

Lead Emission and Assessment



Image showing a filter sampler at the Grand Forks airport on August 19, 2025 with students Bryce Rickbeil and Jenna Post.

Learning Objectives

- Explain the sources and historical trends of atmospheric lead emissions.
- Describe the atmospheric chemistry and transport of lead particles/
- Assess the health and environmental impacts of lead exposure.
- Understand measurement techniques and monitoring networks for atmospheric lead.
- Evaluate the effectiveness of regulatory approaches to lead pollution control.

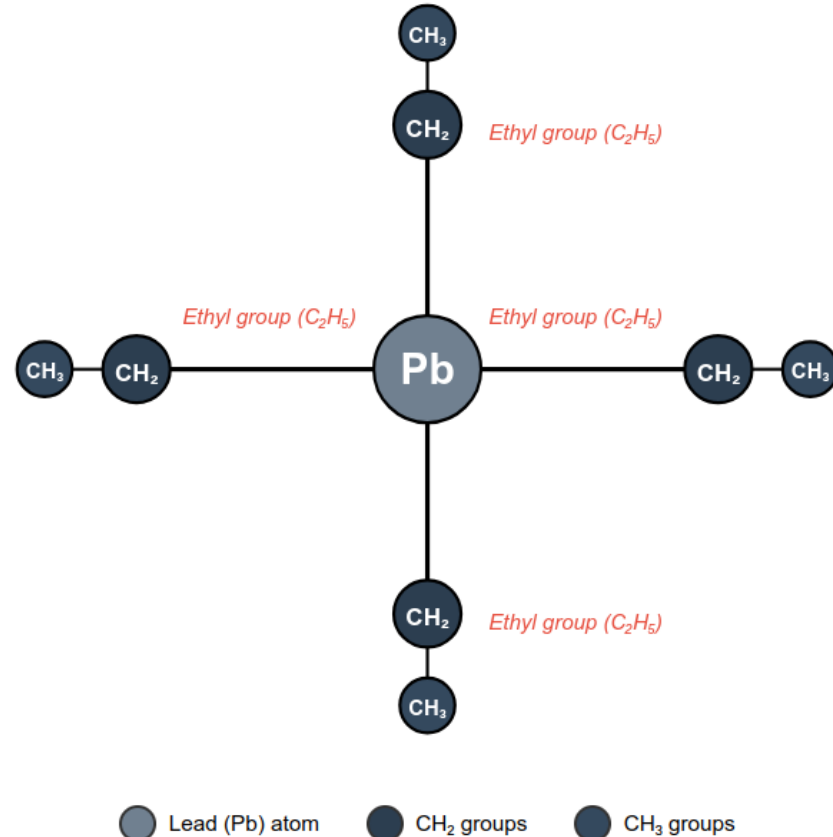


Image showing a high volume filter sampler on top of Clifford Hall and a filter sample obtained with the sampler.

Lead as an Air Pollutant

- Key Characteristics
 - Exists as particulate matter (PM_{2.5})
 - Atmospheric lifetime of days to weeks
 - Does not degrade in the environment
 - Bioaccumulative and neurotoxic at low concentrations
- Common Forms of Lead
 - Lead oxides (PbO, PbO₂)
 - Lead sulfate (PbSO₄)
 - Lead chloride (PbCl₂)
 - Organometallic compounds

Tetraethyl Lead (TEL) $\text{Pb}(\text{C}_2\text{H}_5)_4$ or $(\text{CH}_3\text{CH}_2)_4\text{Pb}$



What are Organometallic Compounds?

Tetraethyl Lead Usage

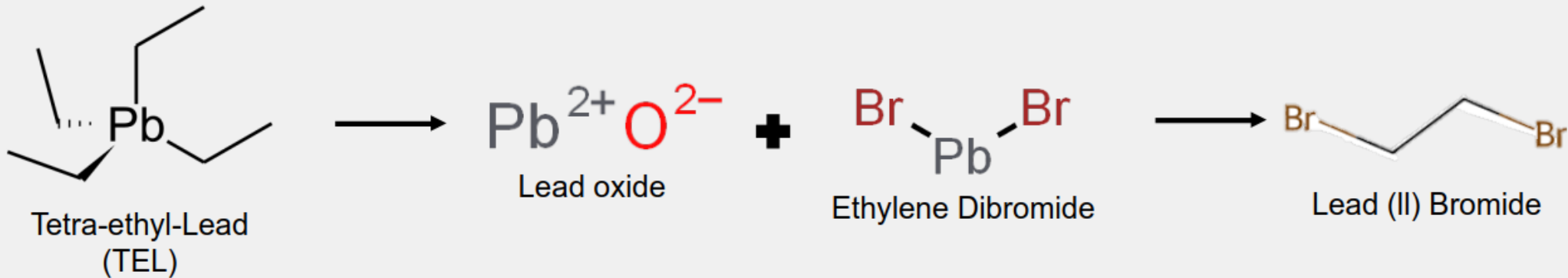
- In 1921, Thomas Midgley Jr. discovers that tetraethyl lead (TEL), which eliminates engine knock.
- Peak United States Usage:
 - Lead usage peaked in the 1970s.
 - Gasoline had 2-3 grams of lead per gallon.
 - The United States used over 200,000 metric tons/year of tetraethyl lead.
 - The urban concentrations of lead was over $2 \mu\text{g}/\text{m}^3$.



Image showing portrait Thomas Midgley, Jr. (1889-1944). Image is courtesy of Science History Institute.

Tetraethyl Lead (TEL) in LL100 Fuel (Avgas)

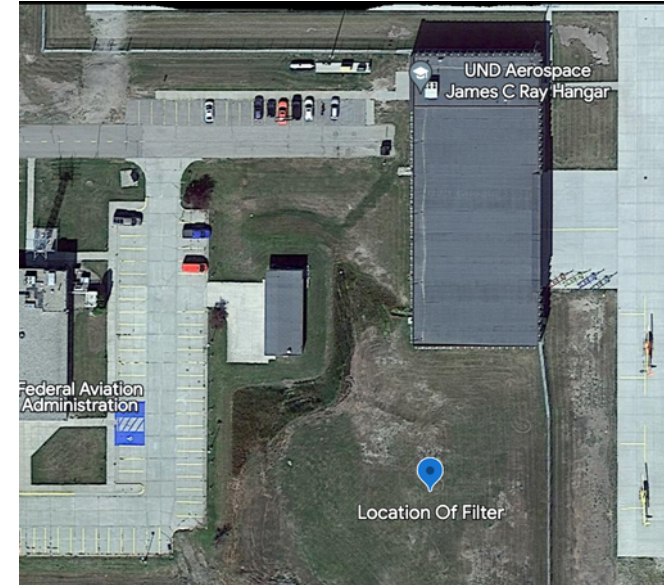
- As LL100 fuel burns, TEL naturally degrades to lead oxide which is what increases the octane rating.
- Deposits are formed due to lead oxides high melting point.
 - These deposits are electrically conductive and is corrosive.
- To prevent deposits forming, ethylene dibromide is used to react with lead oxide to form lead bromide which is a more volatile and a gas around a lower temperature to ensure that lead will be fully exhausted from the engine.



Tetraethyl Lead (TEL) in LL100 Fuel (Avgas)

- Exhausted gas cools to the solid phase in the atmosphere where the lead exists/evolves into different leaded compounds and ions.
- Leaded compounds travel long distances in the air before going into the soil and possibly groundwater.
- Exposure to these lead sources will lead to disruptions of tightly regulated processes due to lead's stronger binding affinity compared to these metal ions (Ca^{2+} , Mg, Zn, Fe, et...) which are known to be involved within functions in biological systems.

UND Aerospace general aviation airport was chosen for the location of high-volume sample. Daily and weekly samples have been collected.

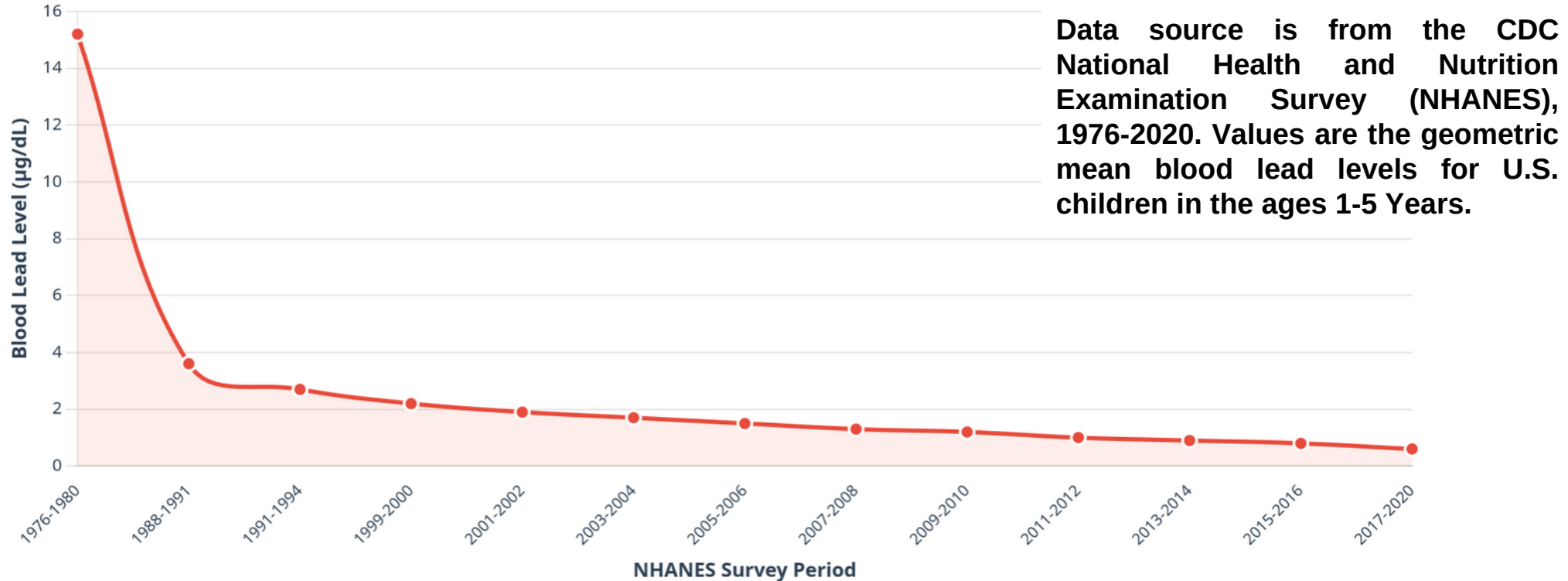


Overview of Health Effects of Lead

- No safe threshold for lead exposure in children
- Bioaccumulation
 - 99 % of blood lead is bound to red blood cells.
 - Lead accumulates in bone with a half-life of years to decades.
 - Children absorb 50 % compared to 10-15% in adults.
- Children
 - Developing Nervous Systems
- Pregnant Women
 - Lead Crosses Placental Barrier
- Occupational Exposure
 - Industrial Workers

Tetraethyl Lead Health Impacts

- Had a massive population exposure.
- Resulted in elevated levels of lead in the blood of people.
- Had neurodevelopmental effects on people.



Neurological Effects of Lead

- **Children**

- Decreased Intelligence
- Impaired Cognitive Function
- Reduced Academic Achievement
- Behavioral Problems
- Effects at Blood Lead <10 $\mu\text{g/dL}$

- **Adults**

- Peripheral Neuropathy
- Cognitive Decline

Mechanisms

- Interferes with Neurotransmitter Function
- Disrupts Calcium Homeostasis
- Impairs Synaptogenesis
- Alters Myelination
- Induces Oxidative Stress

Reduction of Lead in the Environment

- 1970: US Clean Air Act passed
- Mid-1970s: US Phase-down begins
- 1996: Complete elimination from on-road gasoline in the US.
- In 2021 Algeria is the last country to eliminate leaded from gasoline.

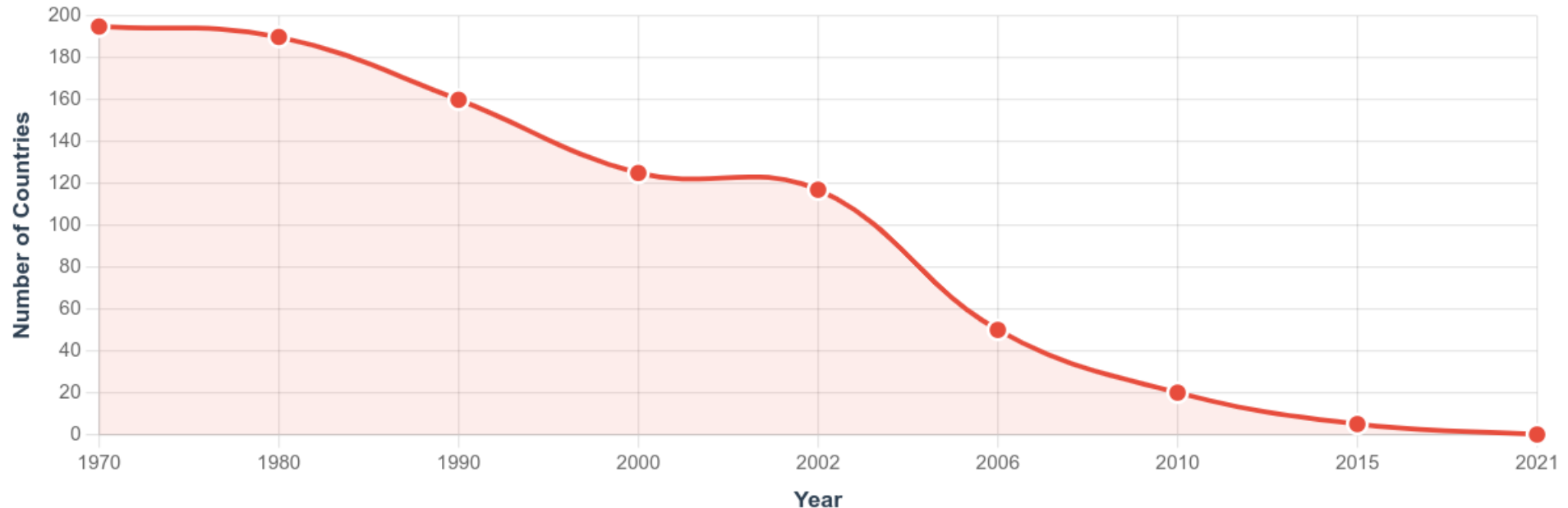


Image showing the reduction of countries using leaded gasoline. Data source is the United Nations Environment Programme (UNEP), 2011 & 2021.

Contemporary Sources of Lead

- **Industrial**
 - Lead Smelters and Refineries
 - Battery Manufacturing
 - Non-ferrous Metal Smelting
- **Aviation**
 - Piston-engine Aircraft use Leaded Avgas
 - Elevated Lead near Small Airports.
- **Other Sources**
 - Waste Incinerators
 - Coal Combustion
 - Resuspended Legacy Contamination

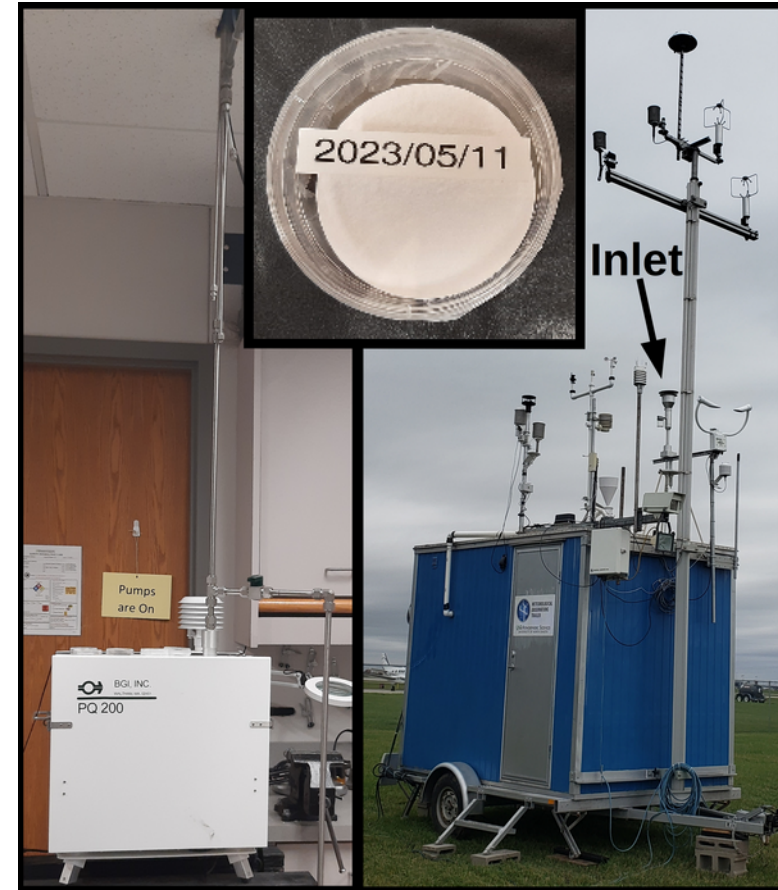


Image showing filter sampler (left), the MetTrailer (right), and a filter sample (top).

Lead Measurements and Monitoring

- **Sampling Methods**

- High-volume Air Samplers
- Size-selective Inlets
 - TSP, PM₁₀, PM_{2.5}
- Teflon or Quartz Filters
- 24-hour Integrated Samples

- **US Monitoring Network**

- ~130 Monitors Strategically Located near Known Sources

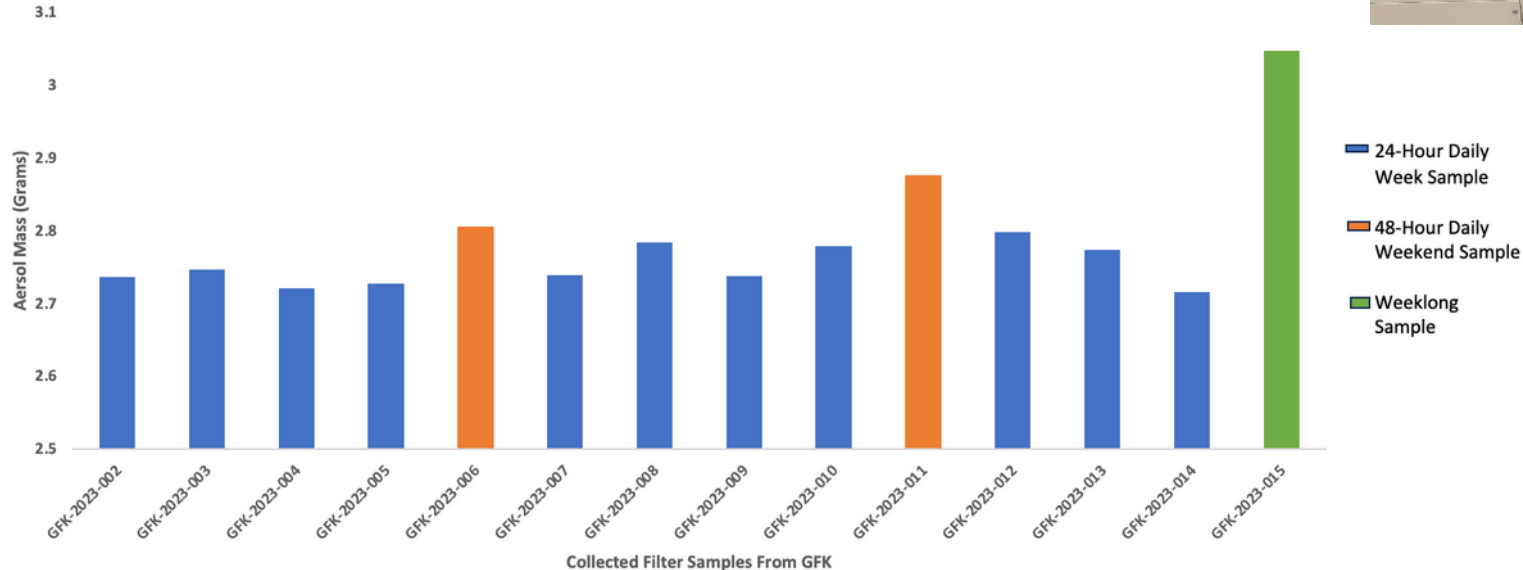
Analytical Methods

- X-ray fluorescence (XRF)
 - Routine Monitoring
- ICP-MS
 - Ultra-low Detection Limits
- Atomic Absorption Spectrometry (AAS)
- Isotopic analysis - source apportionment

X-ray Fluorescence (XRF)

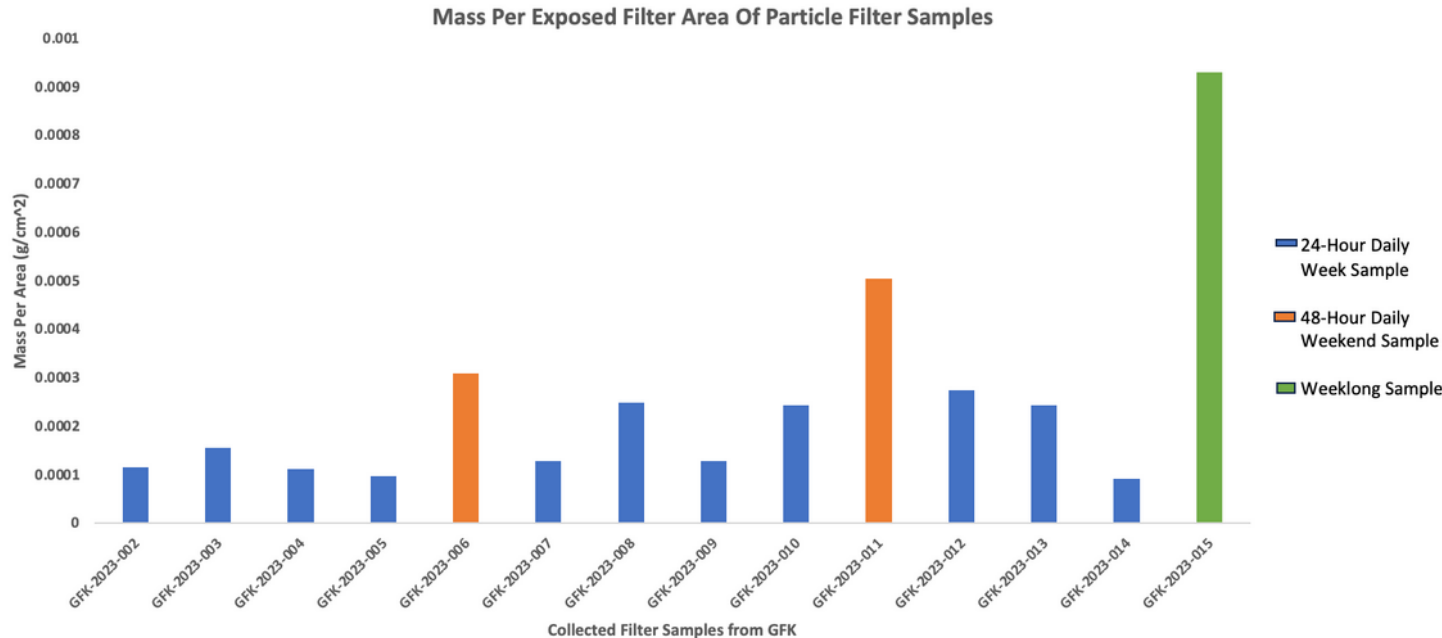
- 8" x 10" glass fiber filter daily and weekly samples were collected. Glass fibers samples were pre and post weighed. X-Ray Fluorescence (XRF) was used to analyze the elemental composition of each filter sample.

Collected Aerosol Mass of Particle Filter Samples



X-ray Fluorescence (XRF) Analysis

- Collected daily and week-long samples.
- Average aerosol mass for each daily sample was 2.78 grams.
- Weights of each sample are affected by factors such as the day of the week, and the weather on that day; therefore, weather data was kept track for each day throughout the summer.



Lead Source Apportionment Methods

- **Isotopic Analysis**
 - 4 Stable Pb Isotopes: ^{204}Pb , ^{206}Pb , ^{207}Pb , ^{208}Pb
 - Ratios Vary by Ore Source
 - Enables Quantitative Source Attribution
 - Measured by TIMS or ICP-MS
- **Chemical Mass Balance**
 - Uses Multiple Chemical Species
 - Requires Source Profiles
 - Linear Combination Approach
- **Positive Matrix Factorization**
 - Multivariate Statistics
 - No Pre-specified Profiles Needed
 - Incorporates Uncertainty

Summary

- Lead pollution has severe health effects with no safe threshold in children.
- Leaded gasoline has been reduced.
 - US children blood lead changed from 15 to <1 $\mu\text{g/dL}$
 - Atmospheric lead reduced greater than 90 %
- Contemporary sources are industrial facilities, **aviation fuel**, and legacy contamination.
- Monitoring shifted from broad coverage to source-oriented approach.
- Regulatory frameworks combining standards, controls, and phase-outs proved effective.