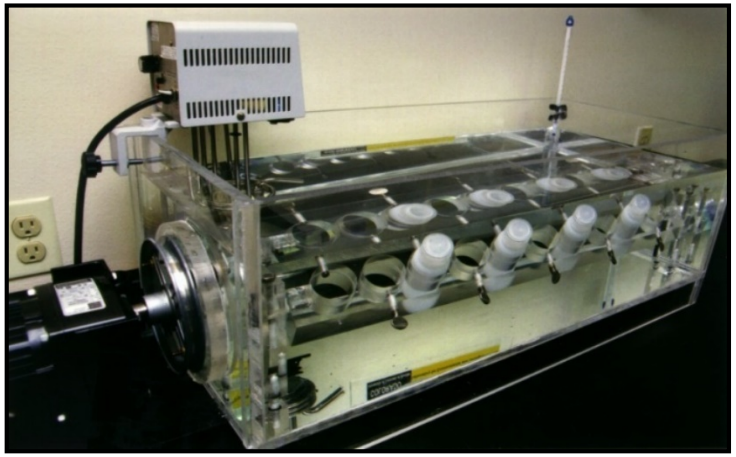
Conclusions and Implications for HHRA

- Animal model provided reliable data on RBA of PAHs
  - Soil at environmentally-relevant concentrations (1-100 ppm)
- Results indicate PAH source material has impact on RBA as measured in animal model
  - Fuel oil higher
  - Soot sources lower
- Varying peat and clay content of soil had little impact
- Addition of 2% charcoal to soil resulted in reduced RBA
  - Suggests that soil amendments may be effective at affecting RBA

In Vitro:*In Vivo* Correlation

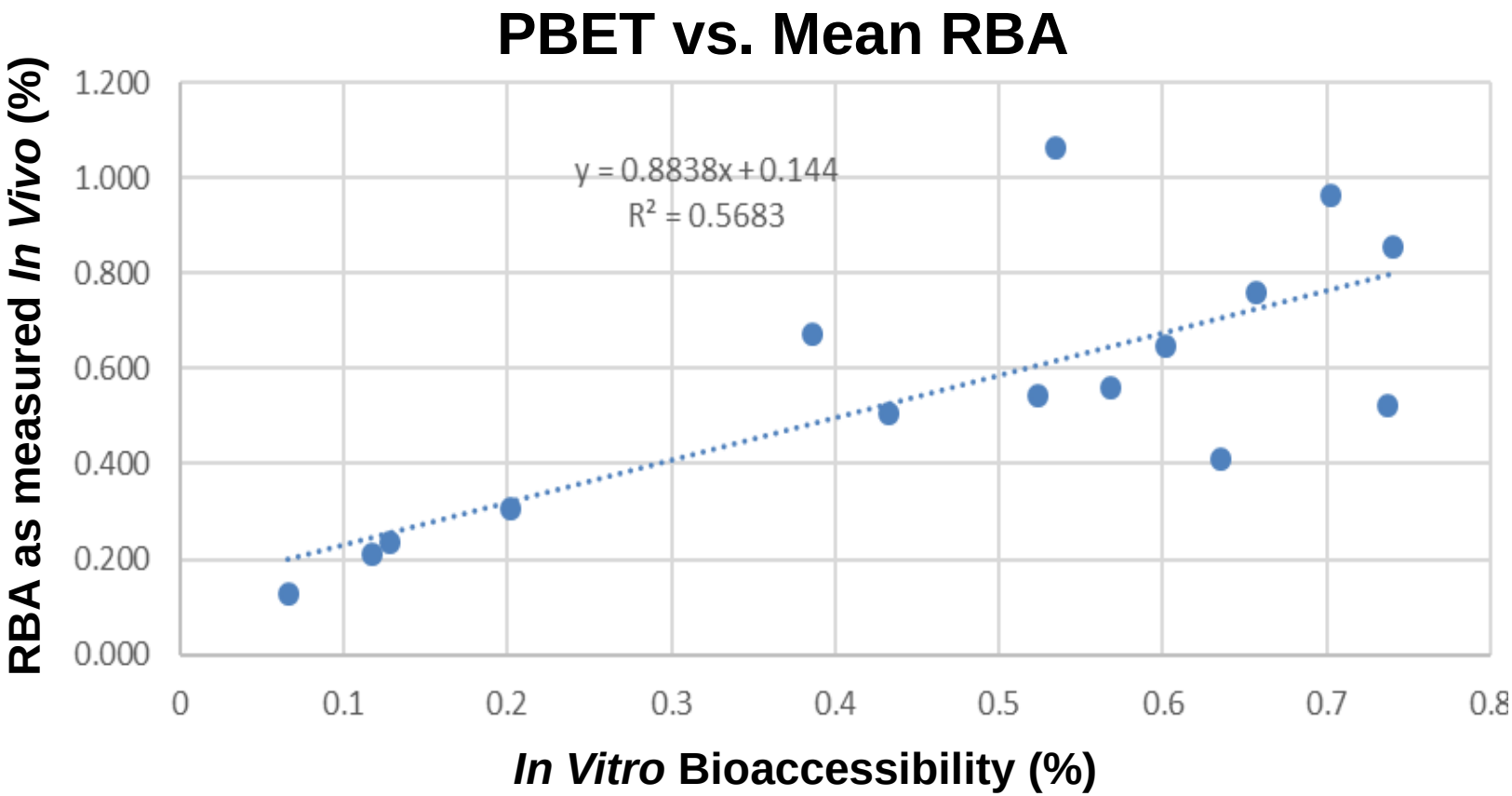
Technical Approach

- Goal: Assess ability of bench-top extraction methods to predict the RBA as measured in animals
- Initial extraction testing
- Validation against animal data
- Testing of library of 15 soils from RBA study
- Five different extraction conditions
  - Physiologically-based extraction
  - n-Butanol
  - EPA Method 3550C
  - ScintiVerse scintillation fluid
  - Solid phase absorption sink (silicon)



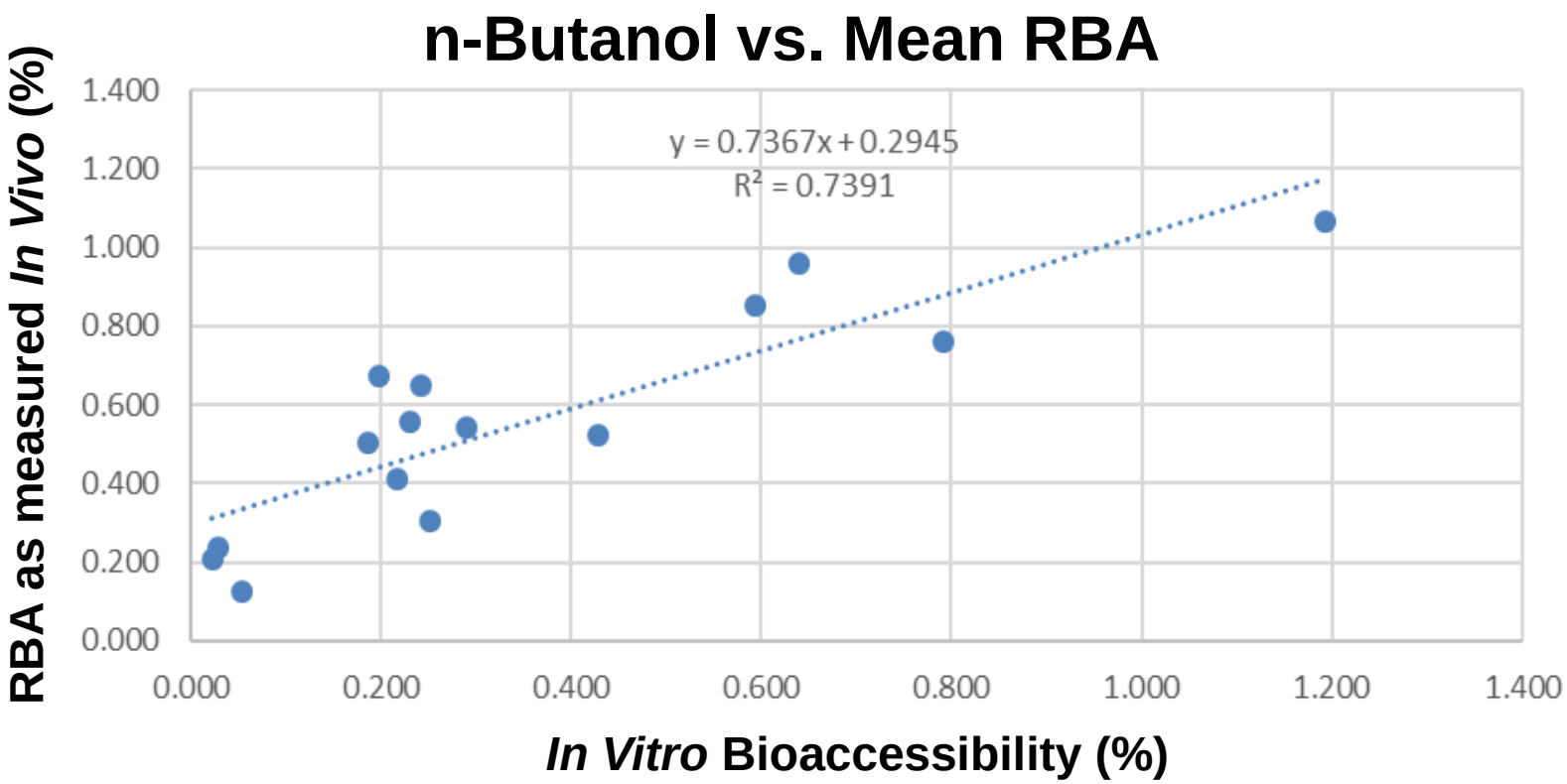
In Vitro:*In Vivo* Correlation

Results



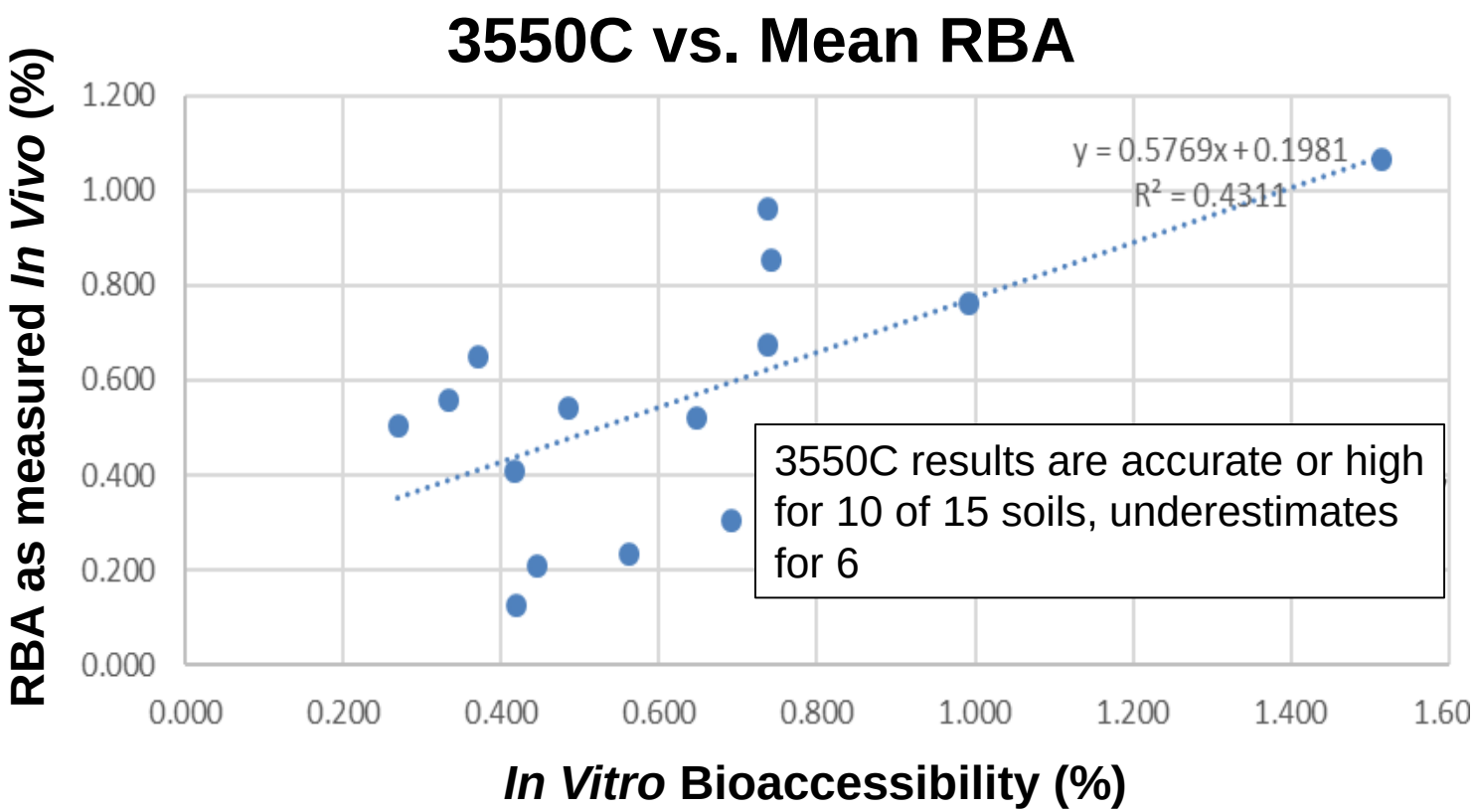
In Vitro:In Vivo Correlation

Results (Cont'd)



In Vitro:In Vivo Correlation

Results (Cont'd)



3550C results are accurate or high for 10 of 15 soils, underestimates for 6

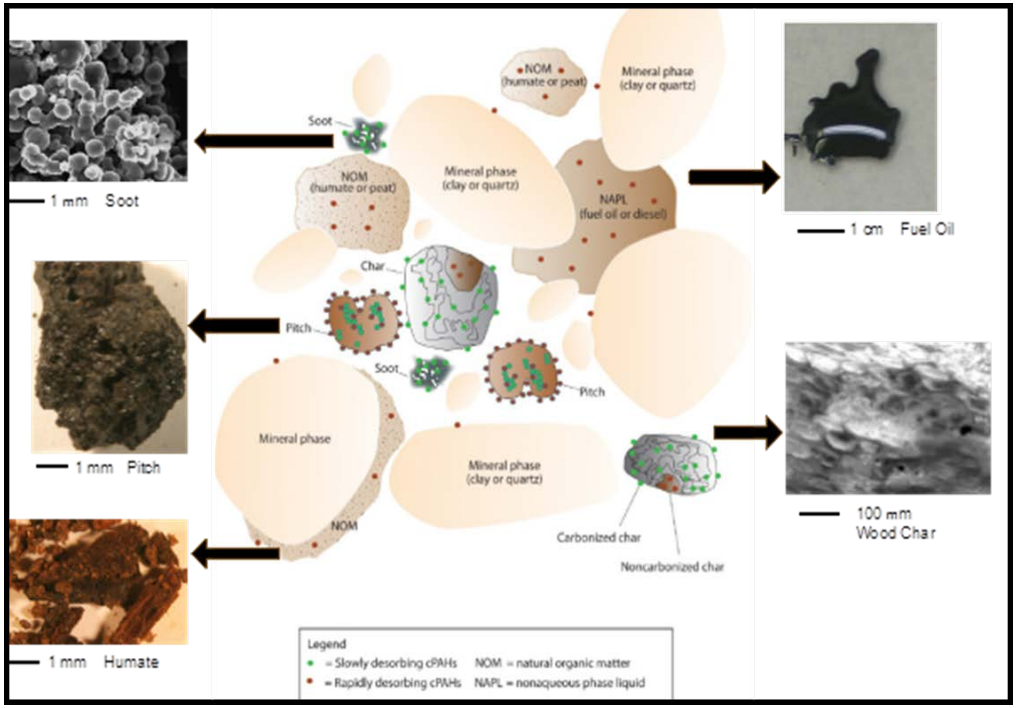
In Vitro:In Vivo Correlation

Conclusions

- Library of soils with RBA values provided strong basis for evaluation of IVIVC
- Results indicate that physiologically-based method provides reasonable estimation of RBA as measured *in vivo*
- Results from extraction testing with n-butanol shows even better correlation with RBA measurements

Overall Research Conclusions

- Source of PAH contamination to soils has significant impact on soil-chemical interactions and bioavailability
  - Indicates that bioavailability adjustments are likely to be appropriate for HHRA of many PAH-contaminated sites
  - Especially for sources such as soot, coal tar pitch (e.g., skeet)
- Soil characteristics (esp. BC) affects PAH binding to soil and bioavailability
  - Potential implications for soil amendment technologies
- *In vitro* methods show good correlation with RBA from animal studies
  - Currently no regulatory standing
  - Useful screening method for sites



Ruby et al., 2016. *Environ. Sci. Technol.* 50: 2151-2164

Acknowledgments

- University of Maryland, BC
  - Laboratory of Dr. Upal Ghosh
- University of Florida
  - Laboratory of Dr. Stephen Roberts
- University of Washington
  - Laboratory of Dr. John Kissel
- Colorado School of Mines
  - Dr. Annette Bunge
- Exponent, Inc.
- Integral Consulting

For additional information, please visit

https://www.serdp-estcp.org/Program-Areas/Environmental-Restoration/Risk-Assessment/ER-1743

Speaker Contact Information

ylowney@alloy-llc.com; 303-589-9955

Q&A Session 2

SERDP DOD • EPA • DOE | ESTCP

Mechanisms and Permanence of Sequestered Lead and Arsenic in Soils: Impact on Human Bioavailability

Nicholas Basta, Ph.D.
The Ohio State University

SERDP DOD • EPA • DOE | ESTCP

Presentation Outline

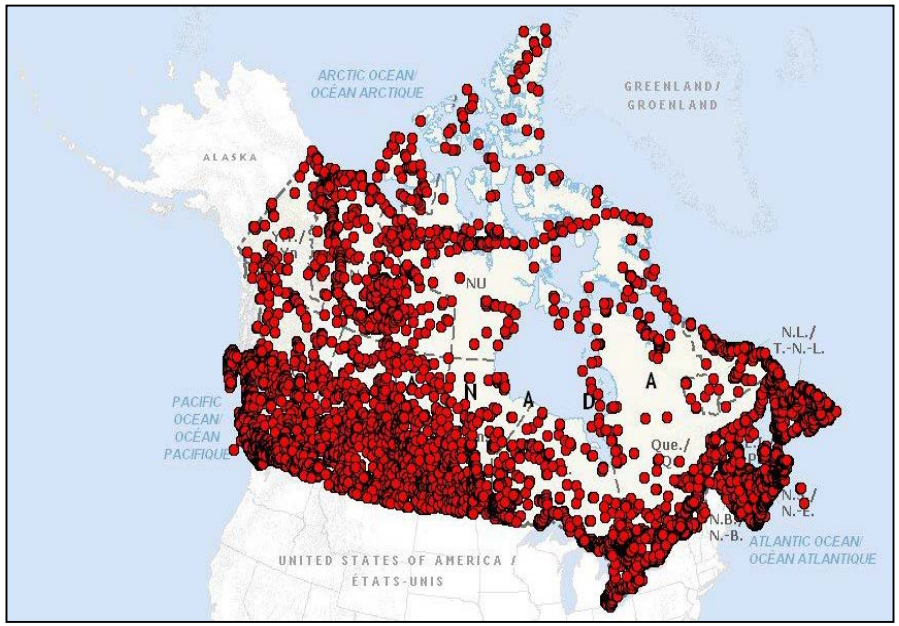
- Why use bioavailability?
- Mechanisms of sequestered arsenic in soils and impact on human bioavailability
- Long-term permanence of lead remediation
- Conclusions
- Validation of *in vitro* methods for DoD sites

Why Use Bioavailability in Assessment?

- To prevent very costly, unnecessary remediation action of ecologically destructive excavation and replacement of soil

Remediation Cost Savings can be Huge

- Bioaccessibility and Bioavailability: The Great Opportunity Not Realized (so far) – Dr. Mark Richardson, Health Canada

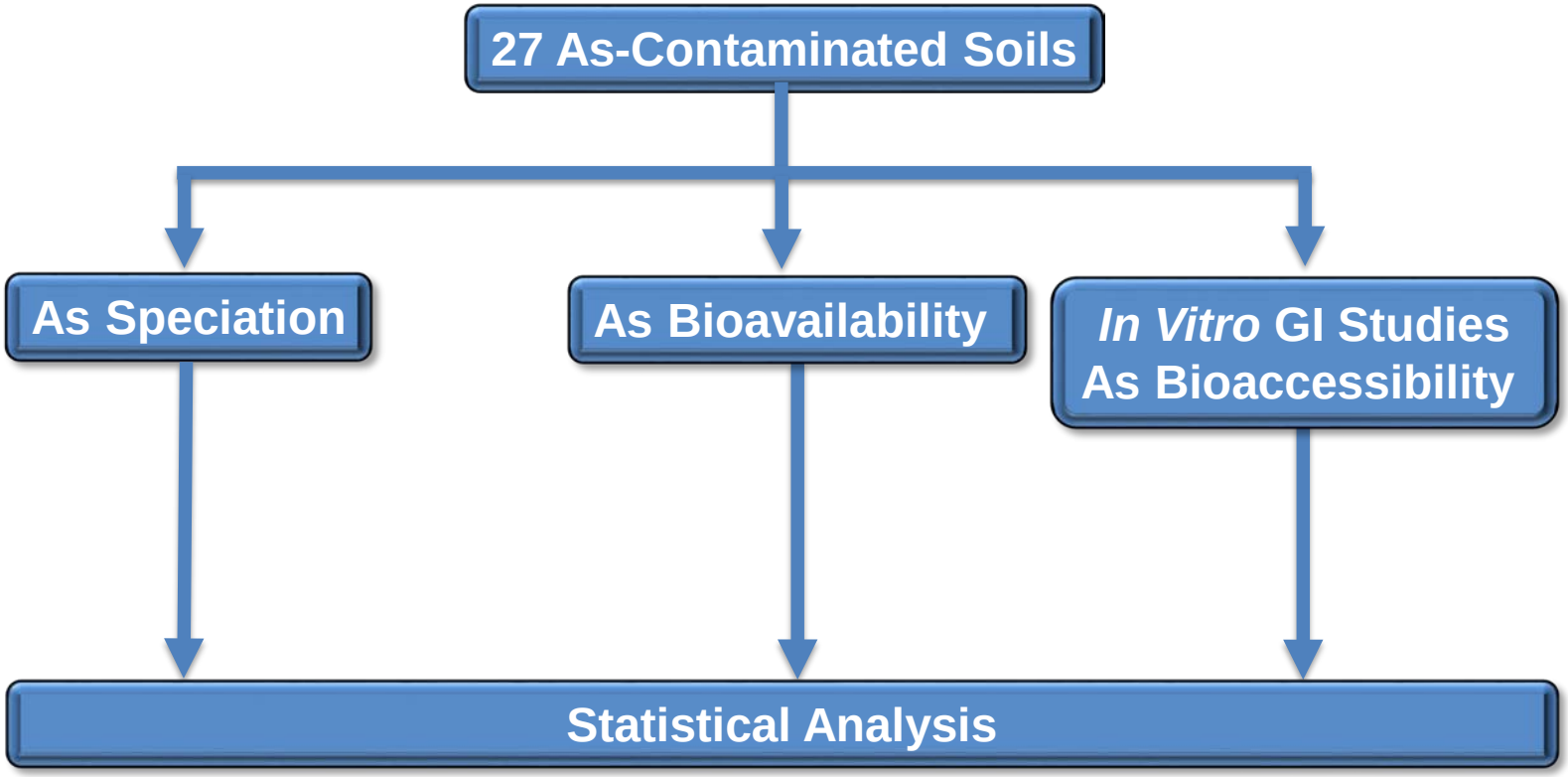


- Average remedial cost savings needed = $564,000/site; cost overrun (saving needed) for all sites = $2.1 billion
- Application of bioaccessibility/bioavailability testing in FCSAP can save $2 billion (the cost overrun)

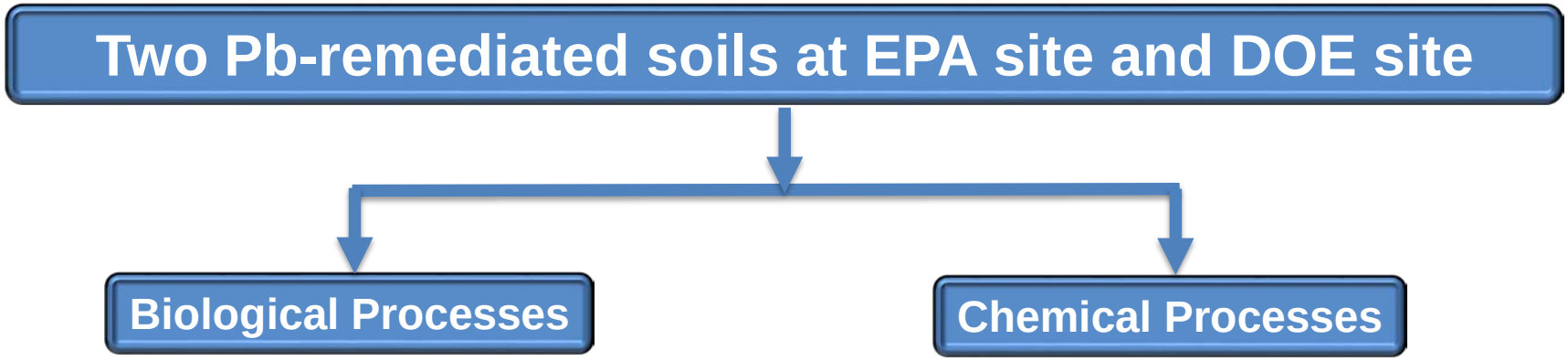
Objectives

- Arsenic (As)
  - To evaluate five cost effective laboratory methods to predict site specific bioavailability of As for adjusting exposure in site specific risk assessment
- Lead (Pb)
  - Evaluate the long-term permanence of Pb contaminated soil remediated by phosphorus soil amendments (i.e., remediation based on reduced Pb bioavailability)

Mechanisms of Sequestered Arsenic in Soils and Impact on Human Bioavailability



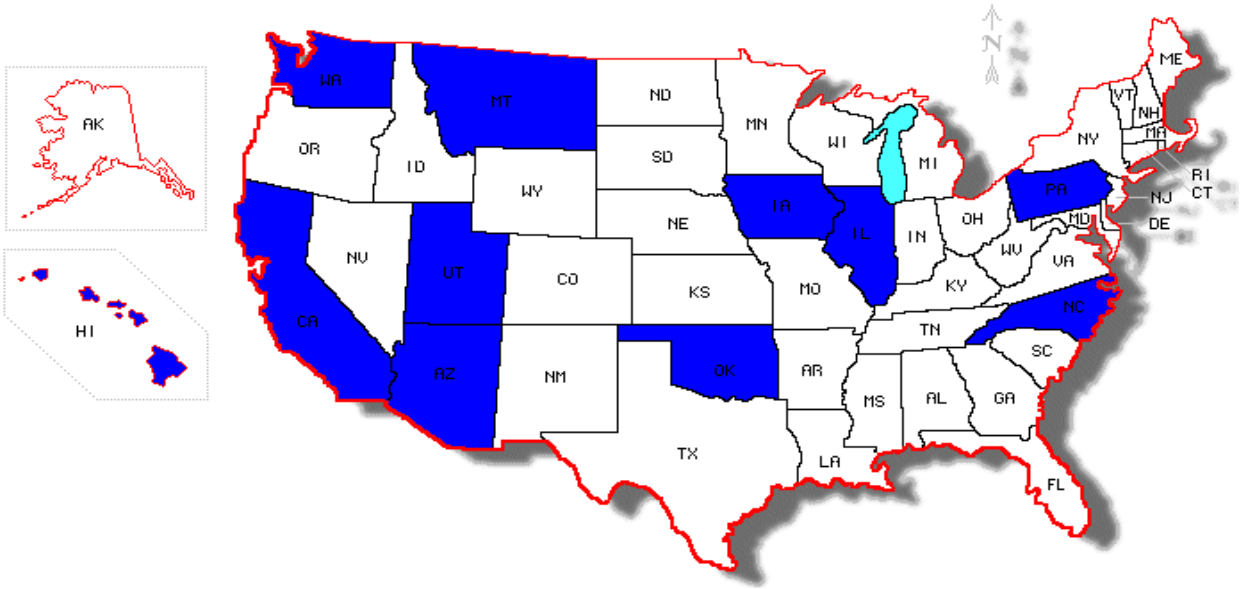
Biological and Chemical Processes and Long-Term Permanence of Lead Remediation



Contaminant Sources for Arsenic Studies

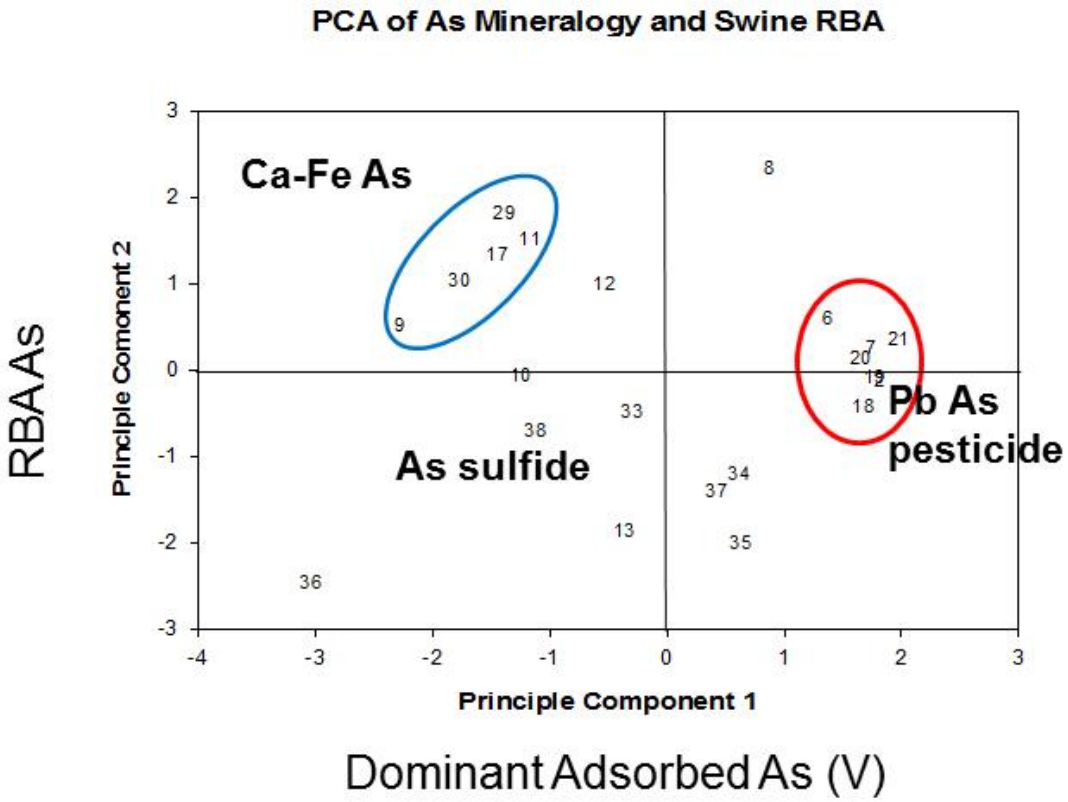
Source	No. Soils
Pesticide	3
Orchard	5
Mining	10
Spiked	3
Glass Making	2
Tailings	2
Smelter	1
Reference Material	1
Total	27

Soil As Concentration (mg/kg)				
Minimum	Maximum	Mean	Median	90th Percentile
162	12483	2209	464	6924



Arsenic Speciation Results

Soil Influences Bioavailability of Soil Arsenic



Ca-Fe As > Pb As pesticide ≥ adsorbed As (V) > As sulfides
Consistent with As bioaccessibility of Menuier et al. (2012)

In Vitro Bioaccessible (IVBA) Arsenic Results

- Five *in vitro* methods previously correlated with bioavailable arsenic
  - U.S. EPA 9200/SBRC (Australia) –“Glycine” method
  - OSU IVG, UBM (EU), RMC PBET (Canada); CAB (California)
- CAB > OSU IVG, UBM, PBET ≥ Glycin Gastric IVBA > Intestinal IVBA

Correlations with *In Vivo* Results

Mouse RBA As vs. IVBA

Method	Glycine	PBET	UBM	OSU	CAB
Slope	0.74	0.74	0.81	0.85	0.72
Y Intercept	13.6	14.2	8.70	10.9	-2.48
r^2	0.82	0.82	0.84	0.89	0.73

Swine RBA As vs. IVBA

Method	Glycine	PBET	UBM	OSU	CAB
Slope	0.71	0.80	0.89	1.09	0.64
Y Intercept	18.3	17.5	14.3	12.6	5.17
r^2	0.60	0.63	0.67	0.73	0.65

All methods predicted bioavailable arsenic for most soils

Long-Term Permanence of Lead Remediation

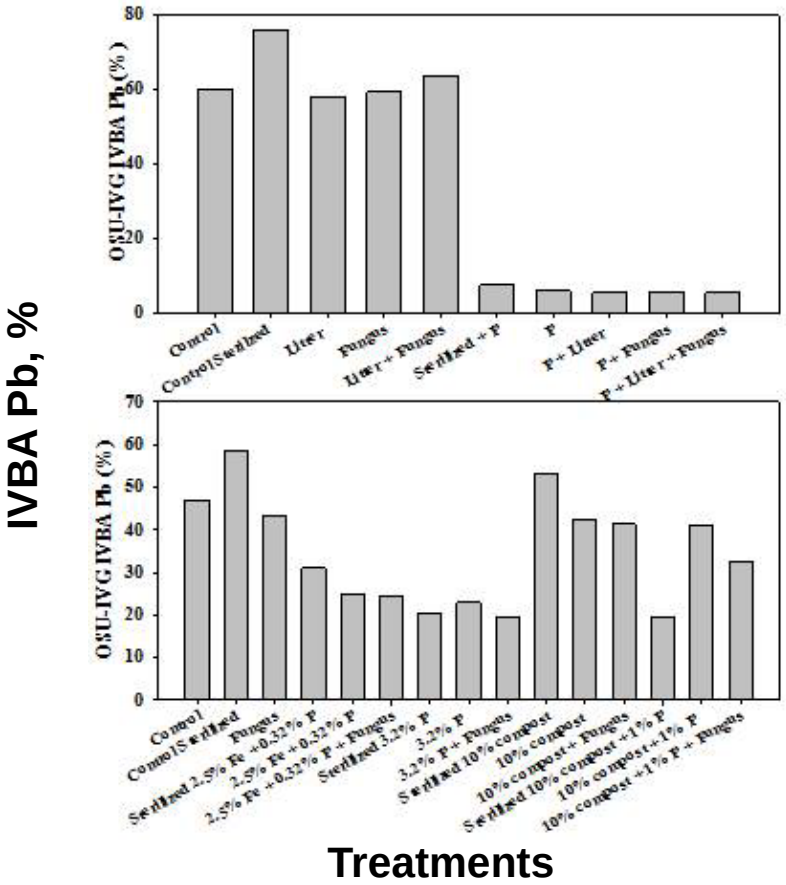
P Soil amendments + bioavailable Pb → Low Pb bioavailability Pb-P minerals

Phosphate-Induced Metal Stabilization (PIMS)

Camp Stanley (ER-200020)

Remediated Lead is Stable

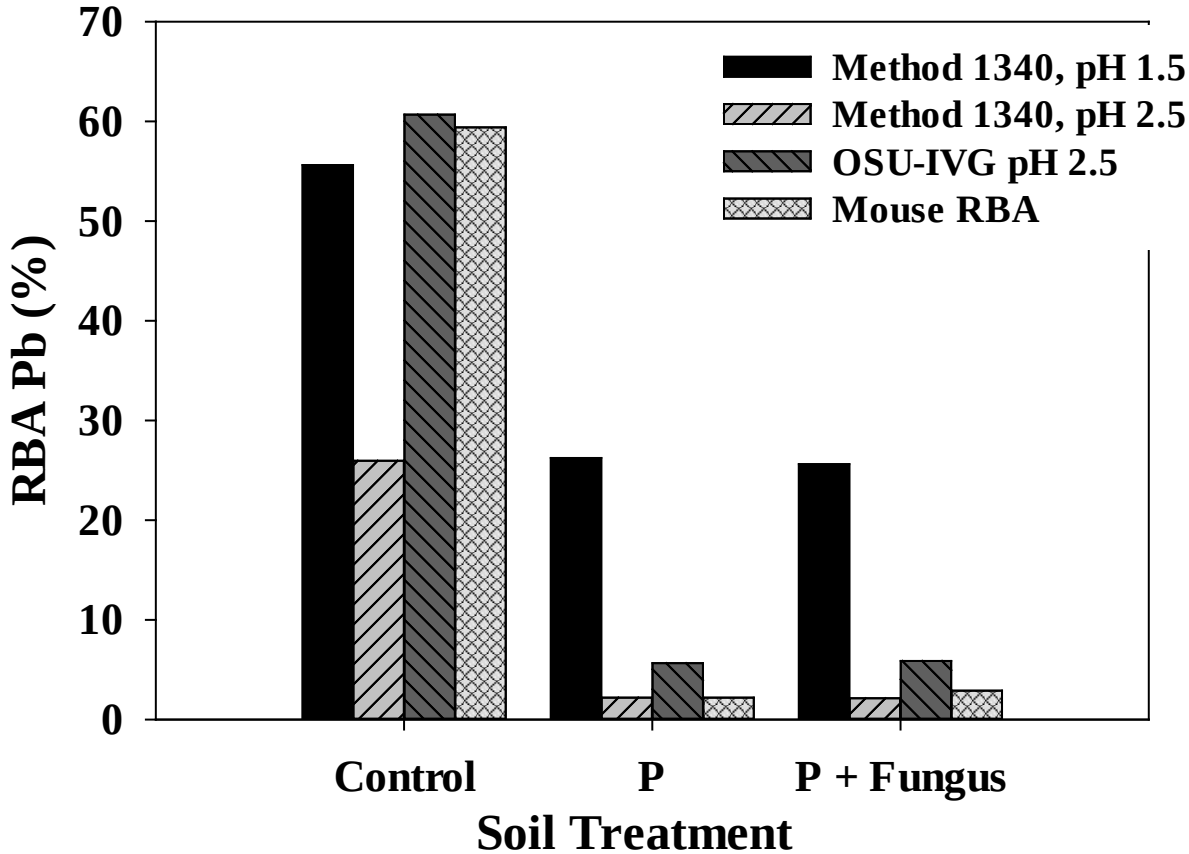
- Soil microbial fungal treatments had no effect on bioaccessible Pb
- Similar results for chemical processes and other endpoints



Oak Ridge Firing Range Pb remediated soil

Joplin Pb Smelter Pb remediated soil

EPA Method 1340



- EPA Method 1340 uses pH 1.5
- Method 1340, pH 2.5 is modified to pH 2.5 not 1.5
- Treated soils are P and P+fungus

Underestimates Reduction in Pb Bioavailability in P-Treated Soil

Conclusions

- IVBA bioaccessibility methods provide reliable estimates of RBA arsenic for use by DoD site managers
- Pb in P-treated soil is stable and soil amendment with P is a long term remediation practice for Pb soils on DoD sites
- Current *in vitro* methods (EPA Method 1340) may not be accurate to evaluate bioavailable Pb and performance of for in situ soil amendment using P remediation

Acceptance for Using Bioavailability Technologies for Soil Risk Assessment

- State of California
  - Aug 22, 2106: Recommended methodology for evaluating site-specific arsenic bioavailability in CA soils
  - California Bioaccessibility Method (CAB)
- EPA
  - *In vitro* method 1340 approved for Pb in 2007 will likely be approved by EPA for As (EPA 9200)
- Interstate Technology Regulatory Council (ITRC)
  - Bioavailability in Contaminated Soil document to assist US State Governments to implement bioavailability (in progress - expected in November 2017)

Further Validation for *In Vitro* Methods to Predict Bioavailability at New Sites

Measure *in vitro* bioaccessible (IVBA) metal(loid) in new site soil

↓

Enter measured IVBA metal(loid) into published IVIVC Regression Equations determined from other soils to predict RBA arsenic

↓

Measure RBA As from Juvenile Swine Dosing Trial

↓

Compare Measured *in vivo* RBA with Predicted RBA from *in vitro*

Validation of *In Vitro* Methods for DoD Sites

- The Effect of Soil Properties on Toxic Metal Bioavailability: Field Scale Validation to Support Regulatory Acceptance
  - ESTCP, ER-200517
  - Dr. Amy Hawkins (PI), NAVFAC Engineering Service Center
  - Ohio State University: Soil processing and bioaccessibility testing
  - University of Missouri, RBA determination using juvenile swine model

In Vitro Methods for Arsenic and Lead

Prediction of Soil RBA Pb

	Measured RBA (juvenile swine)	Predicted RBA using EPA 1340	Predicted RBA using OSU IVG
Mean	99 %	70.3 %	102 %
90% CI	70 % to 127 %		

Prediction of Soil RBA As

	Measured RBA (juvenile swine)	Predicted RBA OSU IVG	Predicted RBA EPA 9200
Mean	14 %	15 %	11.4 %
90% CI	13 % to 15 %		

Accurate Predictors for Soils from 2 DoD Sites

The New Frontier

- Bioavailability-based in situ soil remediation using soil amendments

- Evaluating bioavailability using *in vitro* methods for in situ remediated soil (i.e., P-treated soil)

Acknowledgments

- Dr. Karen Bradham, EPA, NERL, RTP, NC
- Dr. Rufus Chaney, Beltsville, MD, USDA ARS, Beltsville, MD
- Dr. Mark Failla, The Ohio State University
- Dr. Philip Jardine (deceased), University of Tennessee-Knoxville
- Dr. Christopher Schadt, Oak Ridge National Laboratory
- Dr. Kirk Scheckel, EPA NRMRL, Cincinnati, OH
- Dr. David Thomas, EPA NHEEL, RTP, NC

For additional information, please visit

https://serdp-estcp.org/Program-Areas/Environmental-Restoration/Risk-Assessment/ER-1742

Speaker Contact Information

basta.4@osu.edu; 614-292-6282

SERDP DOD • EPA • DOE | ESTCP

Q&A Session 3

SERDP DOD • EPA • DOE | ESTCP

The next webinar is on November 17, 2016

"Novel Coatings Systems for Use as High Performance Chemical Resistant Powder Topcoats"

SERDP DOD • EPA • DOE | ESTCP

Survey Reminder

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

SERDP DOD • EPA • DOE | ESTCP