AN ANALYSIS OF FRESH AND USED AIRCRAFT OIL: AN INDICATION OF EXPOSURE PATHWAY POSSIBILITY TO INORGANIC AND ORGANIC POLLUTANTS

Kevin Hayes

khayes@mtroyal.ca

Tuesday January 13th, 2026

17th Multidimensional Chromatography Workshop

Aircraft Oil

- Aircraft engines require oils that meet MIL-SPEC standards, with different formulations used for piston, turboprop, and jet engines based on temperature and wear demands.
- Oils are often sold with proprietary additive packages to prevent wear, coking, corrosion, and provide thermal stability.
- Oil complexity may be increased by aftermarket additives, which may be optional or mandated by manufacturers or airworthiness directives.

Jet (Turbofan), Turboprop, and Piston Engine Aircraft

The purpose of our study

- Aircraft engine oils and their additives are a documented source of potential occupational exposure, with unfiltered bleed-air pathways allowing oil-derived contaminants to reach aircraft cabins and flightcrews.
- Prior studies have successfully identified oil-related contaminants in aircraft interiors using organic analytical methods, but these typically detect very low surface concentrations and focus on a narrow set of compounds.
- Previous research related to aircraft oil assessment for occupational risk has focused almost entirely on unused oils and has not accounted for how engine operation alters oil composition; comparing new and used oils across engine types directly addresses this gap by revealing elemental accumulation or loss, clarifying exposure pathways, and better defining the occupational risks faced by those who operate and maintain aircraft.

Routine Multi-Elemental Analysis

We had a strong starting off point.

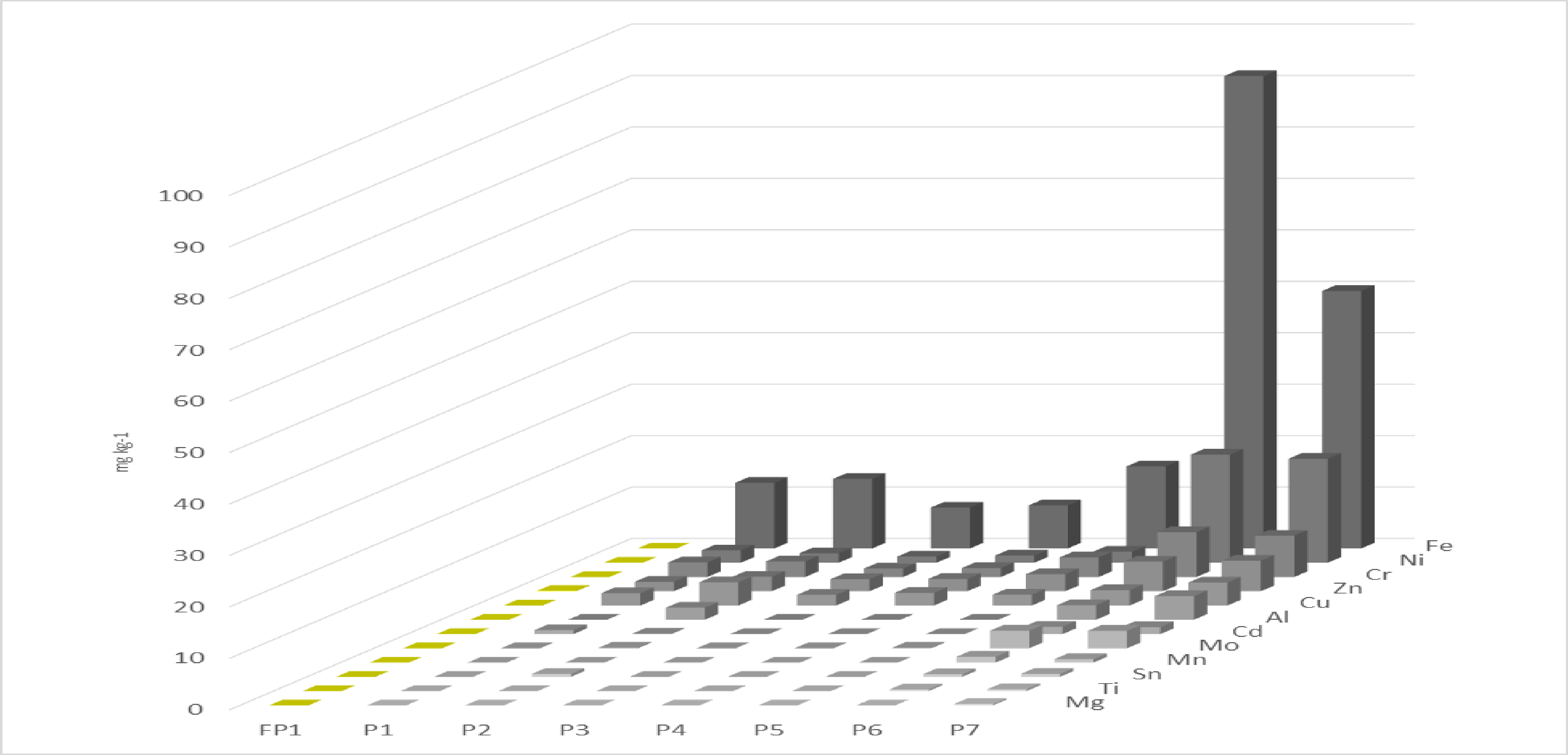
- Standard tool for monitoring aircraft engine wear and oil condition.
- Detects wear metals, additive depletion, and contamination
- Enables early fault detection and preventative maintenance.

We took this a step further to examine operational and occupational exposure risk.

Our elemental analysis – Methods

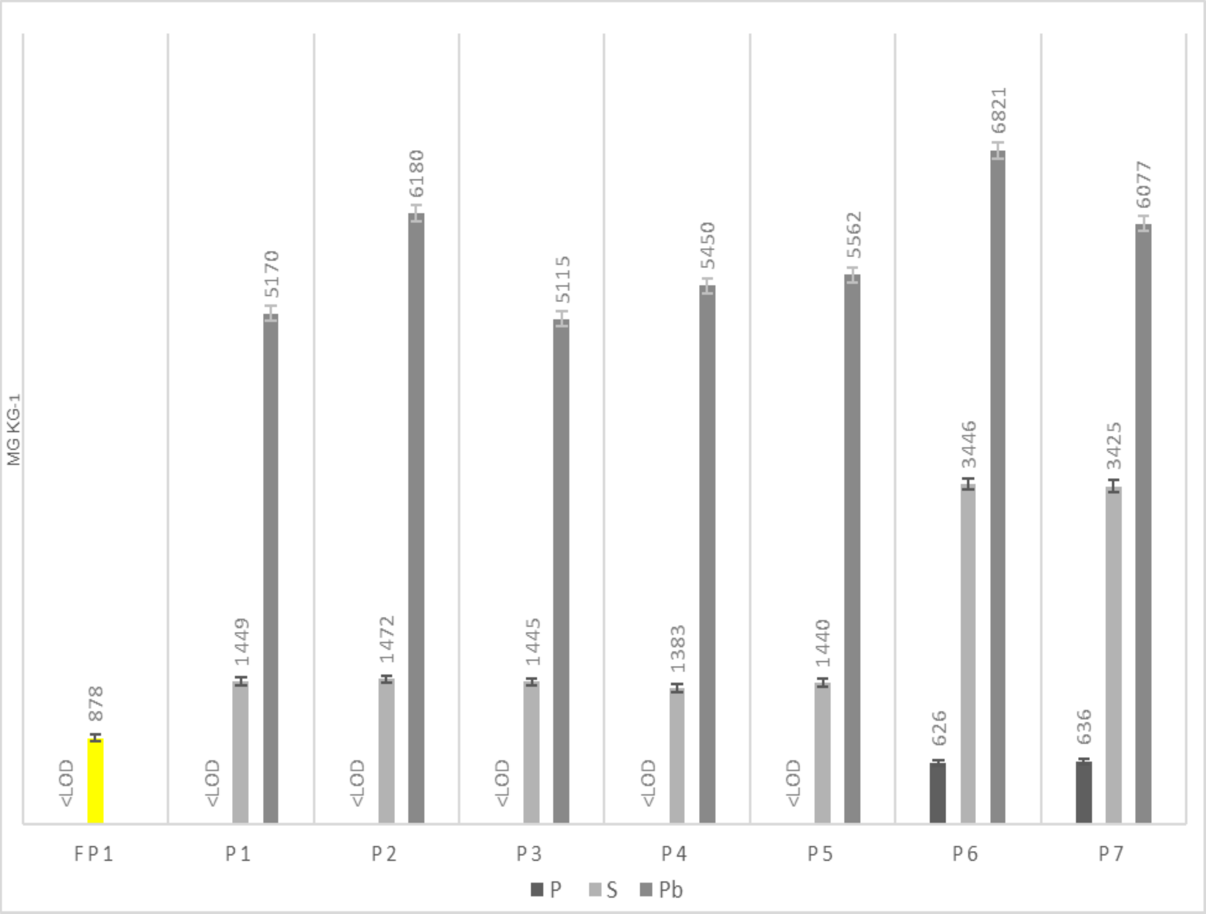
- We collected used piston and turboprop aircraft engine oil with the assistance of the MRU Aviation Program. Used Jet oil was collected from a private jet carrier in Europe.
- Matching new oils were purchased commercially.
- Elemental Analysis was performed using an ICP-OES set up for organics analysis.

Our elemental analysis – Wear Metals Results



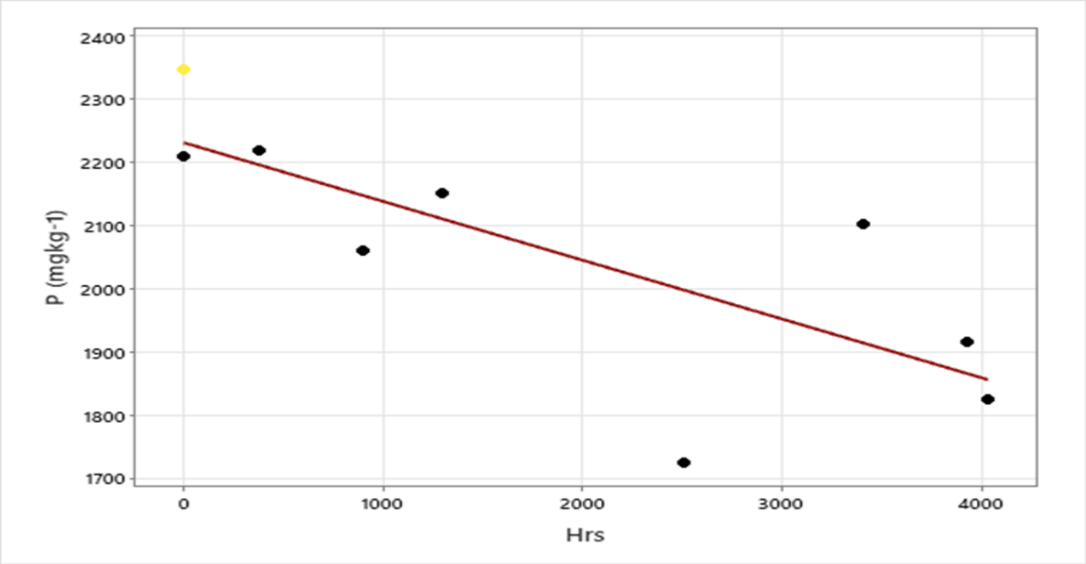
Our elemental analysis – Lead and Phosphorus (Piston)

- Sulfur was present in both new piston engine oil and 100LL fuel, and was found to increase in used oils, with higher sulfur levels observed after normal engine operation.
- Lead was not detected in new oil but accumulated to very high concentrations in used piston engine oils, reflecting the use of tetraethyl lead in 100LL fuel and its retention within the engine–oil system.
- Phosphorus is not expected from the fuel and was not detected in new oil, yet it appeared in some used oil samples, indicating additional contributions to oil.



Our elemental analysis – Lead and Phosphorus (Jet and Turbine)

- Phosphorus was the only element detected above LOQ in new turboprop and jet oils.
- New turboprop and jet oils contained higher phosphorus levels than used oils, indicating loss of phosphorus-based additives during engine operation.
- Replicate analysis of new jet oil showed an average phosphorus concentration of ~2290 mg kg^{-1}, with substantially lower concentrations observed in used oils.
- These findings suggest additive depletion with use, though interpretation is limited by small sample size and lack of detailed engine and operating data.



mg kg^{-1}	FJ1	J1	J2
P	2291 (± 48)	1424 (± 38)	1829 (± 43)
S	<LOD	158 (± 13)	244 (± 16)
Ba	<LOD	20 (± 5)	23 (± 5)

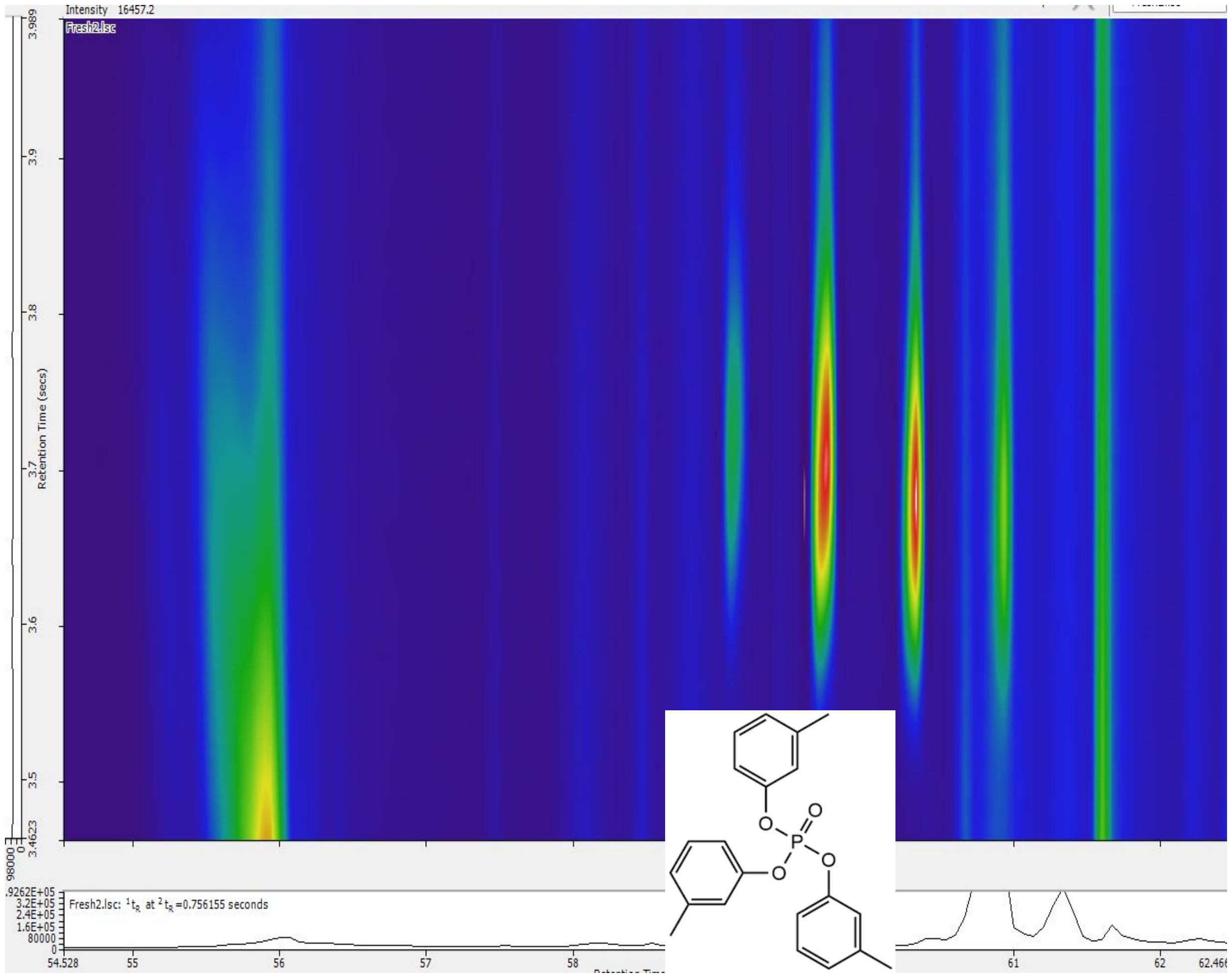
Potential for increased occupational risk?

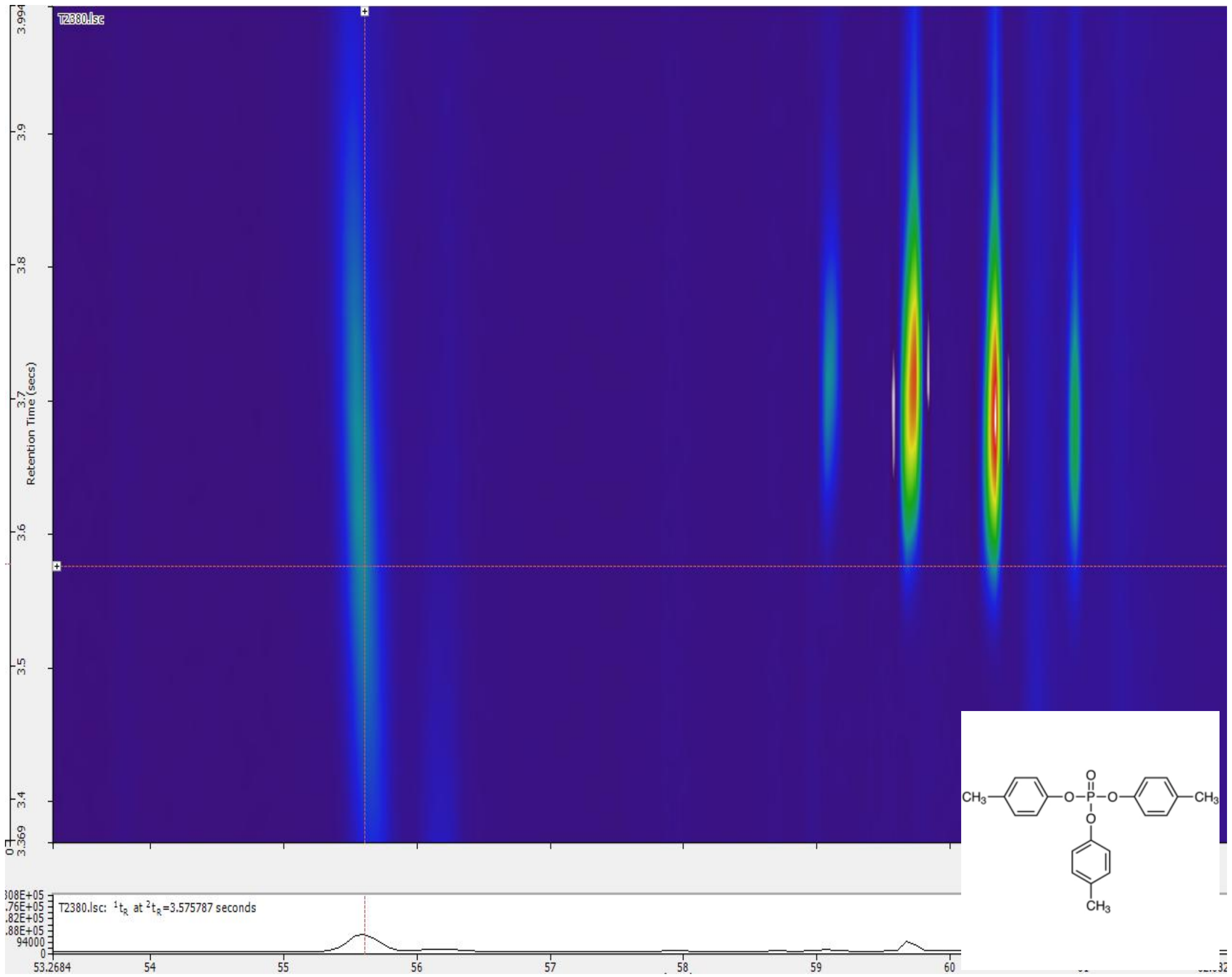
- **Piston engine oils: accumulation and contact risk.** Lead from 100LL fuel accumulates in used piston engine oil but is not identified in oil safety data sheets, despite its known toxicity and ability to be absorbed through the skin. Direct contact with used oil is common during maintenance, and while newer manuals caution against skin exposure, older guidance is inconsistent. Phosphate compounds also accumulate in used oil, altering its composition and potentially posing additional risk depending on their chemical form.
- **Jet and turboprop oils: phosphorus loss and bleed-air implications.** In jet and turboprop engines, phosphorus is lost from the oil during operation, an this suggests that phosphorus-containing compounds are being released or otherwise lost from the oil. This is particularly relevant for bleed-air systems and is amplified by commercial aircraft practices where oil is regularly topped up rather than drained.

GCxGC Method

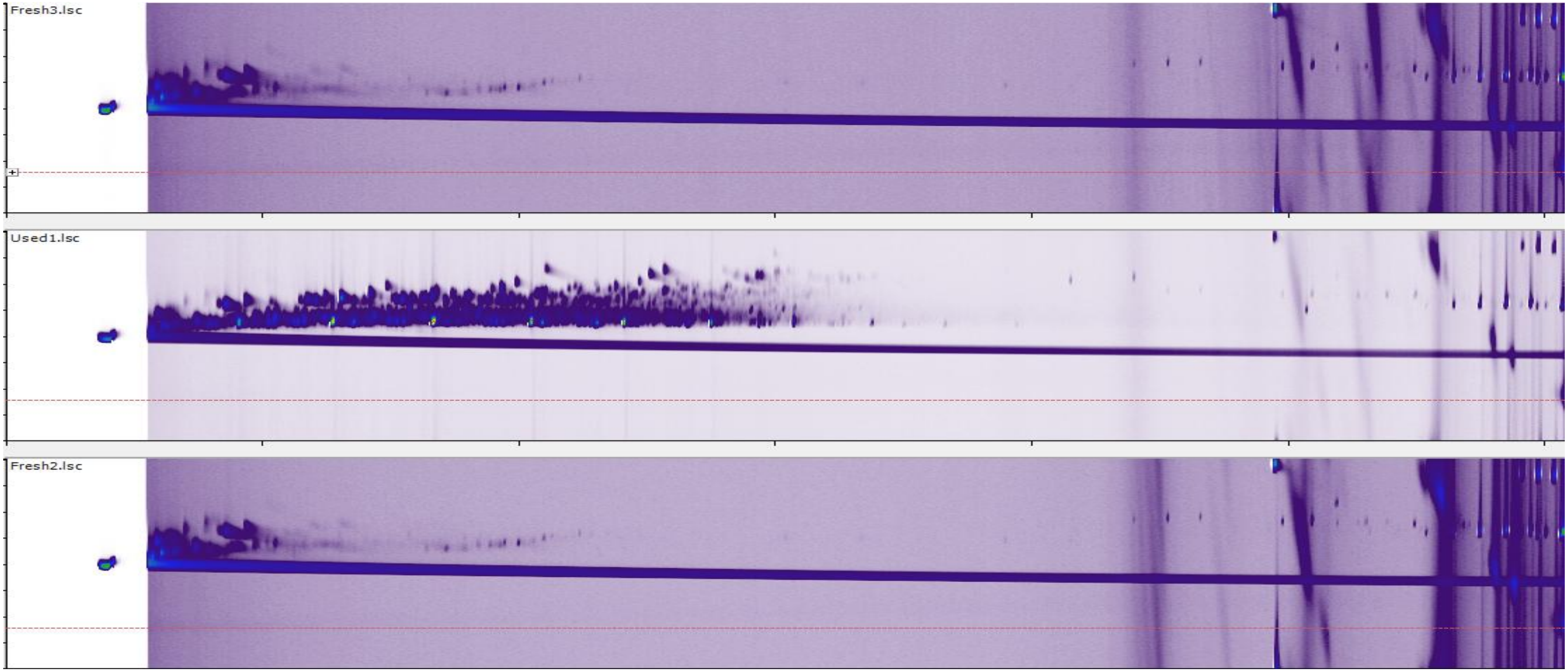
- Instrumental analysis was conducted using flow modulated two-dimensional gas chromatography coupled with time-of-flight mass spectrometry (GCxGC ToFMS).
- Ramp from 60°C at 4°C/min to 320°C
- Modulator – 4 seconds.
- Non-polar 1-D (25m); Semi-polar 2-D (5m).
- Hard ionization = 70eV

Speciation Results – Phosphorus (Jet and Turboprop)

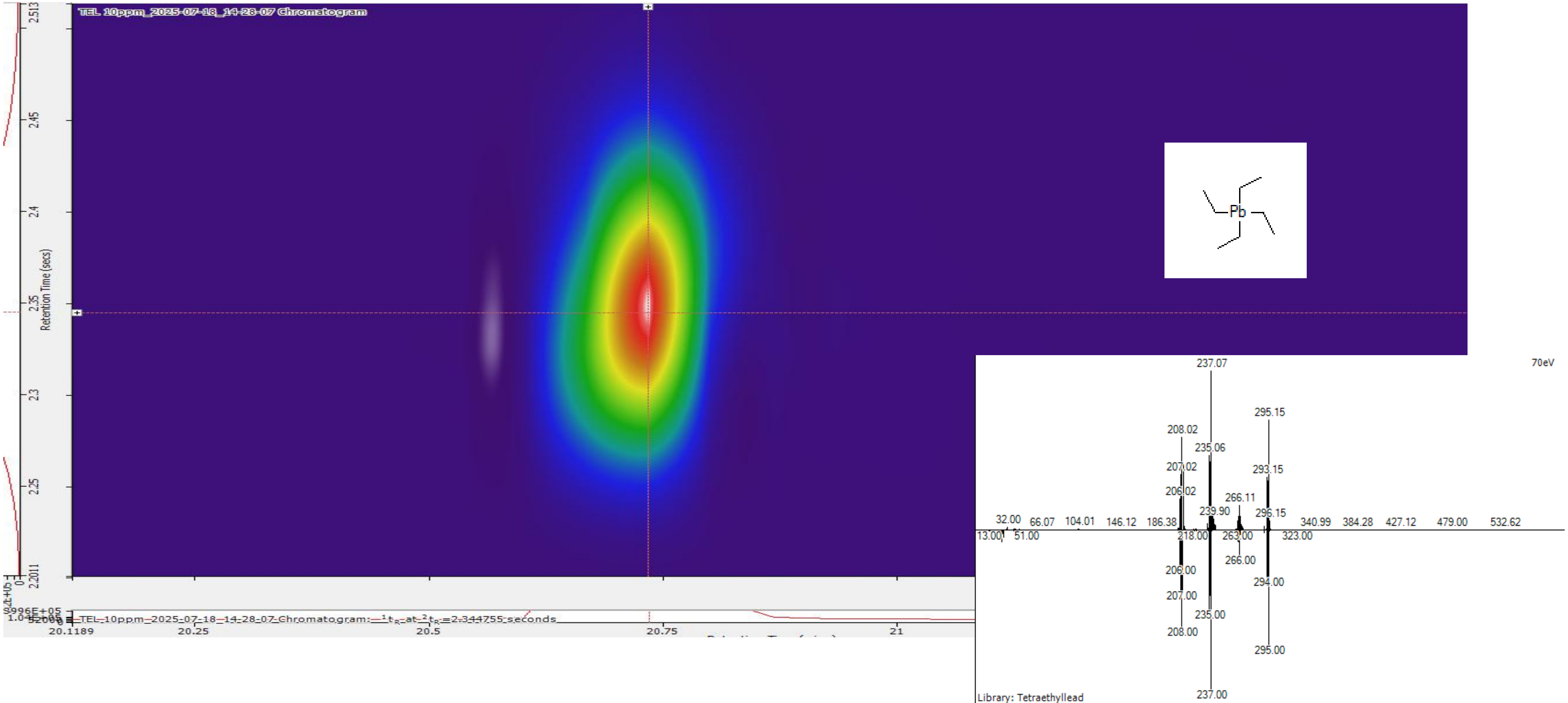




Speciation Results – Phosphorus (Jet and Turboprop)

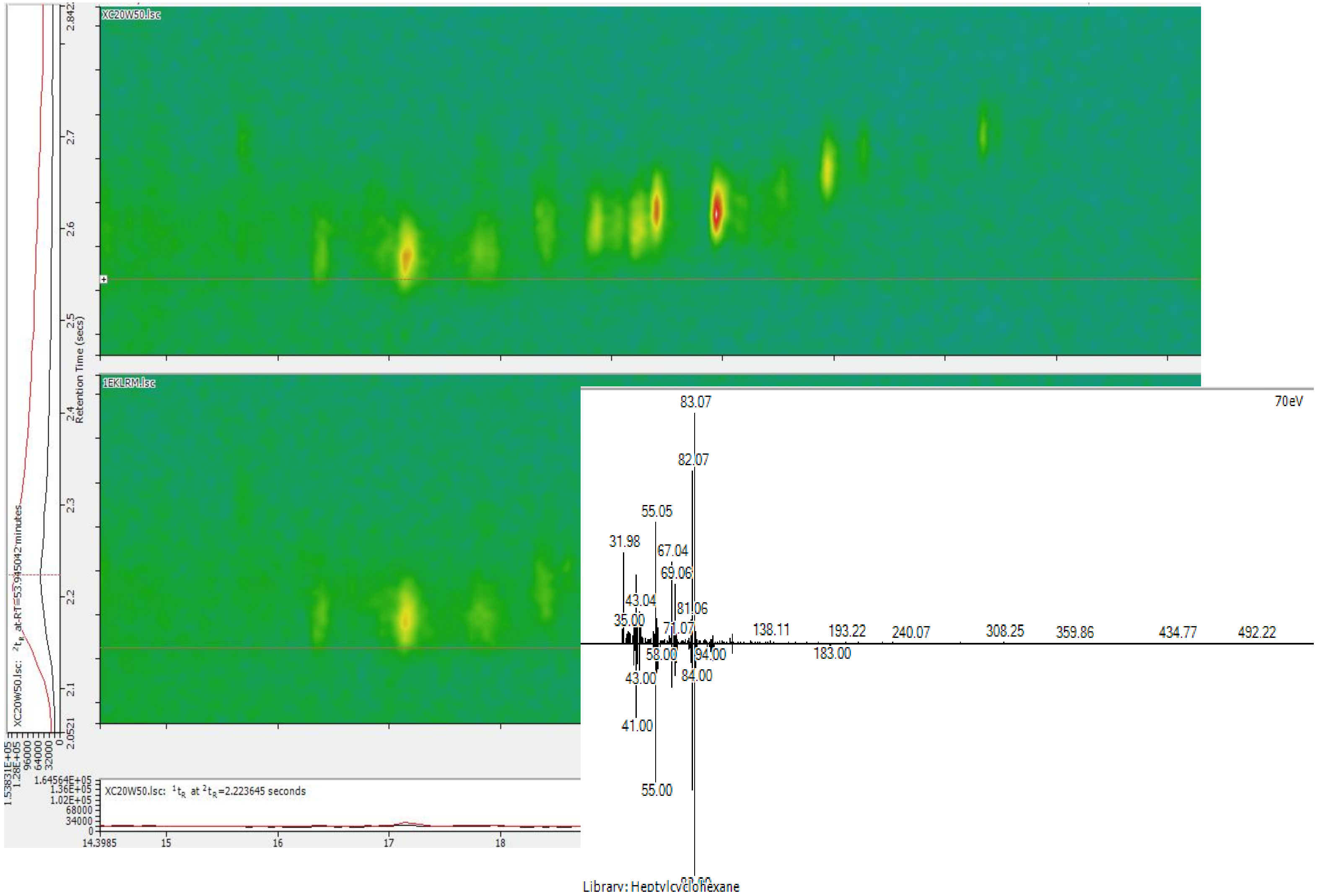


Speciation Results – Lead (Piston)



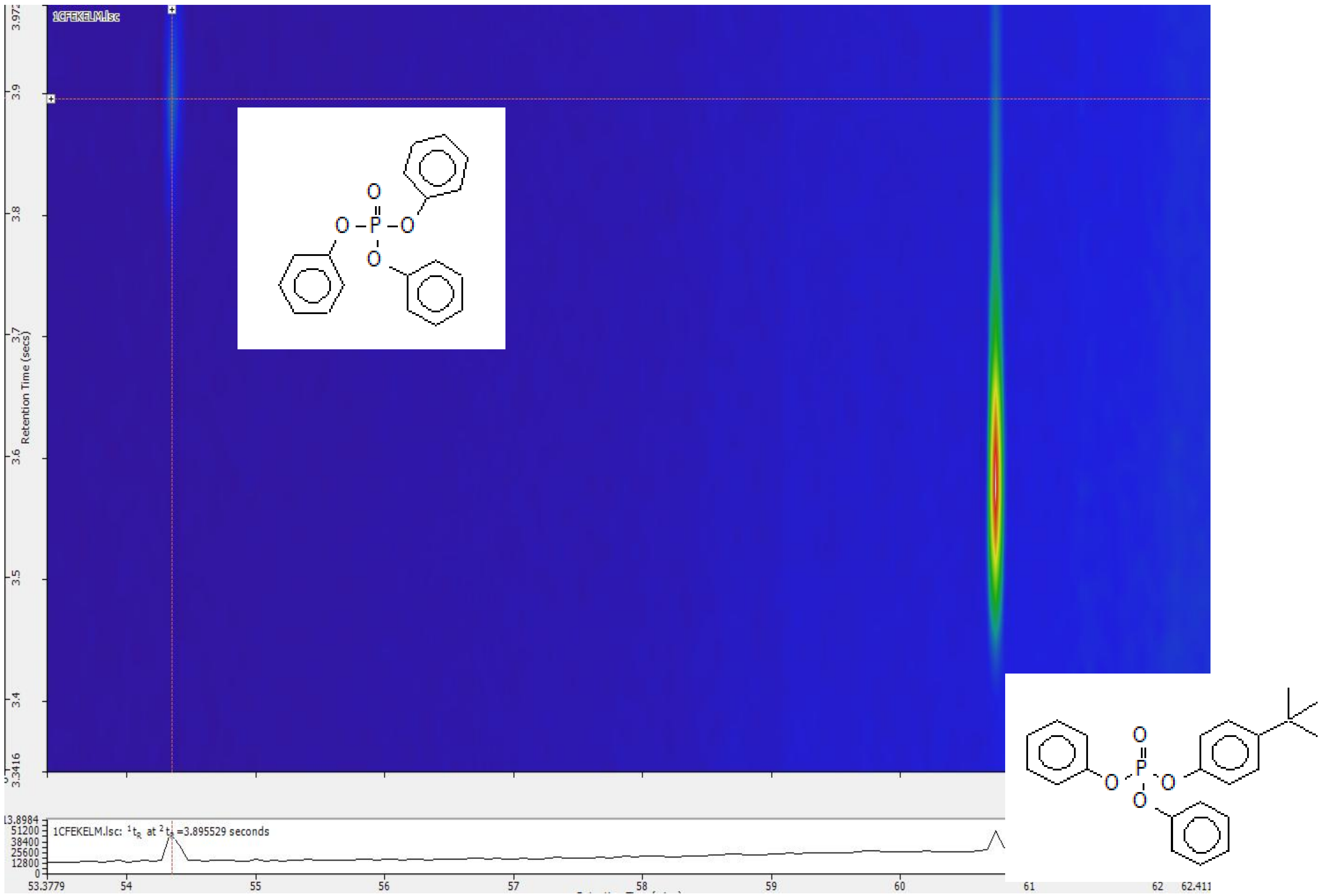
Speciation Results – Lead (Piston)

- No TEL was identified in the used oil samples.
- Likely conversion of the vast majority of TEL to inorganic lead oxide during the combustion process.
- Good, but still toxic.



Speciation Results – Phosphorus (Piston)

- Organophosphates were detected in piston engine oil at relatively high concentrations with no clear engine or environmental source, suggesting they originated from fuel or oil additives.
- Common phosphorus-containing additives, including tricresyl phosphate used in approved fuel and oil treatments, were investigated but not detected in the used oils.
- With GC×GC-ToFMS we instead identified other organophosphates, demonstrating its value in allowing us to move beyond assumptions from prior analyses.



Conclusions

- Aircraft engine oils change substantially during normal operation, with elements and compounds from fuel, additives, and engine processes accumulating or being lost in ways that are not captured by analyses of new oils alone.
- Elemental analysis provides a valuable first-order view of these changes, while GC×GC-ToFMS adds critical molecular-level insight.
- Taken together, these results highlight gaps in current hazard characterization and maintenance-focused assessments, and show that combining elemental and advanced chromatographic approaches offers a more complete basis for evaluating potential occupational and exposure risks.

Acknowledgements

I would like to thank,

Gwen O'Sullivan, David Megson and David McKendry.

Fellow lab members and research assistants within the Environmental Forensics and Arson Lab at MRU - Emily Carroll, Caleb Marx, Kelsey Barratt, and Sam Neumann

The organizing committee of the MDCW

MOUNT ROYAL UNIVERSITY 1910

Manchester Metropolitan University

SepSolve Analytical