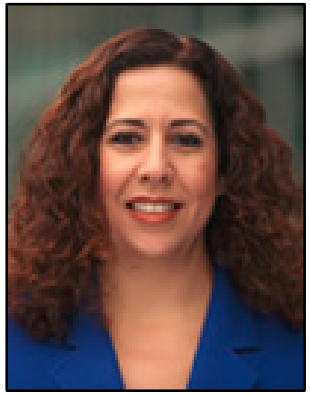
New Tools for Characterizing and Remediating Munitions and Energetics at Military Ranges

May 28, 2015

SERDP DOD • EPA • DOE | ESTCP

Welcome and Introductions



Rula Deeb, Ph.D.
Webinar Coordinator

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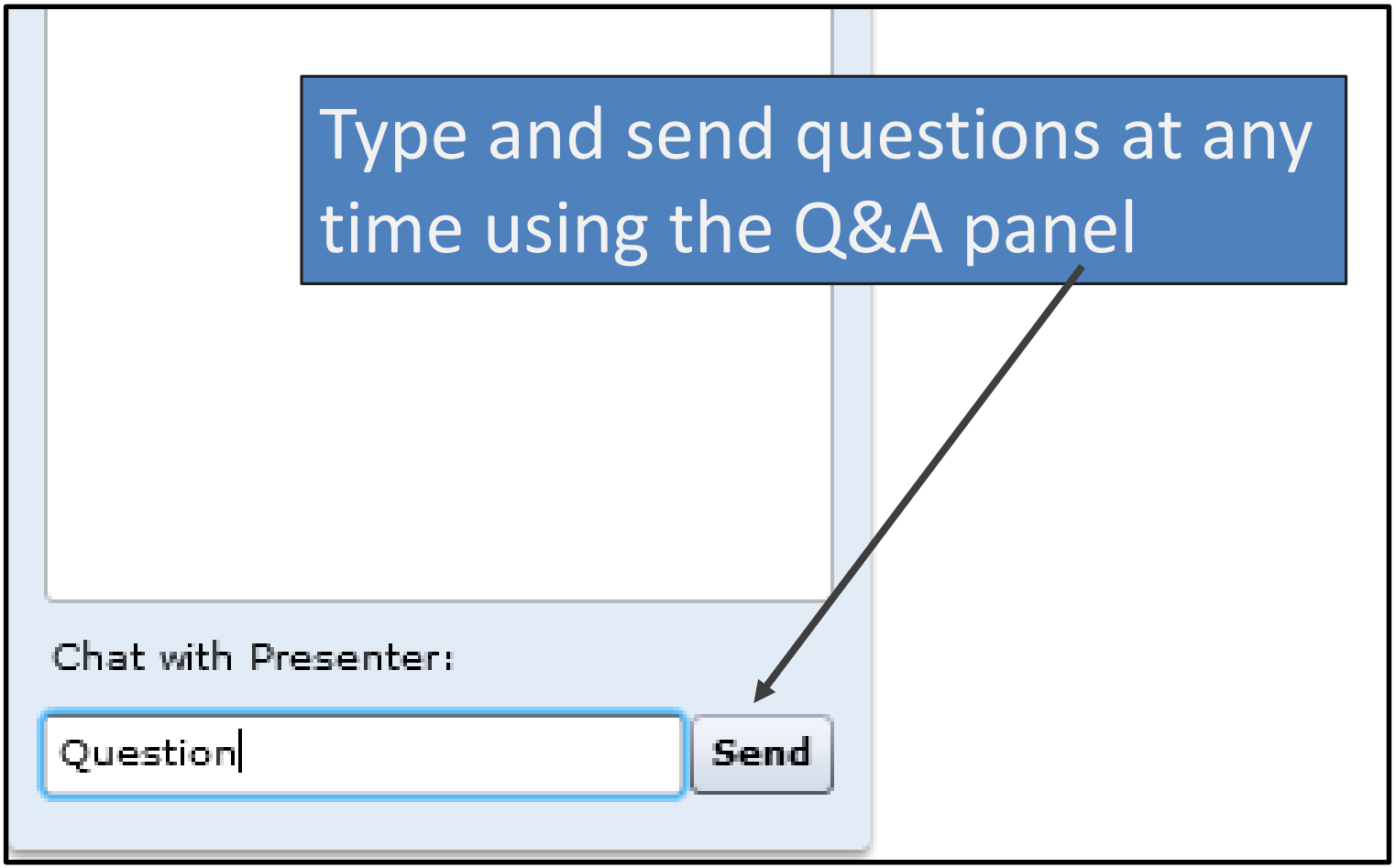
Agenda

- **Webinar Logistics**
  Dr. Rula Deeb
  Geosyntec (5 minutes)
- **Overview of SERDP and ESTCP**
  Dr. Andrea Leeson
  SERDP and ESTCP (5 minutes)
- **Representative Sampling and Analysis for Energetic Residues in Soil**
  Dr. Tom Jenkins
  Private Consultant (25 minutes + Q&A)
- **Bioremediation of Co-Mingled Perchlorate and Explosives in Groundwater at an Active Military Range**
  Dr. Paul Hatzinger
  CB&I Federal Services, LLC (25 minutes + Q&A)
- **Final Q&A session**

How to Ask Questions



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- Delays in the broadcast audio
  - Click the mute/connect button
  - Wait 3-5 seconds
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    - U.S./Canada: 1-877-776-3503
    - International: 330-871-6014
    - Required conference ID: 17905619
- Submit a help request using the chat box

SERDP and ESTCP Overview

Andrea Leeson, Ph.D.
Environmental Restoration Program Manager

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SERDP

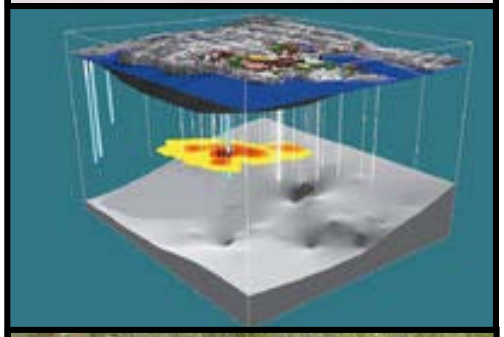
- Strategic Environmental Research and Development Program
- Established by Congress in FY 1991
  - DoD, DOE and EPA partnership
- SERDP is a requirements driven program which identifies high-priority environmental science and technology investment opportunities that address DoD requirements
  - Advanced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

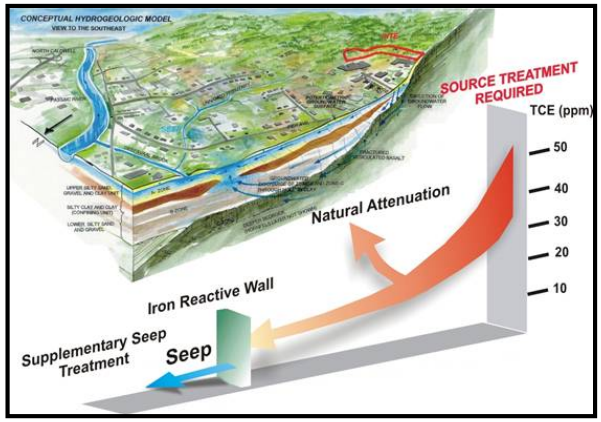
Program Areas

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



Post-Remediation Performance Assessment Solicitation

- ESTCP released a solicitation on May 12, 2015, requesting proposals focused on follow-up monitoring and evaluation of in situ restoration sites
- All proposals are due no later than 2:00 p.m. Eastern Time on June 11, 2015
- For additional information, please visit https://www.serdp-estcp.org/Funding-Opportunities/ESTCP-Solicitations/Post-Remediation-Assessment-Solicitation

SERDP and ESTCP Webinar Series

DATE	Topics
June 25, 2015	Energetics: Colored Smokes and Flares
July 16, 2015	Watershed Assessment and Stormwater Management Optimization Tools
August 6, 2015	Remote Methods for Water Conservation
August 20, 2015	Characterization and Remediation in Fractured Rock Environments
October 1, 2015	Hexavalent Chrome Elimination from Hard Chrome Surface Finishing
October 15, 2015	LED-ing the Way: Sophisticated and Energy Efficient Exterior Lighting Systems for DoD Installations
October 29, 2015	Assessment and Treatment of Contaminated Sediments
November 12, 2015	Munitions Response: Land Based Program Closeout
December 3, 2015	Emerging Contaminants: DoD Overview and State of Knowledge on Fluorochemicals and 1,4-Dioxane
December 17, 2015	Resource Conservation and Climate Change

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

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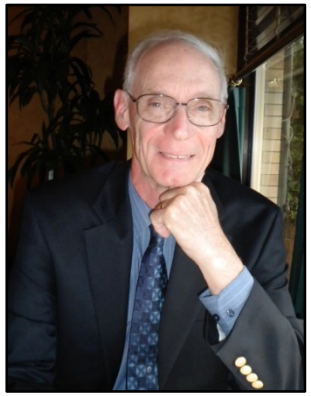
Representative Sampling and Analysis for Energetic Residues in Soil at Military Training Ranges

Tom Jenkins, Ph.D.
Private Consultant



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Representative Sampling and Analysis for Energetic Residues in Soil at Military Training Ranges

SERDP Projects ER-1155 and ER-1481
ESTCP Project ER-200628

Thomas F. Jenkins, Ph.D.

Major Participants in Sampling Studies

- ERDC
  - Dr. Thomas Jenkins, Marianne Walsh, Alan Hewitt, Michael Walsh, Dr. Susan Taylor, Susan Bigl, Dr. Judith Pennington
- EnviroStat
  - Charles Ramsey
- Defence R&D Canada - Valcartier
  - Dr. Sonia Thiboutot, Dr. Guy Ampleman, Dr. Sylvie Brochu, Dr. Emmanuella Diaz, Dr. Isabelle Poulin

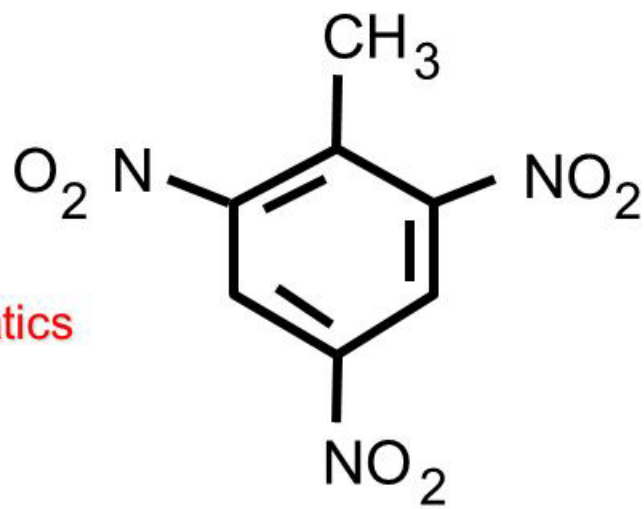
Overview of Presentation

Topics	Purpose
Residue deposition	To understand the nature of energetic residues deposited, propellants at firing points and explosives at impact areas
Range sampling	Develop an improved method of collecting representative soil samples to enable a reliable estimate of the mean concentration of energetic residues within sampling units
Sample processing	Develop a method of processing soil samples in the laboratory to obtain representative subsamples of soil for analysis

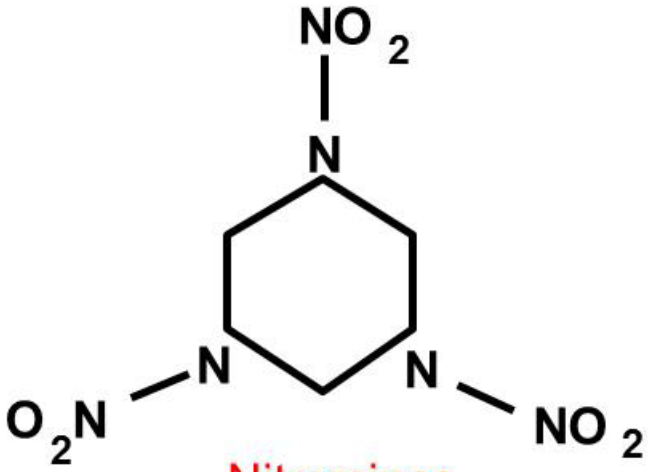
Traditional Grid-Node Sampling Approach

- Site divided into a set of sampling units
- One or several *discrete* soil samples collected to represent each sampling unit
- Subsampling in the lab using scoop-off-the-top approach
- Analytical results from discrete samples *assumed to be normally distributed (and representative)*
- Mean (or 95% upper confidence limit) and estimates of uncertainty computed using *normal statistics*
- But, are these assumptions correct for energetic residues?

Major Classes of Energetic Chemicals Used by DoD

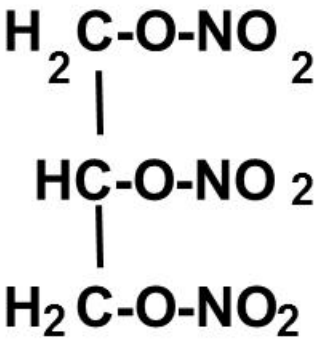


Nitroaromatics
(TNT)

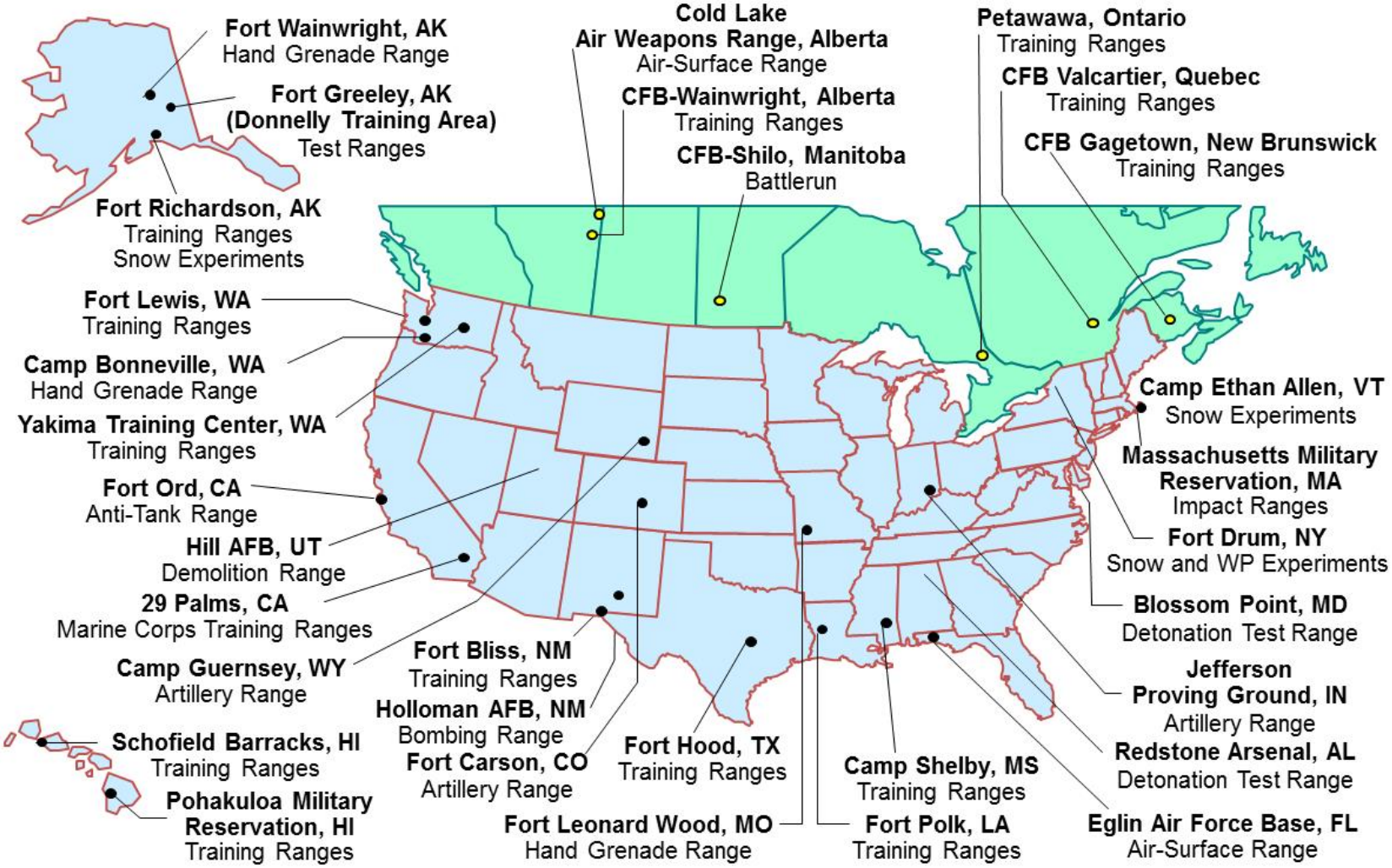


Nitramines
(RDX)

Nitrate Esters
(NG)



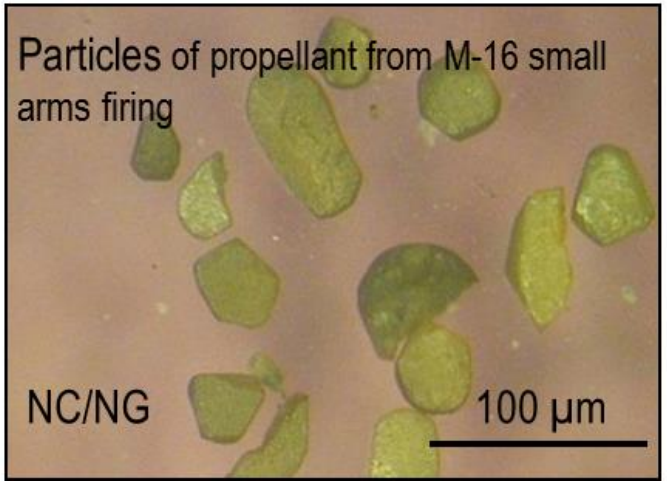
Field Sampling Experiments at 32 Ranges in U.S. and Canada

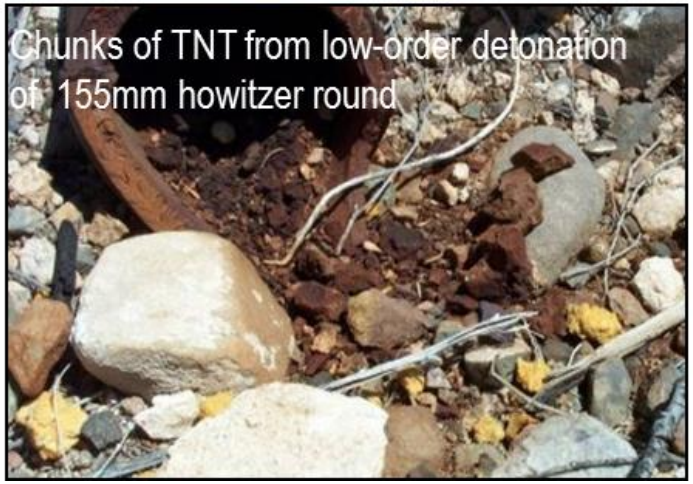


Residue Deposition Experiments

- Designed to provide information on the nature of the residue deposition
- Pans used to collect residues for microscopic inspection
- Conducted at snow-covered training ranges to allow estimation of mass deposited

Propellant and High Explosive Residues are Deposited as Particles





Conclusions from Residue Deposition Studies

- At firing points, *residues are fibers and particles* of NC polymeric propellants imbibed with NG or 2,4-DNT and remain at the surface
- At impact areas, *residues are particulates from low-order detonations* and ruptured rounds and most remain at the soil surface (**one low order detonation produces residues equals 10,000 to 100,000 high order detonations**)
- For most ranges, a *sampling depth of 5 cm* is recommended, including deeper soil just dilutes the concentrations but doesn't affect the mass

Why is Sampling Conducted at Military Training Ranges?

- Major potential problem of migration of energetic compounds off range in aqueous solution
  - Contamination of underground drinking water aquifers (MMR range closed by EPA)
  - Contamination of surface water bodies
- Ecological risk assessments
  - Eagle River Flats impact range (Ft. Richardson) closed due to water fowl poisoning with white phosphorus
- DoD Directive 4715.11 establishes requirement for each DoD component to assess environmental impacts of munitions use on operational ranges (USA)
- MMRP program
  - For non-operational, non-permitted sites under DERP

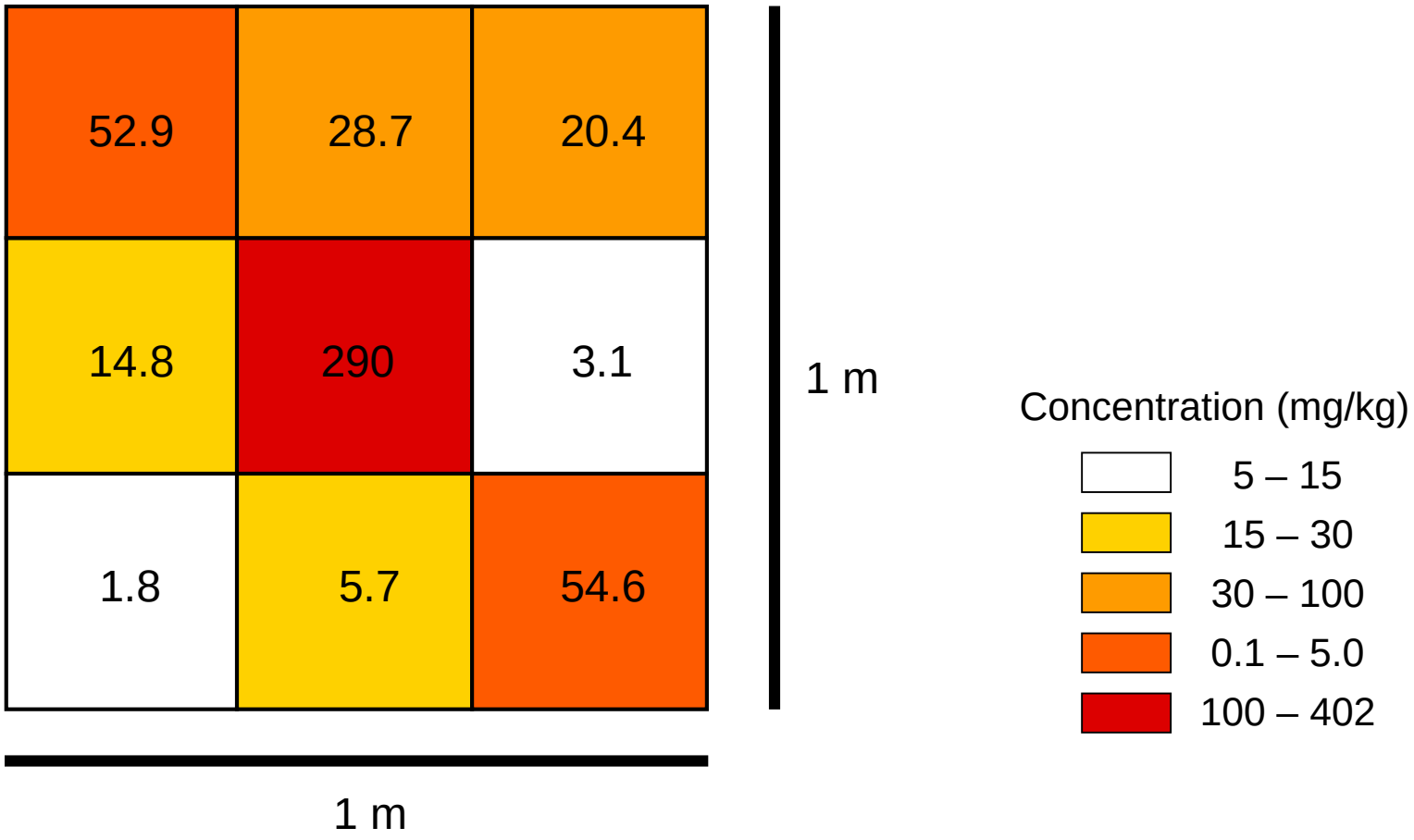
What Do We Want to Know When We Conduct Soil Sampling?

- Is mass of energetic residue in the *sampling unit* sufficient to present an unacceptable risk to ground water and surface water resources?
  - Estimated from *mean concentration* in source zone
- Is *mean concentration* present in the *sampling unit* soils above some risk criteria for target organisms on range?
- Thus, sampling is conducted to enable an estimate of the mean concentration on energetic residues within the sampling unit

TNT Concentrations (mg/kg) in 100 Discrete (Grab) Samples Within a 10-m x 10-m Sampling Unit at Holloman Air Force Bombing Range

1.4	277	53	1.4	53	96	41	30	6.4	28
1.0	33	36	194	21	19	1.4	778	2.7	120
1.2	3.4	71	46	117	2.2	1.8	15	132	149
12	84	2.0	2.3	62	8.4	7.6	12	0.4	4.0
0.2	1.7	0.9	2.6	3.9	8.8	0.2	0.6	0.2	4.2
12	1.8	3.6	44	9.2	39	7.8	0.3	0.3	0.4
1.8	17	40	33	2.7	3.3	7.9	12	1.6	52
0.5	1.6	5.0	79	29	19	26	12	2.6	1.0
2.6	31	37	11	8.4	2.7	2.2	0.4	0.3	1.5
0.3	0.4	1.2	1.6	0.3	6.6	1.9	6.3	51	3.6

TNT Concentrations (mg/kg) for 9 Discrete Samples Collected within One of the 1-m X 1-m Sampling Units at Holloman AFB



RDX Concentrations (mg/kg) in Discrete Samples from a 10- x 10-m Area on Artillery/Mortar Impact Range

17.1	1.27	0.829	0.908	10.9	4.44	0.437	0.354	1.52	0.067
0.805	24.1	7.73	0.539	0.260	0.233	0.366	1.93	0.731	0.138
30.8	1.40	12.5	0.342	0.074	1.11	0.18	0.076	7.11	0.187
12.7	138	53.7	3.85	4.94	1.22	4.63	0.470	2.41	1.06
331	9.70	3.96	1.44	3.67	0.243	3.21	0.254	1.03	0.073
7.52	5.65	1.97	0.571	4.84	19.9	0.825	0.122	1.46	0.070
1.65	1.56	8.51	10.6	2.24	25.2	7.15	0.248	0.175	0.037
48.3	13.3	3.36	6.93	889	21.8	3.75	0.618	0.193	0.081
1.18	1.03	64.3	557	1790	2390	11.3	1.65	0.335	0.263
8.86	3.50	5.02	42.7	385	24.9	3.64	0.96	0.526	0.161

10-m

Concentration (mg/kg)

- 0 – 1.6
- 1.6 – 10
- 10 – 100
- 100 – 2400

Soil Concentration Variability Among 100 Discrete Samples Collected within 10-m x 10-m Sampling Units at Various Training Ranges

Installation	Area*	Range type	Analyte	Concentration (mg/kg)			Distribution
				Range	Median	Mean	
Donnely Training Area (AK)	FP	Artillery	2,4-DNT	0.001-6.38	0.65	1.06	Skewed
CFB-Valcartier (QC)		Antitank rocket	NG	0.02-2.94	0.28	0.45	Skewed
CFB-Valcartier (QC)	IA	Antitank rocket	HMX	5.8-1150	197	292	Skewed
Holloman AFB (NM)		Bombing	TNT	0.15-778	6.4	31.8	Skewed
Ft. Polk (LA)		Mortar	RDX	0.04-2390	1.7	71.5	Skewed
Cold Lake (AB)		Bombing	TNT	0.038-289	6.6	16.2	Skewed
Ft. Richardson (AK)		Artillery	RDX	<0.04-172	<0.04	5.5	Skewed

* Firing point (FP) or Impact Area (IA)

Conclusions from Sampling Studies Using Discrete Samples

- Distribution of explosives residue concentration in soil spatially very heterogeneous even over short distances at all types of military ranges
- Distribution of discrete samples always non normal
- Sampling error using discrete samples at least 10 times total analytical error (subsampling plus determination) in all cases
- Sampling error reduced using some form of composite sampling
- Cannot obtain representative soil samples using one or a few discrete samples

What is the Multi-Increment Sampling (MIS® or ISM) Approach?

- Combining individual increments of soil from within the sampling unit to produce single sample
- Typically used to obtain a more reliable estimate of the mean concentration
- Reduces analytical costs compared with multiple discrete samples
- Normalizes data

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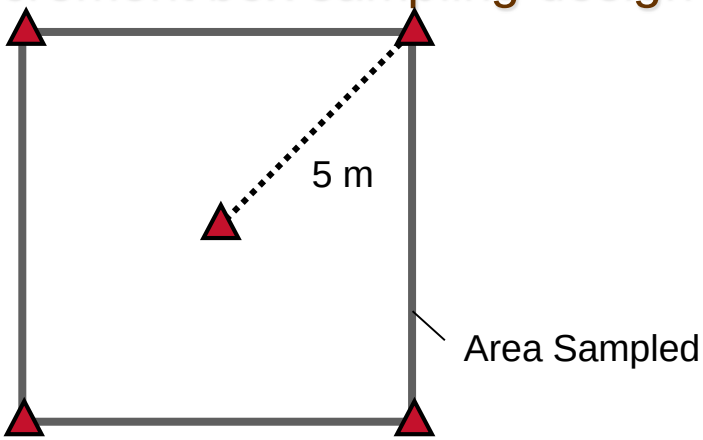
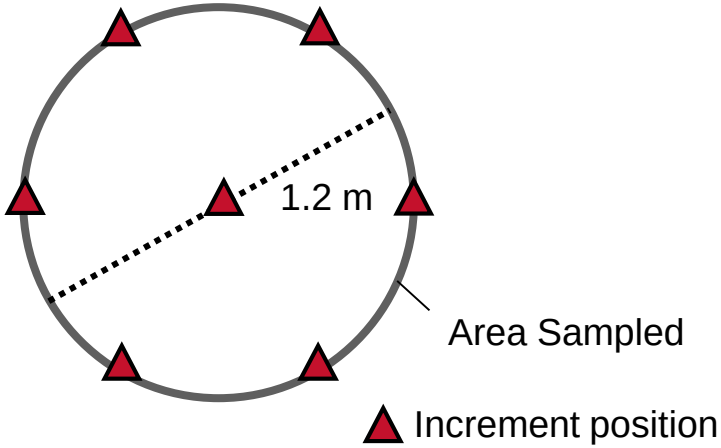
Sampling Designs

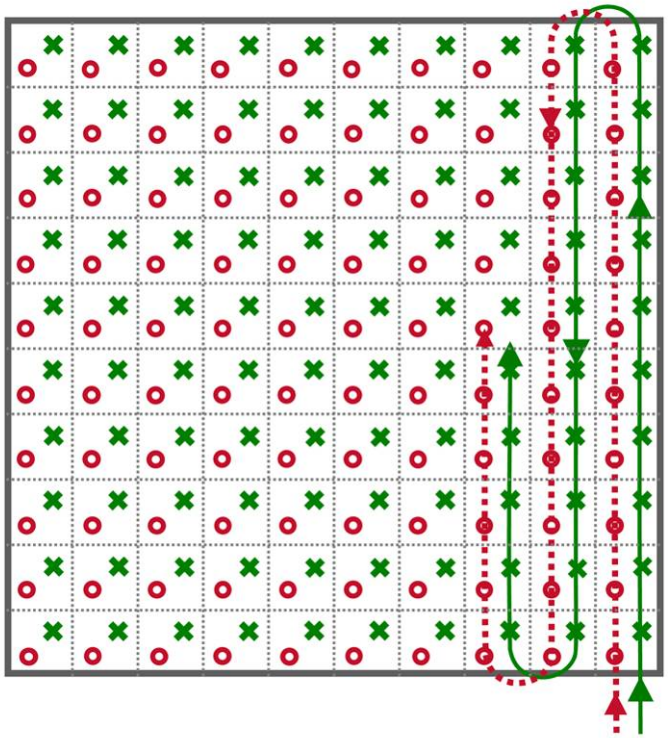
5-increment box sampling design



7-increment wheel sampling design



MULTI INCREMENT® sampling design



Tools for MIS® Sampling

MIS sampling tool developed by Michael Walsh (ERDC-CRREL) available for rent or purchase from EnviroStat Corp.

Fort Lewis Anti-Tank Rocket Firing Point Live-Fire Field Replicates NG Results (mg/kg)

Sample Type	Replicates				Mean	Range	Std Dev	% RSD	95% UCL
	1	2	3	4					
Discrete	2390	1900	1550	6360	3050	1550 - 6360	2230	73	5680
Box	5320	1520	4200	5120	4040	1520 - 5320	1750	43	6100
Wheel	2470	3490	1800	2400	2540	1800 - 3490	701	28	3370
MIS	1630	1890	1990	1950	1870	1630 - 1990	162	9	2060

From Roote et al. (2010), Concurrent Technologies

Holloman Bombing Range Field Replicates TNT Results (mg/kg)

Sample Type	Replicates				Mean	Range	Std Dev	% RSD	95% UCL
	1	2	3	4					
Discrete	1900	11	37	200	537	11-1900	913	170	1610
Box	1100	160	6400	3700	2840	160-6400	2800	99	6140
Wheel	0.6	21000	42	90	5280	0.60-21000	10500	198	17600
MIS	1500	2100	1000	1700	1580	1000-2100	457	29	2110

From Roote et al. (2010), Concurrent Technologies

Sampling Objective: What is the Mean Concentration of 2,4-DNT in a 10-m X 10-m Area at a 105-mm Howitzer Firing Point?

Comparison: Discrete samples collected in 1-m x 1-m cells within a 10-m X 10-m sampling unit. 30-increment MIS samples collected randomly throughout entire 10-m X 10-m sampling unit

Results:	Discrete	Multi-increment
Number of Samples:	100	10
Minimum:	0.0007 mg/kg	0.60 mg/kg
Maximum	6.4 mg/kg	1.35 mg/kg
Mean:	1.1 mg/kg	0.94 mg/kg
Standard Deviation:	1.2 mg/kg	0.24 mg/kg
Median:	0.65 mg/kg	0.92 mg/kg
Distribution:	Skewed	Normal

Central Limit Theorem Applied to Multi-Increment (MIS) Sampling

- As the number of individual increments in each sample gets "large enough," the distribution of replicate samples can be approximated by a normal distribution, regardless of the shape of the distribution of individual increments
- "Large enough"
  - For most populations, the number of increments must be at least 30

Sampling Objective: What is the Mean Concentration of TNT in a 10-m X 10-m Sampling Unit at Holloman AFB Bombing Range?

100-increment samples using a systematic-random design within **10-m X 10-m** area

Results:

Number of Samples:	3
Minimum:	12.5 mg/kg
Max:	17.2 mg/kg
Mean:	14.4 mg/kg
Standard Deviation:	2.45 mg/kg
Median:	13.5 mg/kg

Sampling Objective: What is the Mean RDX Concentration in a 20-m X 20-m Sampling Unit around a Low-Ordered 120 mm Mortar Round?

Comparison: 200 discrete samples collected within a 20-m x 20-m area. 100-increment samples collected throughout entire 20-m x 20-m grid

Results:	Discrete	*MULTI INCREMENT®*
Number of Samples:	200	10
Minimum:	<0.038 mg/kg*	7.3 mg/kg
Maximum	4450 mg/kg	81.8 mg/kg
Mean:		25.8 mg/kg
Standard Deviation:		24.0 mg/kg
Median:	<0.038 mg/kg*	14.0 mg/kg
Distribution:	Left Censored & Skewed	Skewed

* Estimated Reporting Limit

Soil Concentration Variability Among Multi-Increment Samples Collected Within 10-m and 100-m Sampling Units at Various Training Range Impact Areas

Installation	Area	Range type	Increments/ Sample	Replicate Samples	Grid Size	Analyte	Concentration (mg/kg)			Distribution
							Range	Mean	Median	
Donnely Training Area (AK)	FP*	Artillery	30	10	10 m	2,4-DNT	0.60-1.35	0.94	0.92	Normal
Holloman AFB (NM)	IA*	Bombing	100	3	10 m	TNT	12.5-17.2	14.4	13.5	Normal
Ft. Polk (LA)	IA	Mortar	25	10	10 m	RDX	4.6-290	54	25	Skewed**
29 Palms (CA)	IA	Artillery/ Bombing	100	6	100 m	RDX	3.9-9.4	5.6	4.8	Normal
Hill AFB (UT)	DA*	Thermal treatment	100	3	100 m	HMX	4.0-4.3	4.1	4.2	Normal

* Firing point (FP), Impact Area (IA), or Demolition Area (DA)
** Increments collected using totally random sampling design

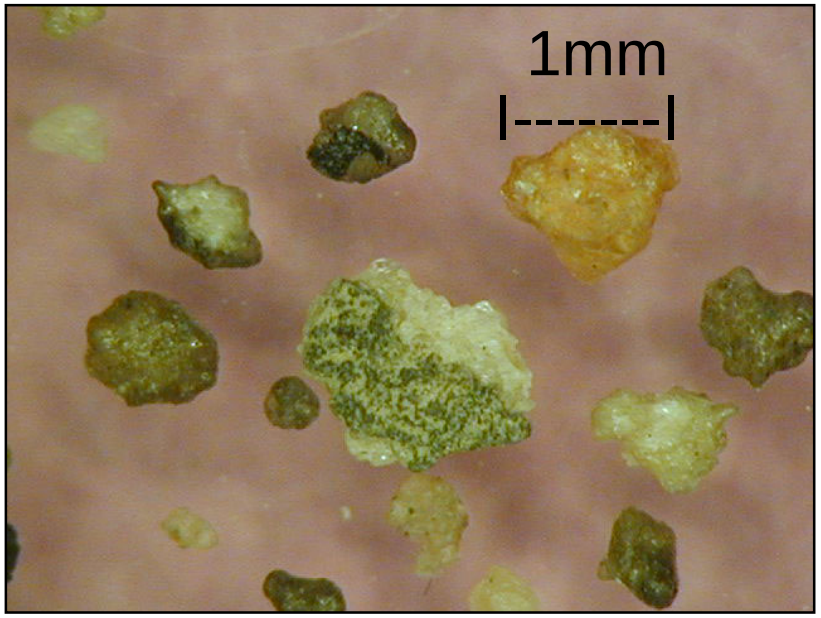
Discrete vs. Multi-Increment Samples

- Large range in data for discrete samples – much smaller range in multi-increment samples
- Distribution of discrete data always non normal – distribution of data from multi-increment samples often normal
- Median from discrete sample almost always less than mean – thus most discrete samples underestimate mean
- Median and mean concentrations generally similar for multi-increment samples
- Use of multi-increment samples often eliminates problem of dealing with “less than” data
- <u>Recommendation</u>
  - Collect replicate systematic 30± increment samples to represent sampling unit

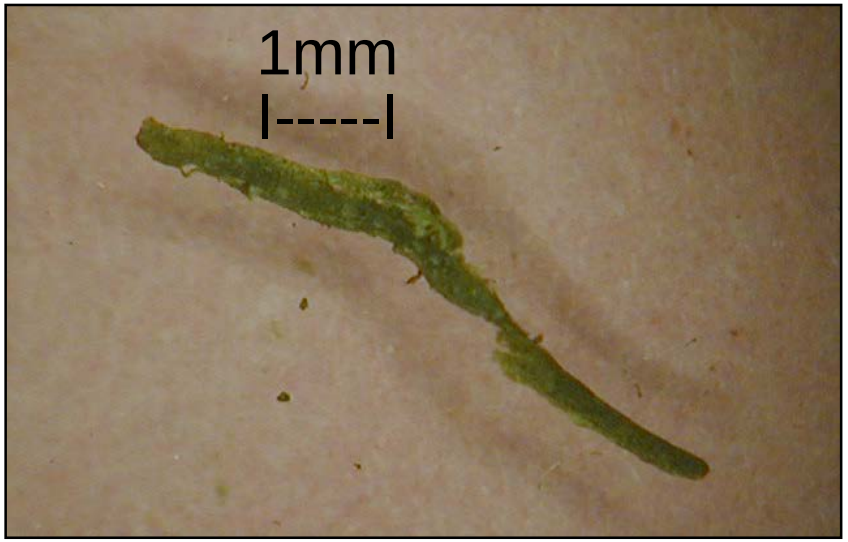
Soil Sample Processing and Subsampling

- Subsampling issues are just a miniature of field sampling issues and are dominated by heterogeneity within the jar or bag
- Processing and subsampling second largest source of characterization error
  - Can lose representativeness gained using multi-increment sampling
- Current laboratory QA addresses instrumental issues but largely ignores sample processing/subsampling

Physical Nature of Energetic Residues in Samples Sent to Laboratories



Particles of Explosives



Fibers and Particles of Propellants

Residues of Composition B in Soil Samples from Impact Areas

- Particles (chunks) of Composition B range in size from micrometer to centimeter
- Soil sized particles are defined as < 2 mm
- One 1-mm spherical particle of Composition B:
  - Weighs about 0.9 mg
  - Contains ~ 0.50 mg of RDX, 0.35 mg of TNT, and 0.05 mg of HMX
- If the soil concentration is 1 mg/kg of RDX, a kilogram sample contains only two of these 1-mm particles

Subsampling Error

- Effect of machine grinding on standard deviation in hand grenade range soil (2-g subsamples)

Subsample	TNT Conc. (mg/kg)		RDX Conc. (mg/kg)	
	Not Ground	Ground	Not Ground	Ground
1	**0.25**	2.03	1.68	4.75
2	1.81	**2.04**	1.77	4.71
3	0.37	2.00	**1.46**	**4.80**
4	1.48	2.03	3.80	4.73
5	**7.93**	1.97	7.83	4.67
6	0.56	2.00	1.81	4.66
7	0.35	1.90	2.35	4.62
8	0.75	2.02	2.51	4.62
9	0.56	1.97	2.08	4.64
10	0.35	1.98	1.98	4.69
11	0.62	**1.90**	1.68	4.66
12	5.62	1.91	**13.0**	**4.60**
mean	1.72	1.98	3.50	4.68
std dev	2.46	0.051	3.47	0.057
RSD	143%	2.57%	99%	1.23%

Conclusions from Sample Processing Experiments

- Entire sample must be processed
  - No scoop-off-the-top allowed
- Soil sample must be air dried
- Soils sample must be ground using a puck mill grinder
  - Other grinders such as roller mill, coffee grinder tested and found ineffective
- Method incorporated into SW846-8330B

Recommended Approach for Site Characterization for Energetic Residues

- Sampling plan
  - Proper stratification of sampling units
- Collection of representative samples within each sampling unit using multi-increment (MIS) sampling
- Soil ground with puck mill grinder to obtain representation subsample (details in appendix of Method SW846-8330B)
- Instrumental determination (HPLC-UV or HPLC-MS)
  - Generally contributes the lowest portion of random error but always receives by far the largest QA/QC attention

Conclusions

- Major portion of residues at impact areas result from low order detonations
- Energetic residues are deposited as particles non uniformly across sampling units at both firing points and impact areas
- Discrete samples are not useful for characterization because of the non uniform distribution of residues
- Multi-increment sampling provides an adequate approach to reliably estimate the mean concentration
- Samples must be ground in the laboratory using a puck mill to enable reliable subsampling

For additional information, please visit

https://serdp-estcp.org/Program-Areas/Environmental-Restoration/Contaminants-on-Ranges/Characterizing-Fate-and-Transport/ER-1155

https://serdp-estcp.org/Program-Areas/Environmental-Restoration/Contaminants-on-Ranges/Characterizing-Fate-and-Transport/ER-1481

https://serdp-estcp.org/Program-Areas/Environmental-Restoration/Contaminants-on-Ranges/Characterizing-Fate-and-Transport/ER-200628

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Q&A Session 1

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Bioremediation of Co-Mingled Perchlorate and Explosives in Groundwater at an Active Military Range

Paul Hatzinger, Ph.D.
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Bioremediation of Co-mingled Perchlorate and Explosives in Groundwater at an Active Military Range

ESTCP Project ER-201028

Paul B. Hatzinger, Ph.D.
CB&I Federal Services, LLC

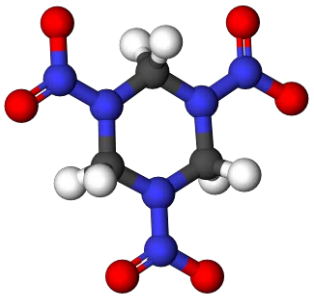
Agenda

Key Question: *How can typical DoD range contamination in groundwater be treated?*

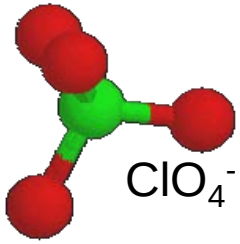
- Background
- Project objectives
- Technical approach
- Demonstration site
- Results
- Supporting stable isotope data
- Conclusions

Background

- Perchlorate and explosives are typical contaminants in soil and groundwater at DoD ranges
- Range sustainability depends on preventing offsite migration of these contaminants via technologies that do not impact testing and training activities



RDX



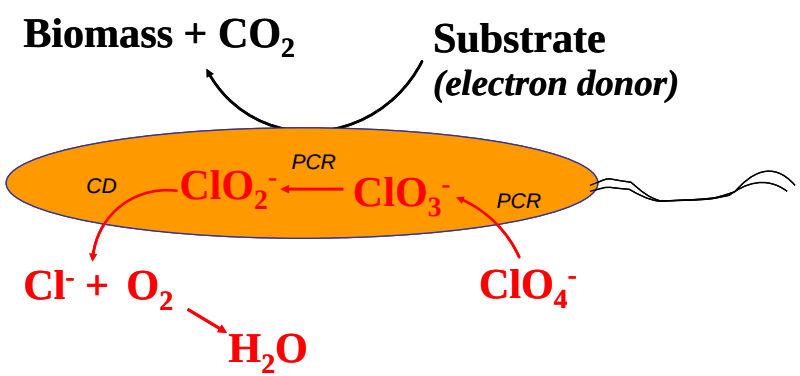
Perchlorate

From USEPA Clu-in website

Background

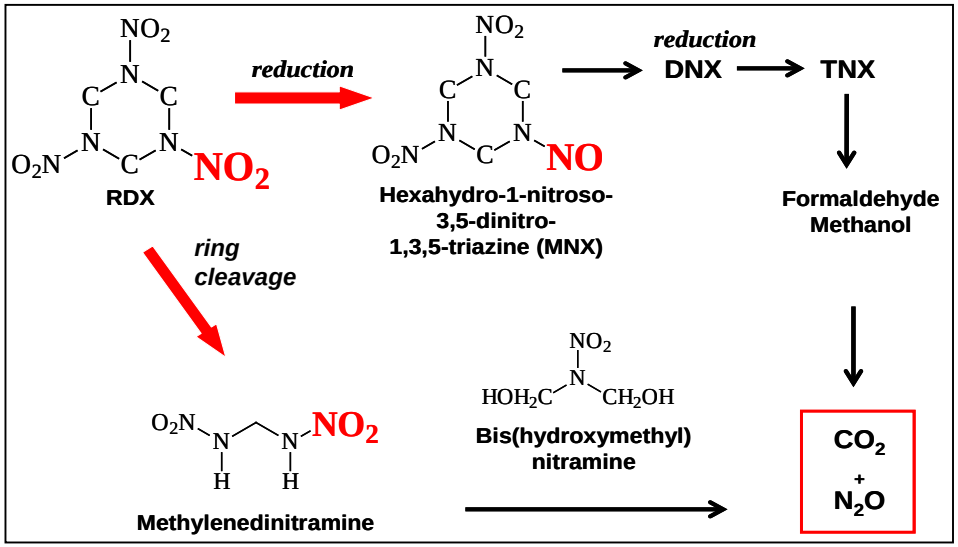
- Studies have shown that perchlorate and nitramine explosives (RDX, HMX) are both readily biodegradable under anoxic conditions when appropriate carbon substrates are supplied

Perchlorate biodegradation



** Perchlorate biodegradation pH sensitive (> ~ 5.5)*

RDX biodegradation



**Aerobic degradation by pure cultures has been reported, but this is rarely documented in the field*

Objective

- Demonstrate and validate the in situ application of an emulsified oil barrier for passive treatment of co-mingled perchlorate, RDX and HMX at an active range
  - Validate effectiveness
  - Implement without affecting mission-critical activities
  - Apply stable isotope analysis as a supporting technique to document RDX biodegradation

Technical Approach

- How do you best apply carbon sources to meet active range requirements?
  - No surface footprint
  - No vulnerable system components
  - Short installation time
  - Minimally invasive (UXO clearance)
  - No power required
  - Minimal O&M

- Passive approach

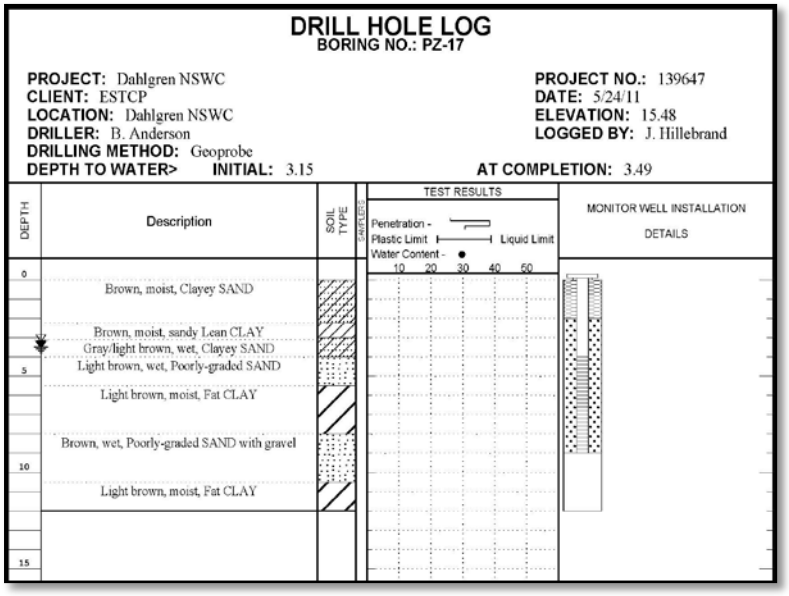
- Slow release substrate

Technical Approach

- Emulsified oil barrier explicitly meets all requirements
  - Emulsified soybean oil injected by direct push, via permanent wells or using trenches
  - The oil binds to soil particles forming a long-term substrate for natural perchlorate and RDX-degrading bacteria
  - Water passes through barrier and contaminants are biodegraded
  - Barriers can last up to 5 years depending on oil concentration, water chemistry, and hydrogeology

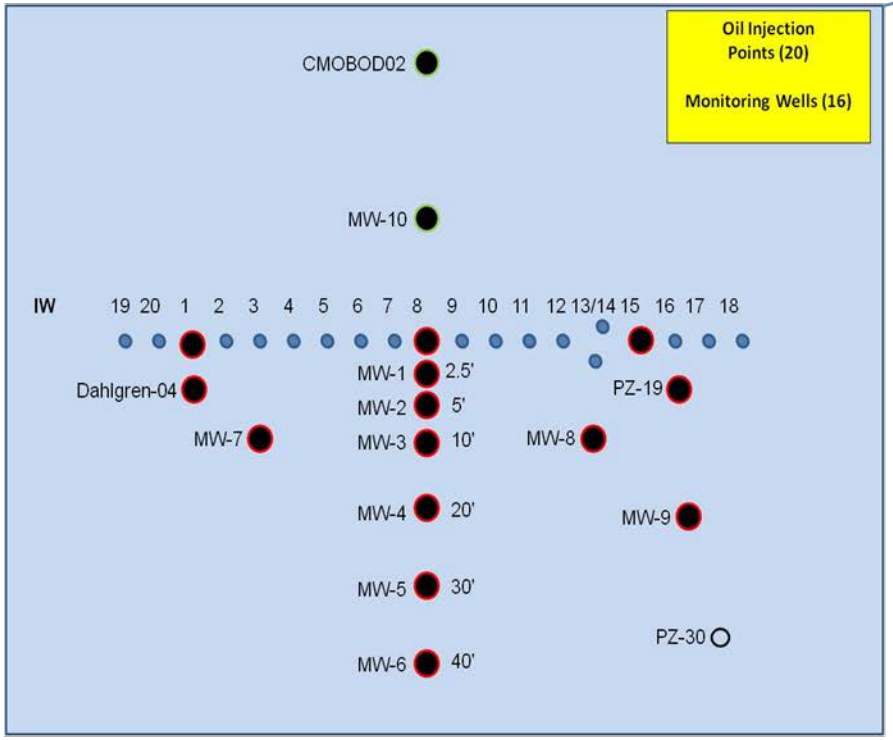
Demonstration Site

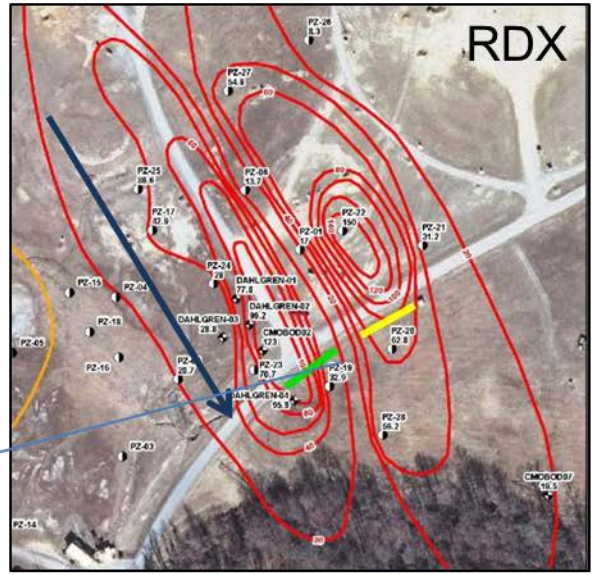
- Churchill Range, Naval Surface Warfare Center, Dahlgren VA
  - Active US Navy testing range
    - Proficiency/safety
    - New formulations
    - Primary charges
    - Rocket motors
  - Shallow perched groundwater aquifer
    - Clay with sand stringers
    - **Low pH (4 – 5 SU)**
    - Generally aerobic
    - Seasonal change in depth
  - RDX, HMX, and perchlorate in several areas of range from testing activities



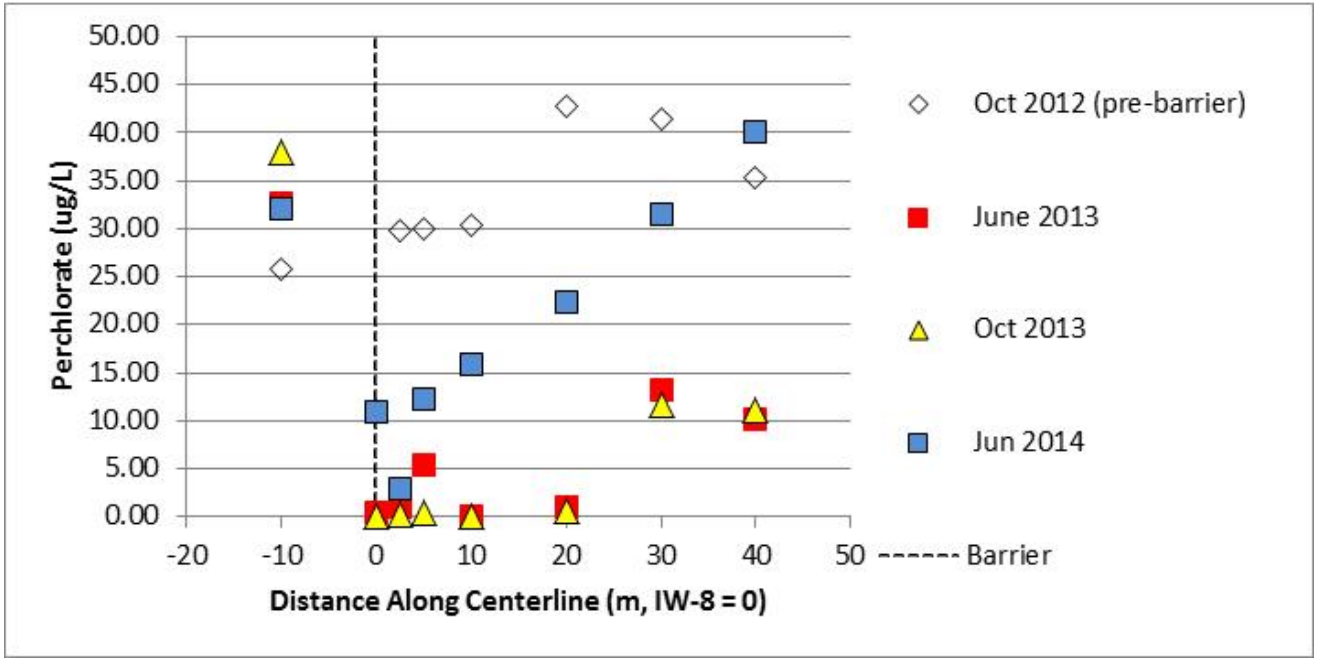
Biobarrier

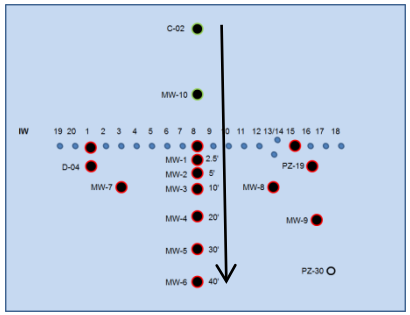
- Pilot scale (30m long; 3-4 m deep)
  - 20 injection points – 1.5m spacing
  - 16 monitoring wells
  - Added average 250L of 4% emulsified oil and 0.75% $Mg(OH)_2$ buffer per injection point
  - 3.5 days to install barrier





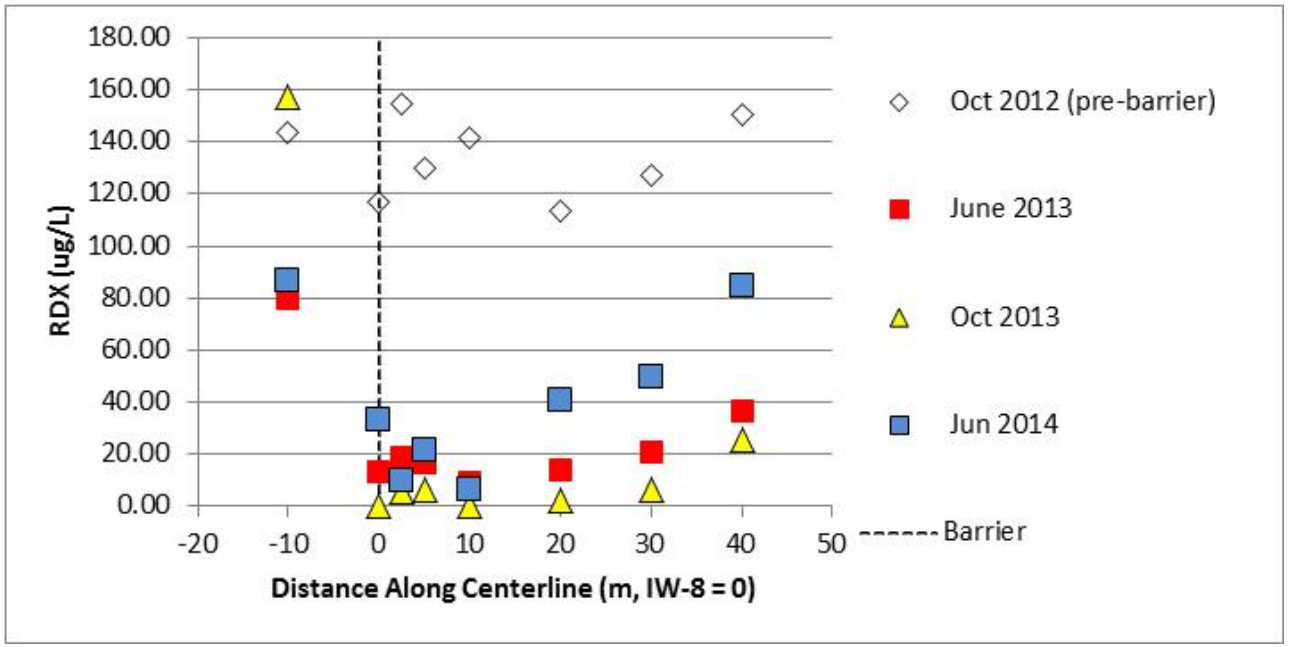
Results: Perchlorate

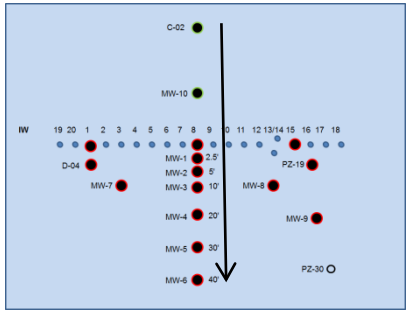




Location	Perchlorate (µg/L)
Upgradient	25 – 40
0-20 ft Downgradient (6/13 – 4 months)	0.5 – 5.3
0-20 ft Downgradient (10/13 – 8 months)	0.1 – 0.7
0-20 ft Downgradient (6/14 – 16 months)	10 – 22

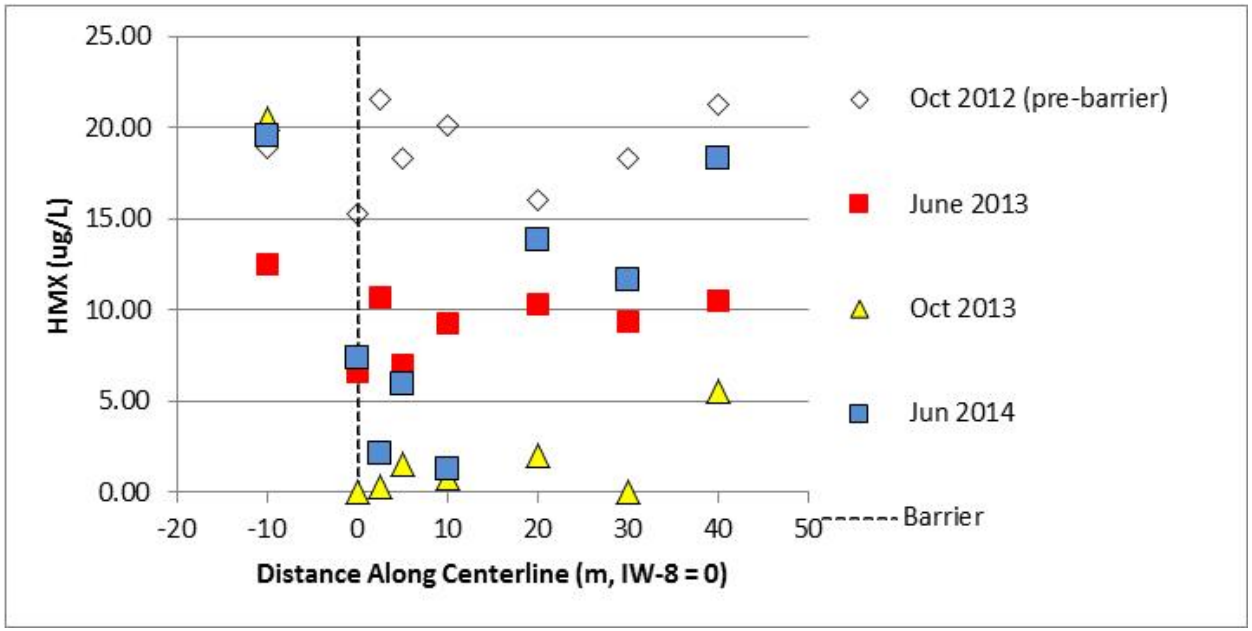
Results: RDX

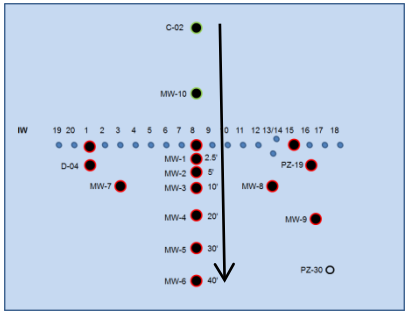




Location	RDX (µg/L)
Upgradient	80 – 160
0-20 ft Downgradient (6/13 – 4 months)	9 – 18
0-20 ft Downgradient (10/13 – 8 months)	0.01 – 6
0-20 ft Downgradient (6/14 – 16 months)	10 – 40

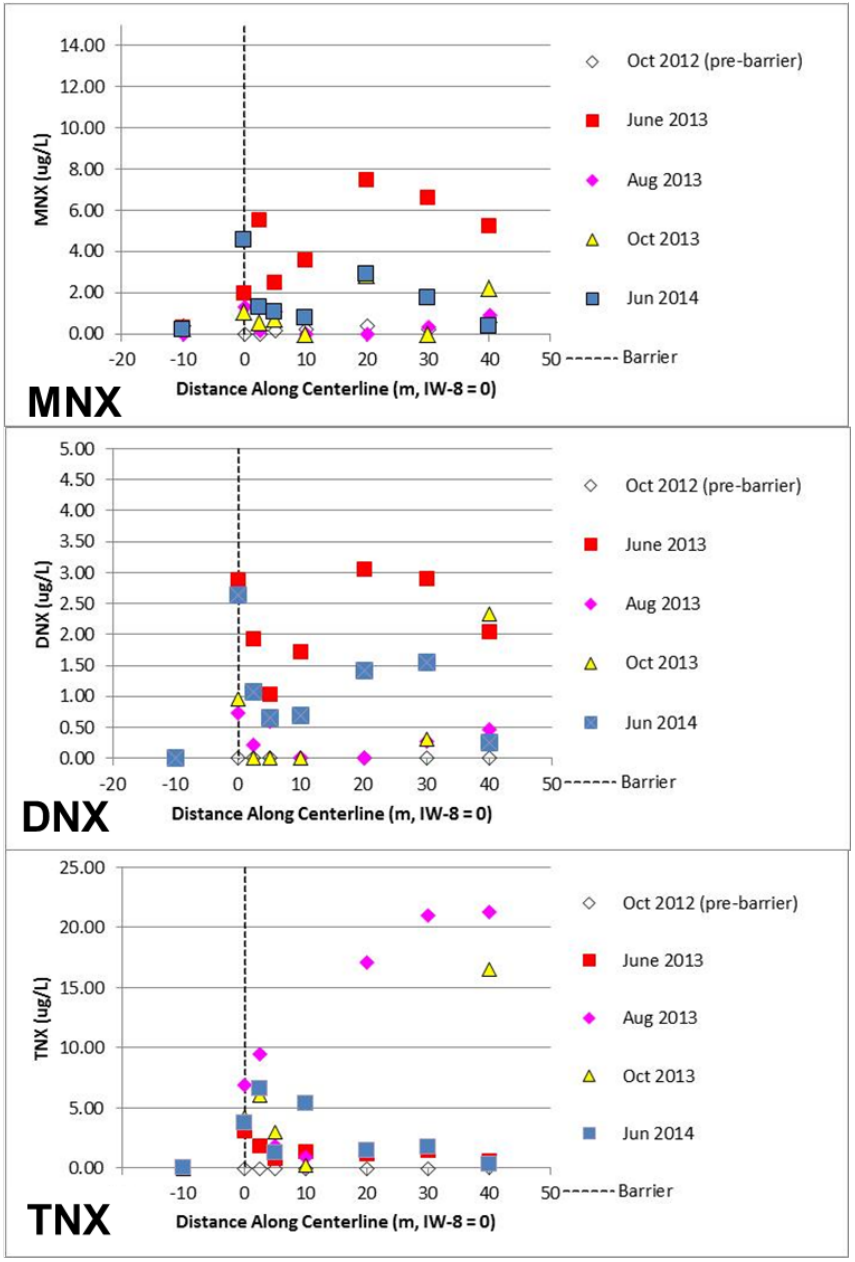
Results: HMX

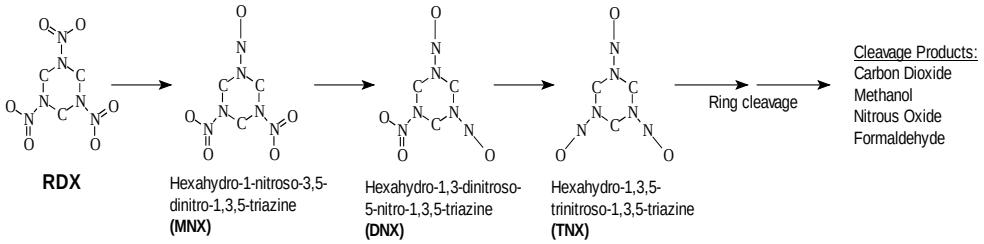


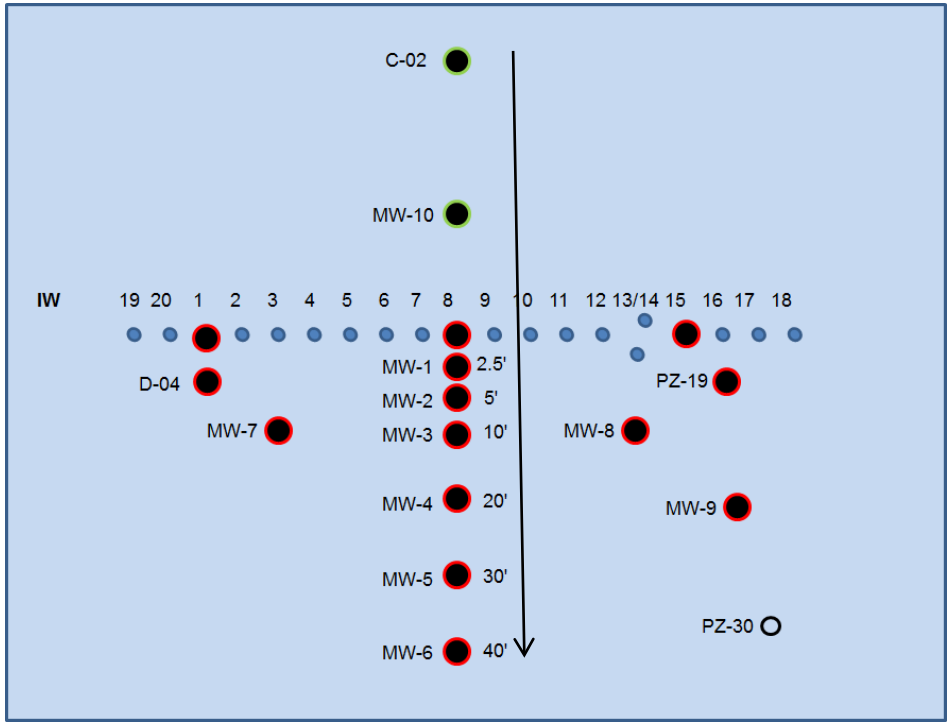


Location	HMX (µg/L)
Upgradient	13 – 20
0-20 ft Downgradient (6/13 – 4 months)	6.6 – 11
0-20 ft Downgradient (10/13 – 8 months)	0.3 – 2
0-20 ft Downgradient (6/14 – 16 months)	3 – 14

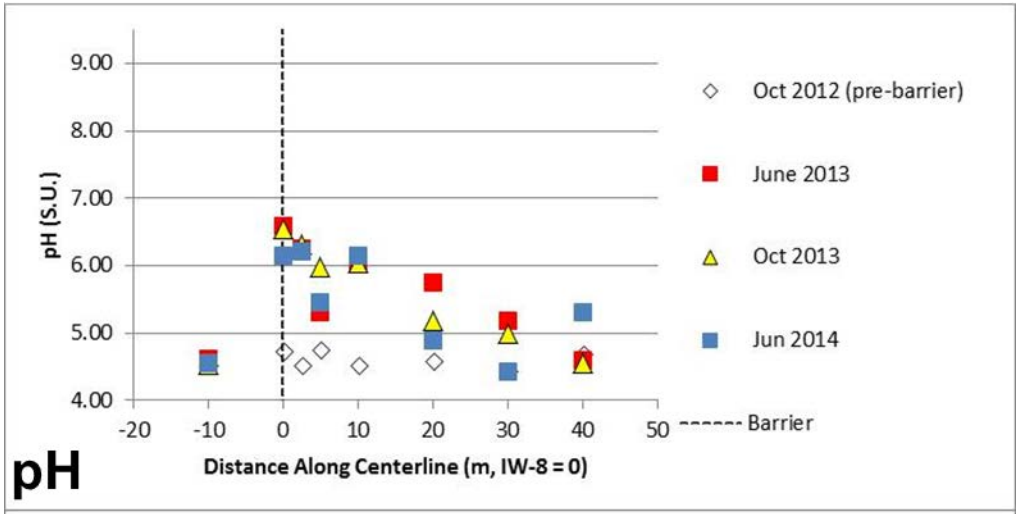
Results: MNX, DNX, TNX

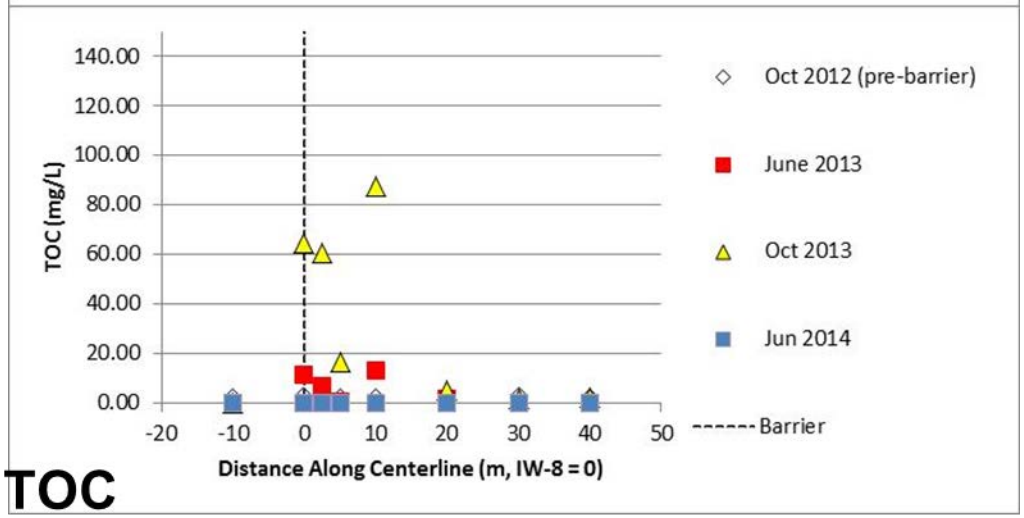






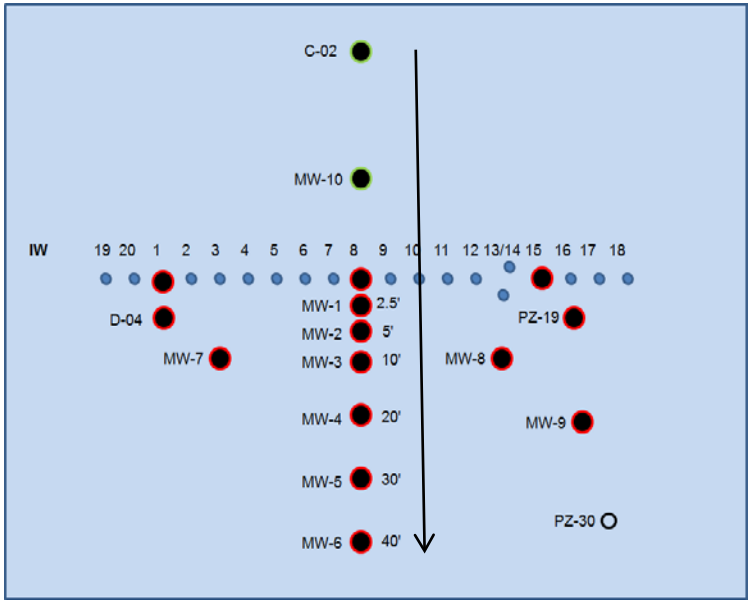
Results: pH and Total Organic Carbon





TOC may be good "trigger" for barrier re-injection

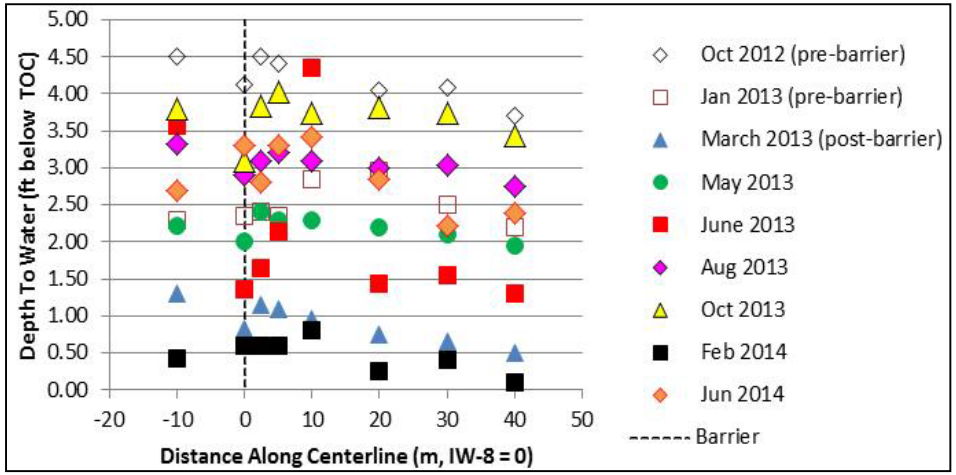
Location	pH (S.U.)
Upgradient	4.5
Downgradient (10/13)	5.2 – 6.3
Downgradient (6/14)	4.9 – 6.2

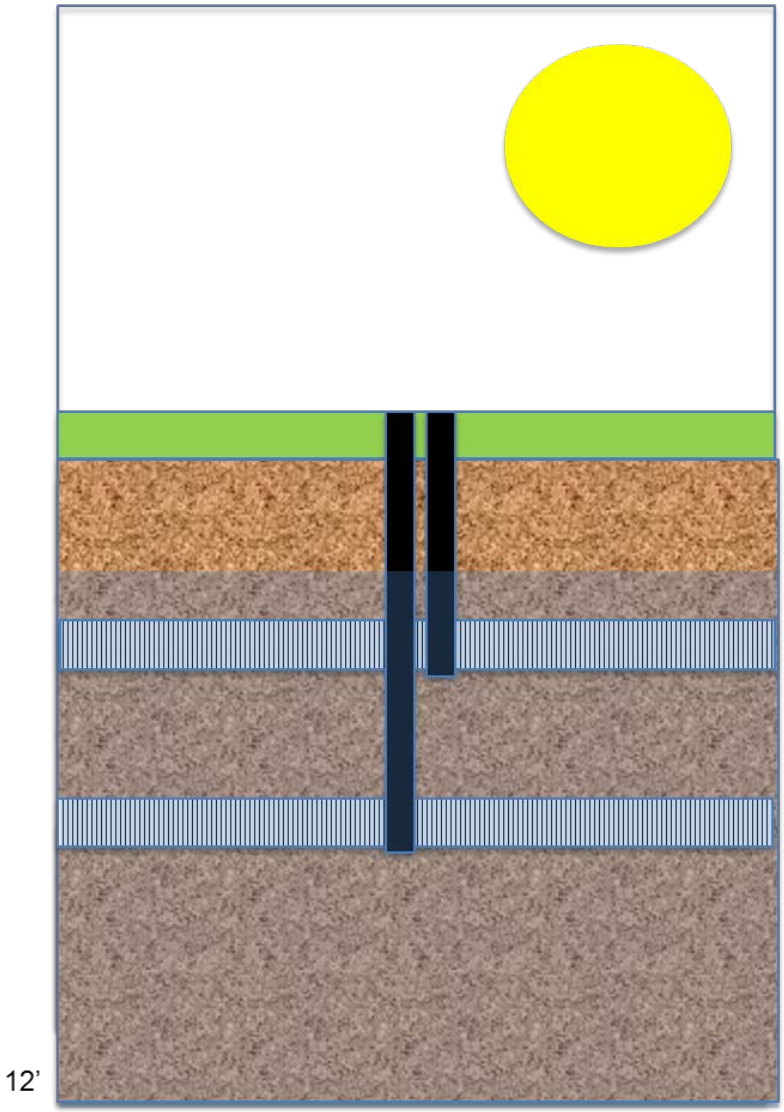


Location	TOC (mg/L)
Upgradient	0
Downgradient (10/13)	5 – 87
Downgradient (6/14)	0

Summary of Biobarrier Performance

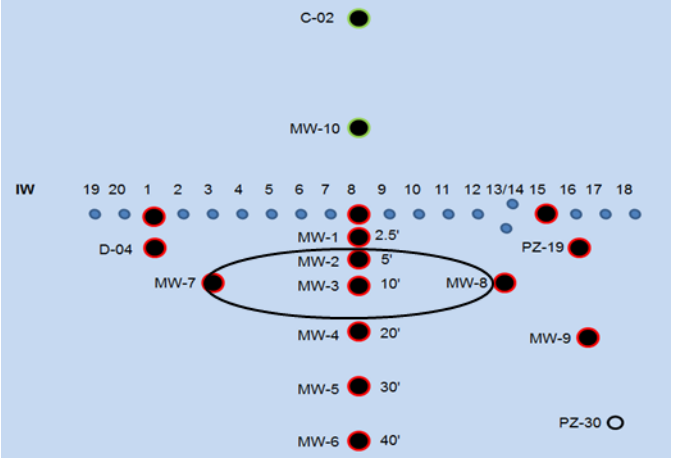
- Remediation objectives met (ClO_4^-, RDX, HMX)
- 1 Year Barrier Life (goal 2+ years)
- High TOC Demand – conservative [oil]
  - Seasonal water table variation
  - Dewatered part of the year
  - Local recharge (oxygenated water)
- Recommend trench barrier with injection lines





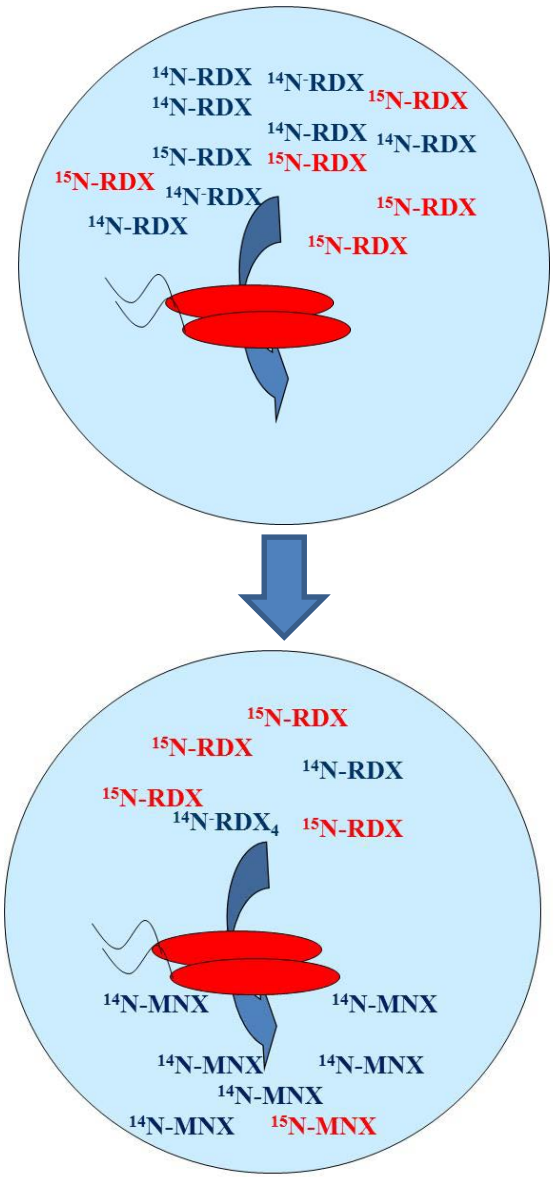
Biobarrier Reinjected

- Select injection points (8) in center of barrier
  - 2700 L of 8% emulsified oil + 0.75% $Mg(OH)_2$ buffer
- Evaluate longevity of more concentrated oil addition



Supporting Data: Stable Isotope Analysis

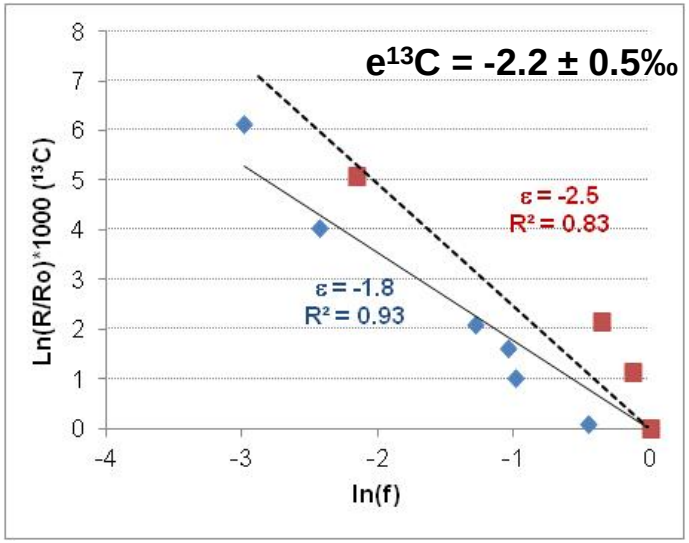
- Bacteria enrich heavy isotopes during biodegradation: “kinetic isotope effect”
- Enrichment can be used as clear evidence of contaminant biodegradation
- Even more powerful with isotope data from multiple elements (i.e., C and N in RDX)



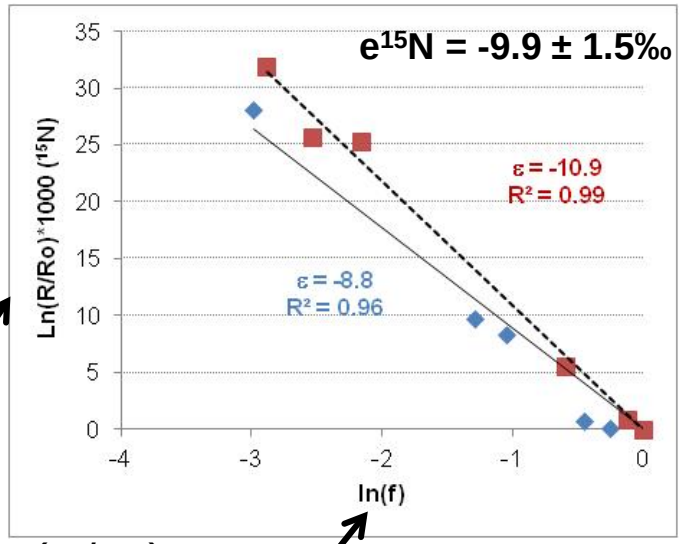
Supporting Data: Stable Isotope Analysis

- Recent studies with anaerobic bacteria document isotopic enrichment of C and N during anaerobic RDX biodegradation (SERDP ER-1435)
- Method developed by Dr. Neil Sturchio, University of Delaware

Desulfovibrio (^{13}C)



Desulfovibrio (^{15}N)

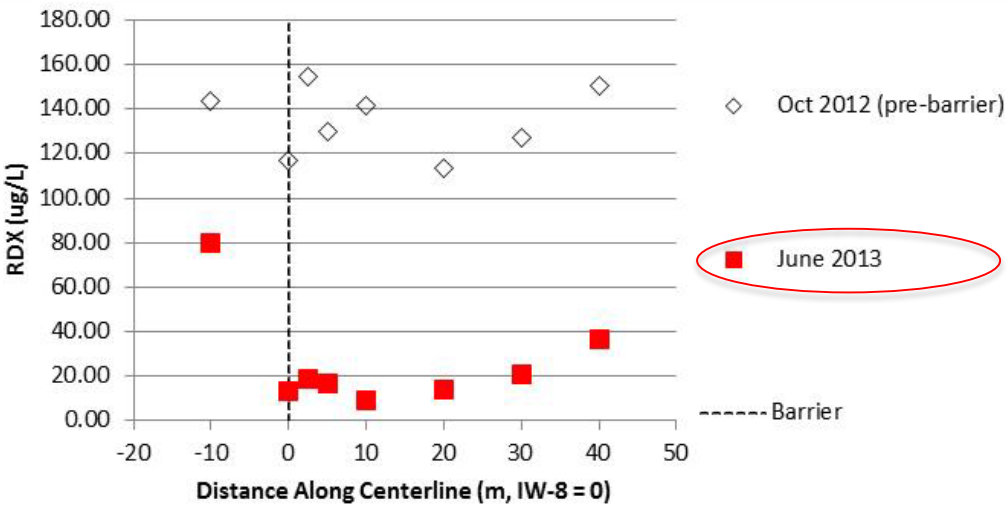


Measure of stable isotope ratio (R/R_o)

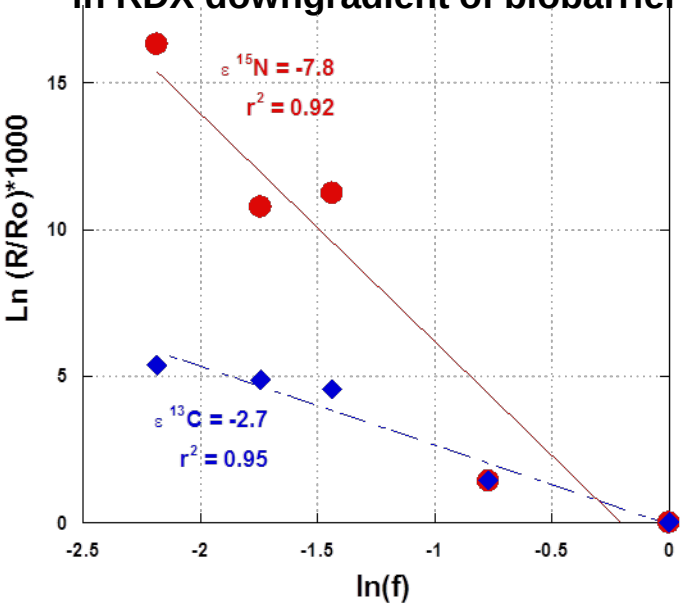
Fraction of contaminant remaining (f)

Supporting Data: Stable Isotope Analysis

- RDX isotope analysis at in situ biobarrier
  - Samples collected prior to barrier installation
  - Samples collected during June 2013 sampling event (data shown)
- Analysis provides clear evidence of anaerobic RDX degradation in the barrier



Isotopic enrichment in N and C isotopes in RDX downgradient of biobarrier



Conclusions

- Passive biobarrier effective for joint treatment of perchlorate and explosives
  - Removal of >90% of co-mingled RDX, HMX, perchlorate for over 1 year
  - Sustained pH control in areas immediately downgradient from the biobarrier
  - Rebound at 16 months – Excessive substrate demand due to geology and water table fluctuations
  - Biobarrier will need to be re-amended with emulsified oil on an annual or semi-annual basis

Conclusions (Continued)

- The biobarrier was installed without affecting any mission-critical range activities
- Stable isotope analysis provides additional documentation of RDX biodegradation
- Approach is expected to be broadly applicable at DoD ranges

For additional information, please visit
https://www.serdp-estcp.org/Program-Areas/Environmental-Restoration/Contaminated-Groundwater/Emerging-Issues/ER-201028

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Q&A Session 2

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The next webinar is on June 25, 2015

Energetics: Colored Smokes and Flares

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