Thank you for signing in early

The webinar will begin promptly at
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  1. Listen to the broadcast audio if your computer is equipped with speakers
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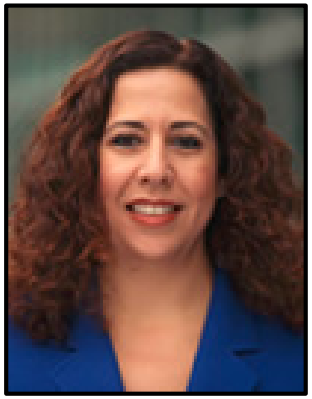
Improved Methods to Evaluate Aerial Emissions and Develop Pollutant Emissions Factors

February 8, 2018

SERDP DOD • EPA • DOE | ESTCP

Welcome and Introductions

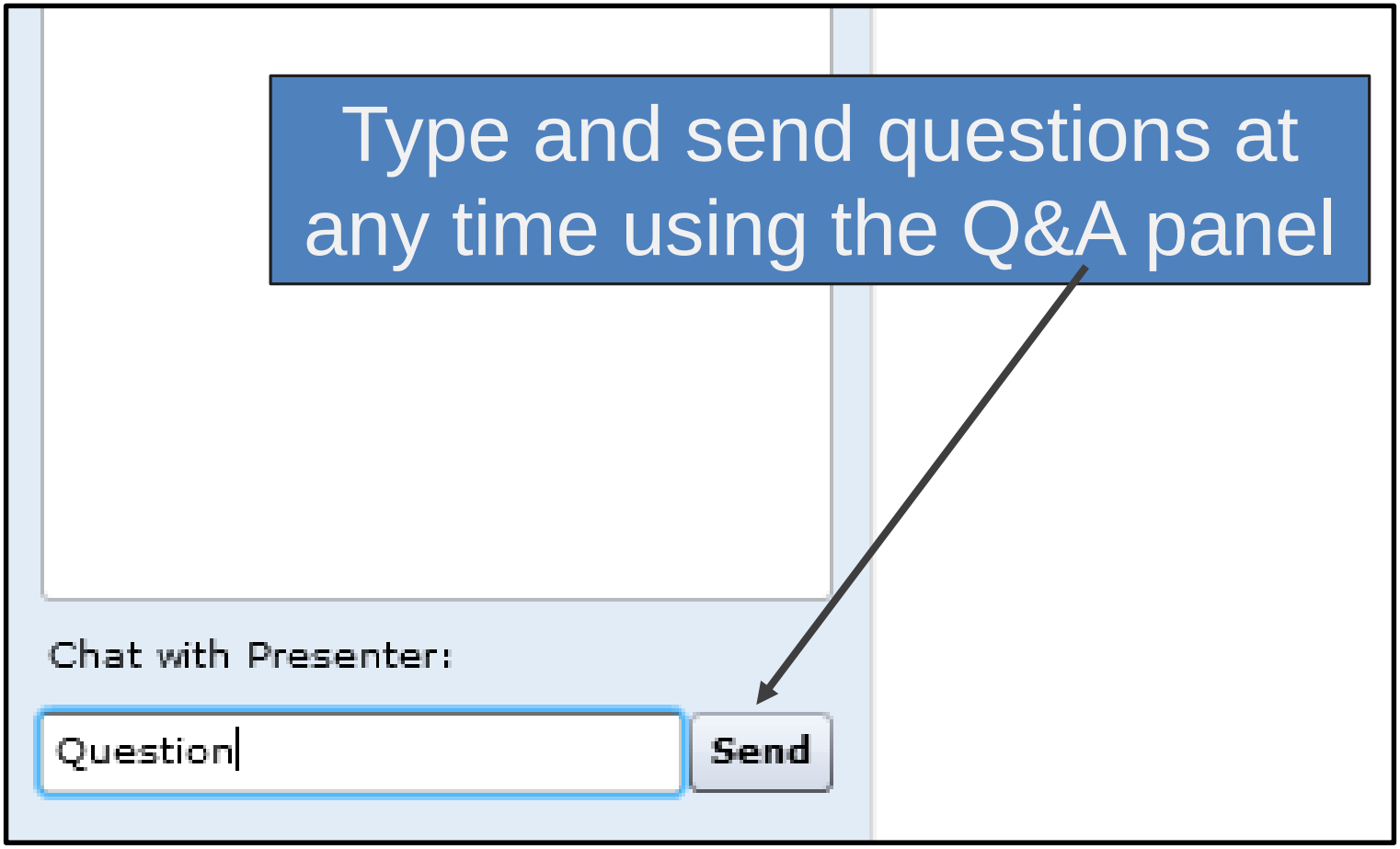


Rula A. Deeb, Ph.D.
Webinar Coordinator

Webinar Agenda

- **Webinar Logistics** (5 minutes)
  Dr. Rula Deeb, Geosyntec Consultants
- **Overview of SERDP and ESTCP** (5 minutes)
  Dr. Robin Nissan, SERDP and ESTCP
- **Development and Application of Aerial Emissions Sampling Methods** (25 minutes + Q&A)
  Dr. Brian Gullett, U.S. Environmental Protection Agency
- **Developing Methods for Evaluating Emissions from Guns and Explosives** (25 minutes + Q&A)
  Dr. Kevin McNesby, U.S. Army Research Laboratory
- **Final Q&A session**

How to Ask Questions



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    - Call into the conference line: 303-248-0285
    - Required conference ID: 6102000
- Submit a question using the chat box

SERDP and ESTCP Overview

Robin Nissan, Ph.D.
SERDP and ESTCP

SERDP

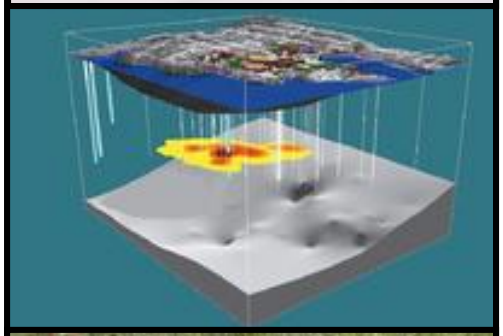
- Strategic Environmental Research and Development Program
- Established by Congress in FY 1991
  - DoD, DOE and EPA partnership
- SERDP is a requirements driven program which identifies high-priority environmental science and technology investment opportunities that address DoD requirements
  - Advanced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



Weapons Systems and Platforms

- Major focus areas
  - Surface engineering and structural materials
  - Energetic materials and munitions
  - Noise and emissions
  - Waste reduction and treatment in DoD operations
  - Lead free electronics

SERDP and ESTCP Webinar Series

Date	Topic
February 22, 2018	Natural Attenuation of Chlorinated Ethenes: Biotic and Abiotic Processes
March 8, 2018	Overview of the Defense Coastal/Estuarine Research Program (DCERP)
March 22, 2018	Energy and Water Program Area Webinar
April 5, 2018	Advanced Nanocrystalline Cobalt Alloys and Composites as Alternatives for Chromium and Nickel Plating in Repair Operations
April 19, 2018	Munitions Response Program Area Webinar
May 3, 2018	Quantifying and Modeling Fugitive Dust Emissions from DoD Activities
May 17, 2018	Environmental Restoration Program Area Webinar
May 31, 2018	Resonant Acoustic Mixing of Energetic Material Formulations

For upcoming webinars, please visit

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

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SYMPOSIUM
2018 | Enhancing DoD's Mission Effectiveness

A three-day symposium showcasing the latest technologies that enhance DoD's mission through improved environmental and energy performance

November 27 - 29, 2018

Washington Hilton Hotel

Registration is coming soon

Development and Application of Aerial Emissions Sampling Methods

Brian K. Gullett, Ph.D.
U.S. EPA

Agenda

- Problem definition
- Relevance to DoD
- Research objective
- Methods
- Field results
- Current and future efforts
- Acknowledgements

Problem Definition

- Open area emission sources are poorly characterized
  - Traditional focus on emission sampling has been on stack sampling from stationary sources
- There are no established EPA methods for sampling open area sources
- Sampling open area sources pose considerable challenges to personnel safety and equipment survivability

Relevance to DoD

- Demilitarization
  - Open burning and open detonation of obsolete and hazardous munitions
    - Air permits
- Waste disposal
  - Burn pits
    - Inhalation exposure
- Land management
  - Prescribed burns
    - Species conservation
    - Military training
- Range management
  - Gun firing
    - Soldier exposure
    - Land contamination

Relevance to DoD

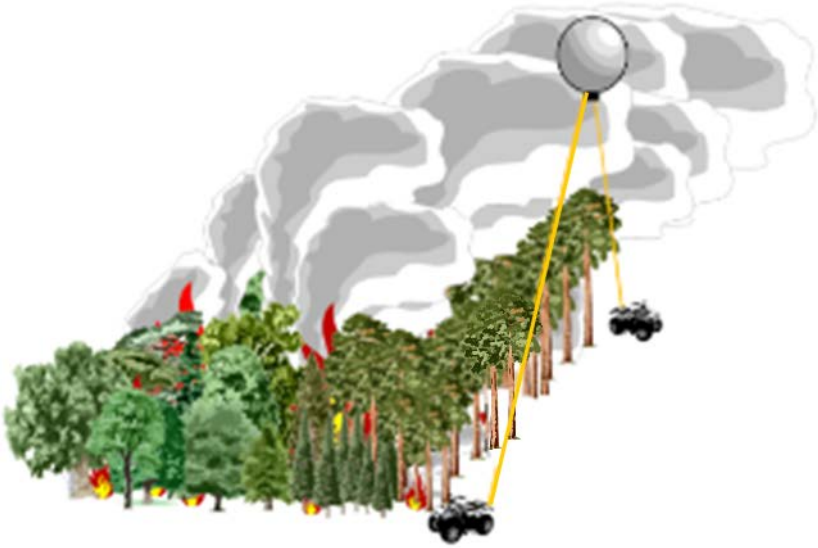
- Target pollutants are those that are relevant to air permits, inhalation exposure, range contamination
  - Particulate matter
  - Metals
  - Volatile and semi-volatile organics
    - Carbonyls
    - Dioxins
    - Energetics
    - Polycyclic aromatic hydrocarbons
  - HCl, ClO_4
  - CO, CO_2

Research Objective

- Develop and demonstrate an emission sampling method relevant to DoD open area sources
- Challenges
  - Survivability of sampling equipment
  - Hazard to personnel
  - Getting samplers into the plumes
  - Variety of source characteristics
  - Representativeness of the sample
  - Data quality
  - Efficiency of sampling

Methods

- Aerial sampling method with helium-lofted instrument package
  - Yields “long” plume residence time

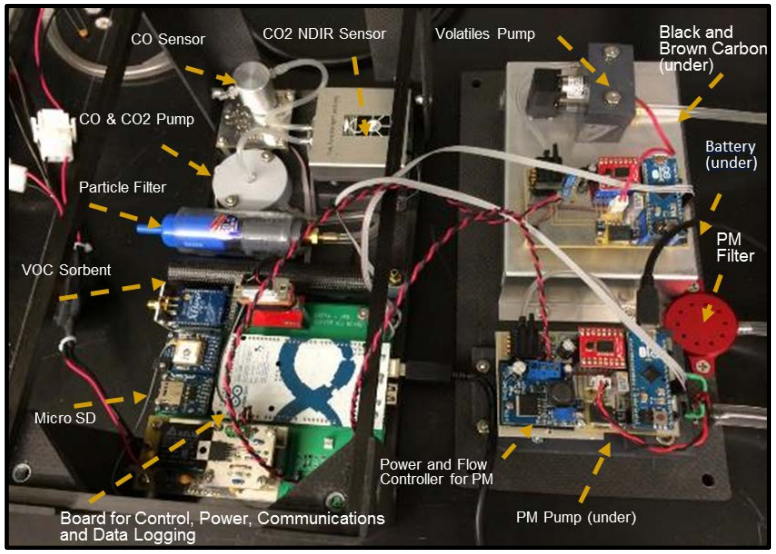


Methods

- The “Flyer,” a lightweight, multi-sensor/sampler sampling instrument was developed
  - Suspended underneath the aerostat
  - Single or double tethers attached to remotely controlled winches mounted on XUVs

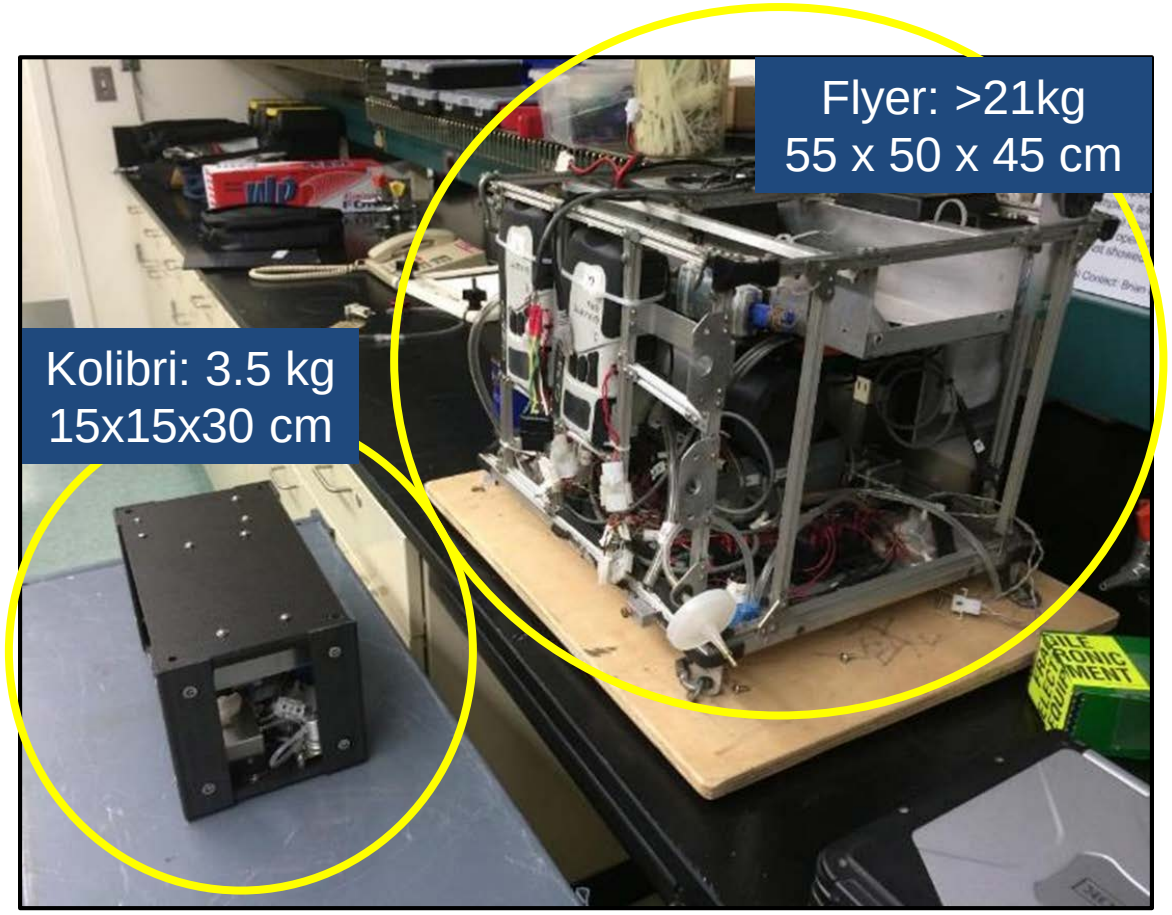
Methods

- The advent of Unmanned Aerial Systems (UASs or "drones"), teensy computers, and 3D printing allowed for the development of the "Kolibri"
  - Smaller and lighter sensor/sampler system
  - Suspended underneath a multicopter drone
  - The multicopter is maneuvered into the plume from a distance, but within line of sight



Methods

The Flyer and Kolibri



Field Results

OB/OD Sampling with the Aerostat/Flyer

Open propellant burns at Tooele Army Ammunition Depot

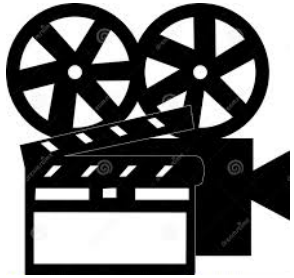
Open detonations at Tooele Army Ammunition Depot

McAlester Army Ammunition Plant (MCAAP) Propellant Burns
NASA hexacopter
10.26.2016 13:50

Field Results

OB Sampling at McAlester Army Ammunition Plant, MCAAAP (Joint Munitions Command Project)

MOVIE



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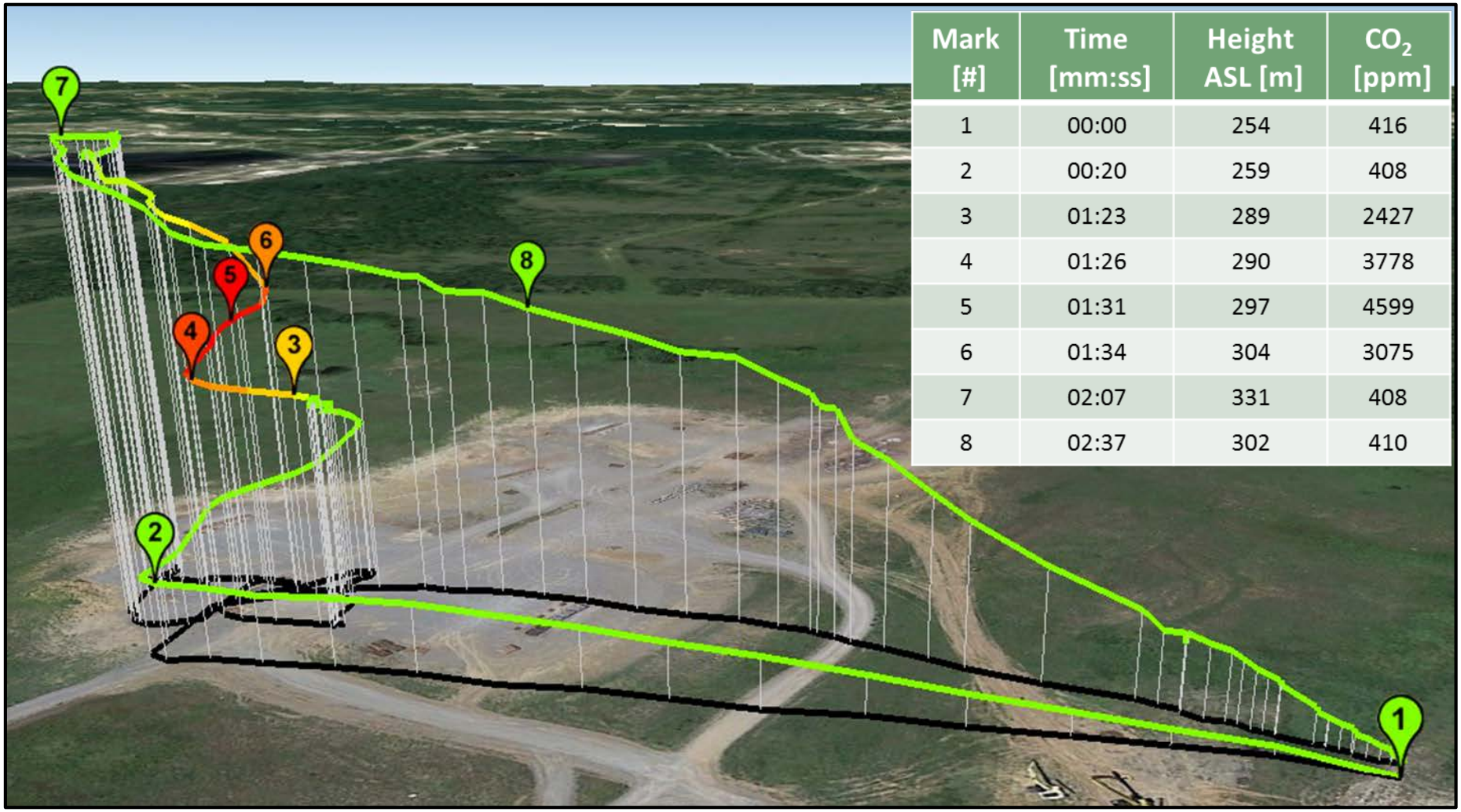
Field Results

UAS Path, OB Sampling at MCAPP



Mark [#]	Time [mm:ss]	Height ASL [m]	CO_2 [ppm]
1	00:00	254	416
2	00:20	259	408
3	01:23	289	2427
4	01:26	290	3778
5	01:31	297	4599
6	01:34	304	3075
7	02:07	331	408
8	02:37	302	410

Field Results

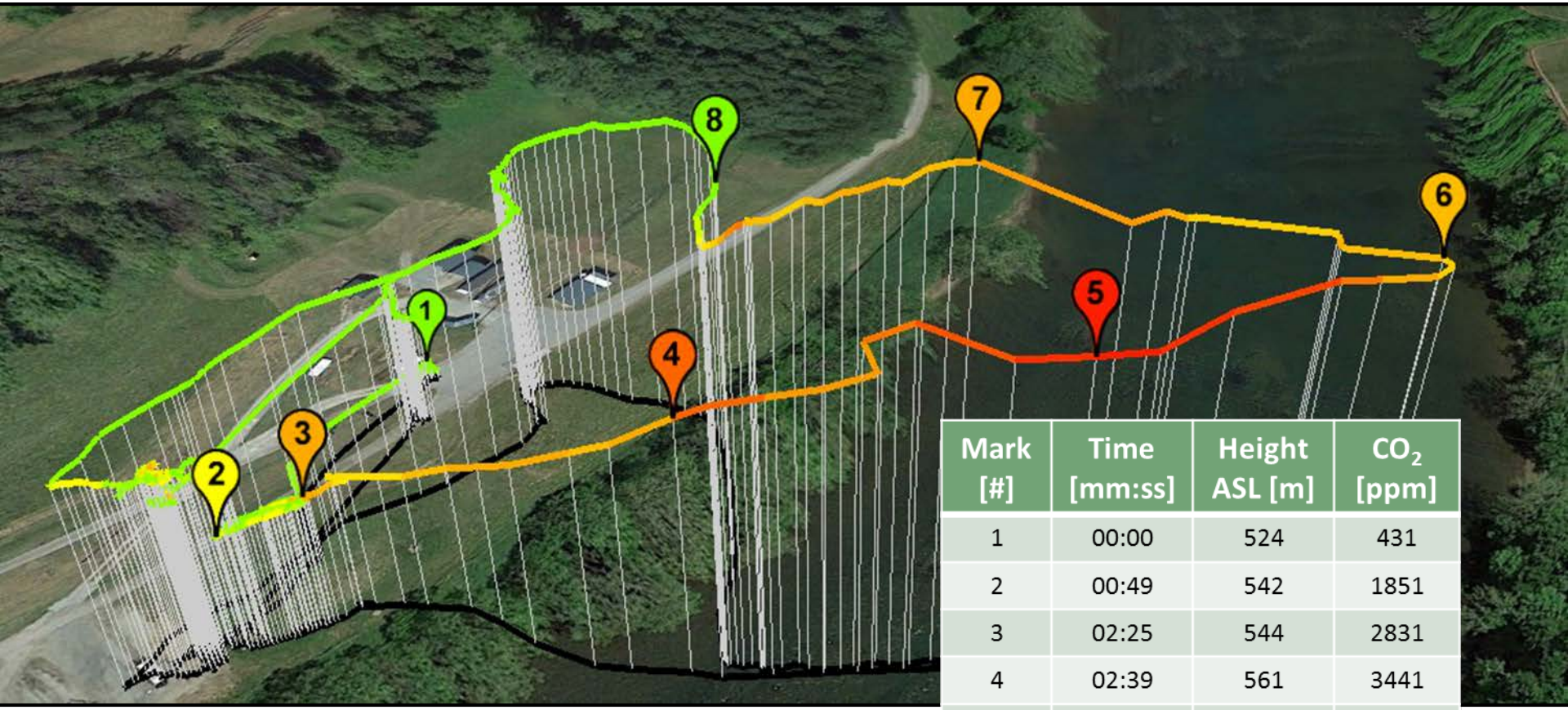
OB Sampling at Radford Army Ammunition Plant (RFAAP)

Field Results

RFAAP

Field Results

UAS Path, OB Sampling at RFAAP



Mark [#]	Time [mm:ss]	Height ASL [m]	CO_2 [ppm]
1	00:00	524	431
2	00:49	542	1851
3	02:25	544	2831
4	02:39	561	3441
5	02:47	572	4085
6	02:54	583	2562
7	03:02	602	2678
8	07:13	586	436

Results

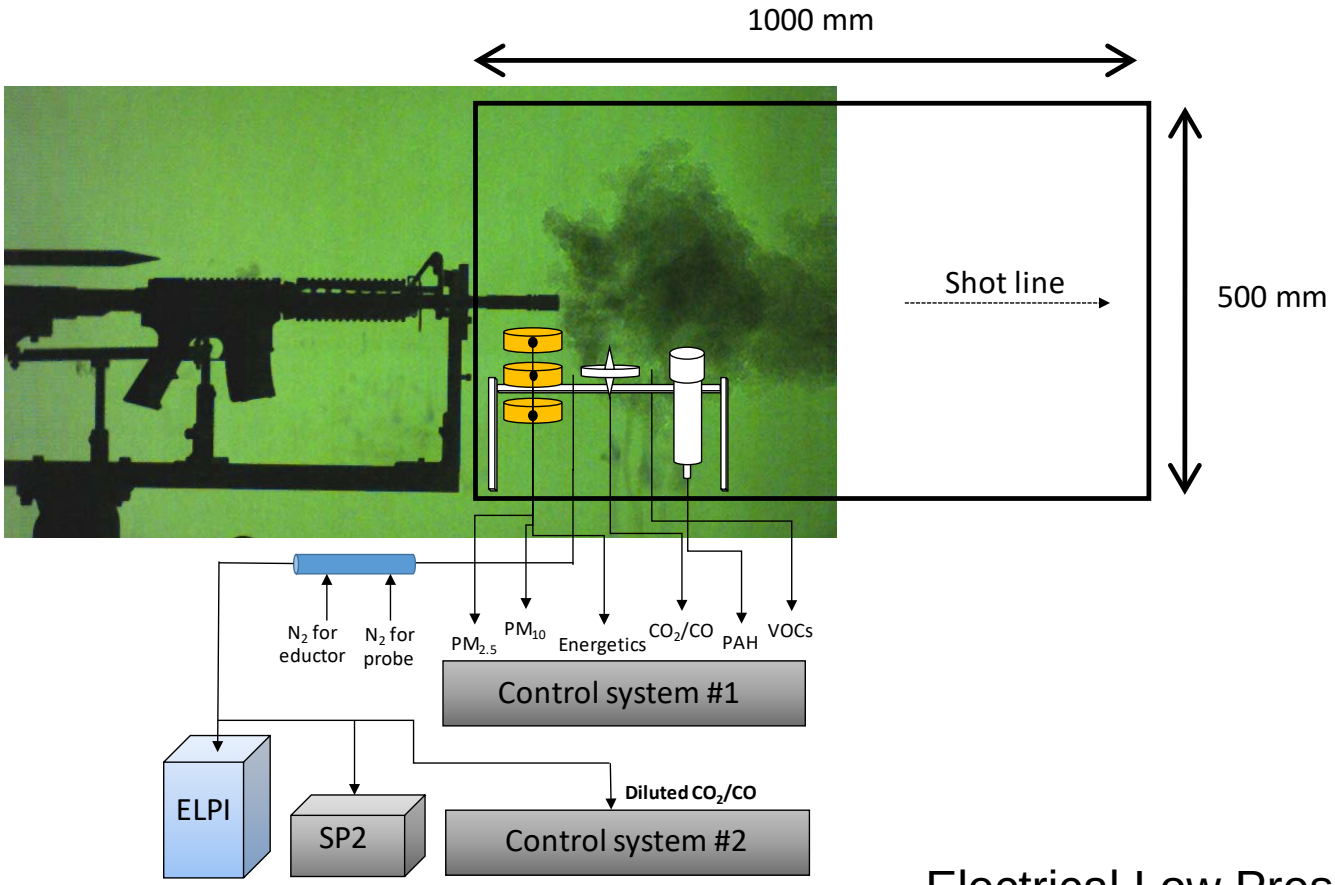
- First-ever plume measurements of $PM_{2.5}$
- First-ever measurements on covered OD
- First-ever measurements of rocket static firing
- Metal partitioning to air vs ash
- No nitroaromatic or nitrocellulose detection
- Majority of emission factors were lower than those used for the risk assessment
- Most comprehensive UAS-based pollutant measurements

Emission Measurements since 2010

Operation	Events	Ordnance Types
OB	332	18
OD	189	9
SF	18	3

Results

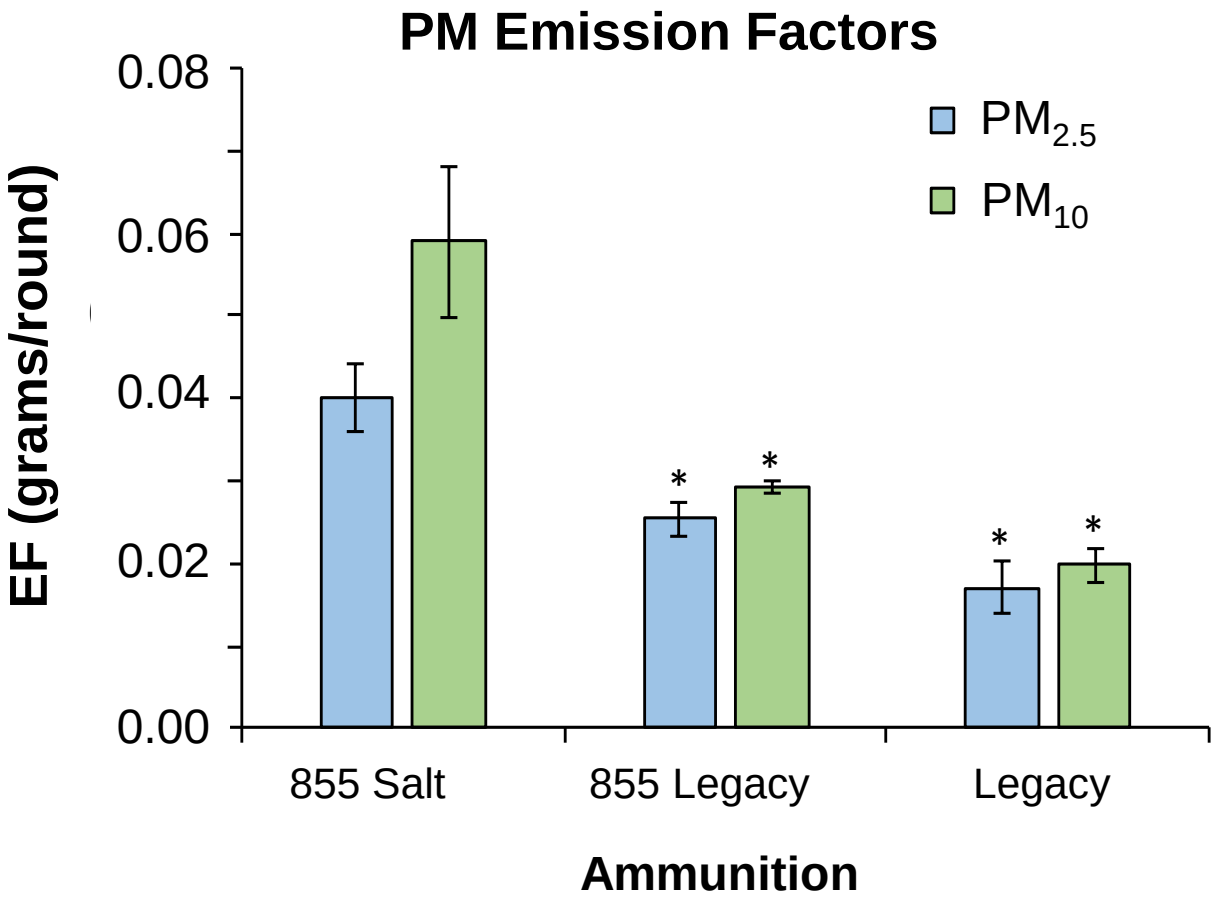
Gun Firings



Electrical Low Pressure Impactor
Single Particle Soot Photometer

Results

Gun Firings



* = range of data

Particulate Matter: 2.5 and 10 micrometers

Results

- We are able to distinguish emissions between bullet types
- Modified Combustion Efficiency, MCE = $CO_2/(CO + CO_2)$ ranges from 0.44 to 0.50 for three bullet types
  - High CO concentration – exposure issues?
  - One firing requires 11 m^3 dilution to meet 1 h ambient air standard
- $PM_{2.5}$
  - One firing requires 267 m^3 dilution to meet the 1 hr ambient air standard

Conclusions

- Methods have been developed and demonstrated in over 20 campaigns to characterize open area emission sources
- These methods are applicable to DoD needs related to demilitarization operations, conservation needs, training lands, range contamination, and soldier health
- The work has provided science-based data to support air permits and land management practices
- Methods are applicable to other open area sources such as lagoons and landfills

Acknowledgements

- SERDP/ESTCP
- EPA/Office of Research and Development
- U.S. Army Joint Munitions Command
- Department of National Defence, Canada
- U.S. Geological Survey
- U.S. Air Force Institute of Technology

For additional information, please visit

https://www.serdp-estcp.org/Program-Areas/Environmental-Restoration/Contaminants-on-Ranges/Characterizing-Fate-and-Transport/ER-2219
https://www.serdp-estcp.org/Program-Areas/Weapons-Systems-and-Platforms/Energetic-Materials-and-Munitions/Munitions-Emissions/WP-1672
https://www.serdp-estcp.org/Program-Areas/Weapons-Systems-and-Platforms/Energetic-Materials-and-Munitions/Munitions-Emissions/WP-2153
https://www.serdp-estcp.org/Program-Areas/Weapons-Systems-and-Platforms/Energetic-Materials-and-Munitions/Munitions-Emissions/WP-2233
https://www.serdp-estcp.org/Program-Areas/Weapons-Systems-and-Platforms/Energetic-Materials-and-Munitions/Munitions-Emissions/WP-2611

Speaker Contact Information

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Q&A Session 1

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Developing Methods for Evaluating Emissions from Guns and Explosives

Dr. Kevin McNesby
U.S. Army Research Laboratory

Presentation Outline

- Introduction
- Facilities
- Gun Firings
- Explosions
- Conclusions

Introduction

- Quantifying gases and metal particles during firing important for soldier safety
- Use observed/measured stages of energy release to guide simulations
- Compare measurement to simulation results
- Determine ways to improve predictions
- Use Modified Combustion Efficiency (MCE) to compare C oxidation
  - $MCE = \Delta C / (\Delta C_{CO_2} + \Delta C_{CO} + \Delta C_{CH_4} + \Delta C_{PC})$
- Use emission factors (EF) to quantify emissions
  - EF = grams emitted / grams fuel

Introduction

Systems Studied

- Gun Firings
  - M4 carbine firing M855 ammunition (copper-jacketed steel/lead bullet; double base propellant (salted and unsalted), #41 primer
- Explosions
  - TNT (neat) and TNT/B/Mg cast formulations (80%/16%/4% by weight); Composition B booster/ pentolite pellet initiator/RP-80 detonator

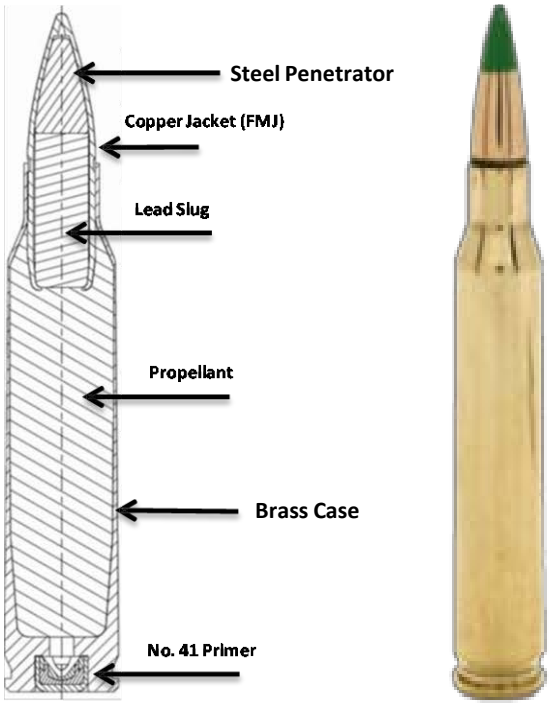
Facilities

- EPA Fieldable Chemical Analysis Rig
  - Remotely controlled chemical analysis sampling suite developed by EPA for aircraft, drone and aerostat deployment – gases and particles
- ARL Indoor Blast Facility
  - Instrumented gun room attached to instrumented blast chamber (20 kg NEW limit)
  - High-speed high definition imaging, spectroscopy and pyrometry

Gun Firings

M4 Carbine

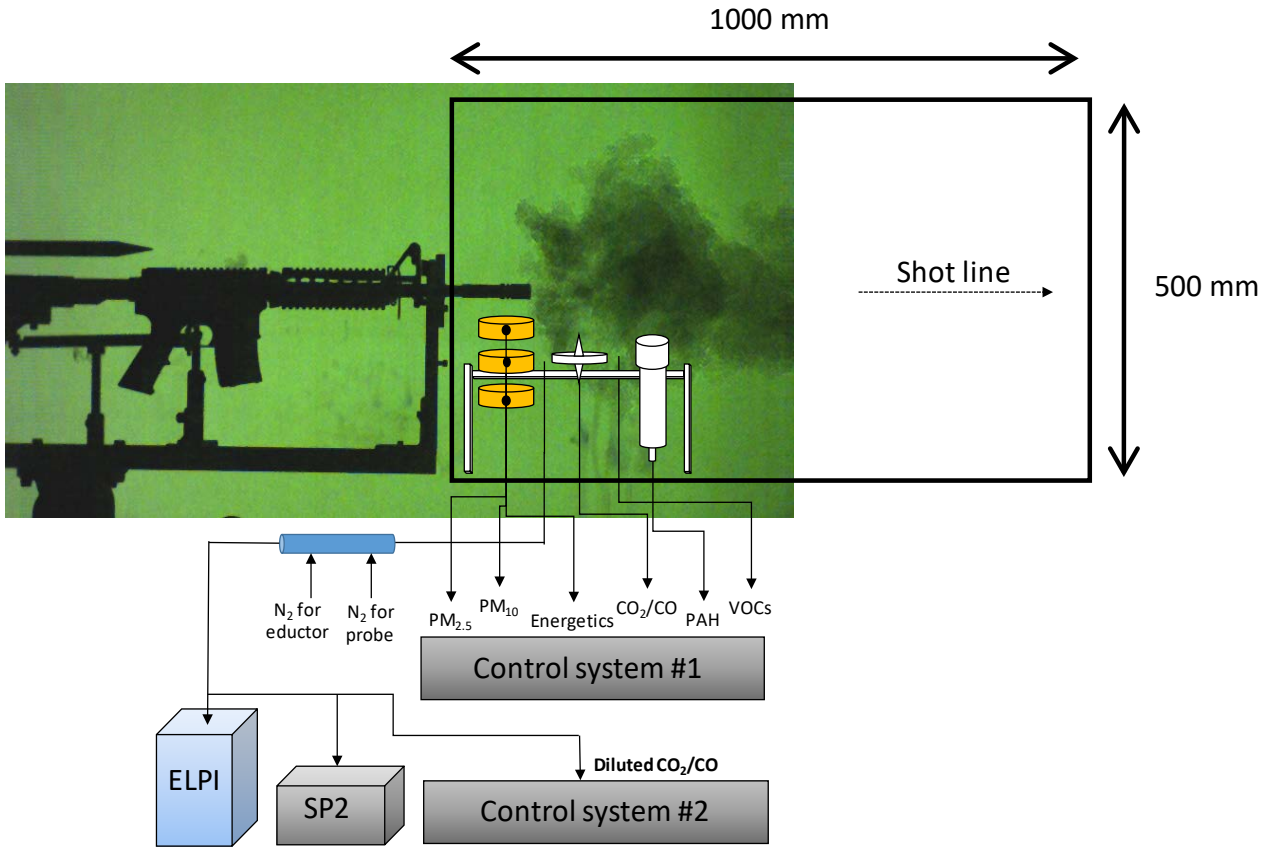
M855 Ammunition

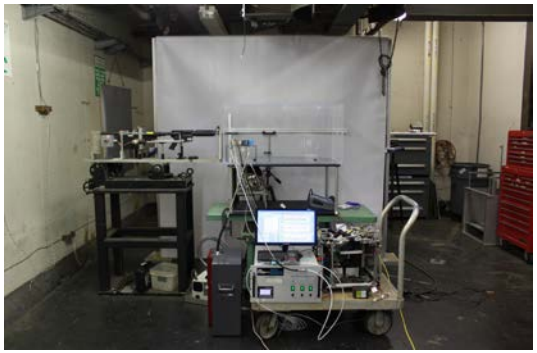


- Lead/steel bullet
- Double-base propellant
- K salts to suppress flash

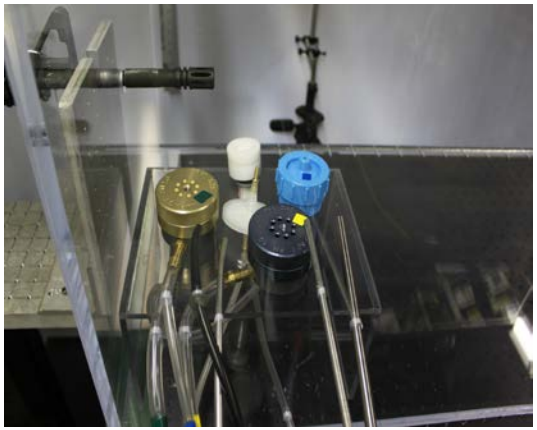
Gun Firings

Methods





Edgerton Shadowgraphy



EPA Modules

Gun Firings

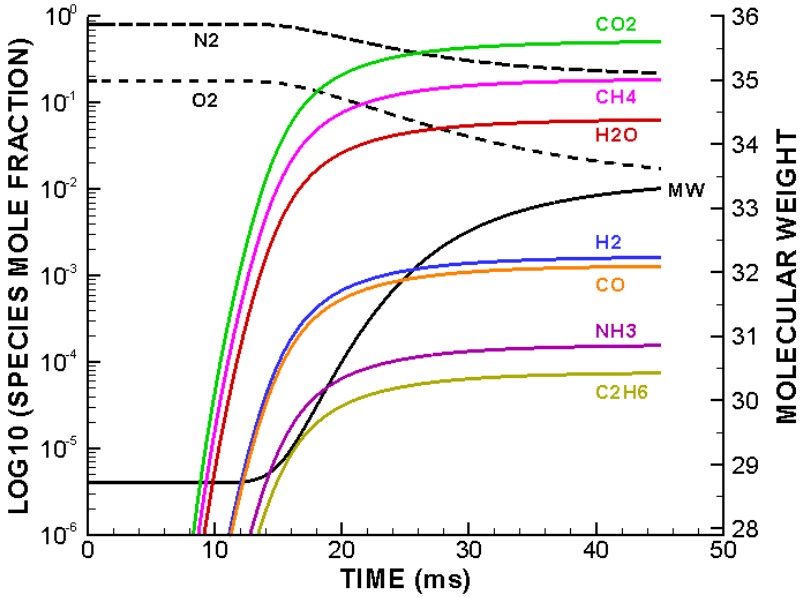
Simulations

- CFD-based simulation
  - 2D 2-phase ballistics model using computational fluid dynamics (CFD)
  - Coupled to constant breech pressure (CBP) model to predict chemical species
  - Species mix with air and combust (NASA-LEWIS thermochemical code)
  - Allows varying levels of soot formation
- For comparison
  - Use standard CHEETAH gun-run as input to chemical kinetic simulator CHEMKIN

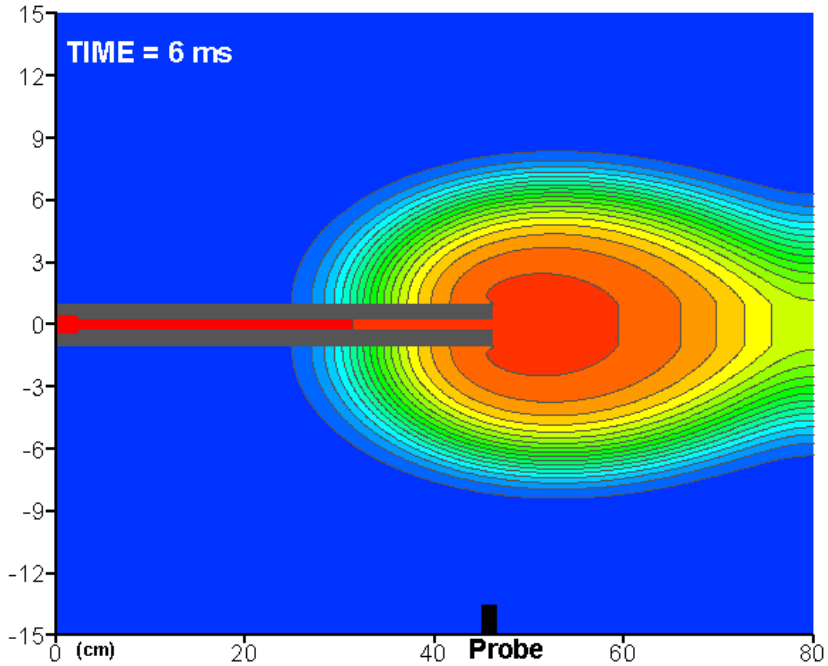
Gun Firings

Simulations: Computational Fluid Dynamics

Predicted species at EPA probe location



Predicted species at muzzle exit



CO_2 (blue to red:0 to 0.6)

Gun Firings

Simulations: Species Predictions

CFD/NASA Lewis Method

Soot formation approximately 25%

Species	Mole Fraction
CO	0.0075
N_2	0.101
CO_2	0.465
H_2O	0.024
CH_4	0.0615
H_4	trace

CHEETAH/CHEMKIN

No predicted soot formation

Simulation	MCE
NASA-Lewis simulation with soot formation	0.732
CHEETAH/CHEMKIN Gun Calculation	0.998

Gun Firings

Experiments: CO and CO_2 Emission Factors and MCE

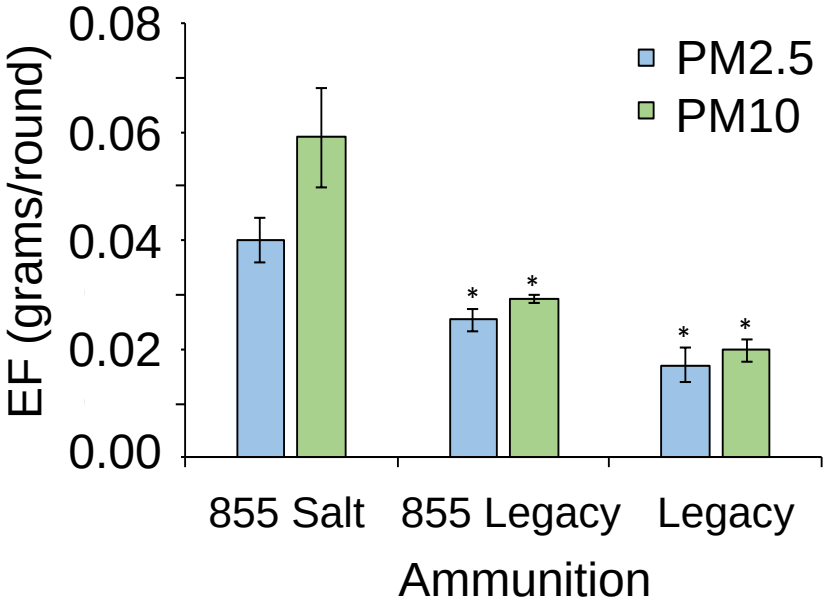
	Number of observations	Average	Standard Deviation	RPD (%)
855-Salted				
CO_2 Emission Factors	5	284	44	15
CO Emission Factors	5	191	17	8.9
MCE	5	0.49	0.056	19
855-Unsalted				
CO_2 Emission Factors	4	300	55	18
CO Emission Factors	4	192	19	9.8
MCE	4	0.5	0.064	22
Legacy				
CO_2 Emission Factors	1	253	56	22
CO Emission Factors	1	208	30	14
MCE	1	0.44	0.08	24

Emission Factors = gram per kilogram fuel
MCE = mole fraction

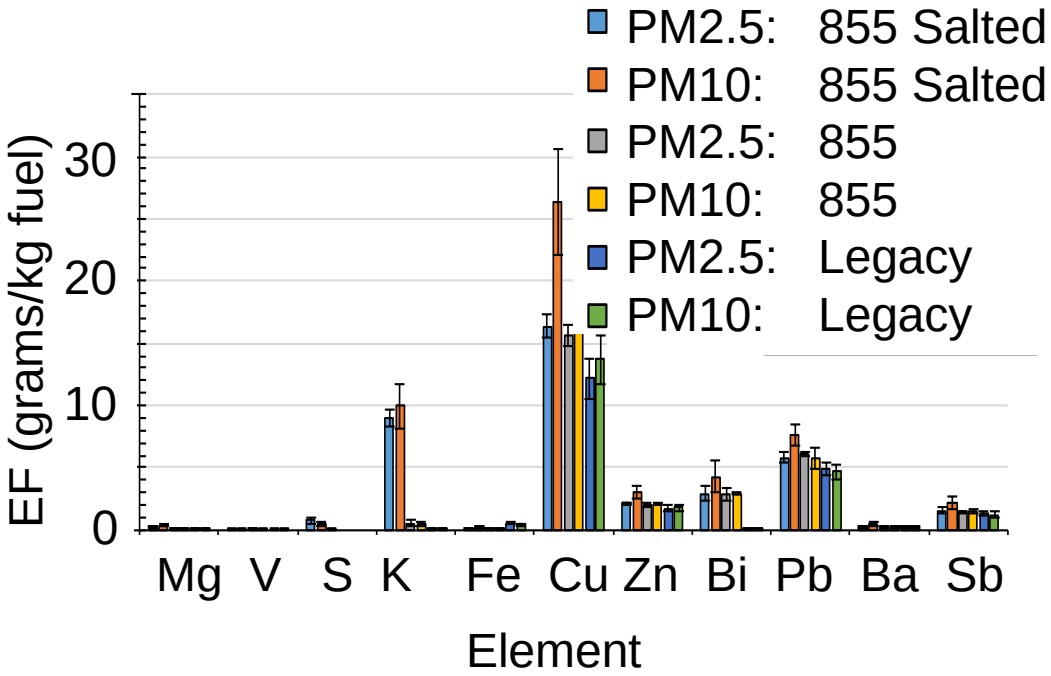
Gun Firings

Experiments

PM Emission Factors

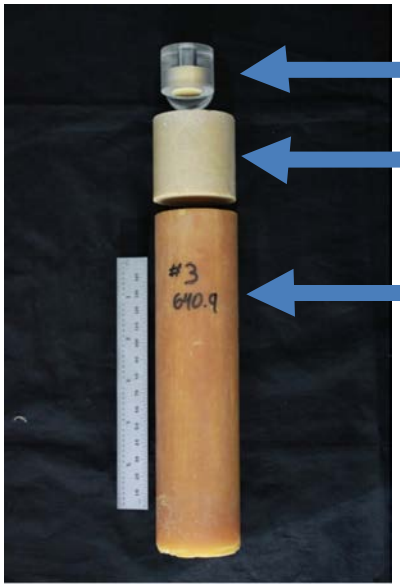


Elemental Emission Factors



* = range of data

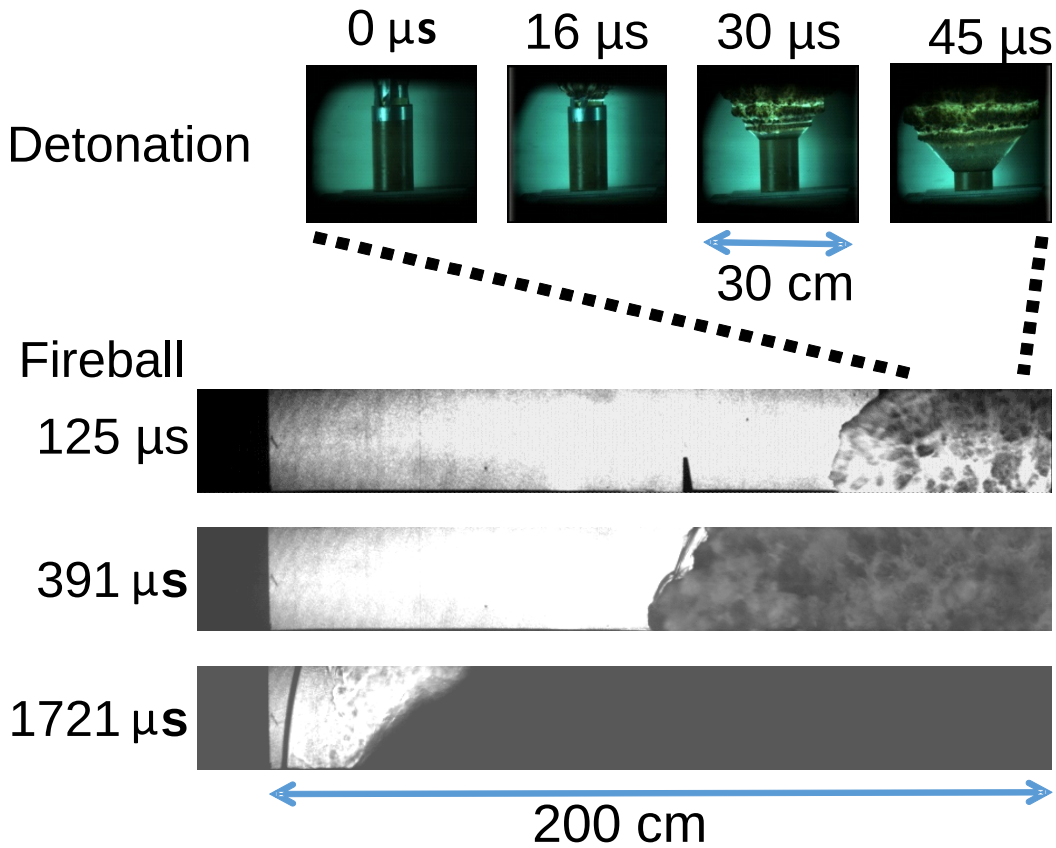
Explosions



TNT Main Charge (640 g)

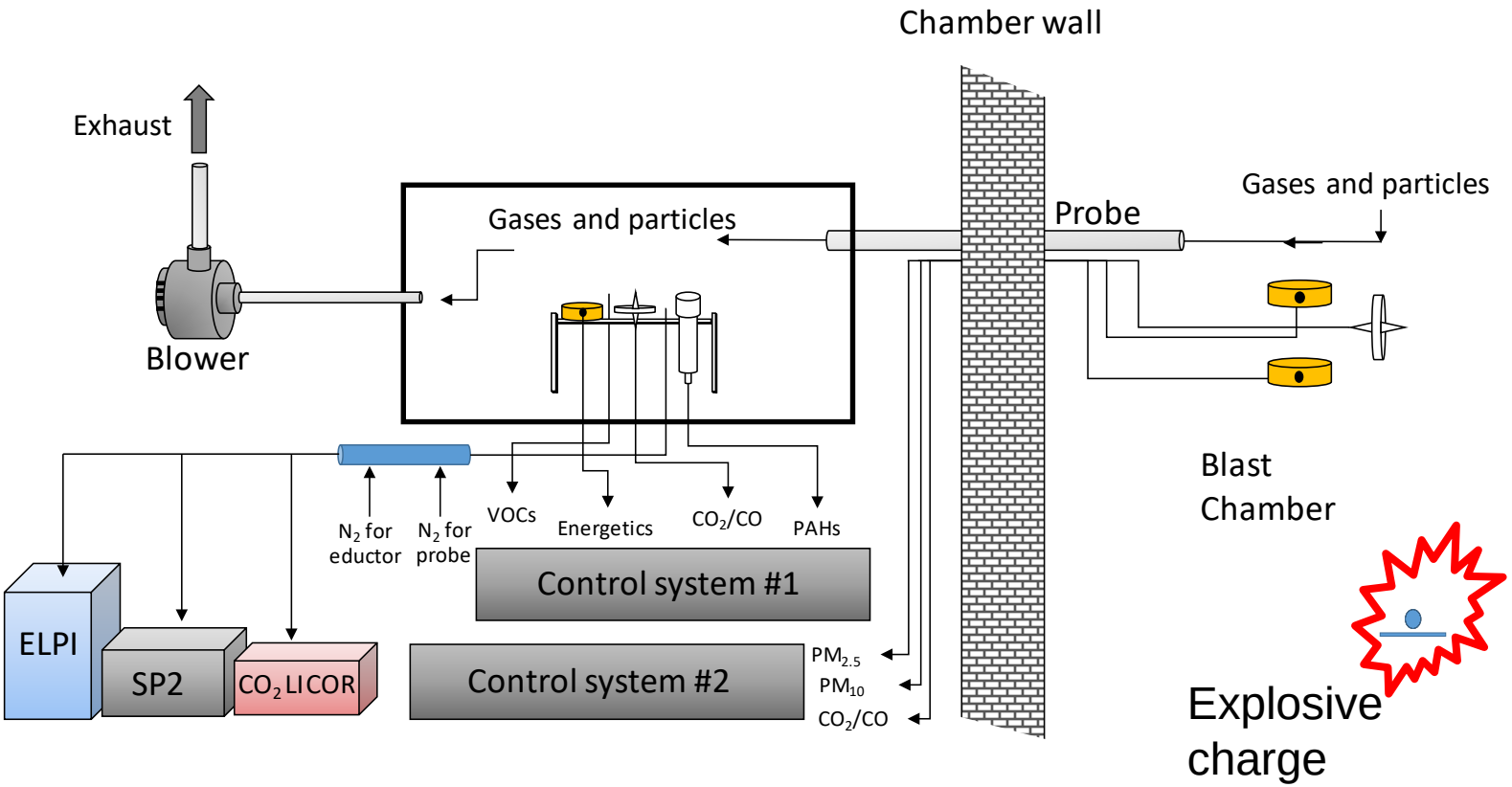
Comp-B booster

Pentolite initiator



Explosions

Methods



Chamber interior = 5m x 5m x 5m

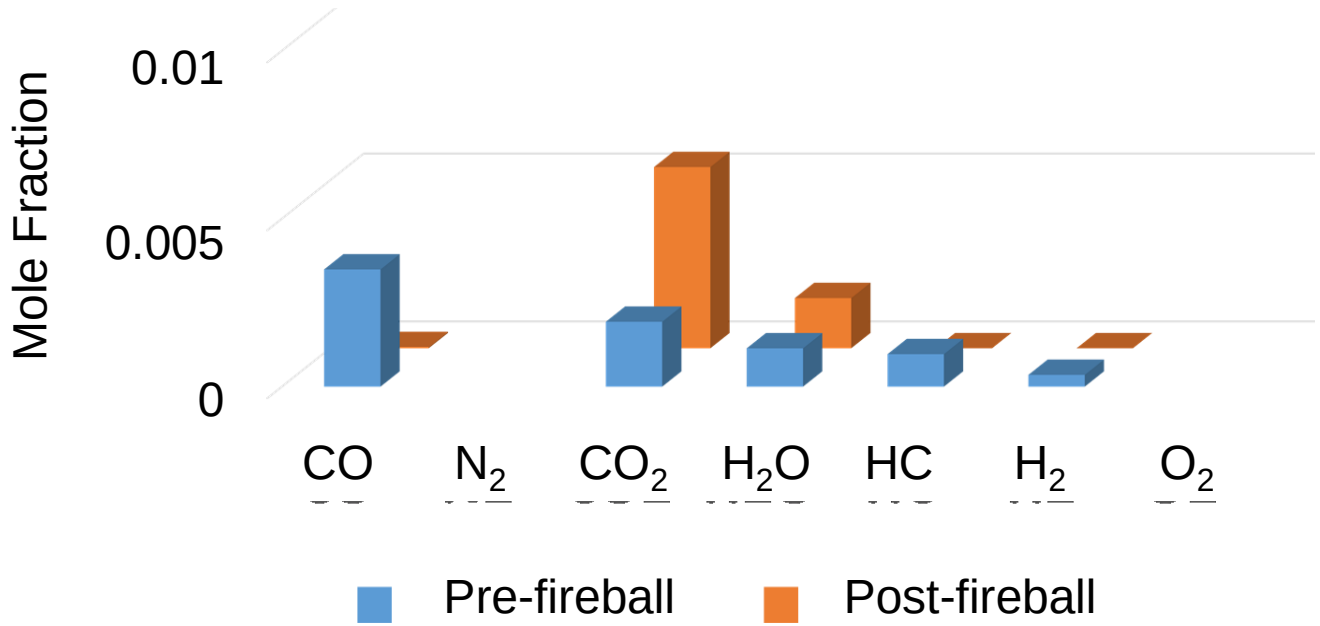
Explosions

Simulations

- CHEETAH to predict chemical species during detonation and near field expansion
- Compile combustion mechanism for predicted detonation products with air
- CHEMKIN used to predict species in fireball following detonation

Explosions
Simulations

- Results of a CHEMKIN calculation of a homogeneous reactor containing a 100:1 by volume mixture of air and TNT detonation products, respectively
- Initial temperature was 1000 K



Note: N_2 and O_2 are not reported on this graph

Explosions

Simulations

Predicted emission factors for explosions of neat TNT

Species	CHEETAH	CHEMKIN 1:1 air	CHEMKIN 100:1 air	Full Combustion
C-graphite	0.13	0.13	0.13	
CO	0.304	0.255	0.005	
N_2	0.182	0.184	0.184	0.184
CO_2	0.264	0.476	1.17	1.36
H_2O	0.064	0.162	0.172	0.176
CH_4	0.0464	trace	trace	
H_2	0.00224	0.00311	trace	

$$MCE = \Delta C_{CO_2} / (\Delta C_{CO_2} + \Delta C_{CO} + \Delta C_{CH_4} + \Delta C_{PC}) = 0.866$$

Emission factors = gram of emitted species per gram of TNT

Explosions

Simulations

B inactive

	Calculated Emission Factors[1]
C(graphite)	0.076
CO	0.00026
CO_2	0.803
B	0.1
MgO	0.165
H_2O	0.165

MCE[2] = 0.74

B active

	Calculated Emission Factors[1]
C(graphite)	0.086
CO	0.00014
CO_2	0.768
B	0.23
MgO	0.165
H_2O	0.158

MCE[2] = 0.71

[1]Calculated Emission Factors = gram of emitted species per gram TNT/Mg/B
[2]MCE for TNT/Mg/B (80:4:16 by weight)

Explosions

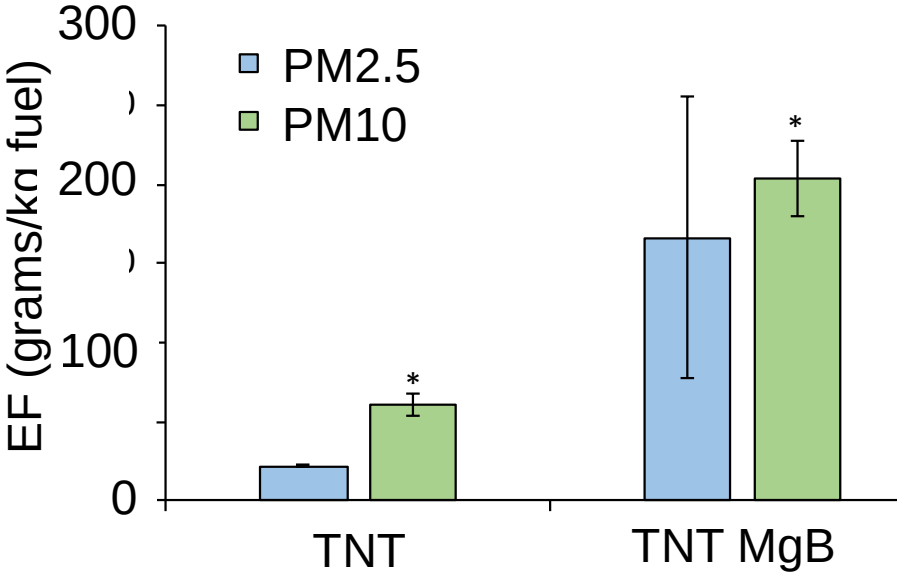
Experiments: CO_2, CO, CH_4 emission factors - MCE

	Number of observations	Average	RPD (%)
TNT			
CO_2 Emission Factors	2	1,314	0.65
CO Emission Factors	2	17	32
CH_4 Emission Factors	2	ND	N/A
MCE	2	0.980	0.66
TNT MgB			
CO_2 Emission Factors	2	1,117	1.5
CO Emission Factors	1	15	16
CH_4 Emission Factors	2	0.16	N/A
MCE	2	0.979	0.35

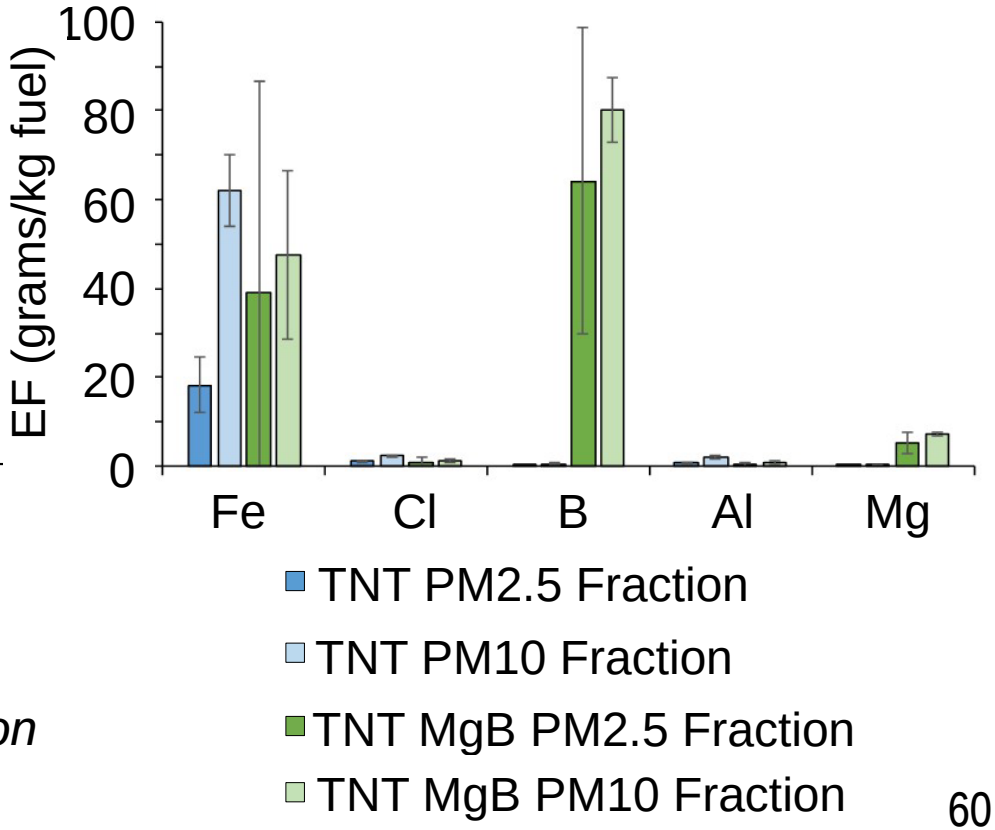
Explosions

Experiments: Detonation of TNT and TNT/Mg/B

PM Emission Factors



Element Emission Factors



Note: Error bars are one standard deviation

Summary

Gun Firings and Explosions

Gun Firings

Method	MCE
M855 Salted (Experiment)	0.49 (0.056)
M855 (Experiment)	0.5 (0.064)
M855 Legacy (Experiment)	0.44 (0.080)
CFD/NASA-Lewis (Simulation)	0.732
M855 CHEETAH/CHEMKIN (Gun Calculation)	0.998

Explosions

Method	MCE
TNT (Experiment)	0.98 (0.66)
TNT/Mg/B (Experiment)	0.979 (0.35)
TNT (Simulation)	0.866
TNT/Mg/B - B inactive (Simulation)	0.74
TNT/Mg/B - B active (Simulation)	0.71

Key Points

Gun Firings

- Average CO concentrations around 1500 ppm after firing suggest that inhalation studies on firing ranges may be warranted
- Emitted particles had mass median diameters between 0.389 and 0.575 µm, a respirable particle size, and up to 6% PM10 and below (g/g propellant)
- Copper was the metal observed in highest concentration for all three round formulations; more than 100% of the lead in the propellant/primer formulations was observed
- Simulation over-predicts MCE at probe location and under-predicts CO at probe location

Key Points

Explosions

- Emissions from the TNT detonations indicate combustion efficiencies of about 98%
- Experiments in a blast chamber provides near-homogeneous reactor mixing conditions
- The addition of Mg/B to the TNT formulations increased the $PM_{2.5}$ emission by a factor of 8
- Simulation under-predicts MCE compared to experiment

Recommendations

- Improve prediction of particulate matter for gun firings and explosions
- Improve prediction of particle combustion kinetics
- Incorporate gas-phase chemical kinetics into CFD model
- Collect data on HCN - NDIR instrument malfunction
- CO levels are of concern in closed environment

For additional information, please visit

https://serdp-estcp.org/Program-Areas/Weapons-Systems-and-Platforms/Noise-and-Emissions/Air-Emissions/WP-2611

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Q&A Session 2

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The next webinar is on February 22, 2018

Natural Attenuation of Chlorinated Ethenes: Biotic and Abiotic Processes

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