Particulate Matter Emissions from Gun Firing

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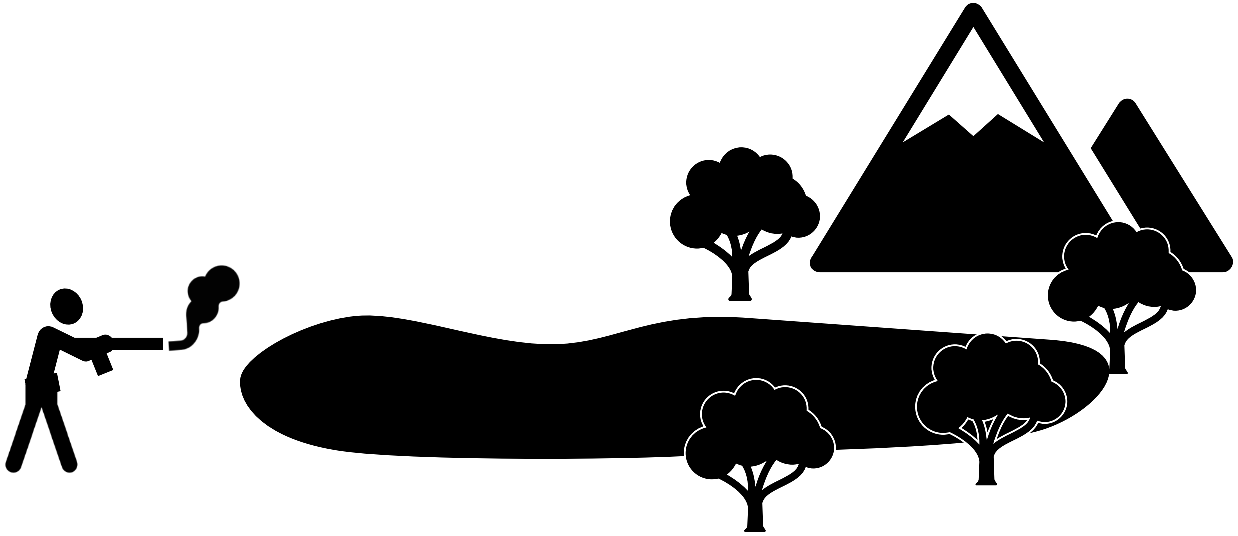
2018 | Enhancing DoD's Mission Effectiveness

Environmental and health impacts from gun firing

Small arms firing emits hazardous combustion products (soot, polycyclic aromatic hydrocarbons, volatile organic compounds) as well as toxic metals derived from the ammunition and the gun barrel



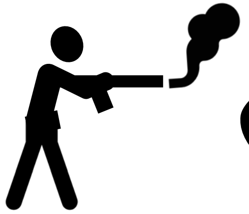
Environmental and health impacts from gun firing

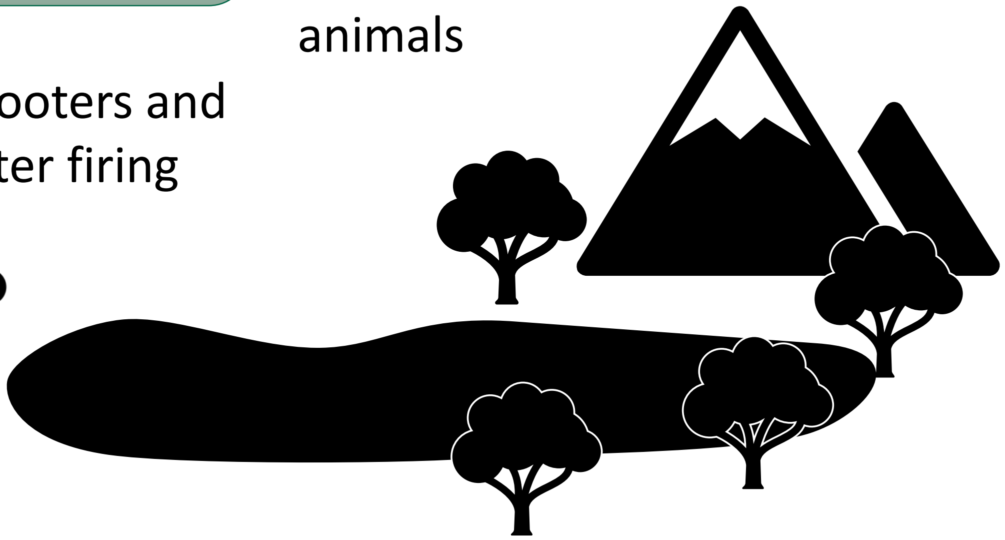
Bullets, primer, and propellant often contain lead, an EPA criteria pollutant

Lead persists in the environment adversely impacting plants and animals

Blood lead levels of shooters and instructors increase after firing (Laidlaw et al. 2017)

Lead is a toxic heavy metal associated with cardiovascular mortality and neurological effects



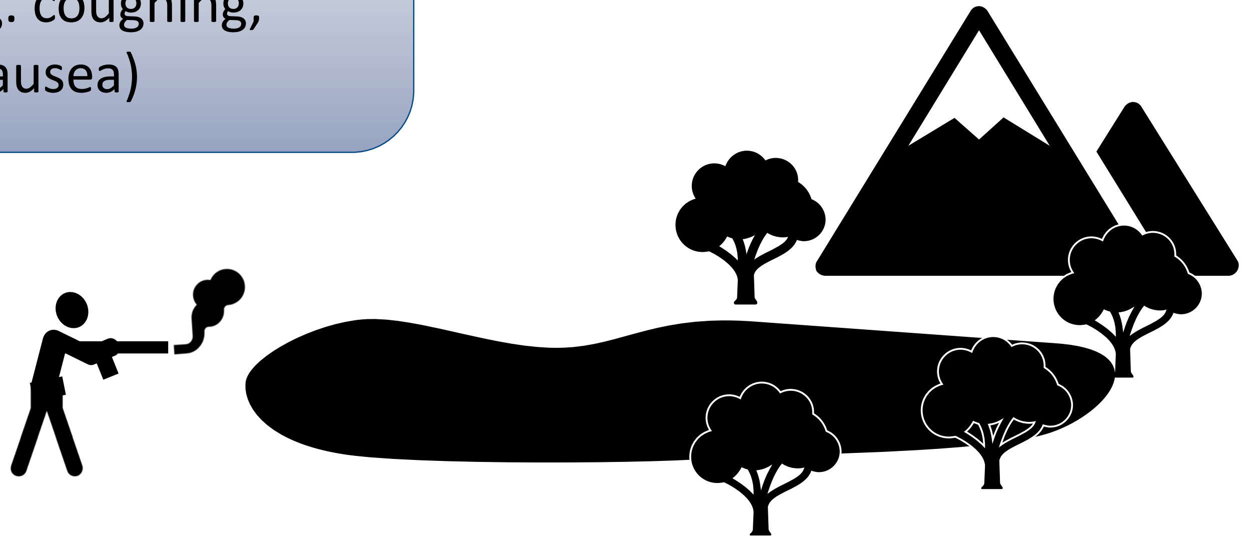


Laidlaw, Filippelli, Mielke, Gulson, Ball (2017) Lead exposure at firing ranges – a review, Environmental Health 16:34

Environmental and health impacts from gun firing

Different types of ammunition (e.g. lead free) have resulted in varying health effects (e.g. coughing, wheezing, nausea)

More information is needed to determine the composition of these emissions and their impacts on health and the environment

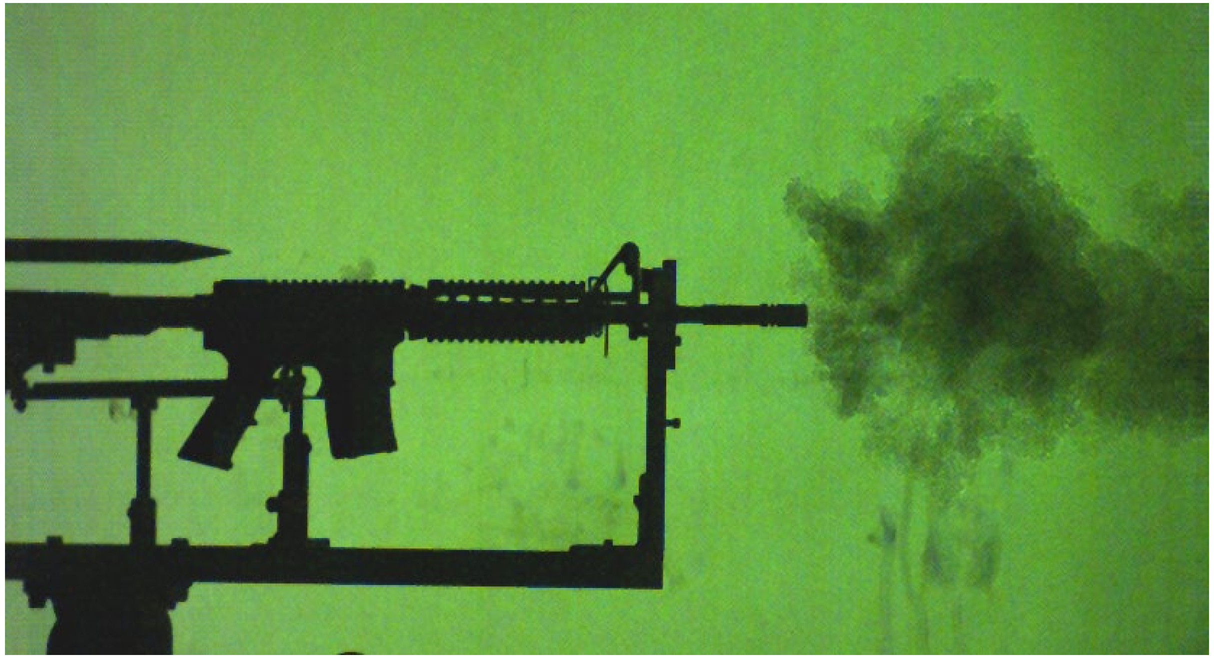


Study Objectives

Characterize PM emissions from gun firing activities

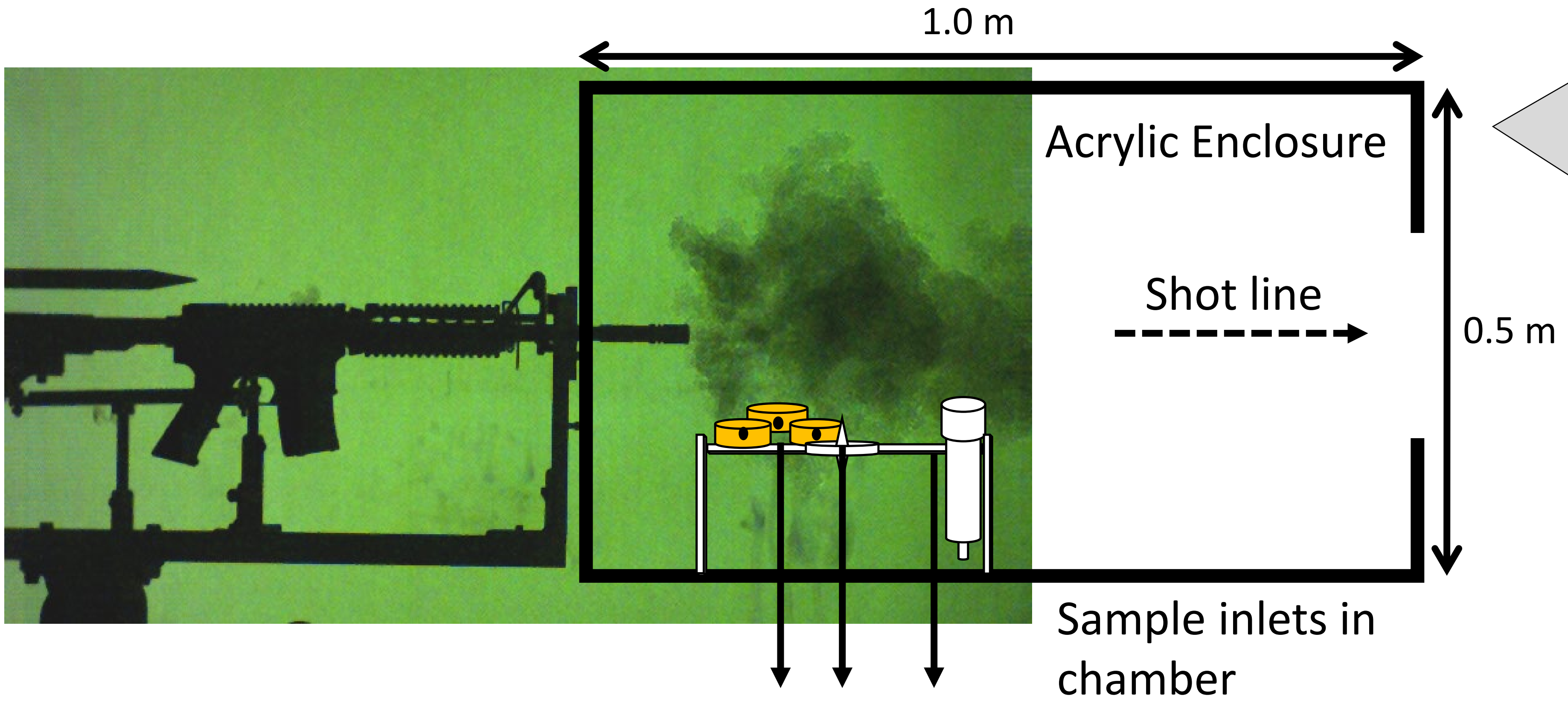
Particle number and mass concentration	• Determines the dose
Size distribution	• Determines atmospheric lifetime and lung deposition
Composition & Morphology	• Determines the environmental impact and adverse human health effects

Measurement Approach



- Experiments carried out in the Army Research Laboratory at Aberdeen Proving Ground
- Used an M4 Carbine firearm commonly used by U.S. military and North Atlantic Treaty Organization (NATO)
- Measured emissions from three ammunition types all with copper (Cu)/zinc (Zn) jacket, steel penetrator, and lead (Pb) slug:
  - M855
  - M855 with potassium nitrate (KNO_3) anti-flash agent
  - M855 legacy (Vietnam era ammo) same composition as M855

Measurement Approach



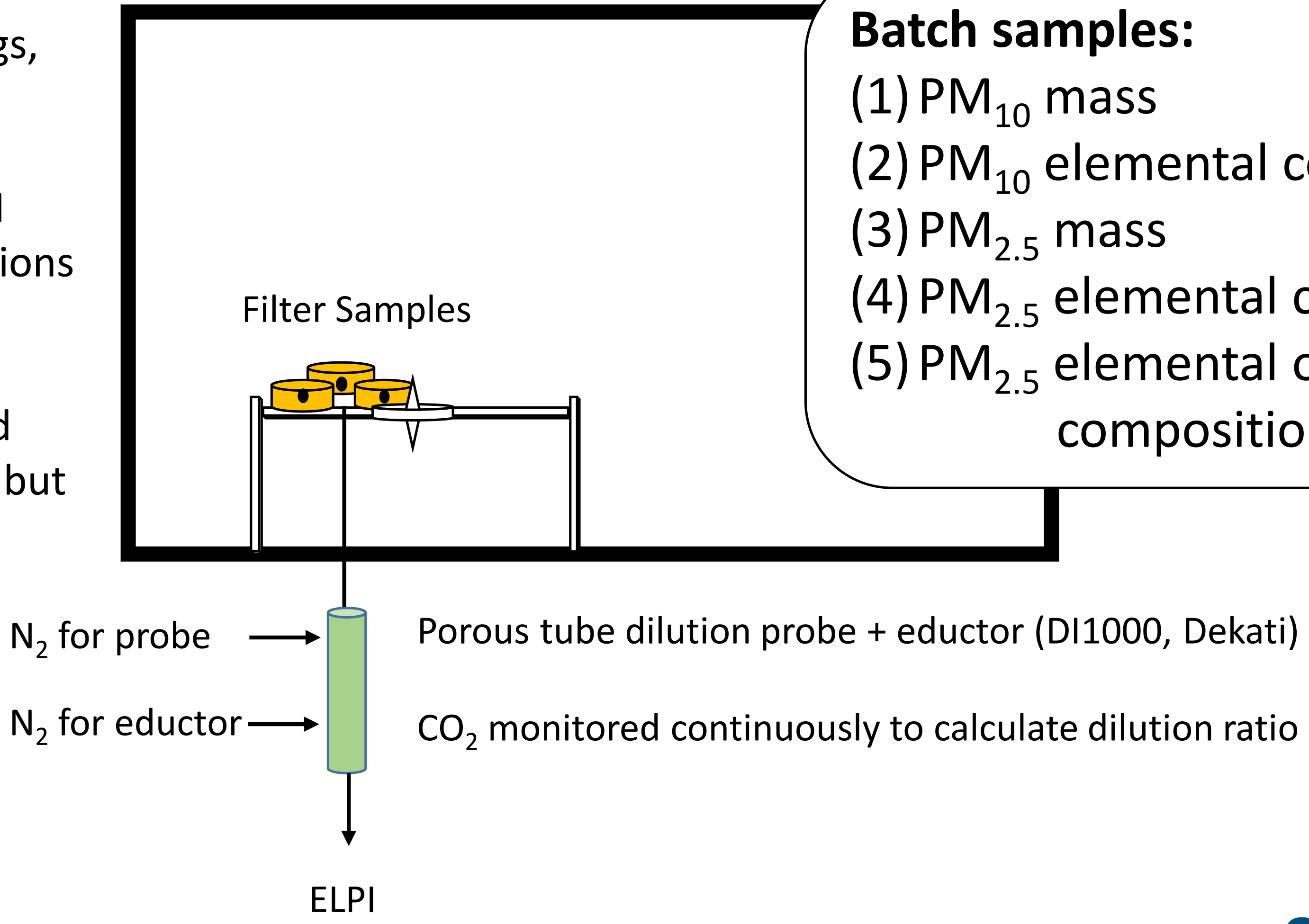
Transparent acrylic enclosure contains emissions for sampling while allowing visualization of the blast

PM Characterization Measurements

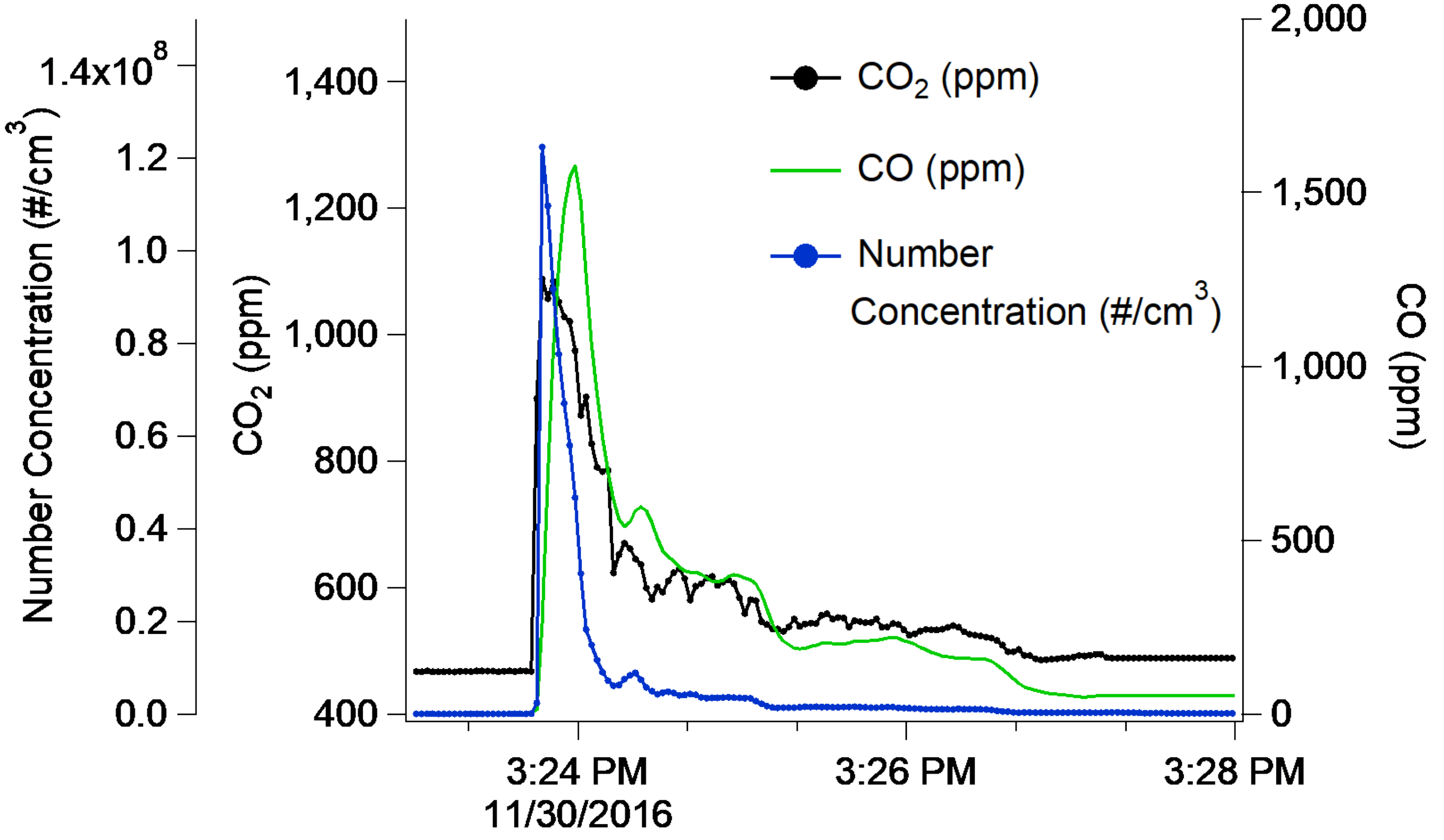
- No standard test method for sampling or analysis of gun firings, actively researching best measurement approach
- Continuous measurement of PM size, number, and mass distributions with an Electrical Low Pressure Impactor (ELPI, Dekati)
- Many other pollutants measured and emission factors calculated, but not presented here

Batch samples:

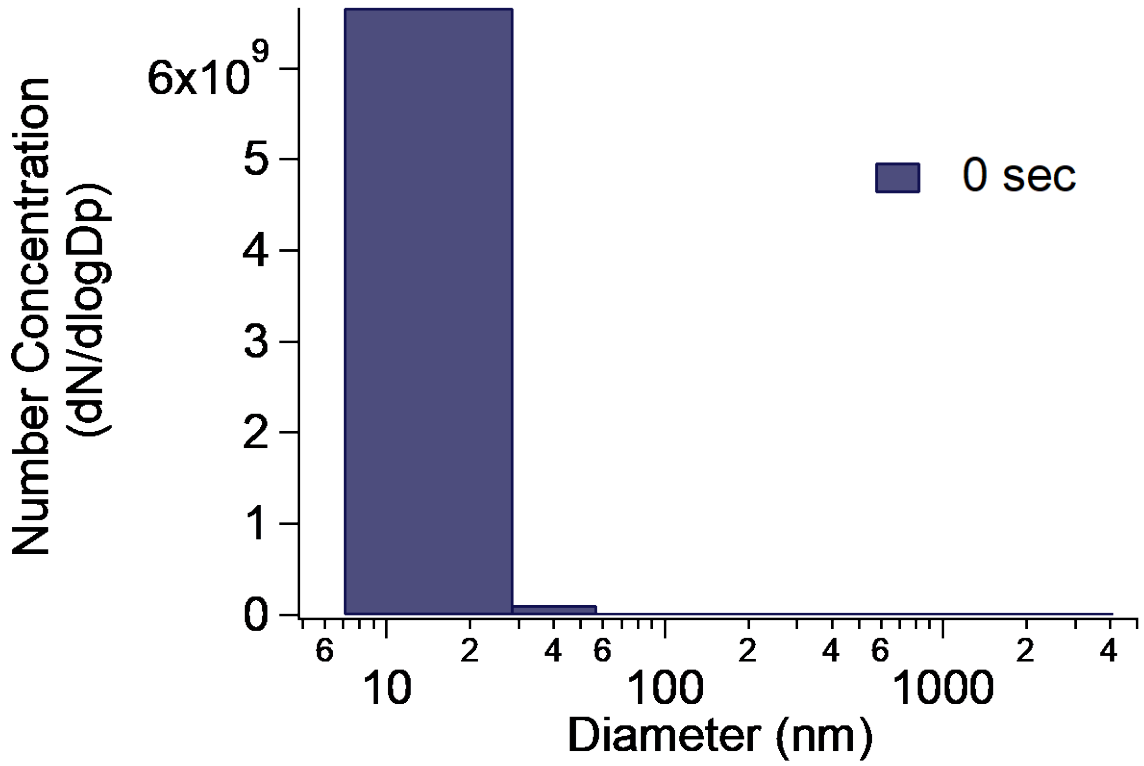
(1) PM_{10} mass
(2) PM_{10} elemental composition
(3) $PM_{2.5}$ mass
(4) $PM_{2.5}$ elemental composition
(5) $PM_{2.5}$ elemental organic composition



Firing Emissions Time Series



PM Number Distribution Evolution After Firing



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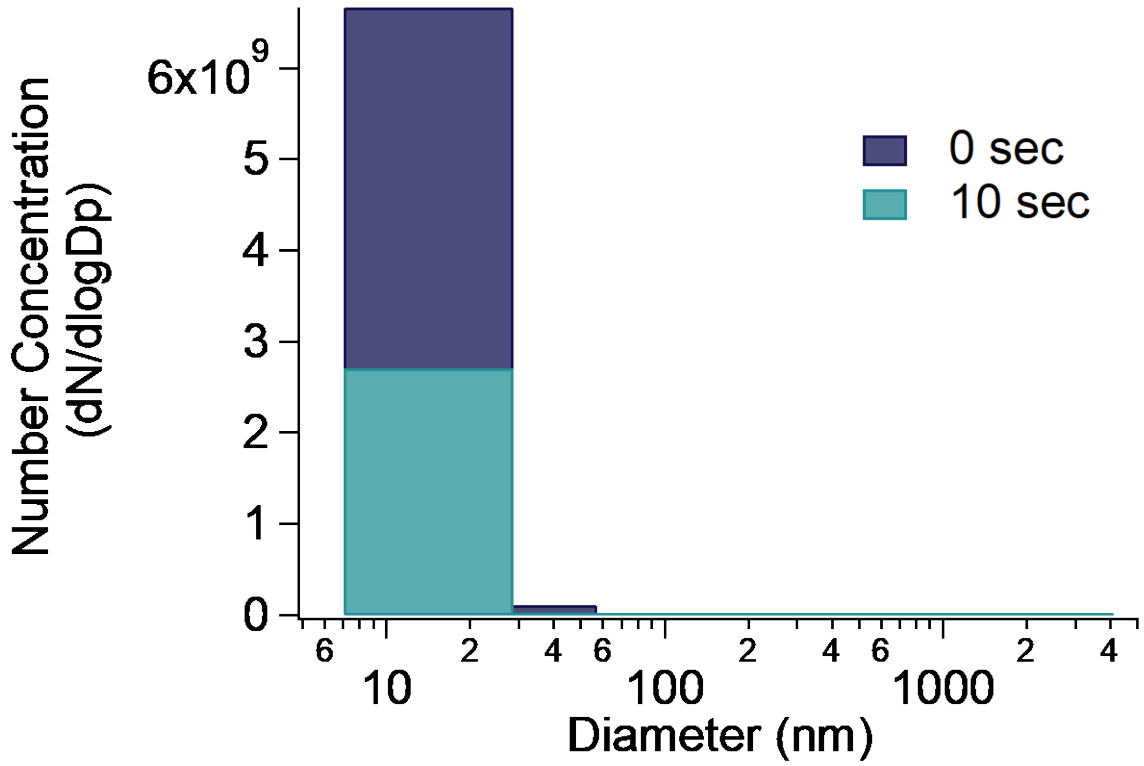

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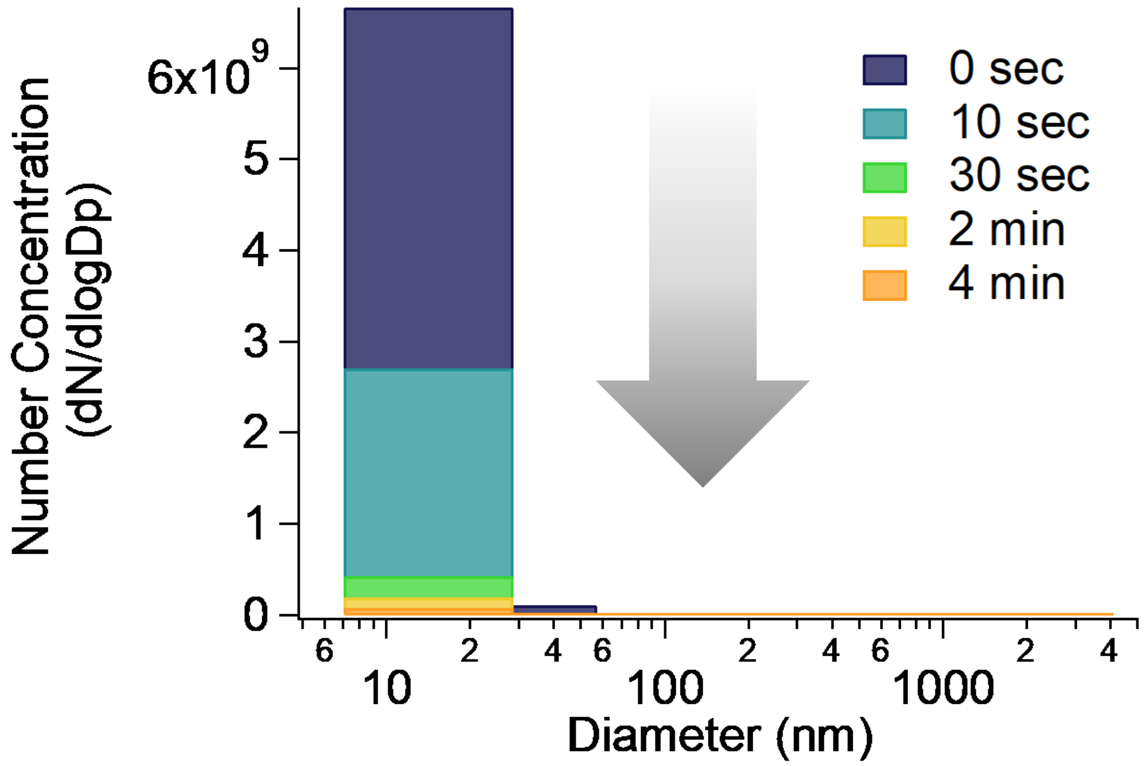
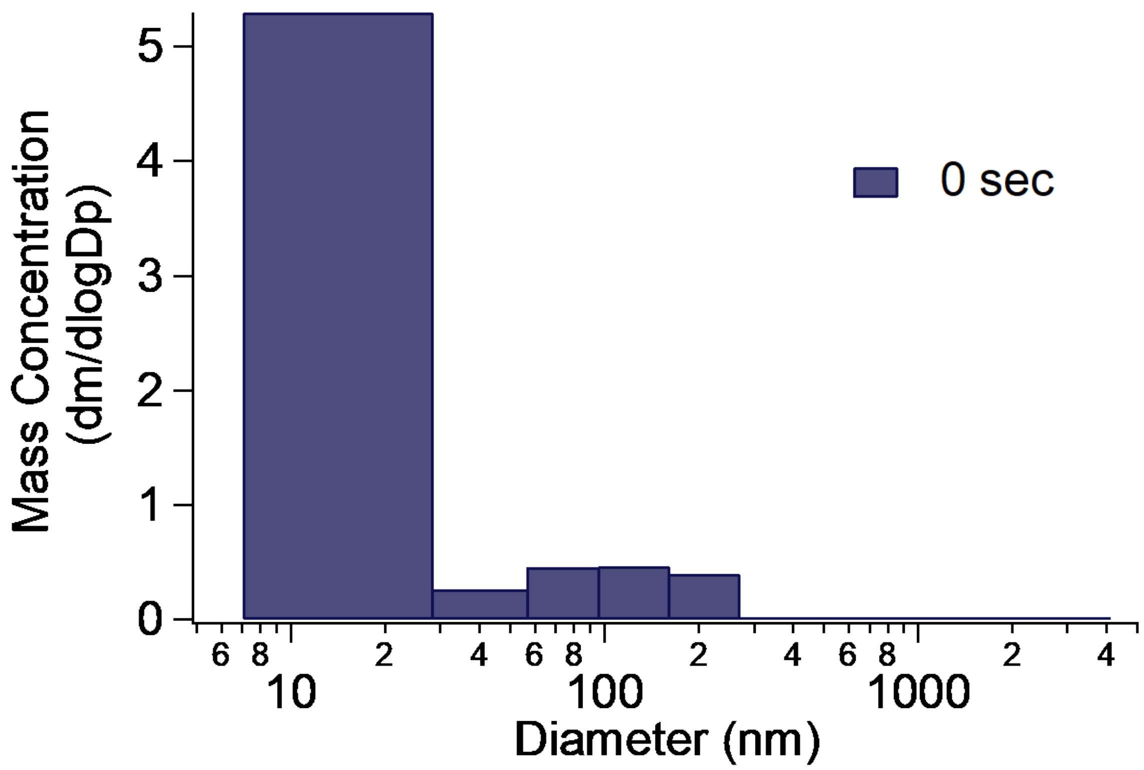


Number concentrations decrease rapidly over time

Smallest particles continue to dominate number distribution

PM Mass Distribution Evolution After Firing



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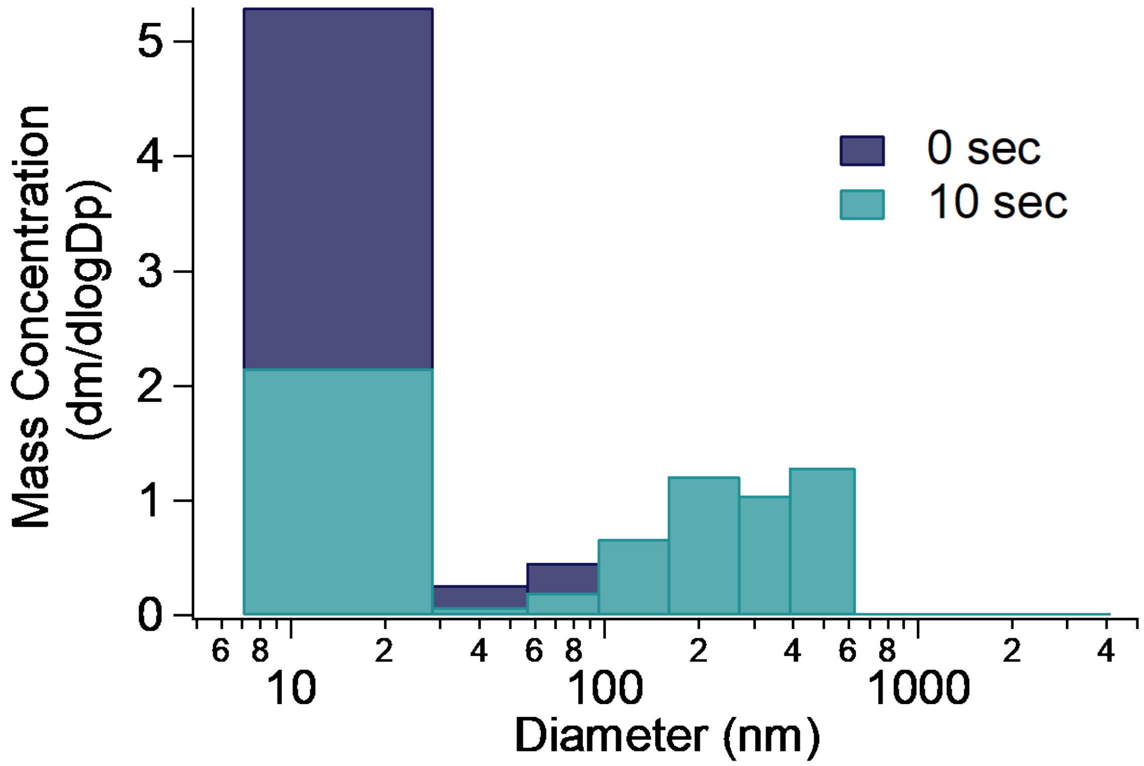

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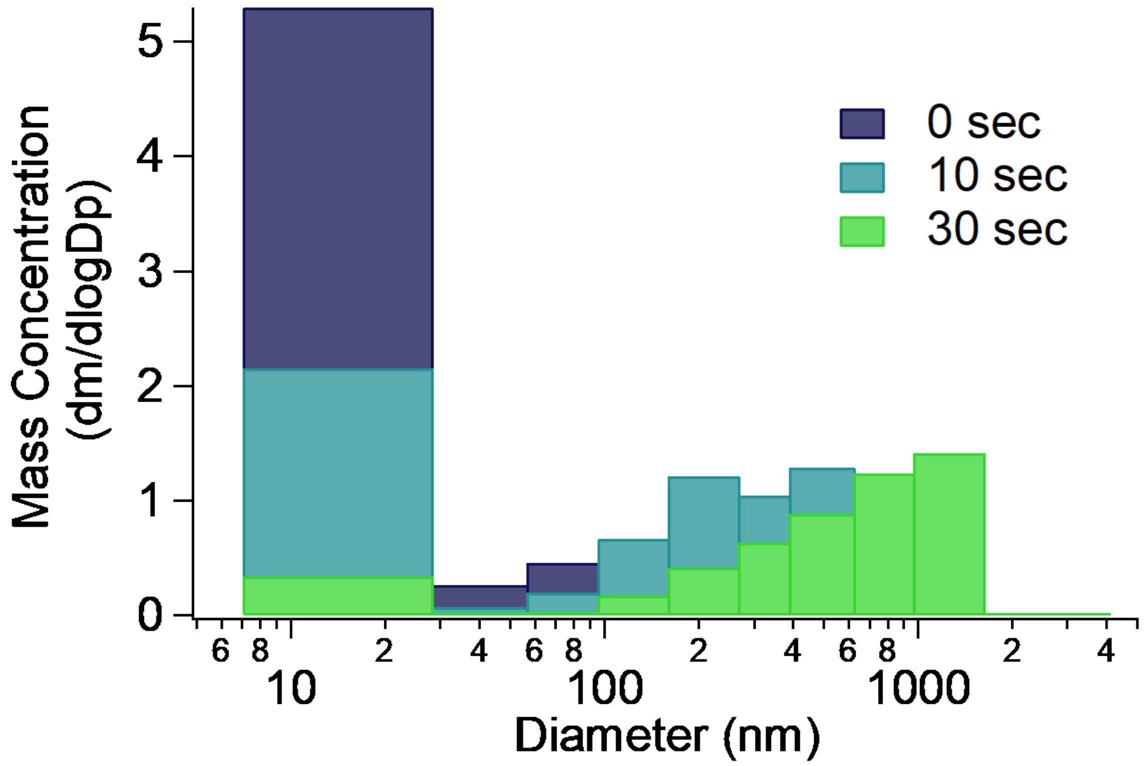

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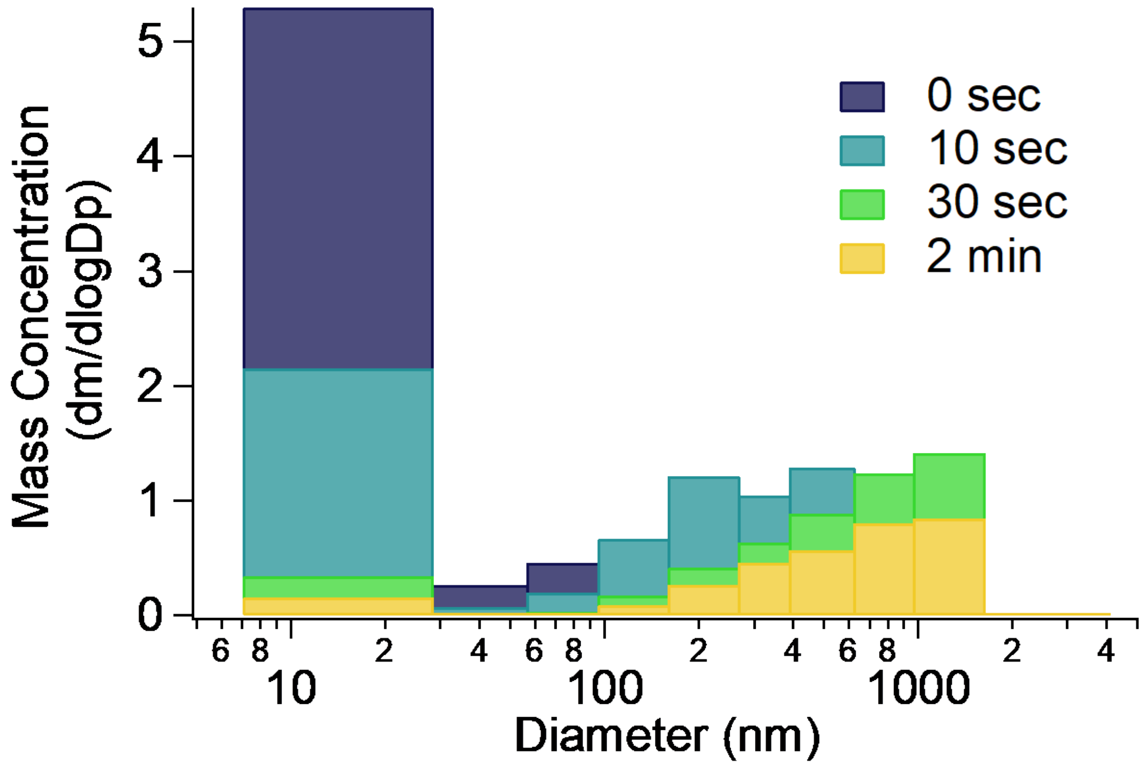

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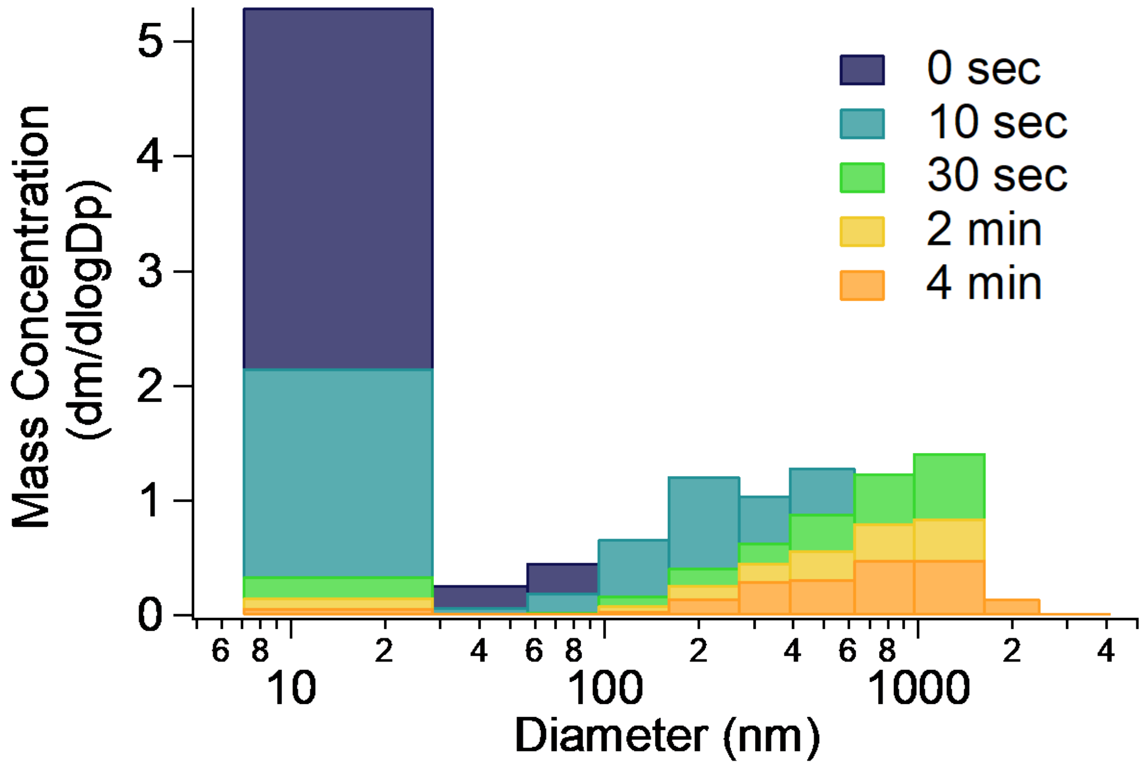

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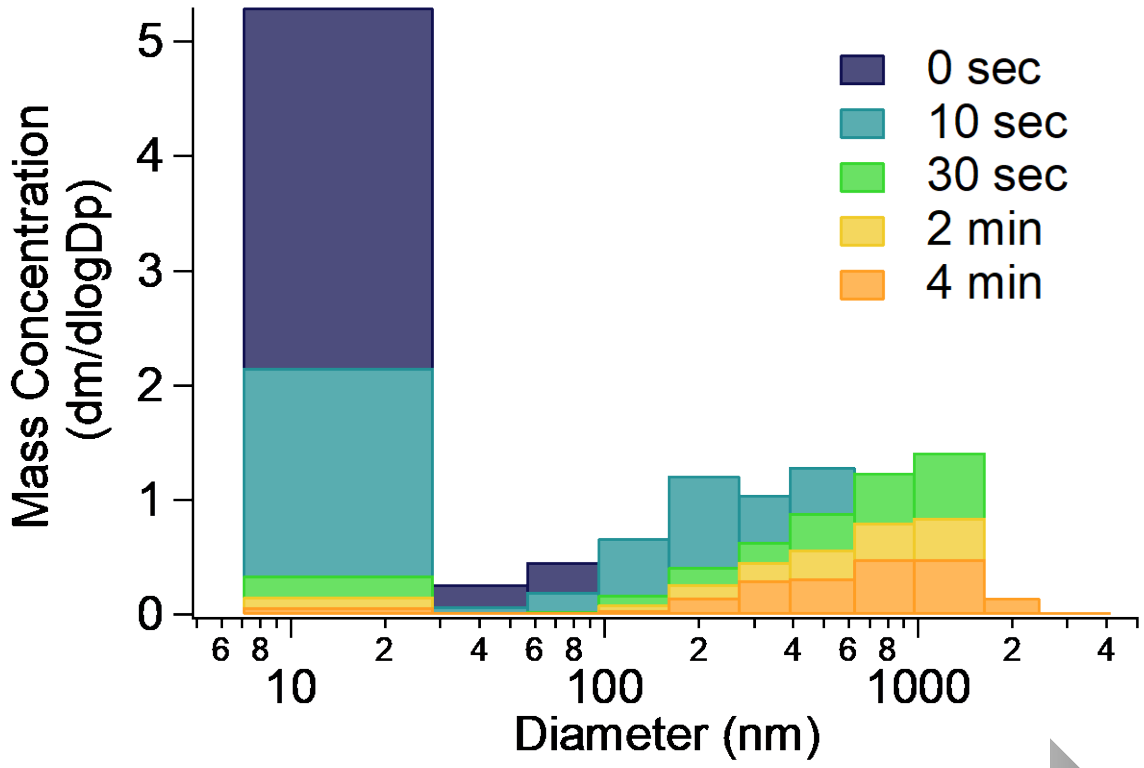
PM Mass Distribution Evolution After Firing

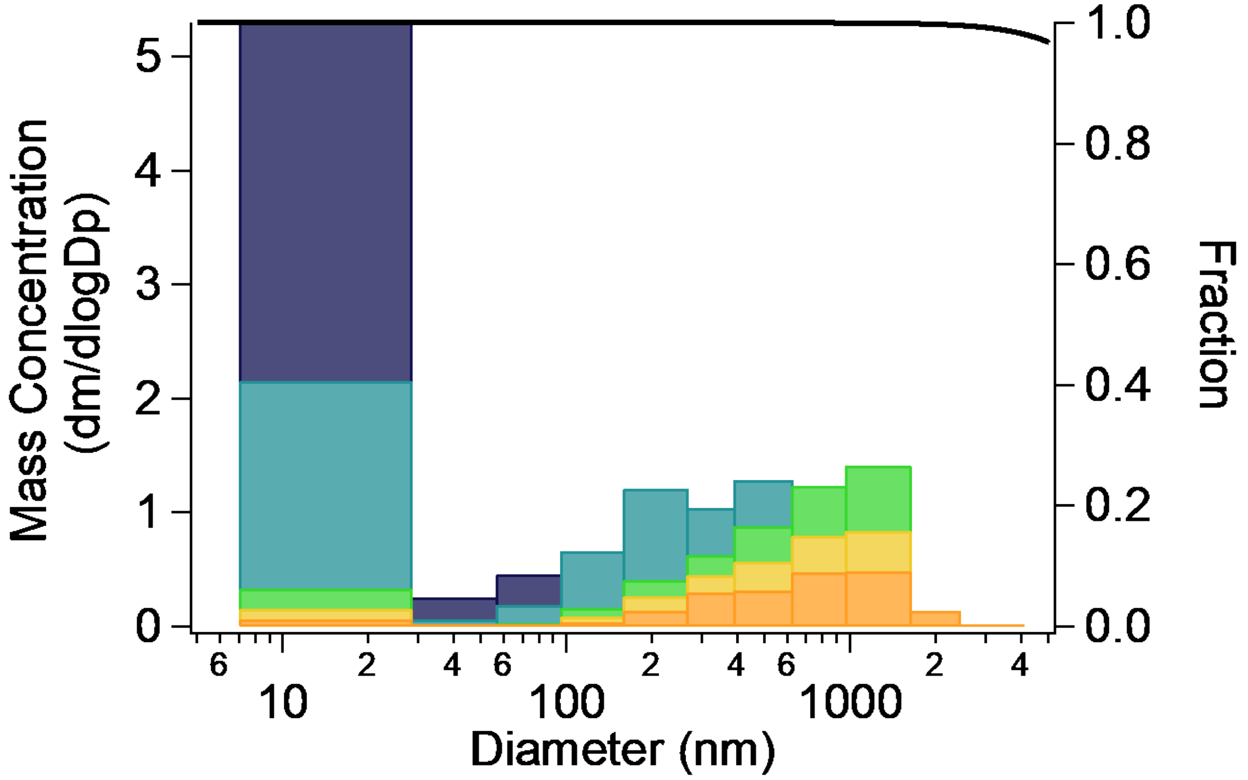


Mass distribution shifts to larger diameters

This shift depends on dilution conditions

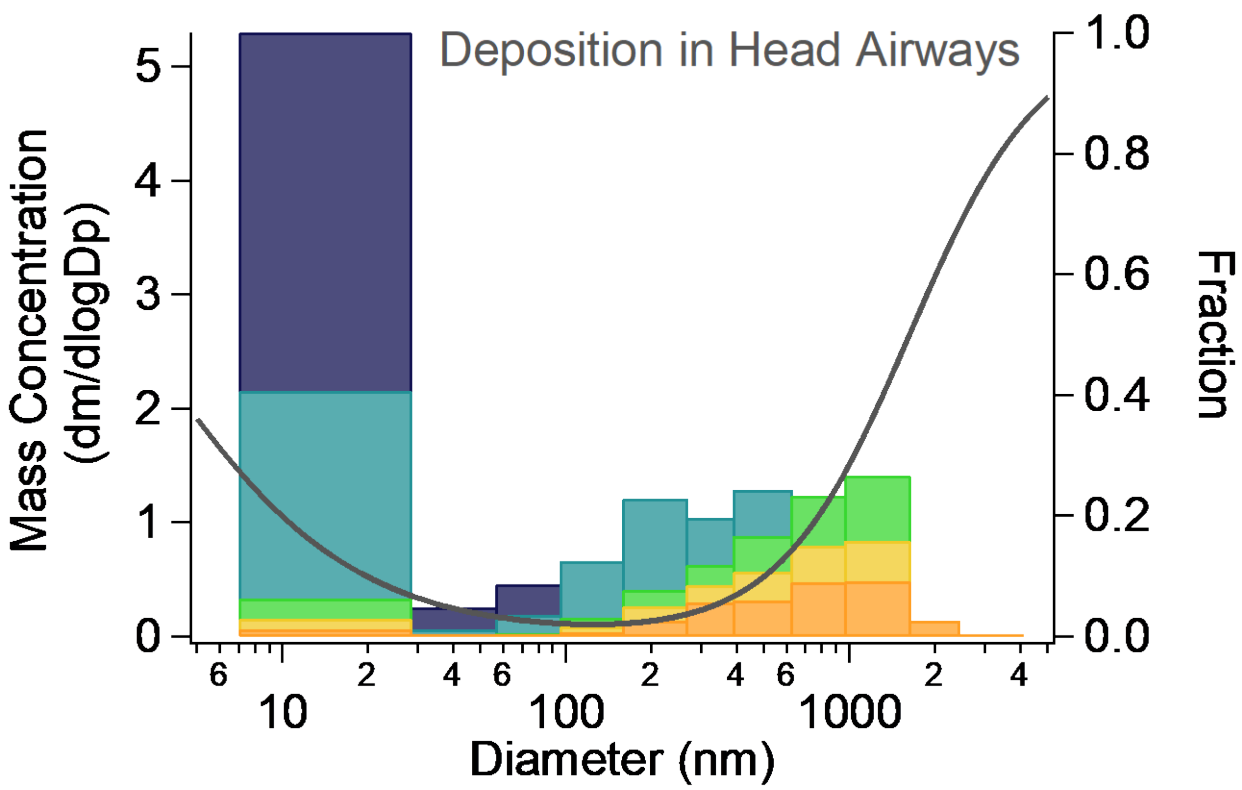
Particles will remain smaller under more realistic ventilation conditions

Results: PM Size Distribution



All particles are inhalable

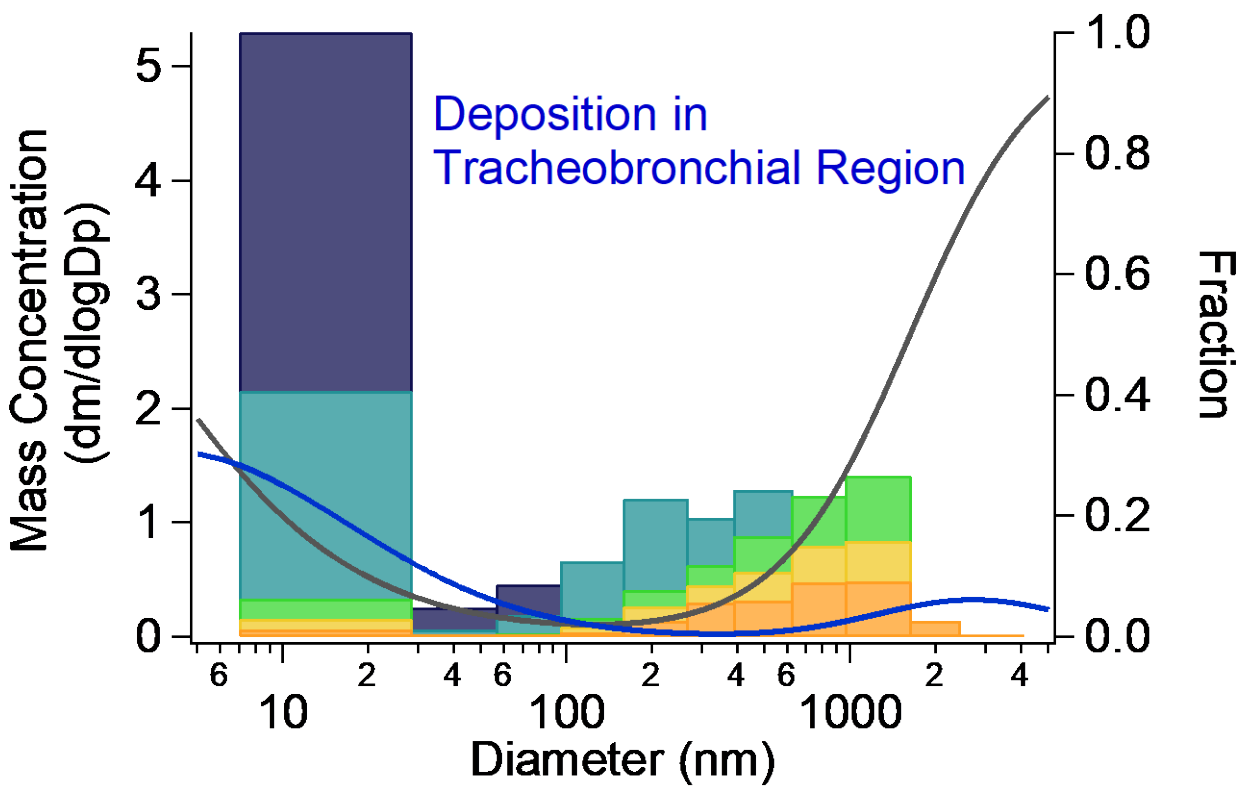
Results: PM Size Distribution



All particles are inhalable

Larger particles deposit in head airways

Results: PM Size Distribution



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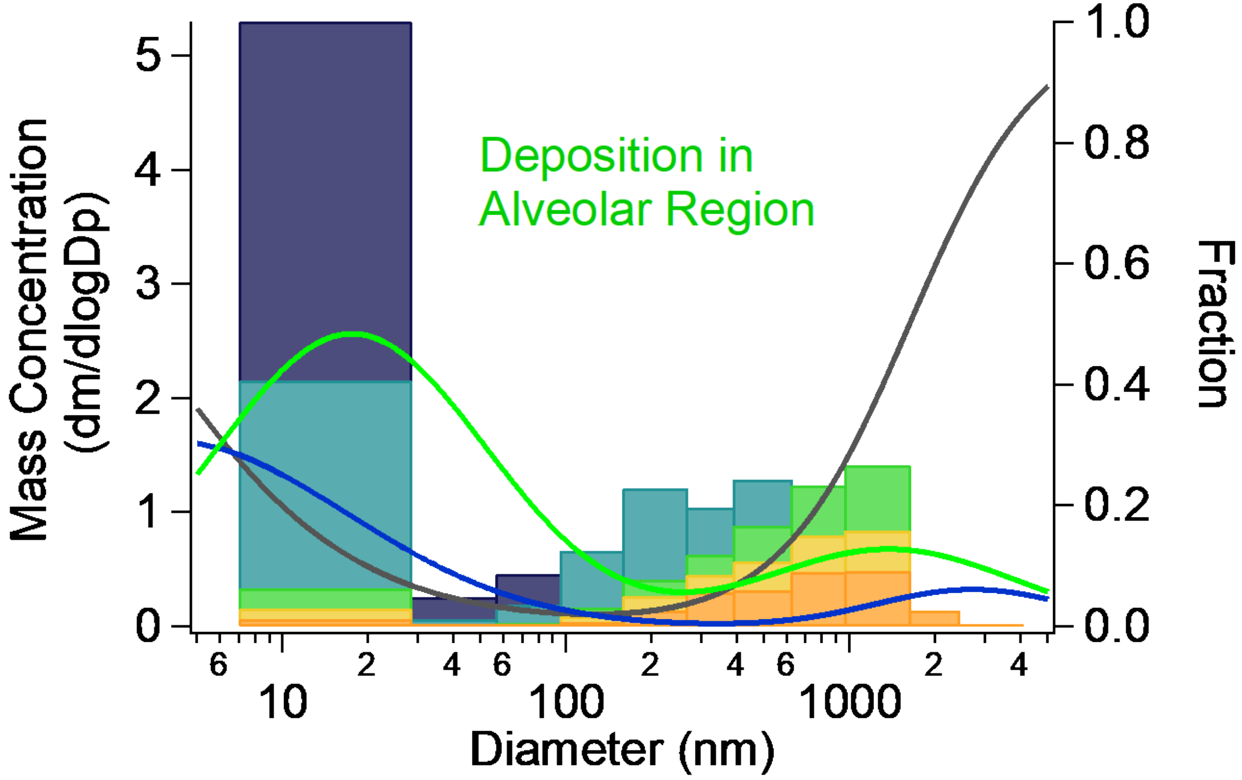
Larger particles deposit in head airways

Small and large particles deposit in tracheobronchial region

Results: PM Size Distribution



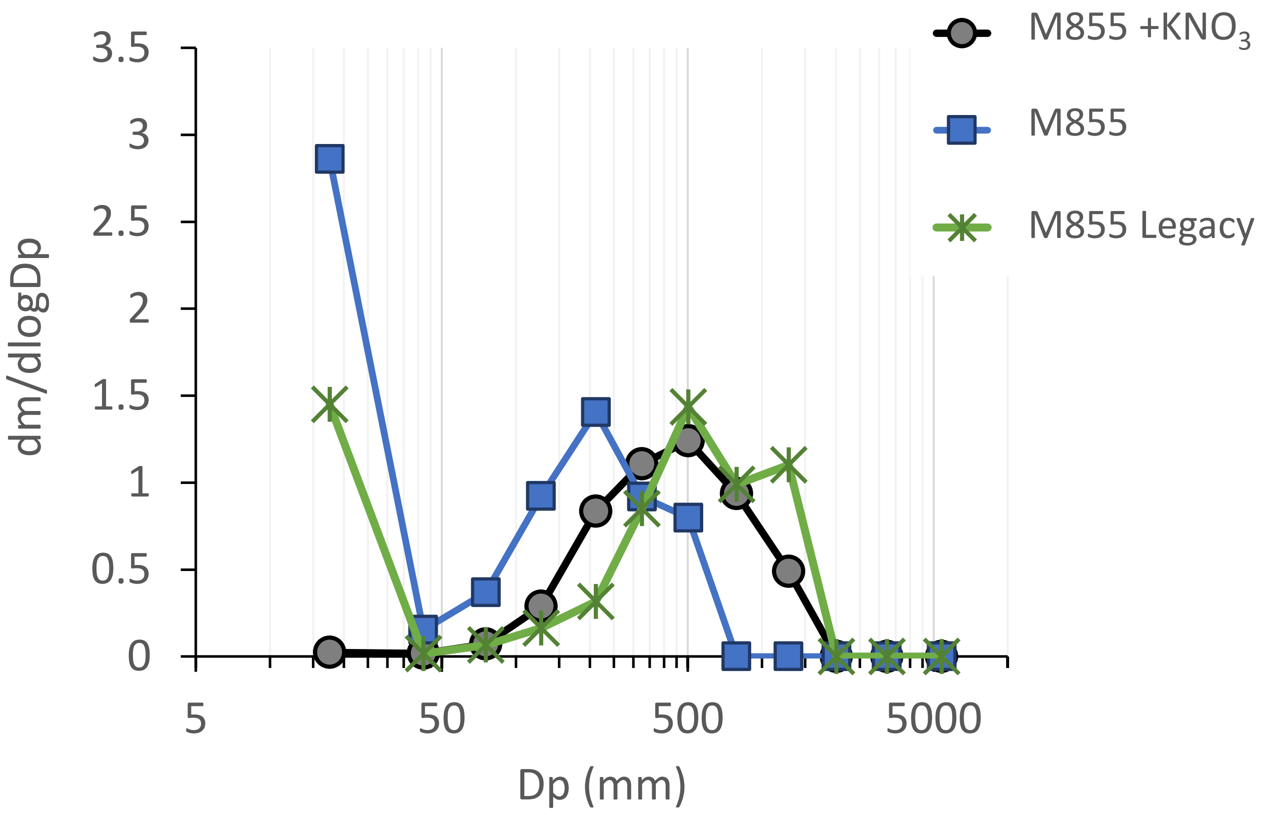
All particles are inhalable

Larger particles deposit in head airways

Small and large particles deposit in tracheobronchial region

Smallest particles deposit in alveolar region

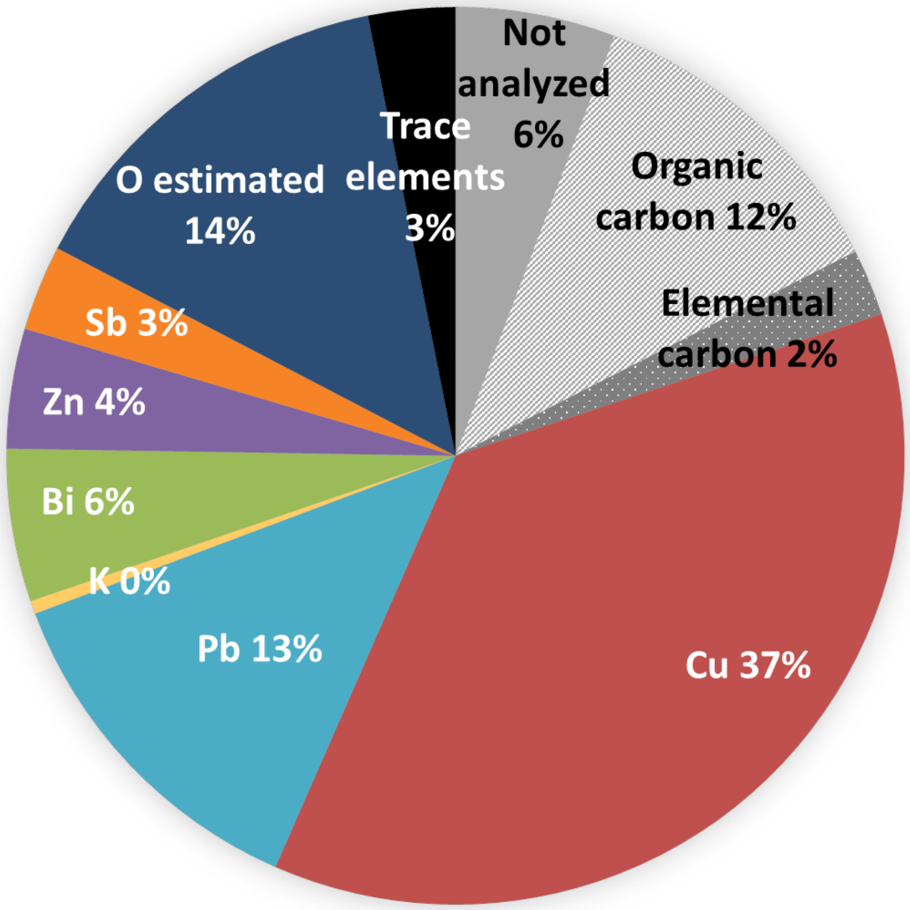
Size Distributions for Different Ammunition



Initial size distribution shows some variation between ammunition types

Addition of KNO_3 anti-flashing agent minimizes mass in the small particle fraction

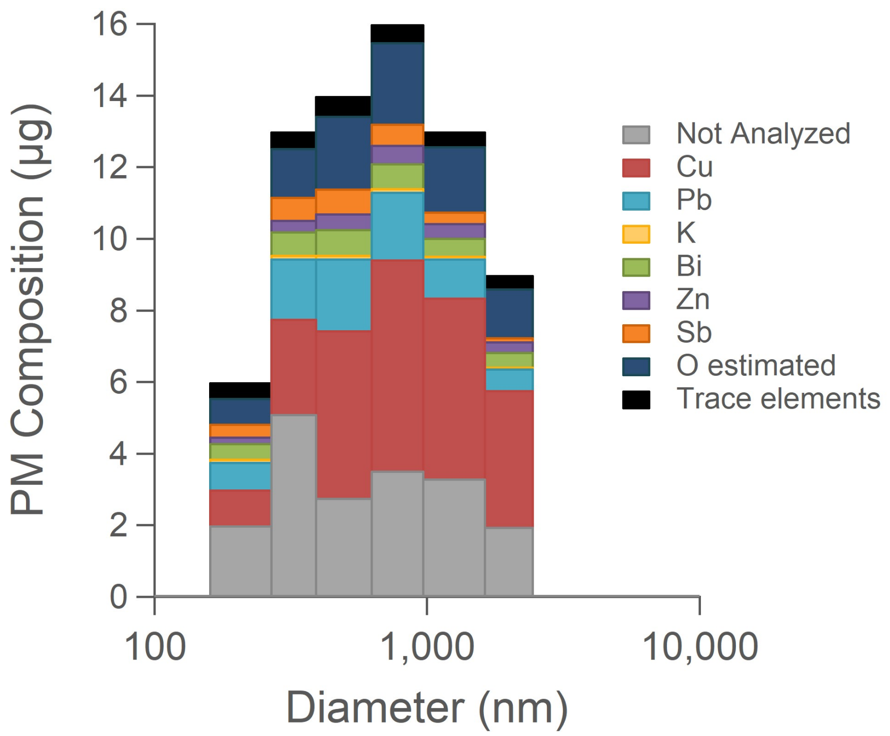
PM Composition



- Major composition is Cu, likely from bullet jacket
- Soot (i.e. carbonaceous particles generated from combustion) is only 14% of PM_{10} mass
- Pb is sizable fraction of the PM
- Balance of PM mass are metals like antimony (Sb), Zn, bismuth (Bi)-many of which are toxic

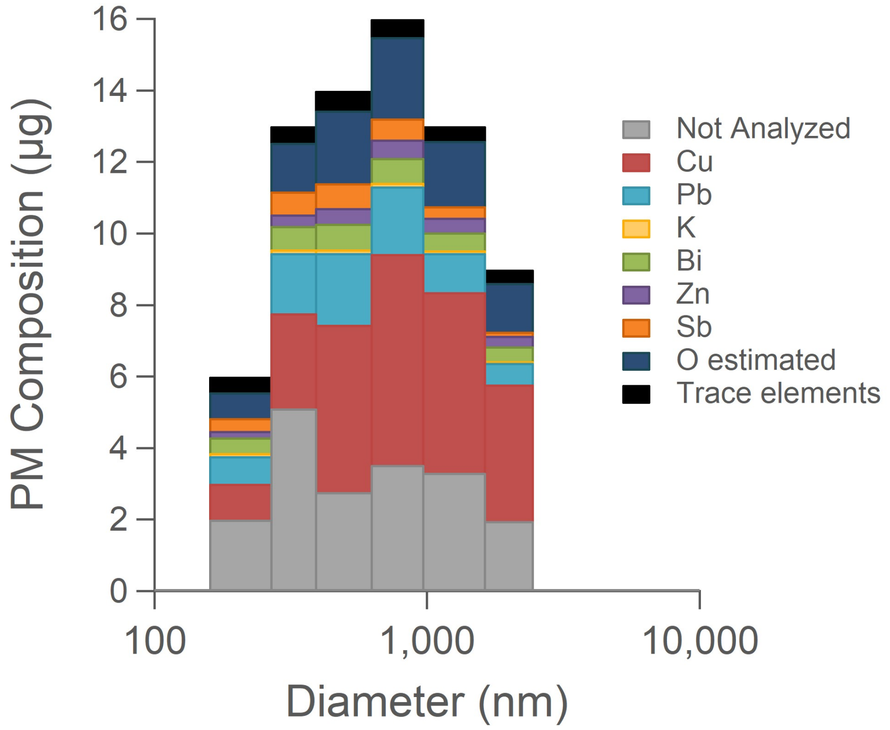
Results: PM Composition by Particle Size

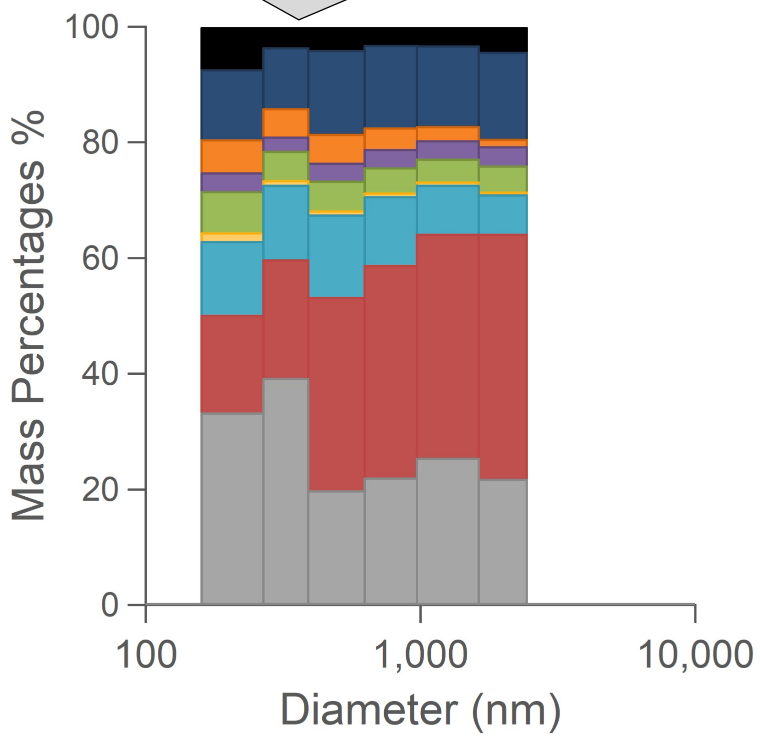
Mass distribution peaks around 1 µm and elements are distributed across all size ranges



PM Composition by Particle Size

Normalizing the mass distribution shows that Cu is enriched in the larger fractions and Pb, Bi, Sb are enriched in the smaller size fractions





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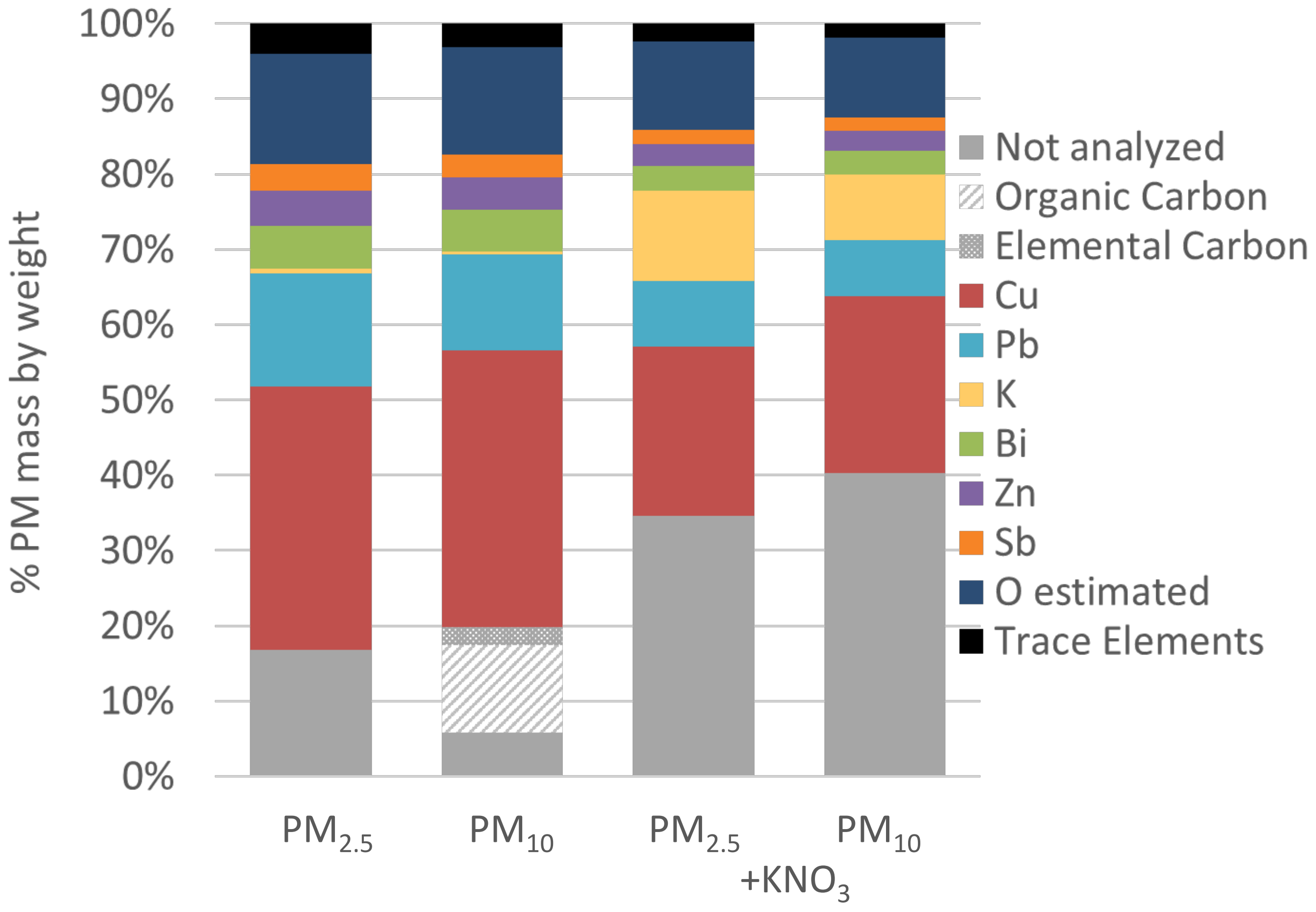
PM Composition Variation with Ammo Type



- $PM_{2.5}$ and PM_{10} compositions are almost identical (most PM mass is ultrafine)
- Elevated K levels with addition of KNO_3 for flash suppression
- Likely more soot formed with flash suppression

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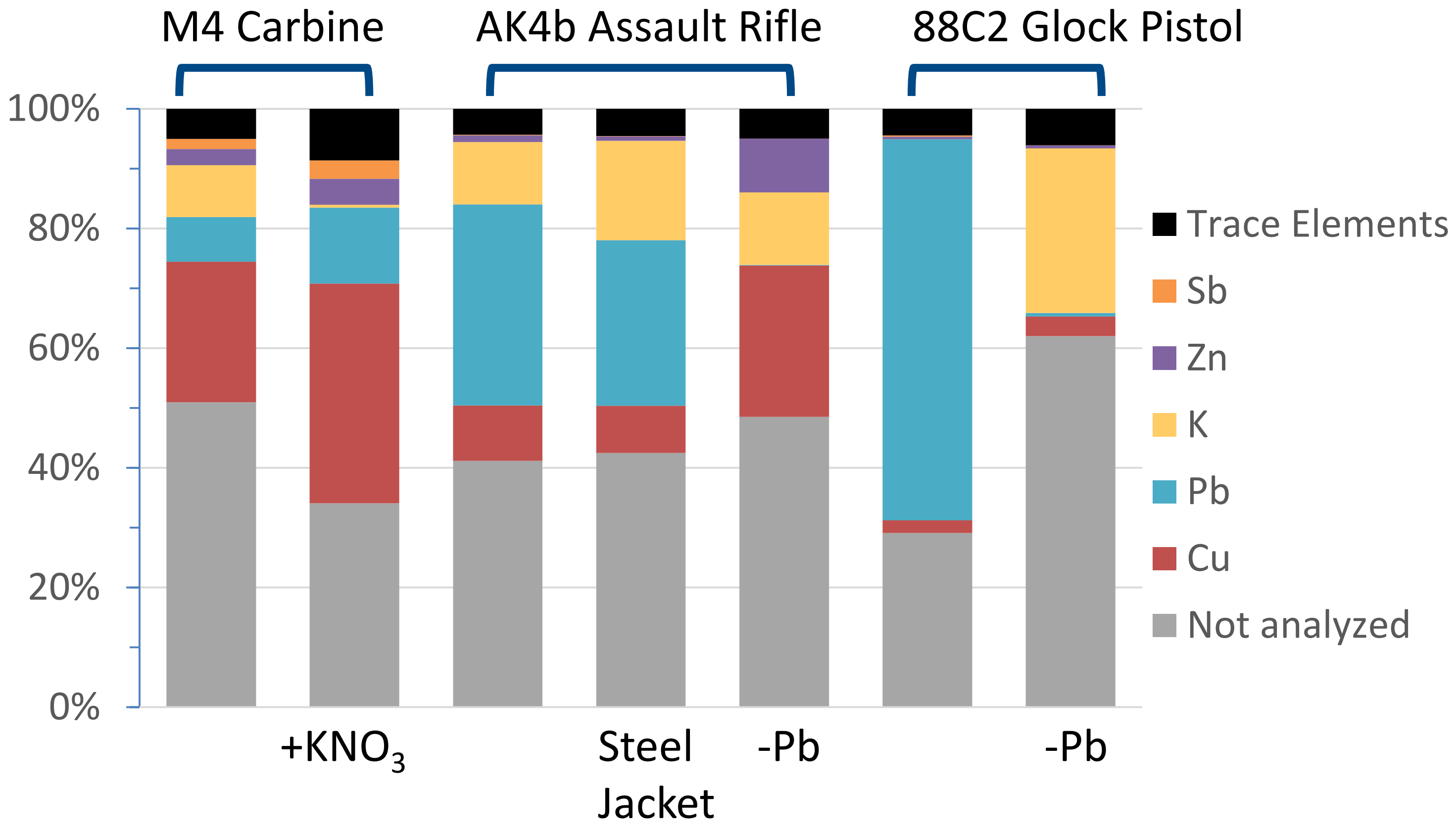
Comparison with Emissions from Other Guns



Bergstrom et al. Journal of Toxicology and Environmental Health, Part A (2015)

Weapon/ Caliber (mm)	Bullet Composition
M4 (5.56)	Cu/Zn alloy Jacket, Steel Penetrator, Lead slug
$+KNO_3$	KNO_3 flash suppressor
AK4B (7.62)	Cu/Zn alloy jacket, lead slug
+Steel	Steel jacket, lead slug
-Pb	Lead free
88C2 (9)	Cu-Zn alloy covered steel, lead slug
-Pb	Lead free

EPA

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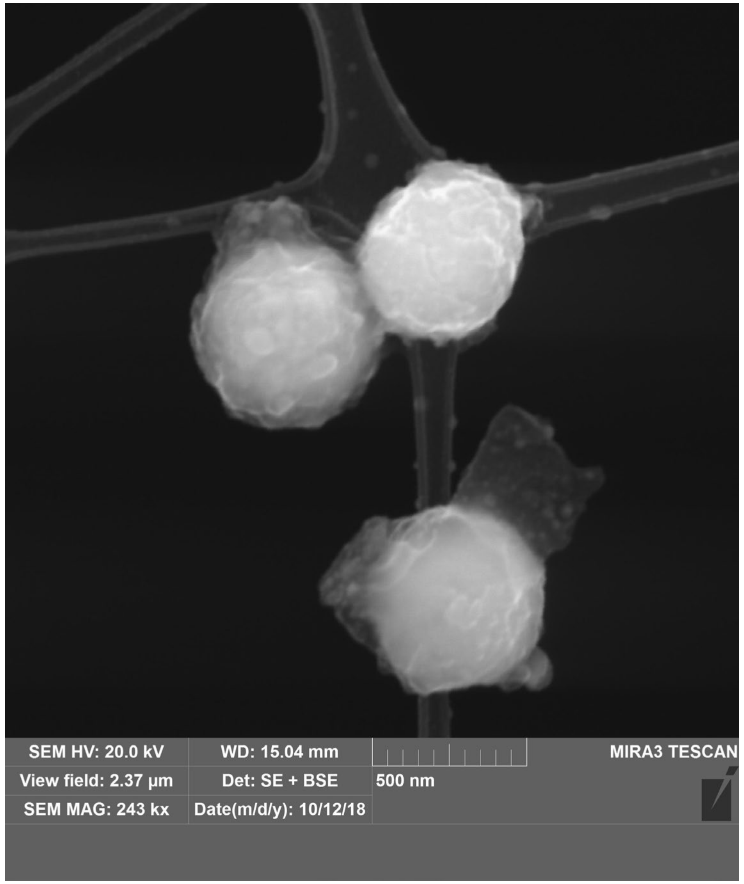
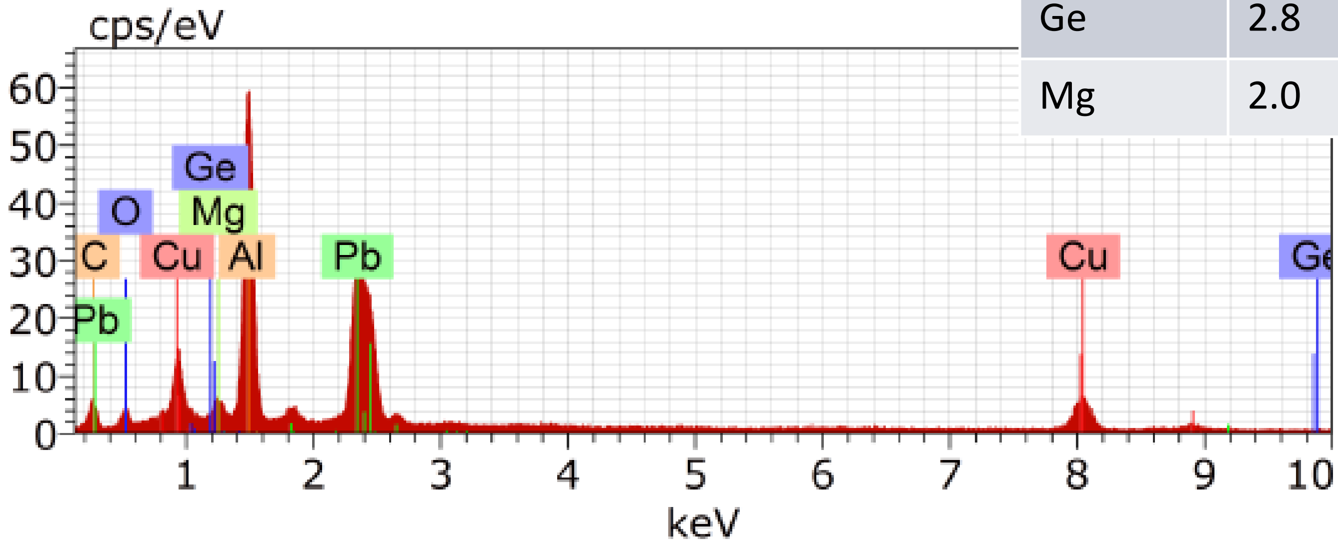
Results: PM Morphology



Mostly spherical particles containing a variety of metals derived from different parts of the bullet

Element	Estimated Weight %	
	Particle 2	Particle 1
Pb	45.3	1.5
Al	24.5	36.6
C	14.0	34.3
Cu	14	51.1
O	7.3	7.8
Ge	2.8	2.3
Mg	2.0	3.1



Conclusions

High PM number and mass emissions were observed from gun firings

- Dose in unventilated areas may be high

Size distribution similar to other combustion emissions

- Almost all PM is respirable and in the fine range (< 2.5 µm)
- Almost all PM number is in the ultrafine range (< 100 nm) capable of depositing deep in the lung

PM is composed of numerous toxic metals: Cu, Sb, Pb

- PM composition derived from bullet composition
- Metals are distributed across all particle sizes
- Harmful metals (e.g. Pb) are enriched in the ultrafine fraction