

ERA24FA110

AIRWORTHINESS

Group Chair's Factual Report - Attachment 4
GE Research CF34 Liquid Fuel Analysis 051624
May 8, 2025

— GE Aerospace Research CF34 Liquid Fuel Analysis

— GE Aviation Research
Originally Shared: May 3 2024

Active Investigation – The information contained in this document is provided in response to a request from the National Transportation Safety Board (NTSB) and pertains to an active investigation. This document and its contents are intended solely for the purposes of the referenced investigation

Fuel Sample List

Barcode	Sampling location
335617	right engine heat exchanger
335618	left main (unreadable)
335619	right engine fuel filter bowl
335620	left engine heat exchanger
335621	left engine fuel filter bowl
335622	APU
335804	left engine fuel flow meter and fuel manifold
335809	right engine fuel flow meter
335810	AFT tail tank
335811	left engine fuel control unit
335812	right engine fuel pump
335813	right engine fuel control



Summary of Findings – Liquid Fuel Analysis

- The liquid fuel samples were all analyzed for the presence of common fuel additives and biocides known to have caused past fuel systems issues (namely Kathon FP 1.5 biocide, Biobor JF biocide, SAP and Diesel Exhaust Fluid)
- No compounds that could be attributable to Kathon FP 1.5, Biobor JF, SAP or Diesel Exhaust Fluid (DEF) were detected in the fuel samples
- Overall hydrocarbon profiles of the fuel look similar for all samples by both LCMS and 2D GCMS
- In comparison to photographs showing fuel color, no definitive correlation to color based on degree of oxidation of the fuel was observed by LCMS or GCMS
- Sample 335619 right engine fuel filter bowl may contain slightly higher amounts of lower molecular weight species. Further work is needed to identify these lower weight species
- No evidence was observed for biological compounds in any of the fuel samples
- Several of the fuel samples also contained solid particles. A portion of each fuel sample was centrifuged to isolate these solid particles and further analysis is under way to identify the composition of the solid particles. See next slide for particle summary

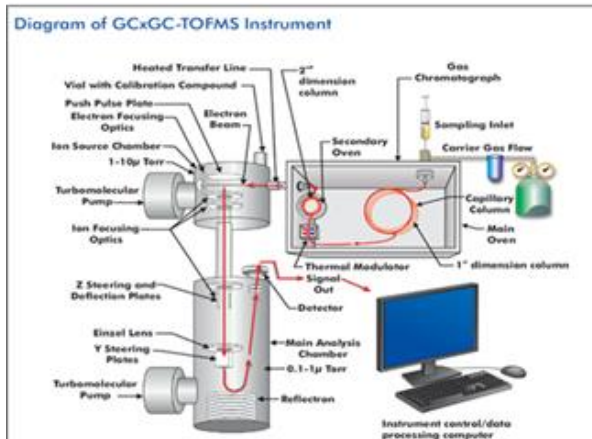
Summary of Findings – Particles Isolated from Fuel

- Several of the fuel samples contained solid particles. A portion of each fuel sample was centrifuged to isolate these solid particles. The collected solid particles were then analyzed by IR spectroscopy and SEM/EDS to assess their chemical composition
- The material and composition of the particles are detailed in the table below
- No particles were found that could be attributable to SAP or Diesel Exhaust Fluid were detected in the fuel samples
- Some fine metal particles (Ti, Cr, Fe, Ni, Cu) are present in small quantities
- O-S-Ca (likely calcium sulfate) crystals were found in 335811
- Solids in 335812 contain significant levels of Ti, which was not observed in the other samples

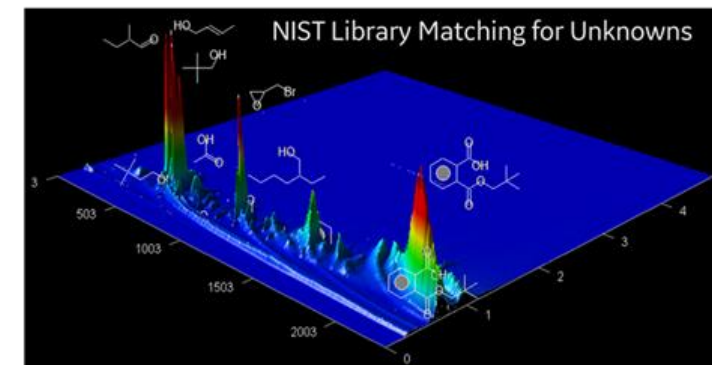
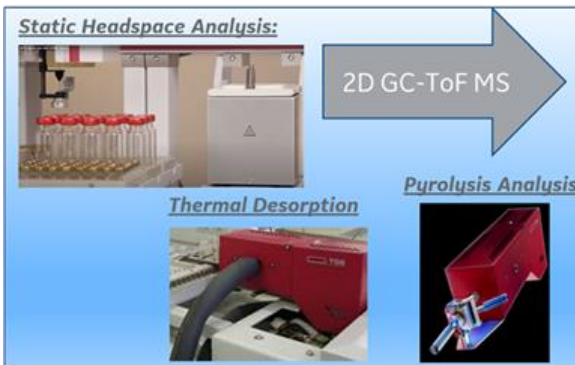
Barcode	Sampling location	Particle type from IR spectroscopy	SEM/EDS elemental composition of particles
335617	right engine heat exchanger	Aluminosilicate + calcium carbonate	S Si O C Al
335618	left main (unreadable)	aromatic polyamide polymer + silicone (PDMS) with aluminum hydroxide filler	Si O C Al
335619	right engine fuel filter bowl	poly(2-ethylhexyl acrylate) plastic sheet	C O Ca S
335620	left engine heat exchanger	lignocellulose (plant material) + Coke + silicon dioxide + calcium carbonate	C O Si Ca S
335621	left engine fuel filter bowl	none	
335622	APU	silicone (PDMS)	Si O C Ca S
335804	left engine fuel flow meter and fuel manifold	none	
335809	right engine fuel flow meter	none	
335810	AFT tail tank	none	
335811	left engine fuel control unit	lignocellulose (plant material) + calcium sulfate	Ca S O C
335812	right engine fuel pump	silicon dioxide	Si O C S Cr Ti
335813	right engine fuel control	silicone (PDMS) + lignocellulose (plant material)	Si O C S Al Mg

- HPLC Electro Spray Ionization ToF MSMS Data of Liquid Fuel Samples

GE Aerospace Research: Analysis of Jet A Fuels using Direct Injection 2D GC-ToF MS and HPLC ESI ToF MSMS



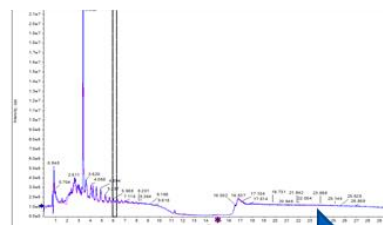
2D GC ToF MS Sampling Techniques:



HPLC ESI ToF MSMS Experimental:

HPLC ESI ToF-MS Method Parameters:

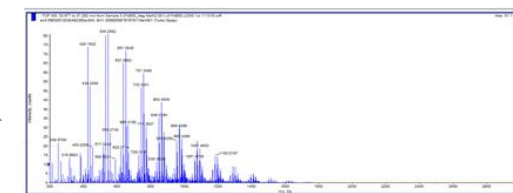
- 1) Flow Rate: 0.2ml / min
 - 2) Solvent A: 99.99% DI Water (+ 0.1% Formic Acid)
 - 3) Solvent B: 99.99% ACN (+ 0.1% Formic Acid)
 - 4) Step Gradient Conditions: 0-5min (100% Solvent A), 5-15min (0-100% Solvent B), 10min Equilibration to Initial Condition
-
- 1) Column: Intakt Cadenza CD-C18 2mm x 50mm
 - 2) Injection Volume: 5ul



Sample
Introduction

HPLC Separation

TripleTOF System Technology

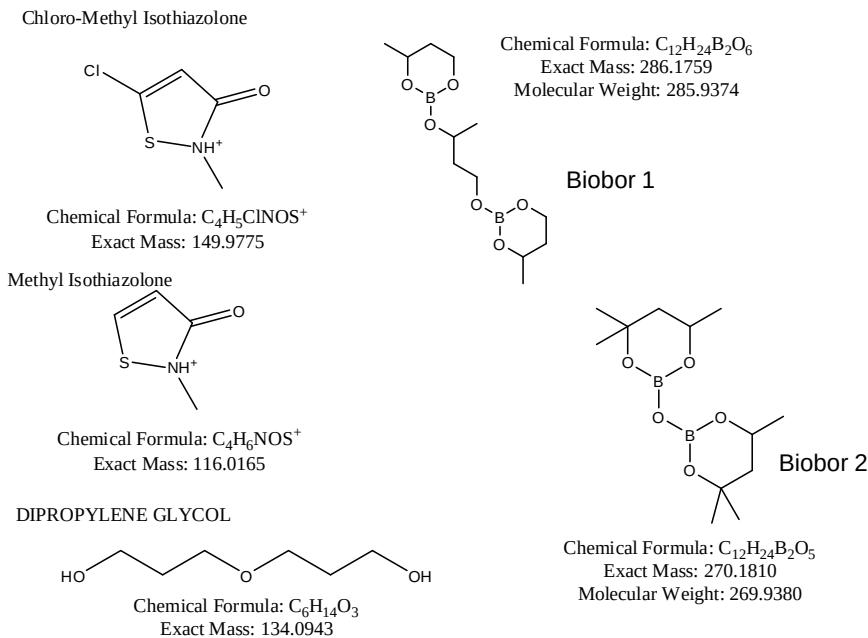


Time of Flight
Mass Spectrum



GE Aerospace Research: Analysis of Additives in Jet A Fuels using HPLC ESI ToF MSMS

- The liquid fuel samples were all analyzed for the presence of common fuel additives and biocides known to have caused past fuel systems issues (namely Kathon FP 1.5, Biobor JF, SAP and Diesel Exhaust Fluid) using high-performance liquid chromatography electrospray time of flight tandem mass spectrometry (HPLC ESI ToF MSMS)
- No compounds that could be attributable to Biobor JF or Kathon FP 1.5 were detected in the fuel samples
- Spike run showing typical response from 500ppm Biobor JF and Kathon FP 1.5 is shown for comparison. The biocides were undetectable in the fuel samples

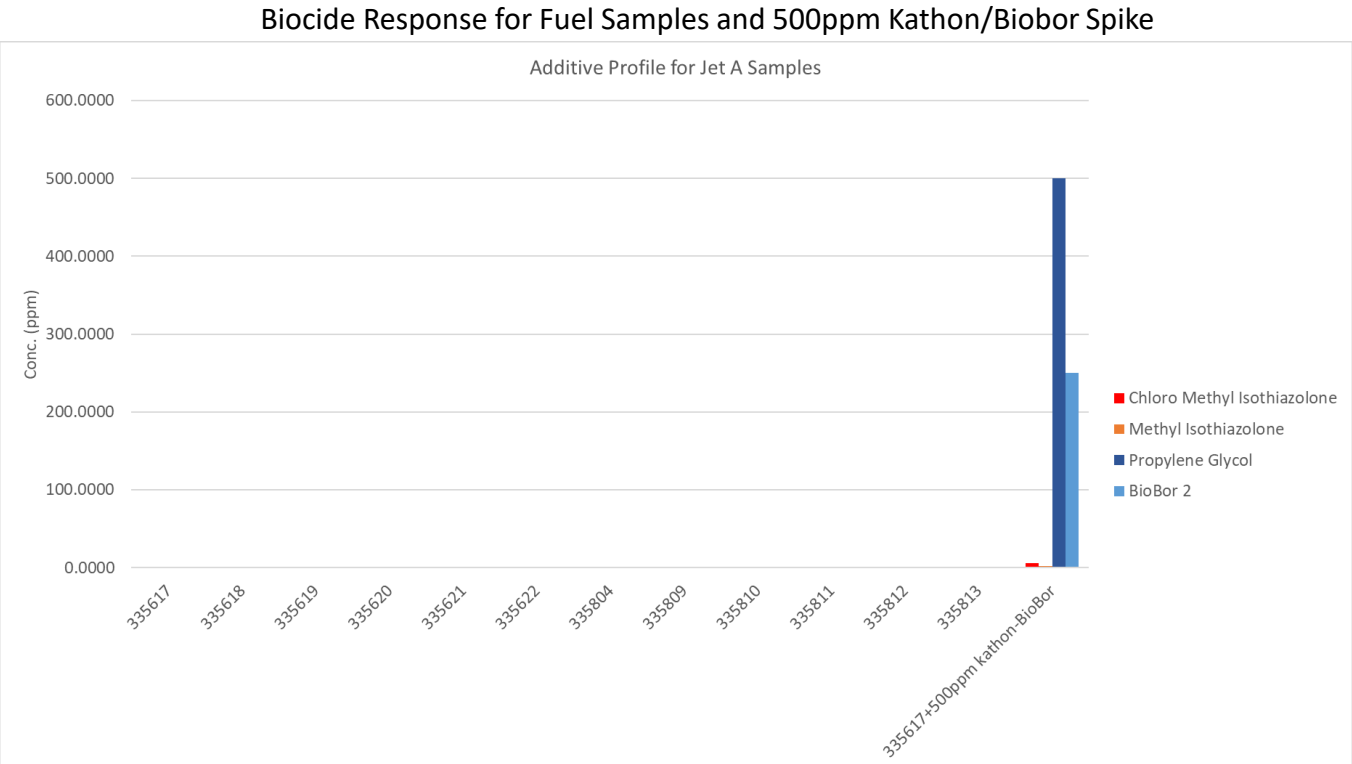


Biocide Response for Fuel Samples and 500ppm Kathon/Biobor Spike



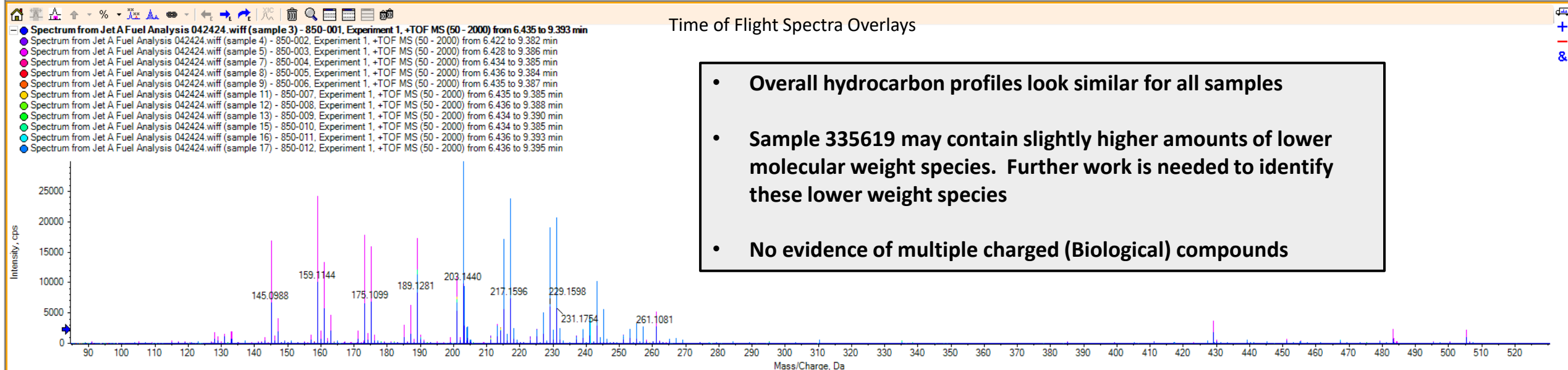
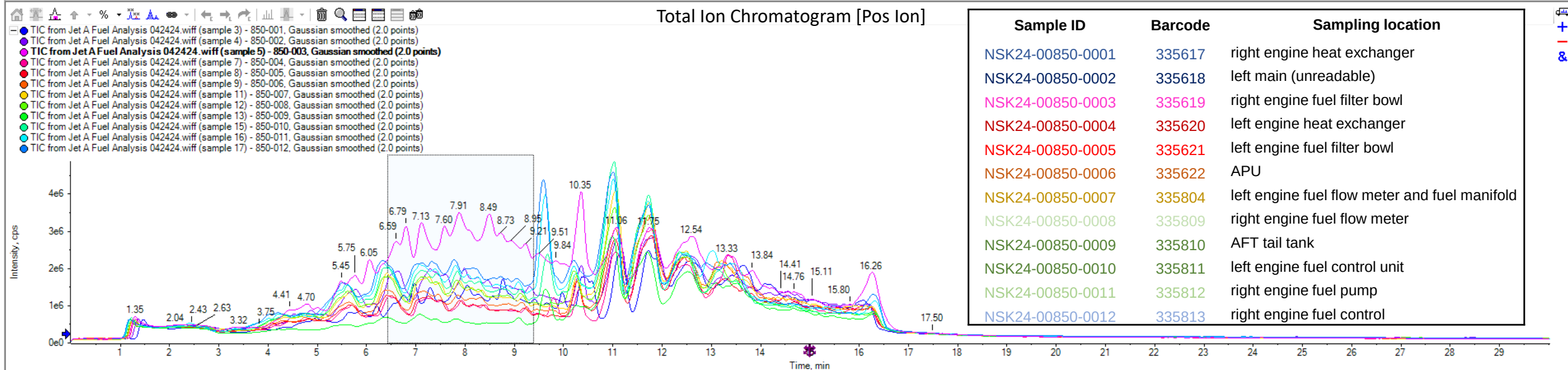
GE Aerospace Research: Analysis of Additives in Jet A Fuels using HPLC ESI ToF MSMS

Semi Quant (ug/ml)				
Resp Factor	1.23E-05	2.50E-05	1.14E-03	0.001668892
Precursor Mass	149.977	116.016	135.102	269.196
Sample Name	Chloro Methyl Isothiazolone	Methyl Isothiazolone	Propylene Glycol	BioBor 2
335617	0.0000	0.0000	0.0000	0.0000
335618	0.0000	0.0000	0.0000	0.0000
335619	0.0000	0.0000	0.0000	0.0000
335620	0.0000	0.0000	0.0000	0.0000
335621	0.0000	0.0000	0.0000	0.0000
335622	0.0000	0.0000	0.0000	0.0000
335804	0.0000	0.0000	0.0000	0.0000
335809	0.0000	0.0000	0.0000	0.0000
335810	0.0000	0.0000	0.0000	0.0000
335811	0.0000	0.0000	0.0000	0.0000
335812	0.0000	0.0000	0.0000	0.0000
335813	0.0000	0.0000	0.0000	0.0000
335617+500ppm kathon-BioBor	5.3567	2.4473	499.8900	250.1660

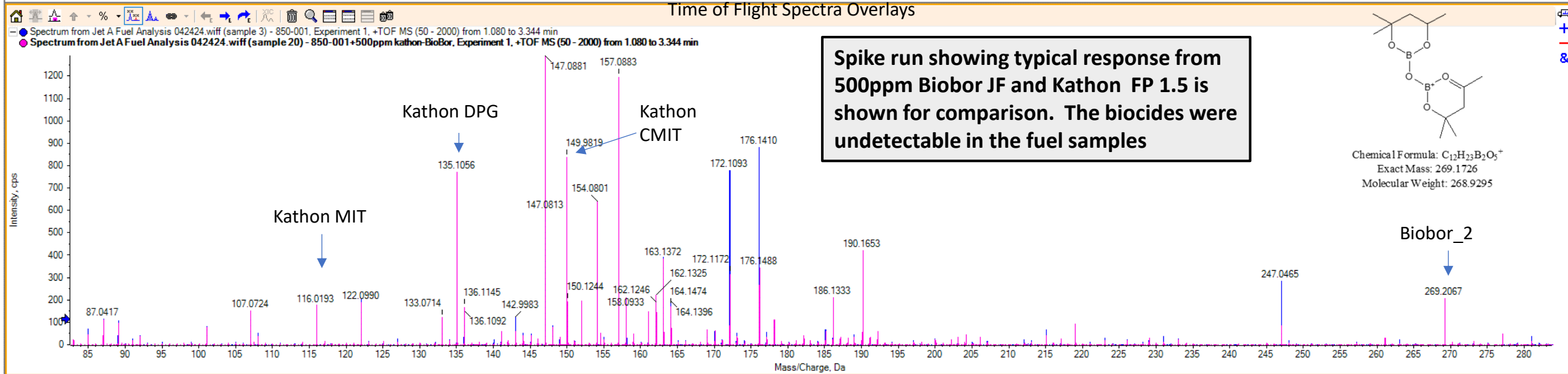
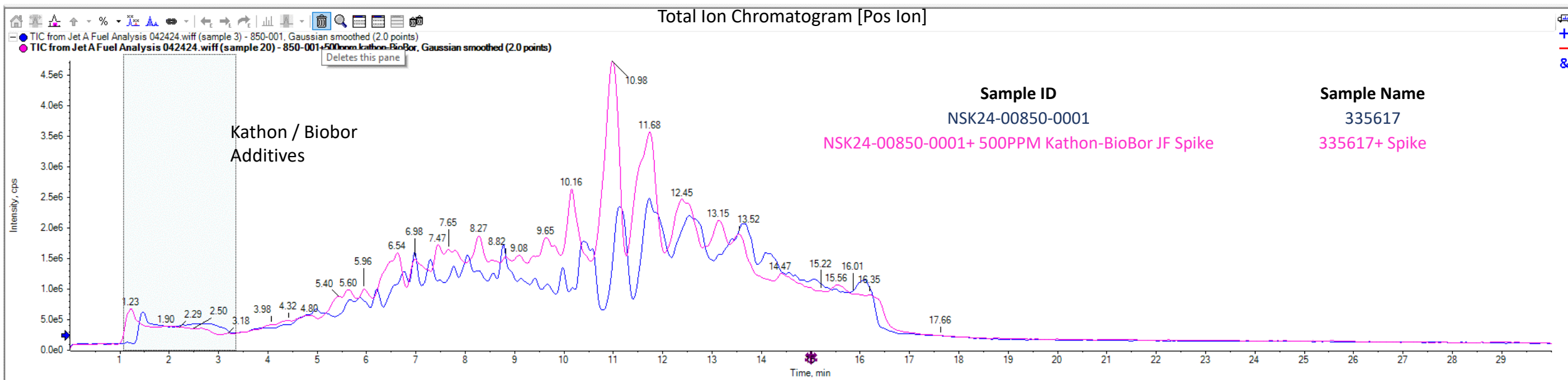


- No compounds that could be attributable to Biobor JF or Kathon FP 1.5 were detected in the fuel samples
- Spike run showing typical response from 500ppm Biobor JF and Kathon FP 1.5 is shown for comparison. The biocides were undetectable in the fuel samples

GE Aerospace Research: Hydrocarbon Profiles for Jet Fuel Samples



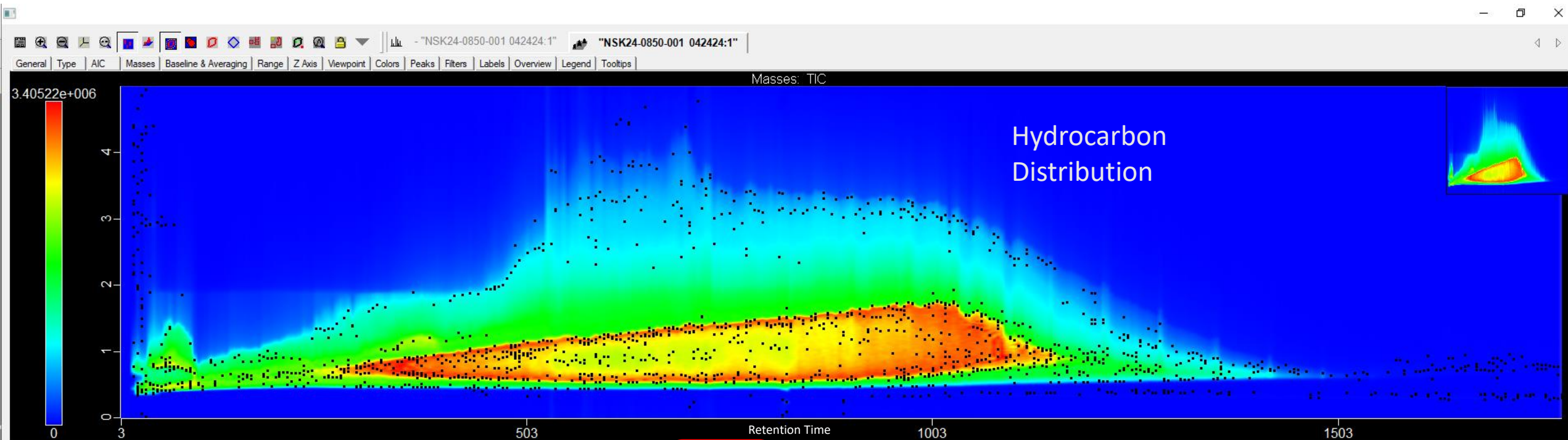
GE Aerospace Research: Response from Biocide Spiked Standard



- 2D GCMS Data of Liquid Fuel Samples

GE Aerospace Research: Analysis of Jet A Fuels using Direct Injection 2D GC-ToF MS [Contour Plot for TIC]

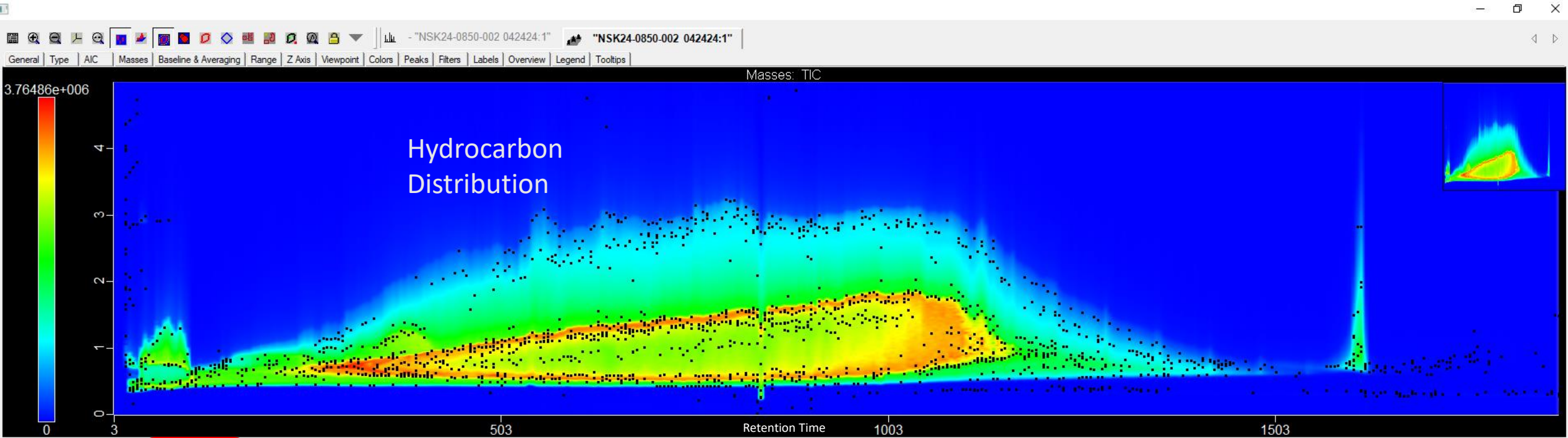
LIMS ID	Barcode	Sampling location
NSK24-00850-0001	335617	right engine heat exchanger



GE Aerospace: NOT SENSITIVE – suitable for external release

GE Aerospace Research: Analysis of Jet A Fuels using Direct Injection 2D GC-ToF MS [Contour Plot for TIC]

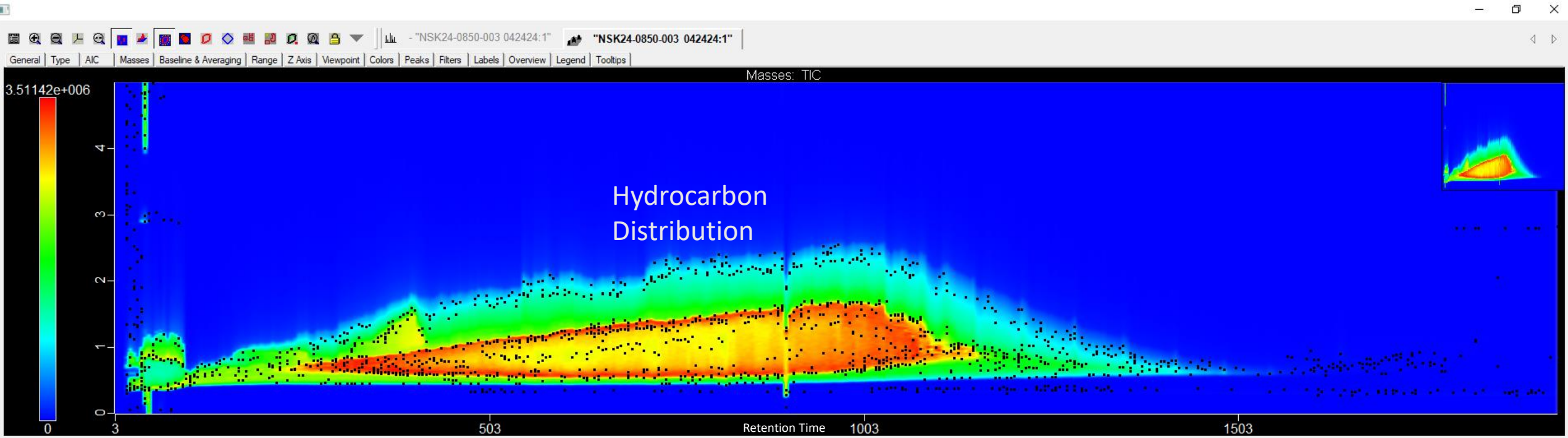
LIMS ID	Barcode	Sampling location
NSK24-00850-0002	335618	left main (unreadable)



GE Aerospace: NOT SENSITIVE – suitable for external release

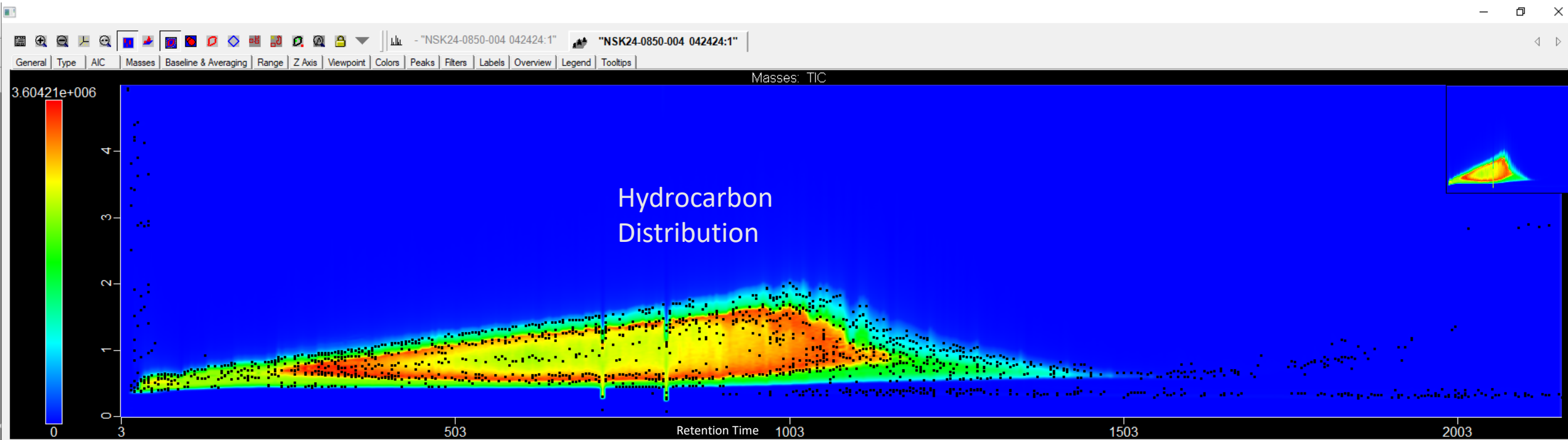
GE Aerospace Research: Analysis of Jet A Fuels using Direct Injection 2D GC-ToF MS [Contour Plot for TIC]

LIMS ID	Barcode	Sampling location
NSK24-00850-0003	335619	right engine fuel filter bowl



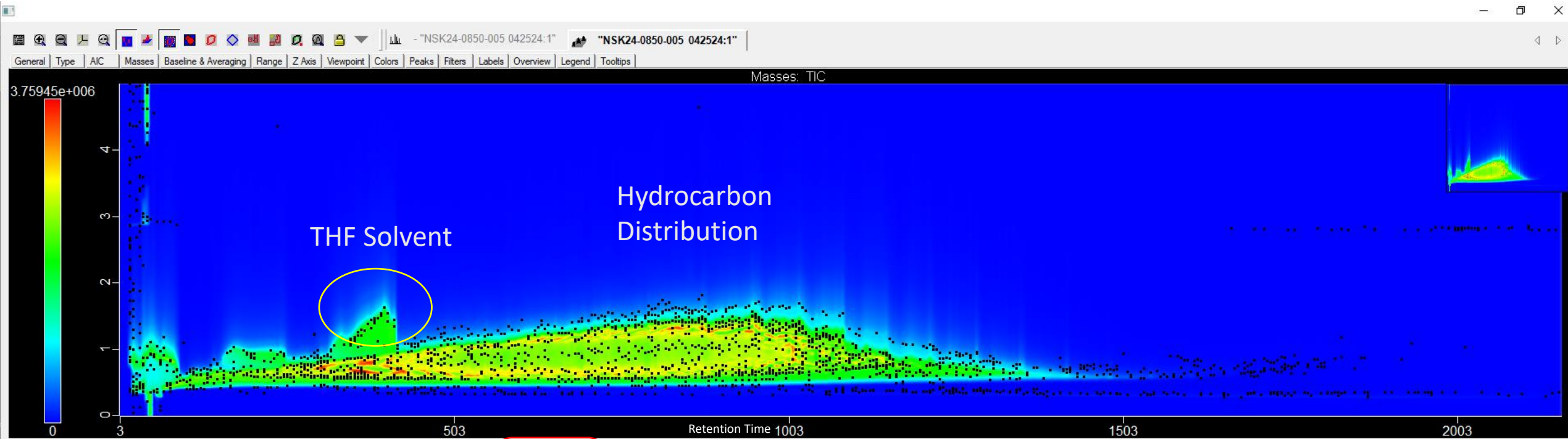
GE Aerospace Research: Analysis of Jet A Fuels using Direct Injection 2D GC-ToF MS [Contour Plot for TIC]

LIMS ID	Barcode	Sampling location
NSK24-00850-0004	335620	left engine heat exchanger



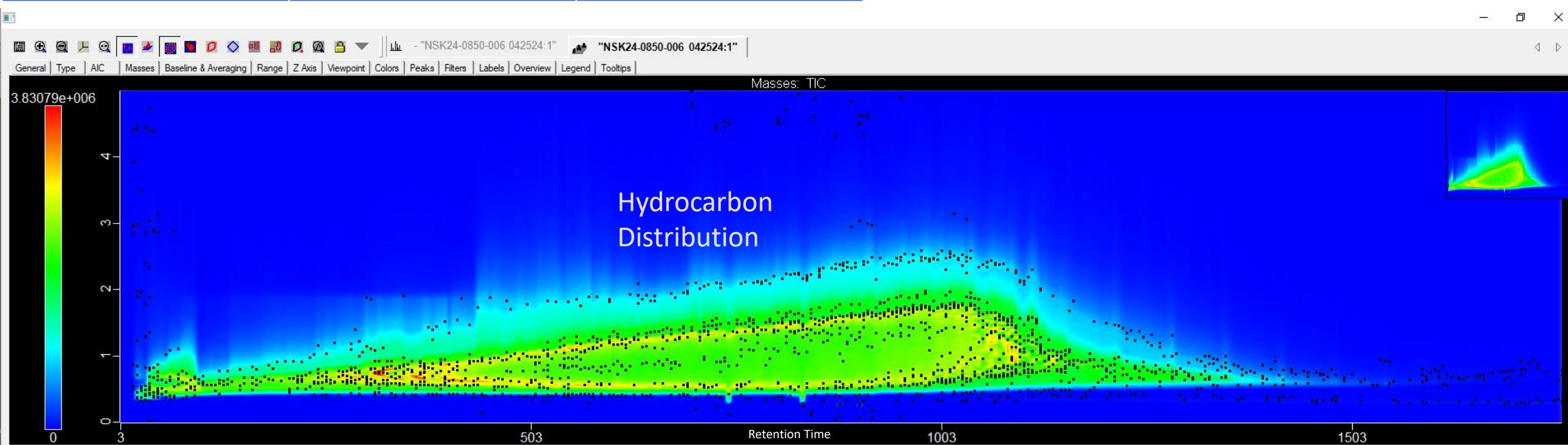
GE Aerospace Research: Analysis of Jet A Fuels using Direct Injection 2D GC-ToF MS [Contour Plot for TIC]

LIMS ID	Barcode	Sampling location
NSK24-00850-0005	335621	left engine fuel filter bowl



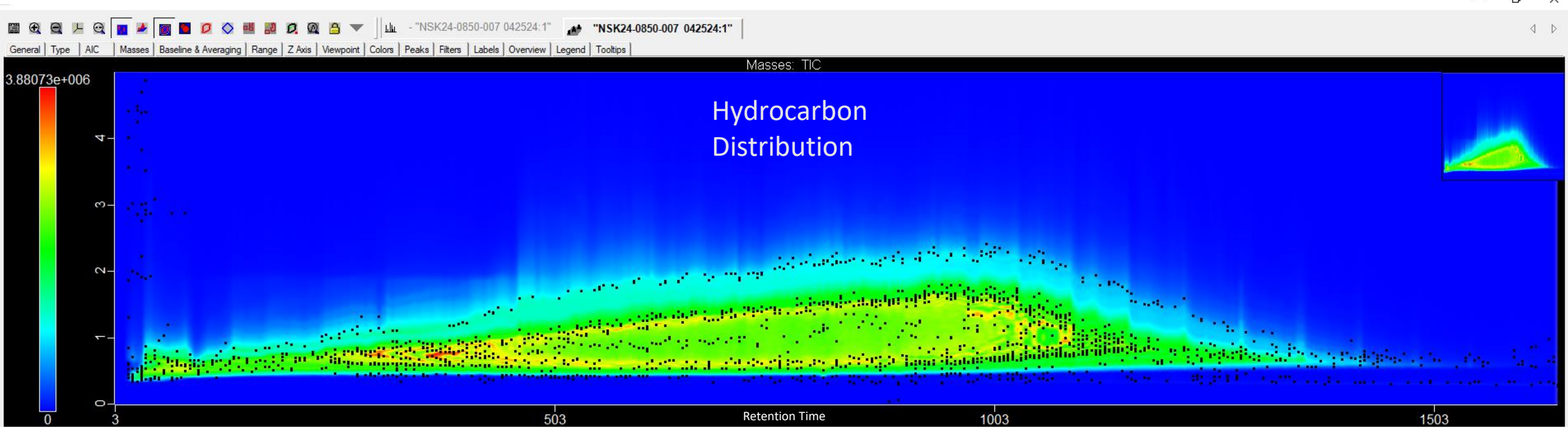
GE Aerospace Research: Analysis of Jet A Fuels using Direct Injection 2D GC-ToF MS [Contour Plot for TIC]

LIMS ID	Barcode	Sampling location
NSK24-00850-0006	335622	APU



GE Aerospace Research: Analysis of Jet A Fuels using Direct Injection 2D GC-ToF MS [Contour Plot for TIC]

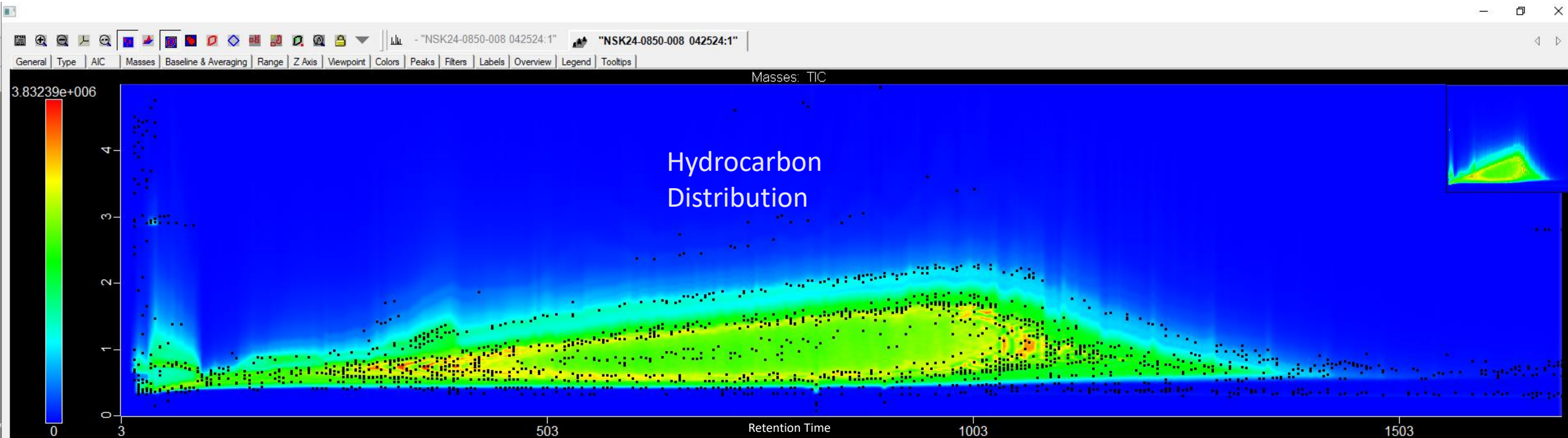
LIMS ID	Barcode	Sampling location
NSK24-00850-0007	335804	left engine fuel flow meter and fuel manifold



GE Aerospace: NOT SENSITIVE – suitable for external release

GE Aerospace Research: Analysis of Jet A Fuels using Direct Injection 2D GC-ToF MS [Contour Plot for TIC]

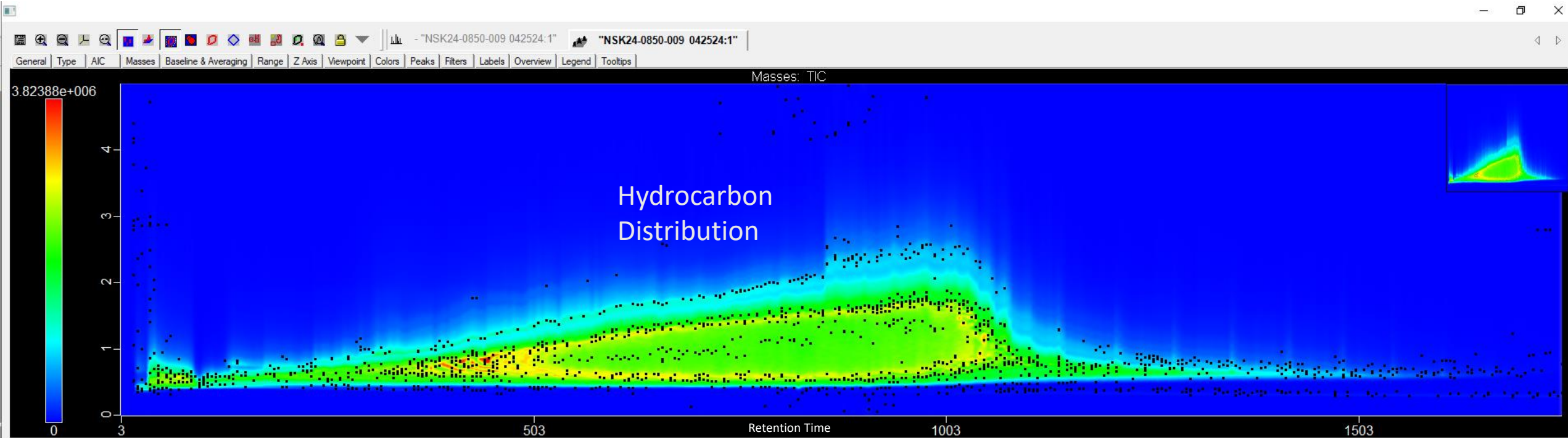
LIMS ID	Barcode	Sampling location
NSK24-00850-0008	335809	right engine fuel flow meter



GE Aerospace: NOT SENSITIVE – suitable for external release

GE Aerospace Research: Analysis of Jet A Fuels using Direct Injection 2D GC-ToF MS [Contour Plot for TIC]

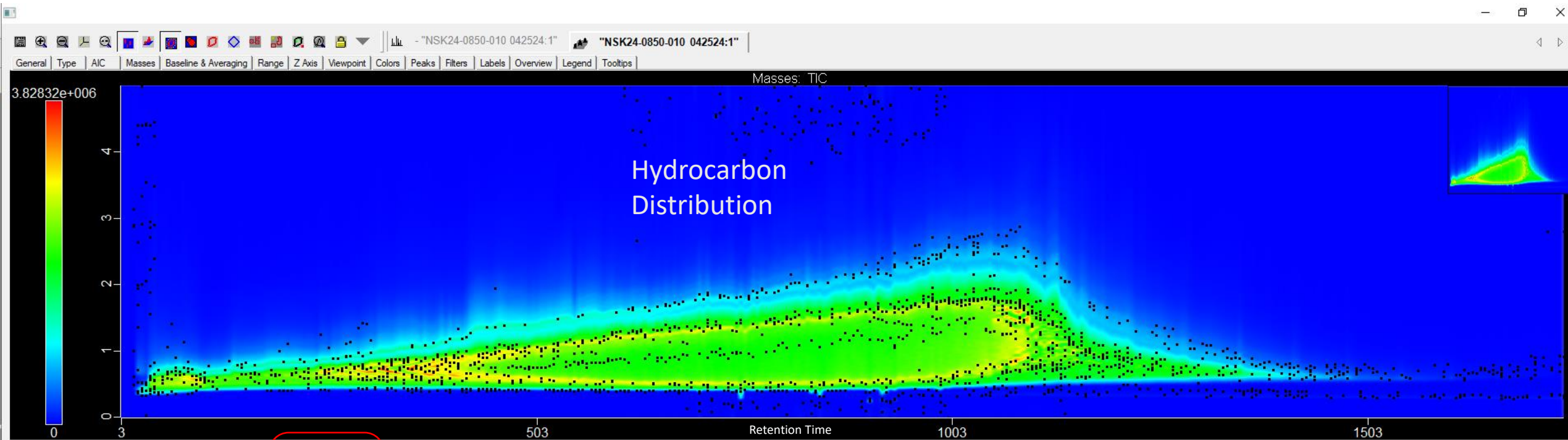
LIMS ID	Barcode	Sampling location
NSK24-00850-0009	335810	AFT tail tank



GE Aerospace: NOT SENSITIVE – suitable for external release

GE Aerospace Research: Analysis of Jet A Fuels using Direct Injection 2D GC-ToF MS [Contour Plot for TIC]

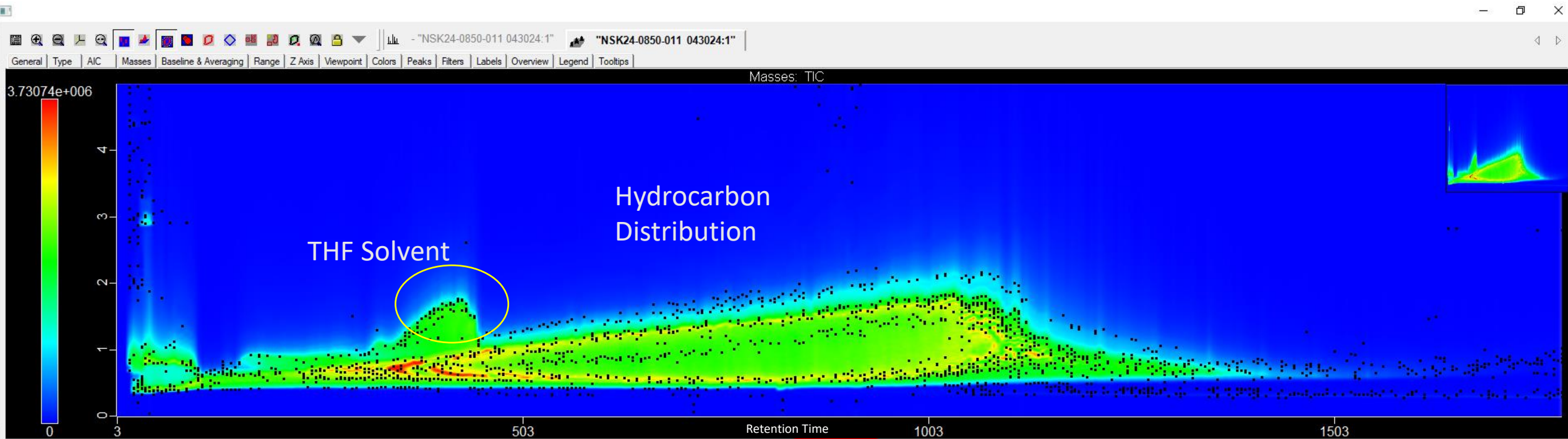
LIMS ID	Barcode	Sampling location
NSK24-00850-0010	335811	left engine fuel control unit



GE Aerospace: NOT SENSITIVE – suitable for external release

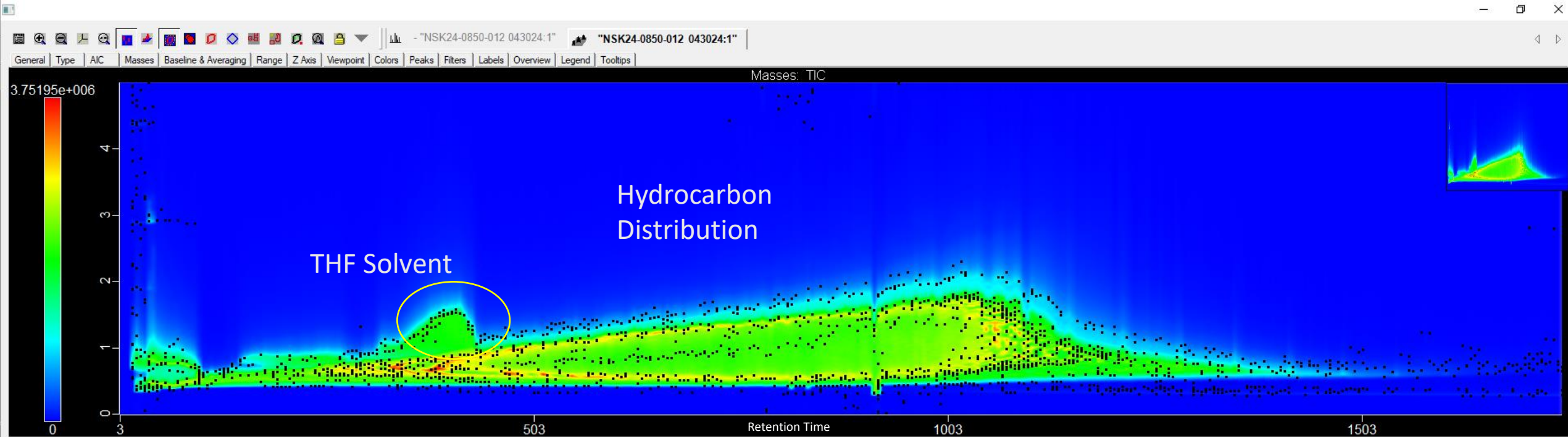
GE Aerospace Research: Analysis of Jet A Fuels using Direct Injection 2D GC-ToF MS [Contour Plot for TIC]

LIMS ID	Barcode	Sampling location
NSK24-00850-0011	335812	right engine fuel pump



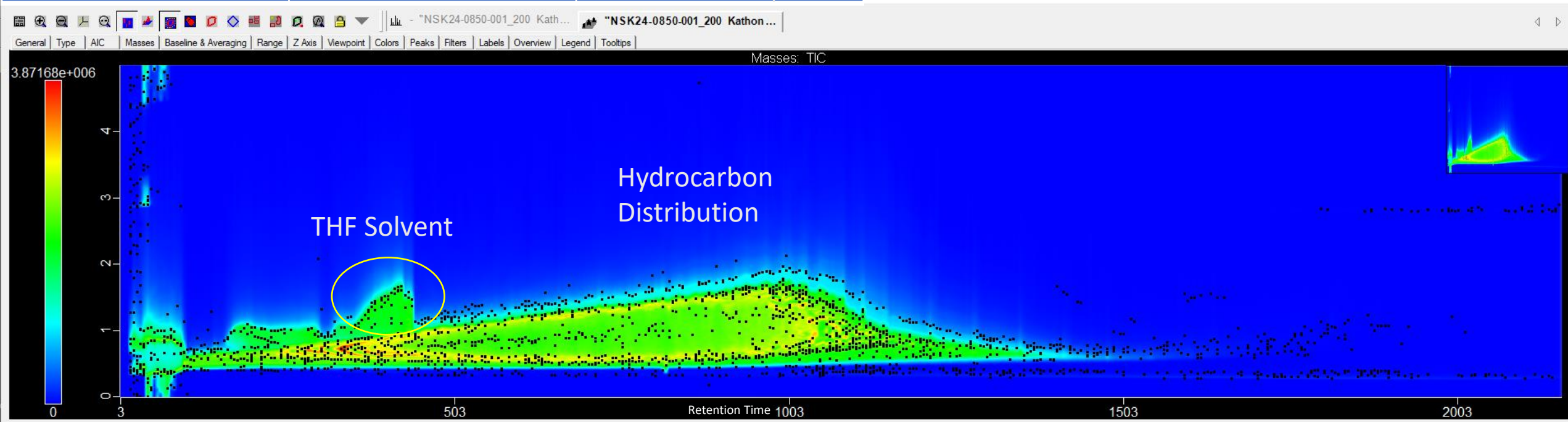
GE Aerospace Research: Analysis of Jet A Fuels using Direct Injection 2D GC-ToF MS [Contour Plot for TIC]

LIMS ID	Barcode	Sampling location
NSK24-00850-0012	335813	right engine fuel control



GE Aerospace Research: Analysis of Jet A Fuels using Direct Injection 2D GC-ToF MS [Contour Plot for TIC]

LIMS ID	Barcode	Sampling location
NSK24-00850-0001+Spike	335617+Spike	200PPm Kathon and BioBor JF Spike



- IR Spectroscopy of Solid Particles in Fuel Samples

Summary of Findings – IR Analysis of Solid Particles from Fuel Samples

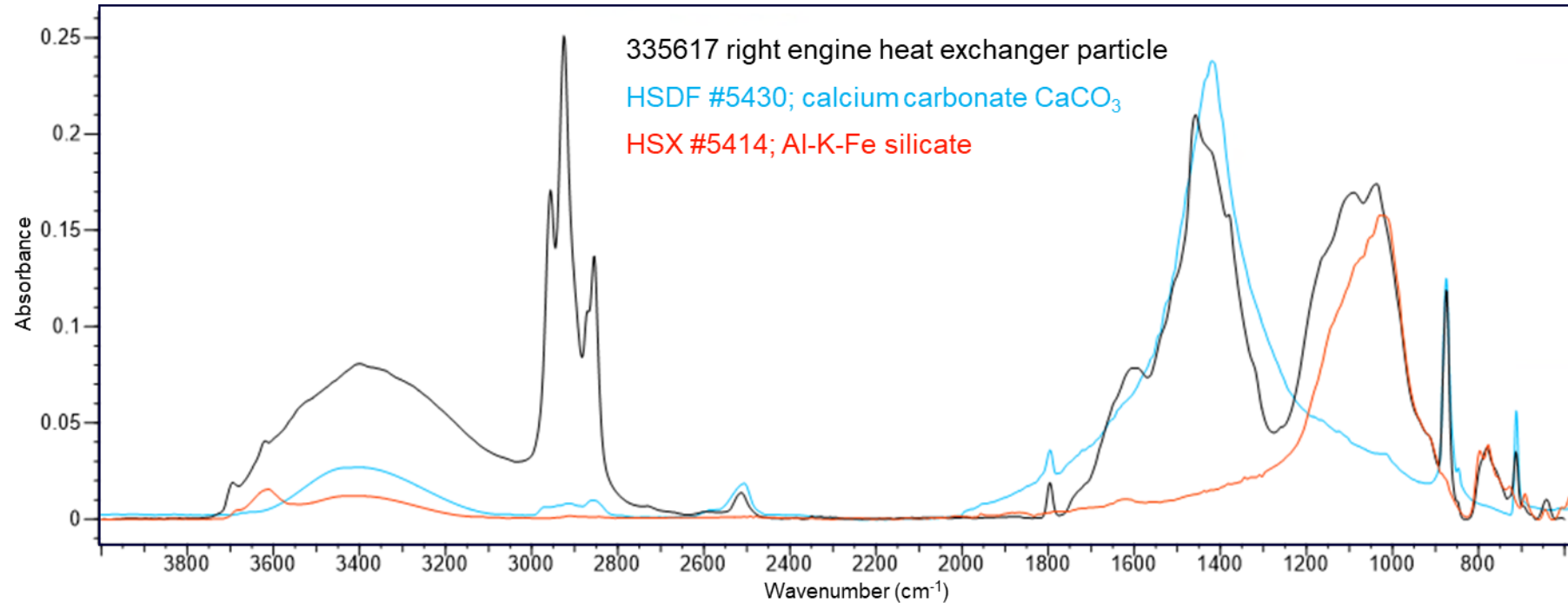
- Several of the fuel samples contained solid particles. A portion of each fuel sample was centrifuged to isolate these solid particles. The collected solid particles were then analyzed by IR spectroscopy and SEM/EDS to assess their chemical composition
- The particle types identified are detailed in the table below
- No particles were found that could be attributable to SAP or Diesel Exhaust Fluid were detected in the fuel samples

Barcode	Sampling location	Particle type from IR spectroscopy
335617	right engine heat exchanger	Aluminosilicate + calcium carbonate
335618	left main (unreadable)	aromatic polyamide polymer + silicone (PDMS) with aluminum hydroxide filler
335619	right engine fuel filter bowl	poly(2-ethylhexyl acrylate) plastic sheet
335620	left engine heat exchanger	lignocellulose (plant material) + Coke + silicon dioxide + calcium carbonate
335621	left engine fuel filter bowl	none
335622	APU	silicone (PDMS)
335804	left engine fuel flow meter and fuel manifold	none
335809	right engine fuel flow meter	none
335810	AFT tail tank	none
335811	left engine fuel control unit	lignocellulose (plant material) + calcium sulfate
335812	right engine fuel pump	silicon dioxide
335813	right engine fuel control	silicone (PDMS) + lignocellulose (plant material)

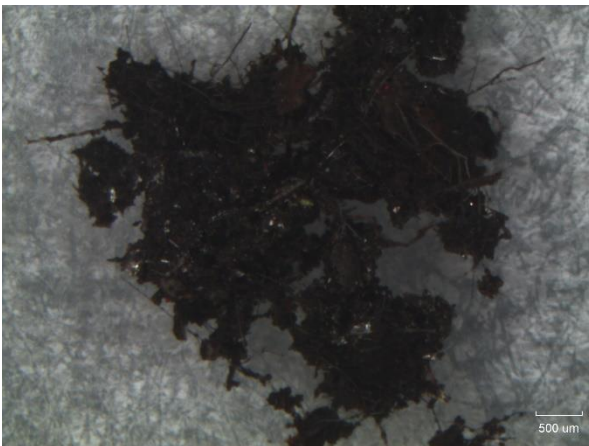


IR Spectroscopy of Solid Particles Isolated from Fuel

Comparison to IR Spectral Database

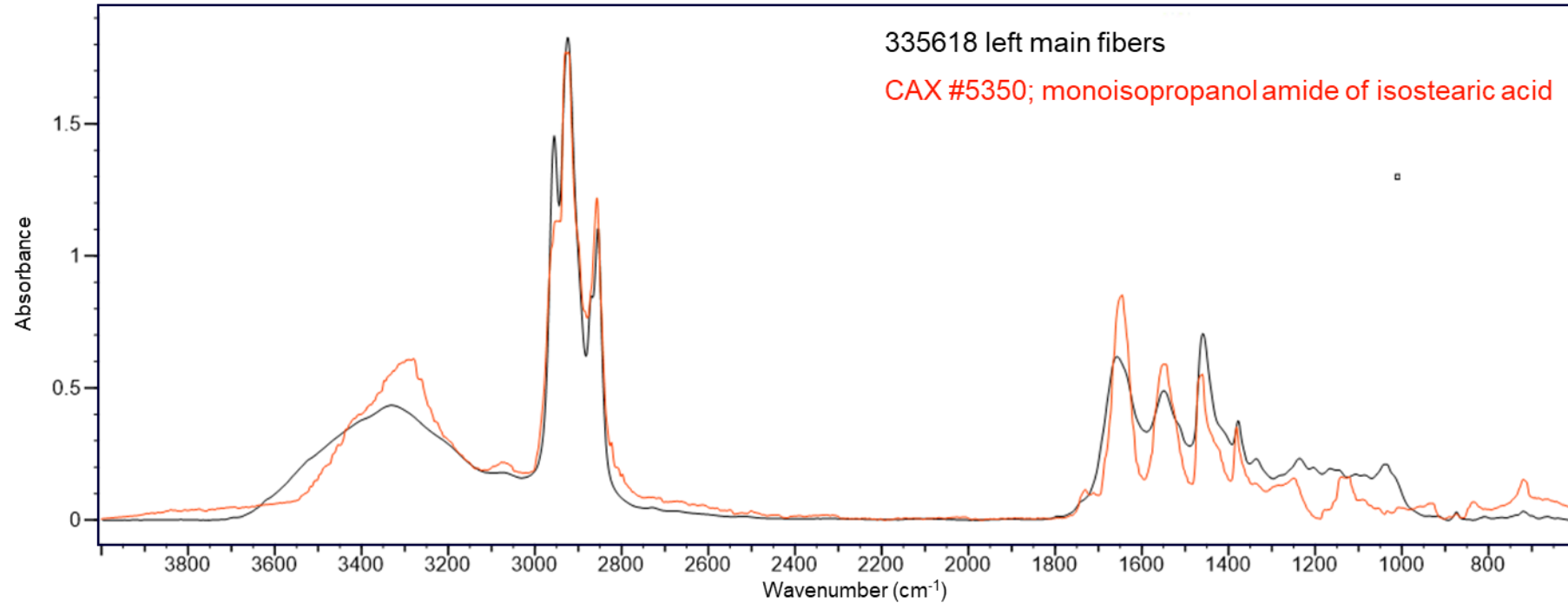


Dark particles recovered from 335617 are a good match to the IR spectral features of a **mixture of aluminosilicate (sand) and calcium carbonate**



IR Spectroscopy of Solid Particles Isolated from Fuel

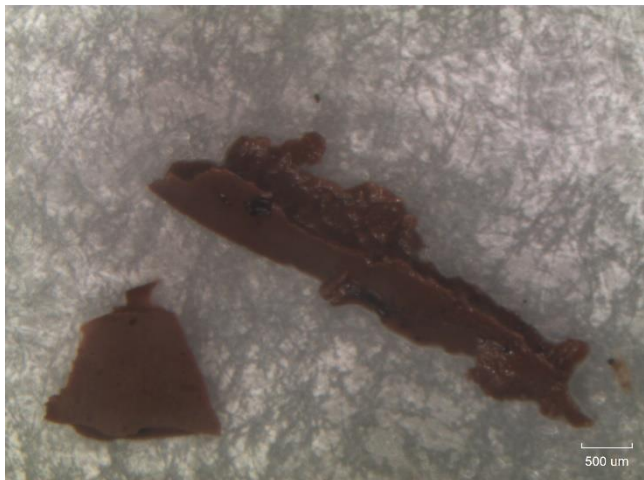
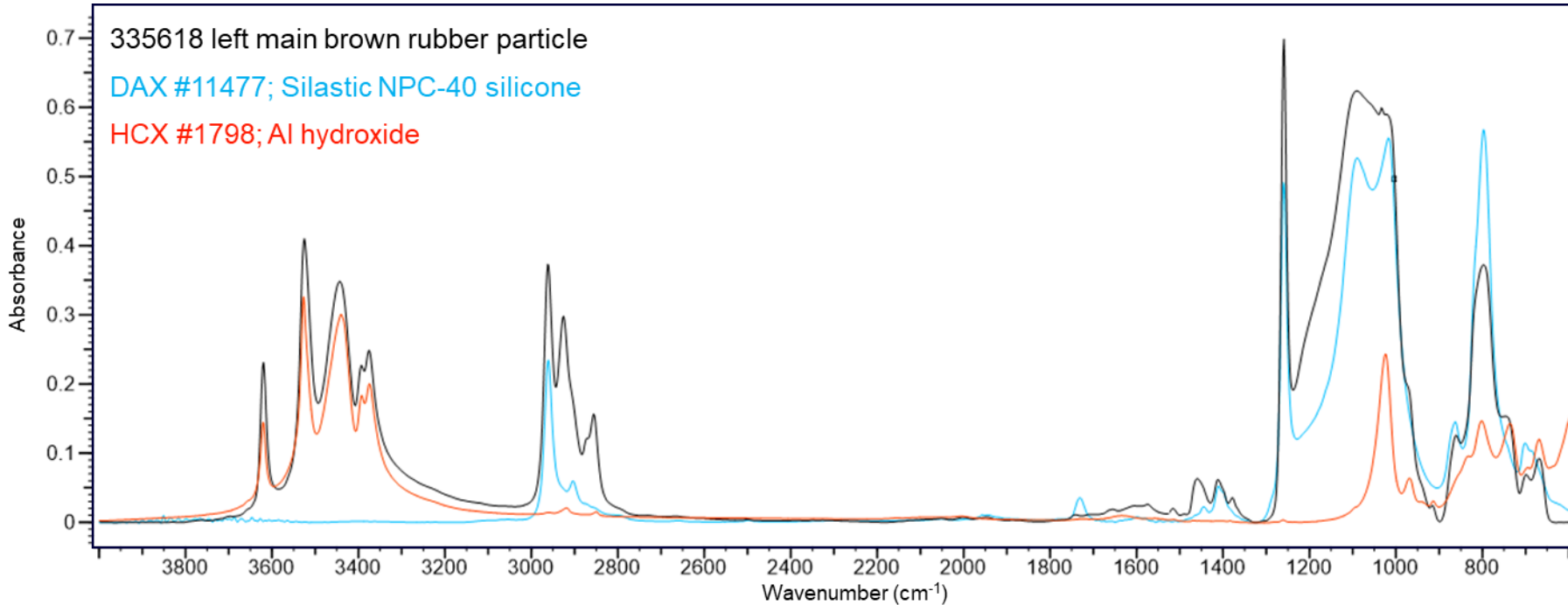
Comparison to IR Spectral Database



Dark fibers recovered from 335618 are a good match to the IR spectral features of an **aromatic polyamide polymer**

IR Spectroscopy of Solid Particles Isolated from Fuel

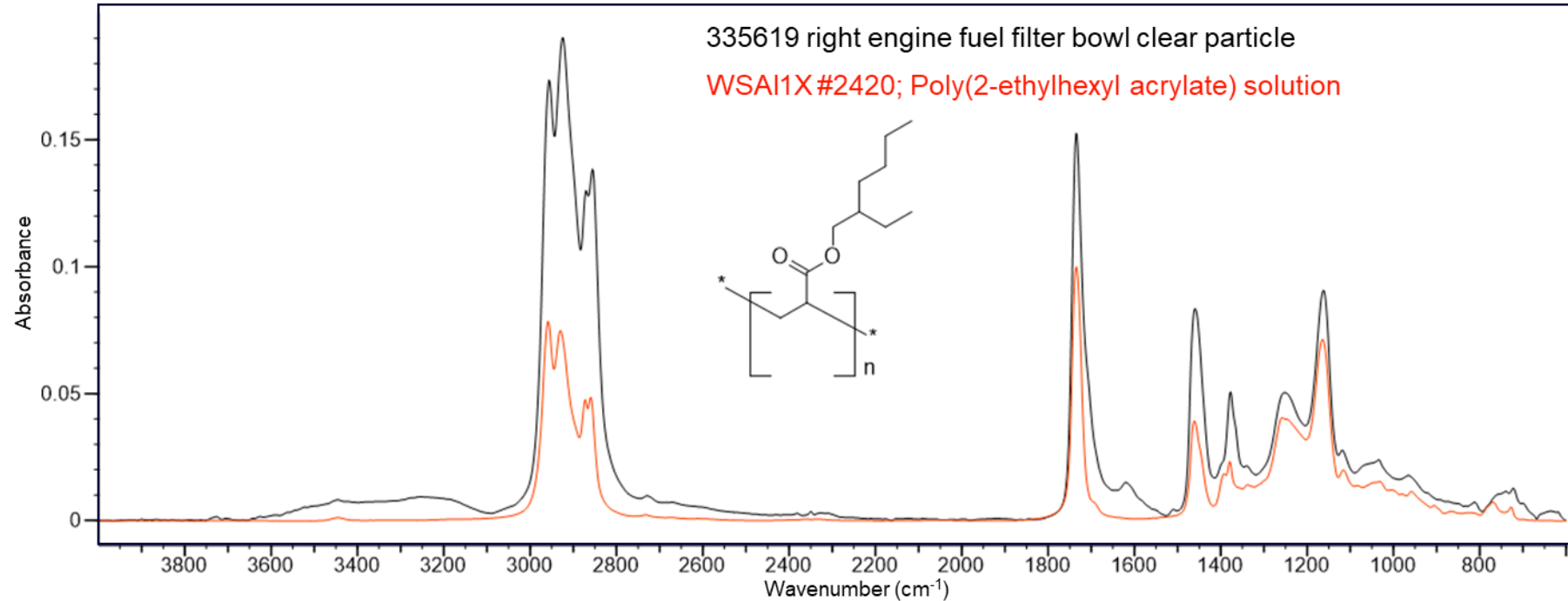
Comparison to IR Spectral Database



Chunks of brown material recovered from 335618 is a good match to the IR spectral features of a silicone such as **poly(dimethyl siloxane) (PDMS)** using an **aluminum hydroxide** filler

IR Spectroscopy of Solid Particles Isolated from Fuel

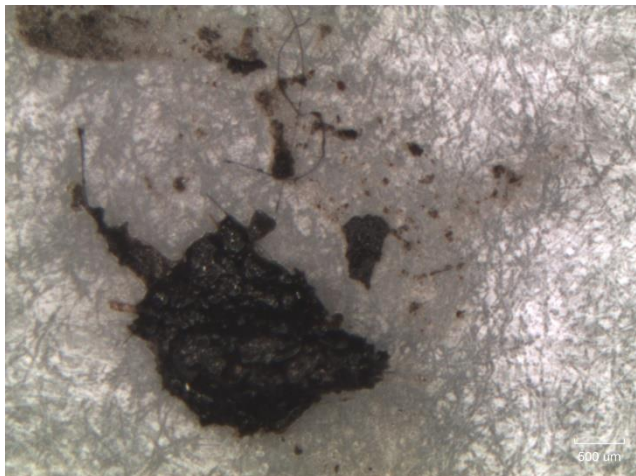
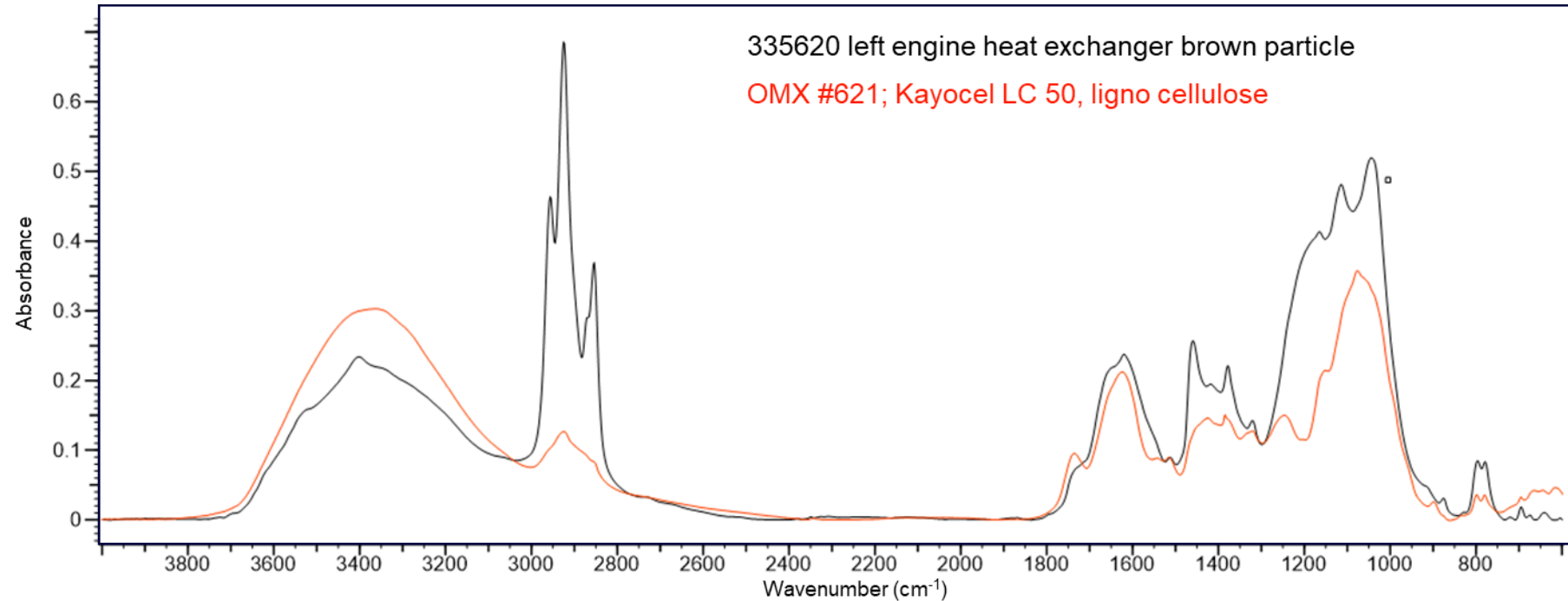
Comparison to IR Spectral Database



A brown sheet recovered from 335619 is a good match to the IR spectral features of a **poly(2-ethylhexyl acrylate) plastic**

IR Spectroscopy of Solid Particles Isolated from Fuel

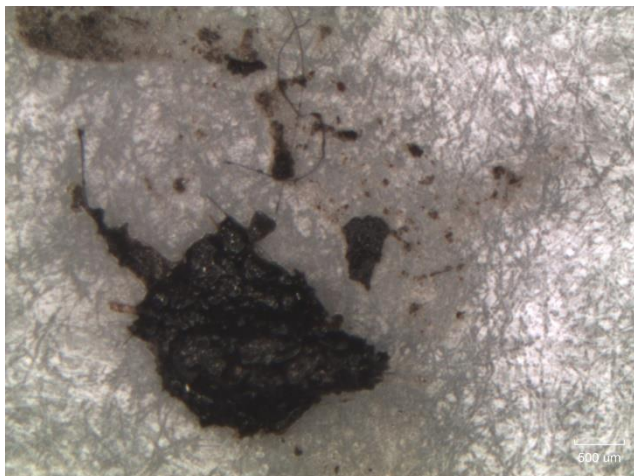
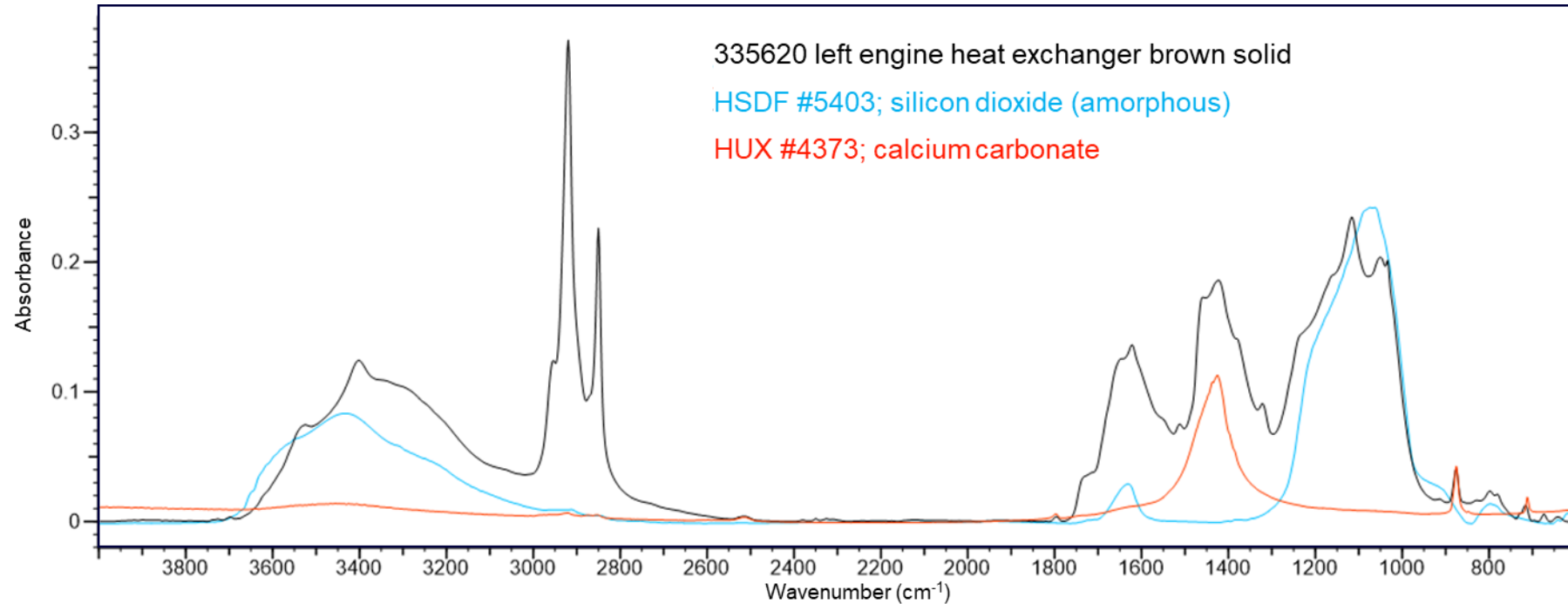
Comparison to IR Spectral Database



A brown sheet recovered from 335620 is a good match to the IR spectral features of **lignocellulose (plant material)**

IR Spectroscopy of Solid Particles Isolated from Fuel

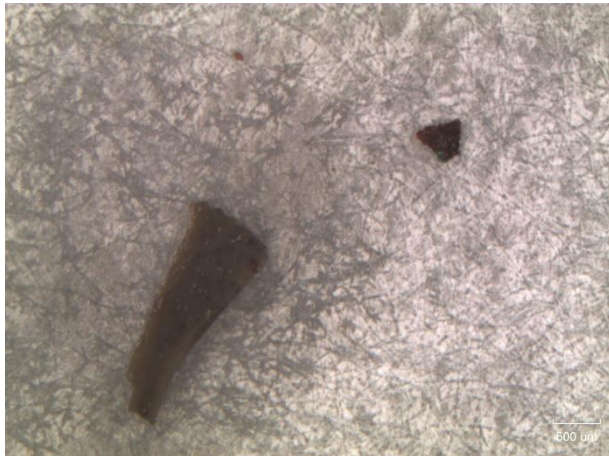
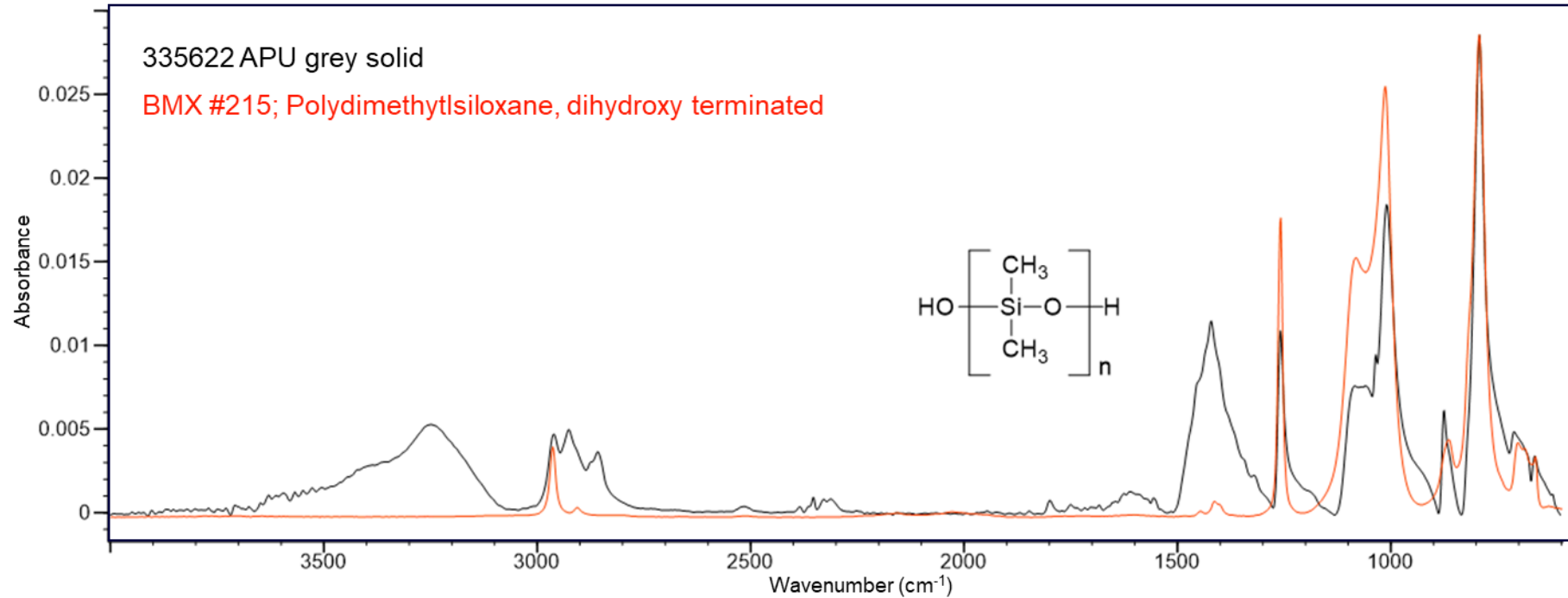
Comparison to IR Spectral Database



Dark particles recovered from 335620 are a good match to the IR spectral features of a mixture of **silicon dioxide and calcium carbonate**. The remaining unfit IR bands are likely associated with **degraded fuel residue (coking)**

IR Spectroscopy of Solid Particles Isolated from Fuel

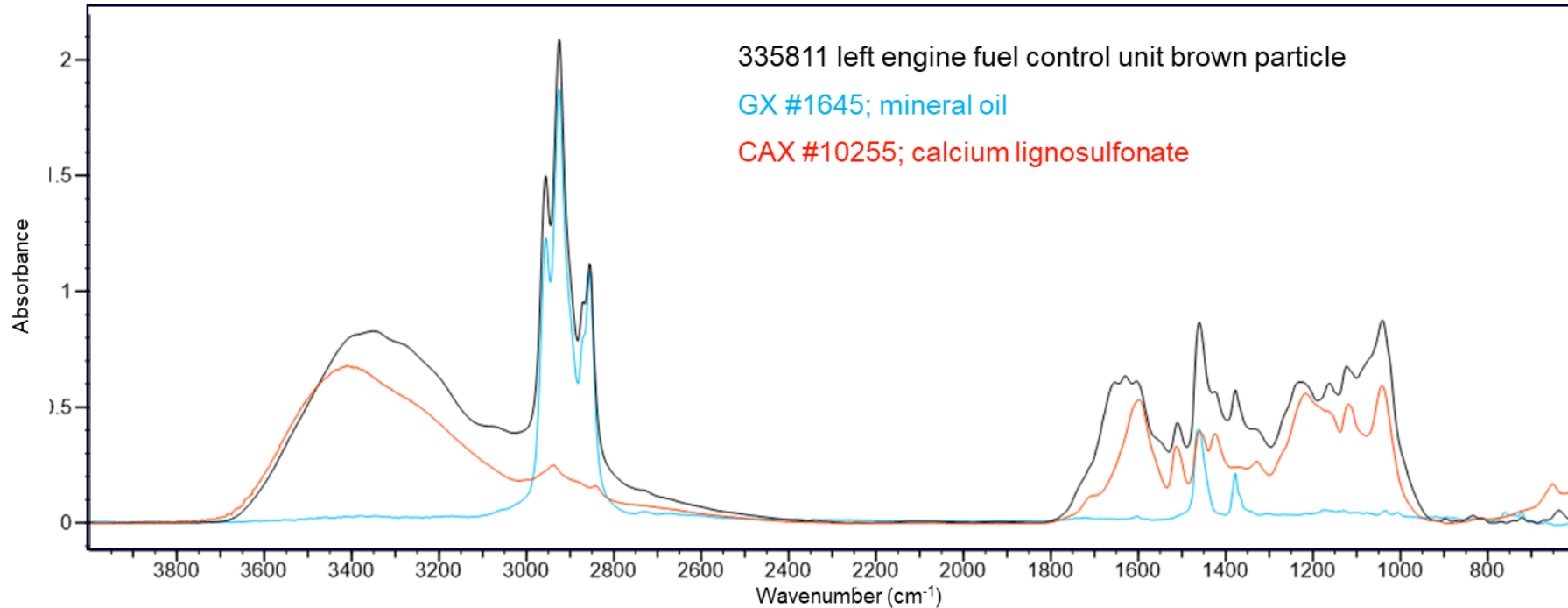
Comparison to IR Spectral Database



Chunks of brown material recovered from 335622 is a good match to the IR spectral features of a silicone such as poly(dimethyl siloxane) (PDMS)

IR Spectroscopy of Solid Particles Isolated from Fuel

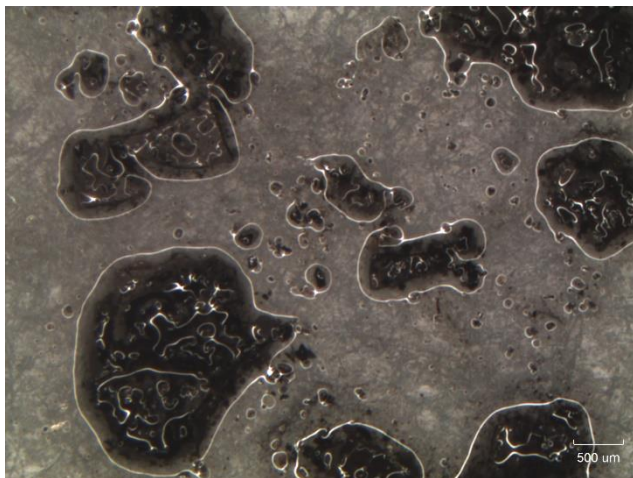
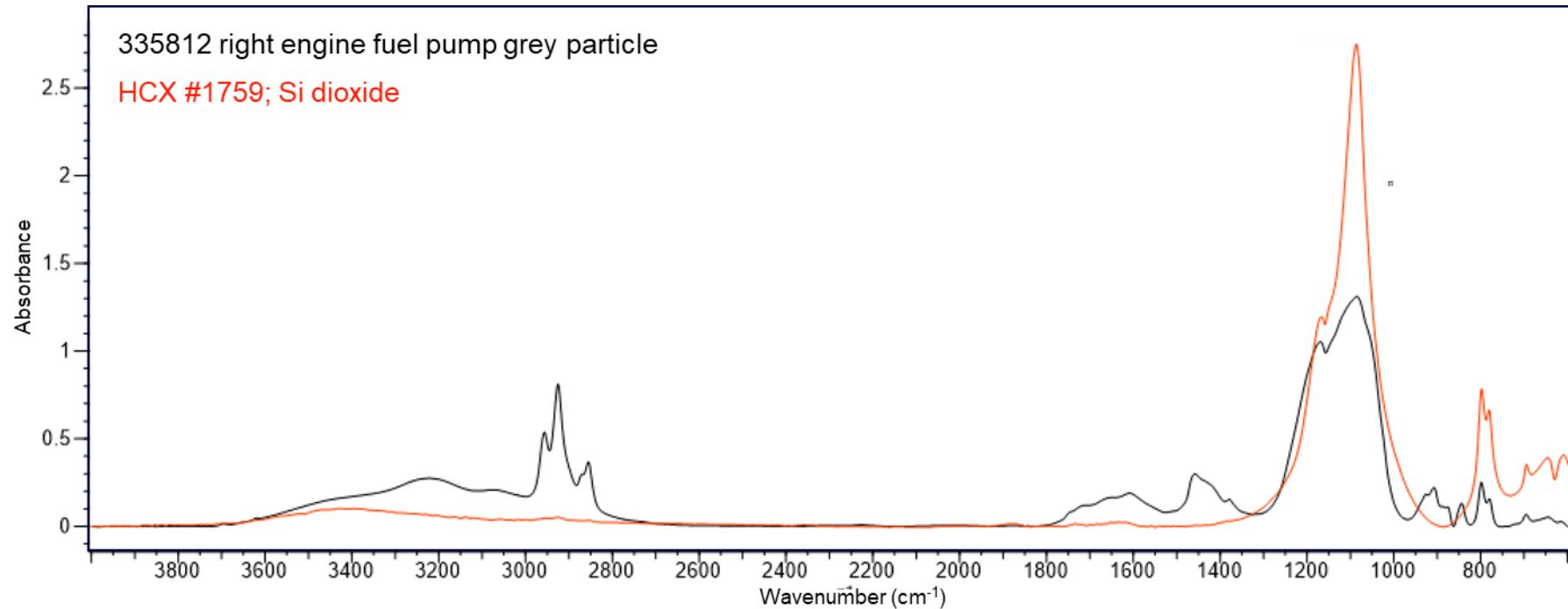
Comparison to IR Spectral Database



A brown sheet recovered from 335811 is a good match to the IR spectral features of **calcium lignosulfonate and mineral oil**. Alternatively, this material **could also be a mixture of calcium sulfate, lignocellulose and mineral oil**.

IR Spectroscopy of Solid Particles Isolated from Fuel

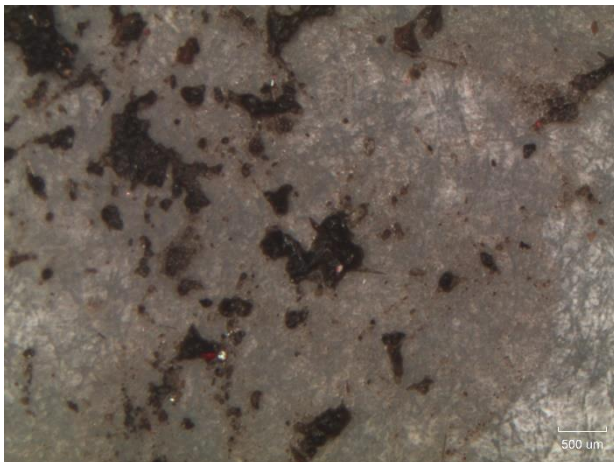
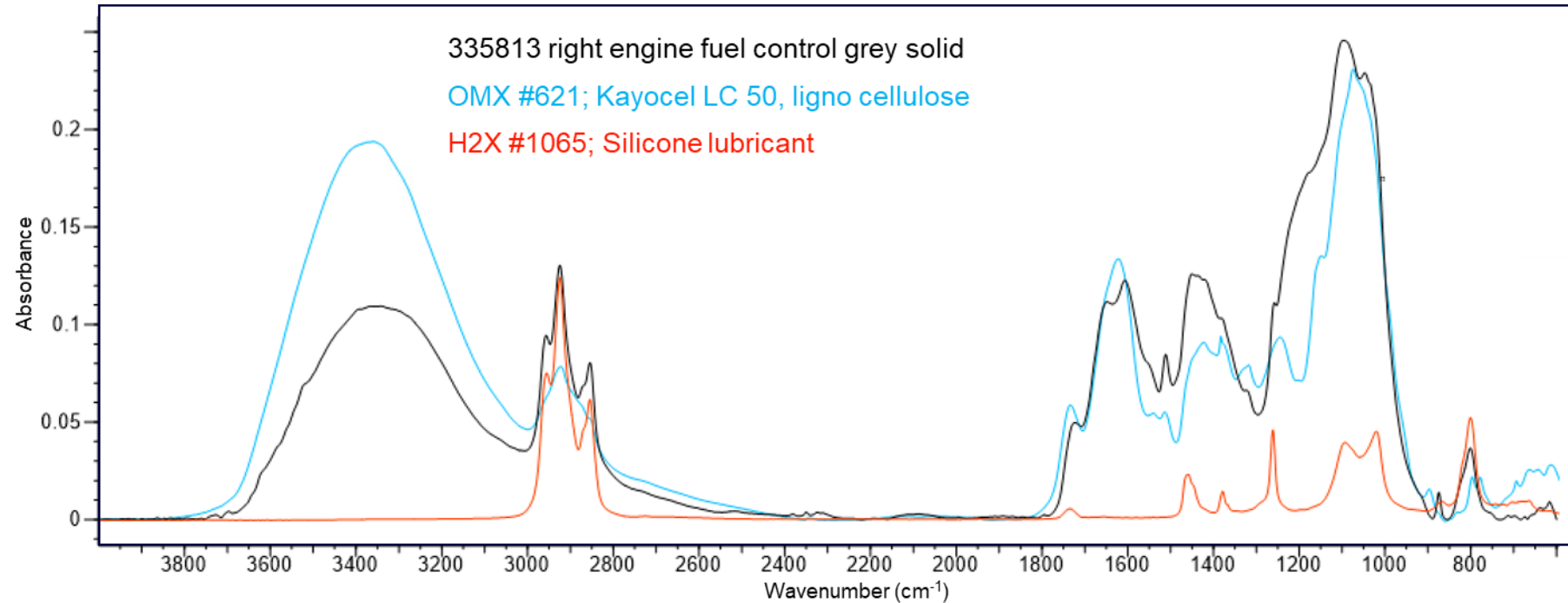
Comparison to IR Spectral Database



Black/grey solids recovered from 335612 is a good match to the IR spectral features of a **silicon dioxide SiO₂**

IR Spectroscopy of Solid Particles Isolated from Fuel

Comparison to IR Spectral Database



Chunks of brown material recovered from 335813 is a good match to the IR spectral features of a **mixture silicone (PDMS) and lignocellulose (plant material)**

IR Spectroscopy Experimental Details:

Microscope - Solid (On Diamond Plate) - IR spectra were obtained with a Bruker Optics, Hyperion 3000 IR microscope attached to a Bruker Optics, Vertex 70 FTIR. The Hyperion 3000 is configured with a narrow-band MCT detector. For use with the microscope the associated bench is configured with a Ge on KBr beamsplitter. For this examination, a small particle of the sample was pressed between diamond plates. Then the plate with the sample was placed in the IR microscope and examined in transmission mode. A total of 128 interferograms were collected prior to the Fourier transform. A background spectrum was obtained by examining a sample free area in the field of view. Most spectra are baseline corrected to eliminate slopes and gentle curves. The region around 2100 wavenumbers may be obscured by the strong diamond absorbance in this region.

IR spectroscopy is generally only sensitive to bulk composition down to ~0.1-1% by weight for most common species. All metals and some metal oxides are not readily detectable by this technique.

- SEM/EDS Analysis of Solid Particles in Fuel Samples

Summary of Findings – SEM/EDS of Solid Particles from Fuel Samples

Observations from SEM/EDS:

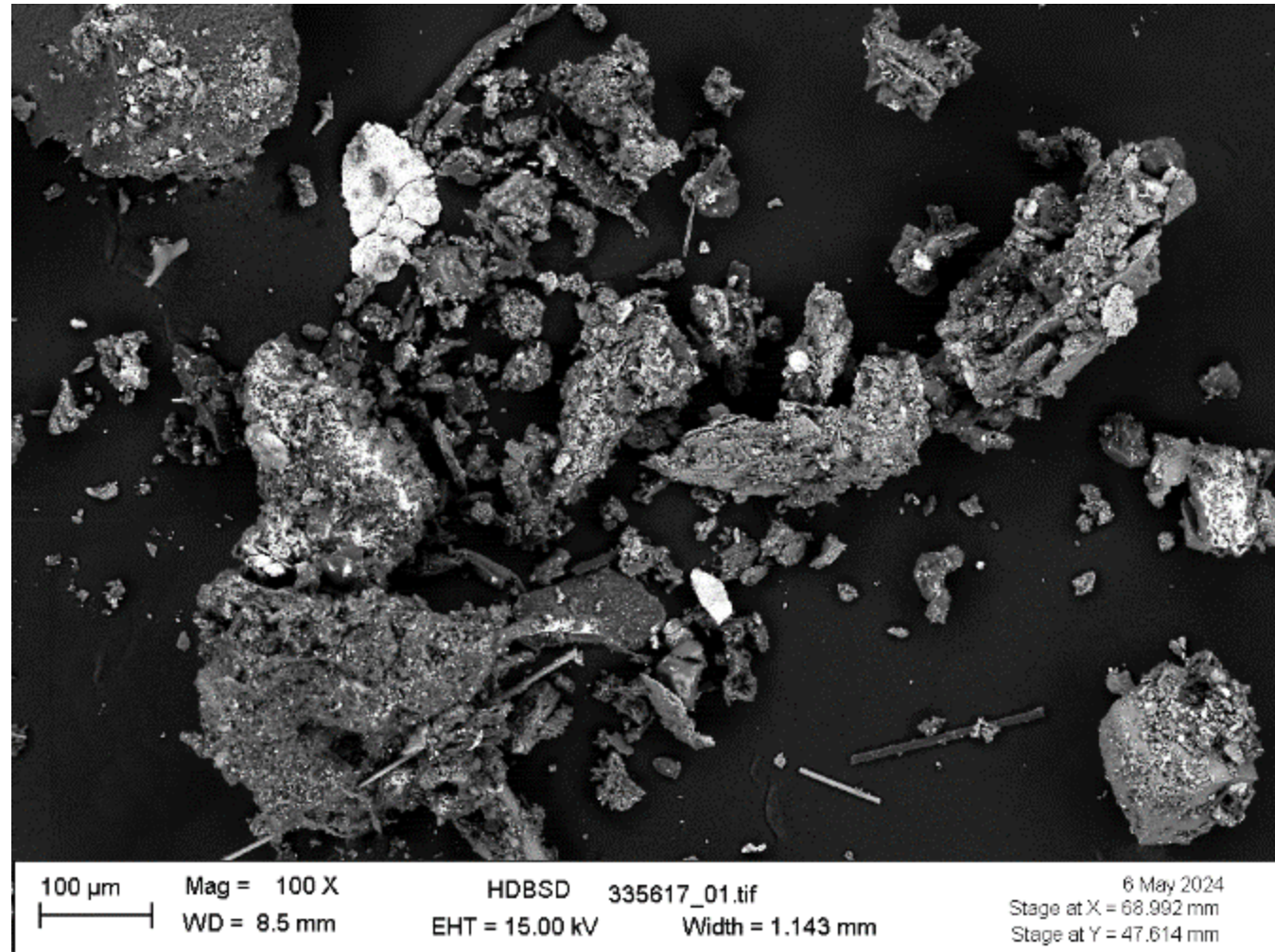
- Several of the fuel samples contained solid particles. A portion of each fuel sample was centrifuged to isolate these solid particles. The collected solid particles were then analyzed by IR spectroscopy and SEM/EDS to assess their chemical composition
- The elemental composition of the particles are detailed in the table below
- Some metal particles (Ti, Cr, Fe, Ni, Cu) are seem in small quantities
- O-S-Ca (likely calcium sulfate) crystals were found in 335811
- Solids in 335812 contain significant levels of Ti, which was not observed in the other samples

Experimental Details:

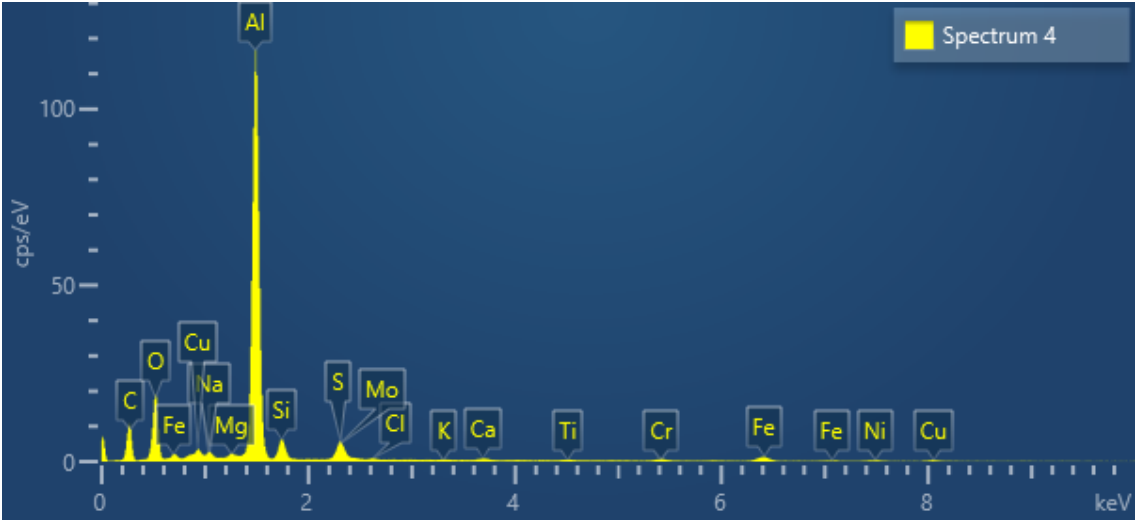
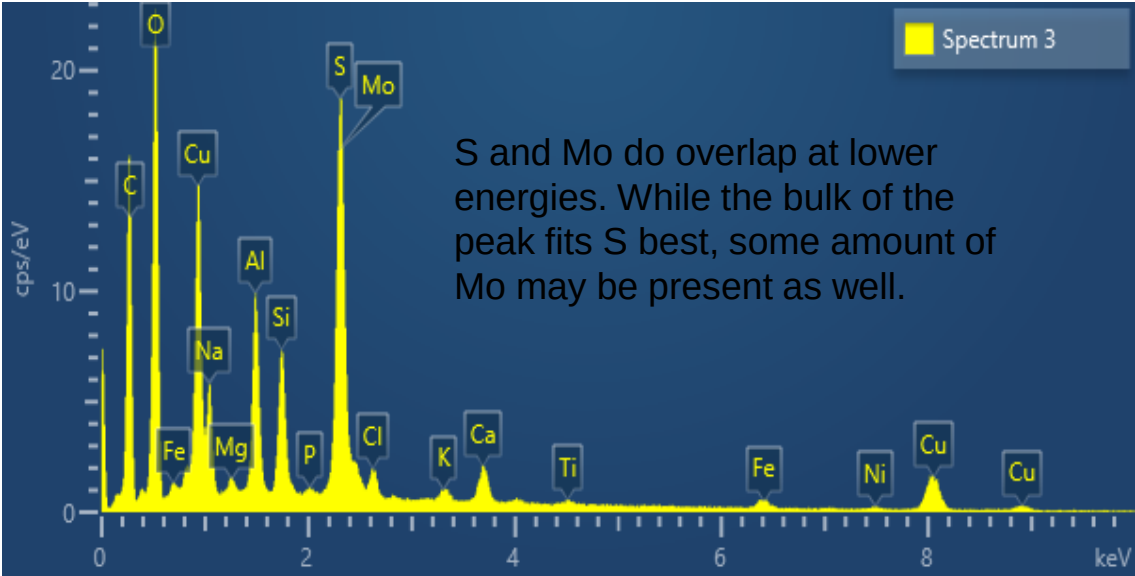
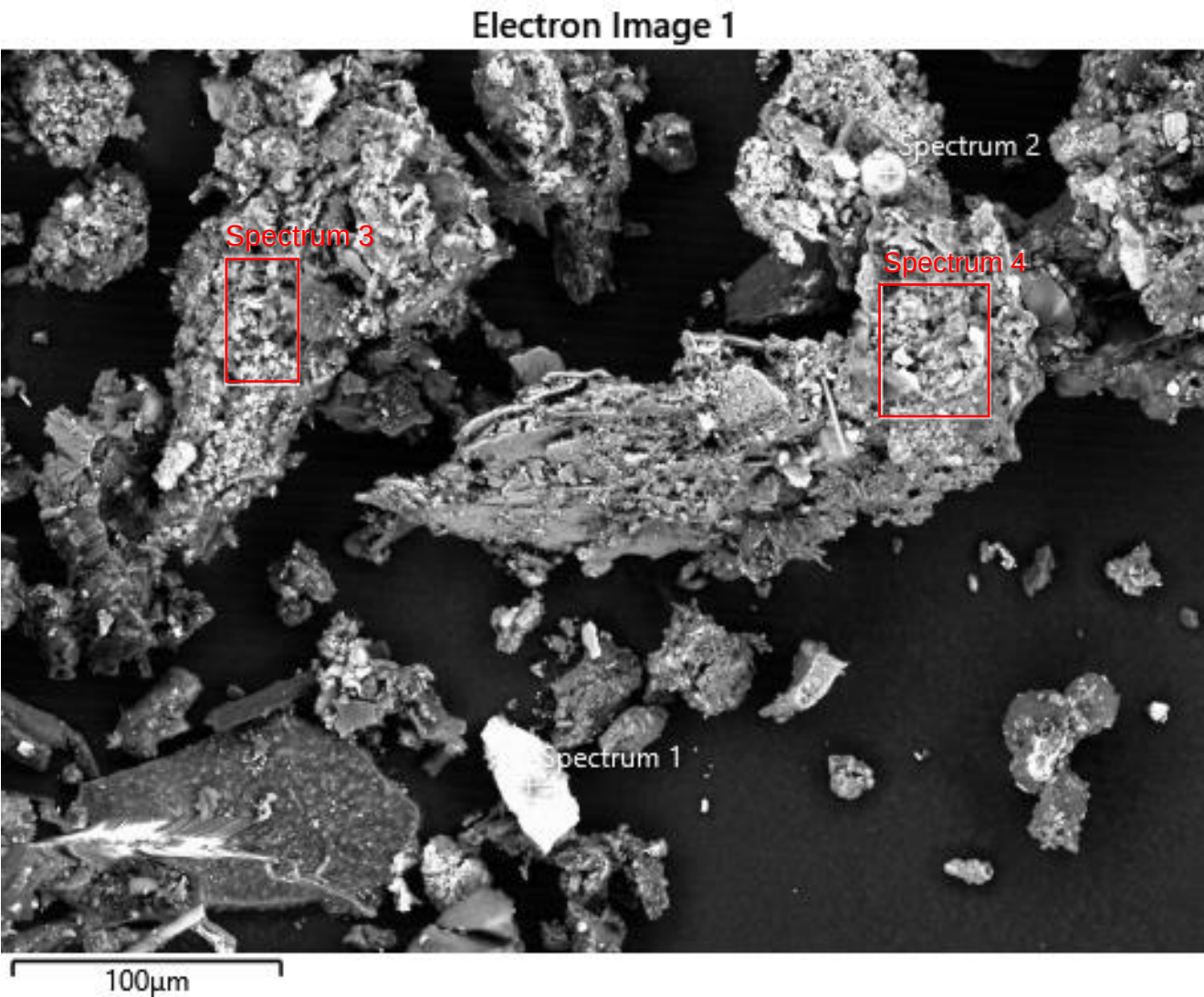
- SEM: Zeiss Supra 55VP
 - 15 kV
 - 60 µm Aperture
- EDS: Oxford Instruments X-Max 80mm² EDS Detector
- Approximately 4 nm of platinum coating was applied to each sample

Barcode	Sampling location	SEM/EDS elemental composition of particles
335617	right engine heat exchanger	S Si O C Al
335618	left main (unreadable)	Si O C Al
335619	right engine fuel filter bowl	C O Ca S
335620	left engine heat exchanger	C O Si Ca S
335621	left engine fuel filter bowl	
335622	APU	Si O C Ca S
335804	left engine fuel flow meter and fuel manifold	
335809	right engine fuel flow meter	
335810	AFT tail tank	
335811	left engine fuel control unit	Ca S O C
335812	right engine fuel pump	Si O C S Cr Ti
335813	right engine fuel control	Si O C S Al Mg

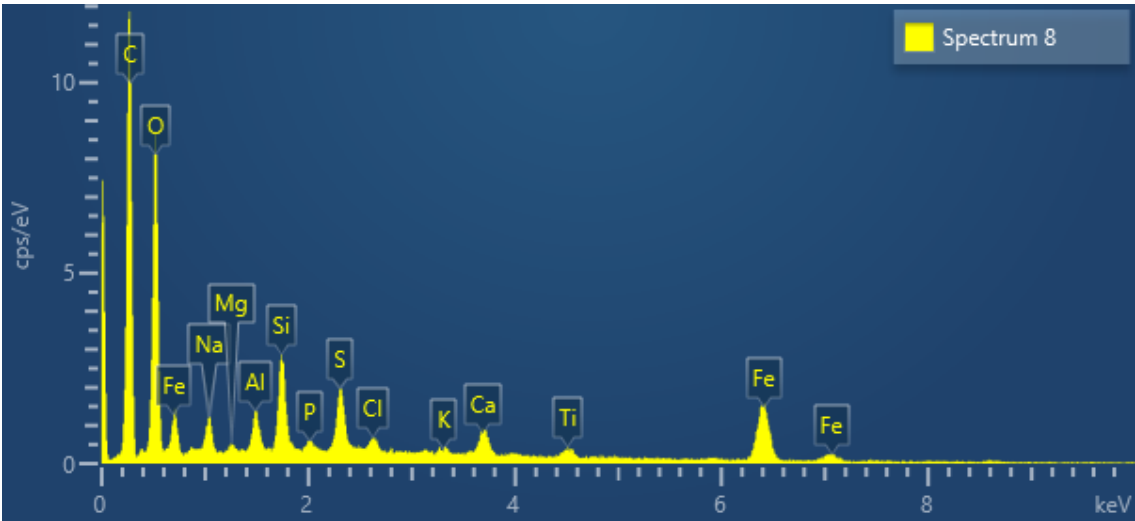
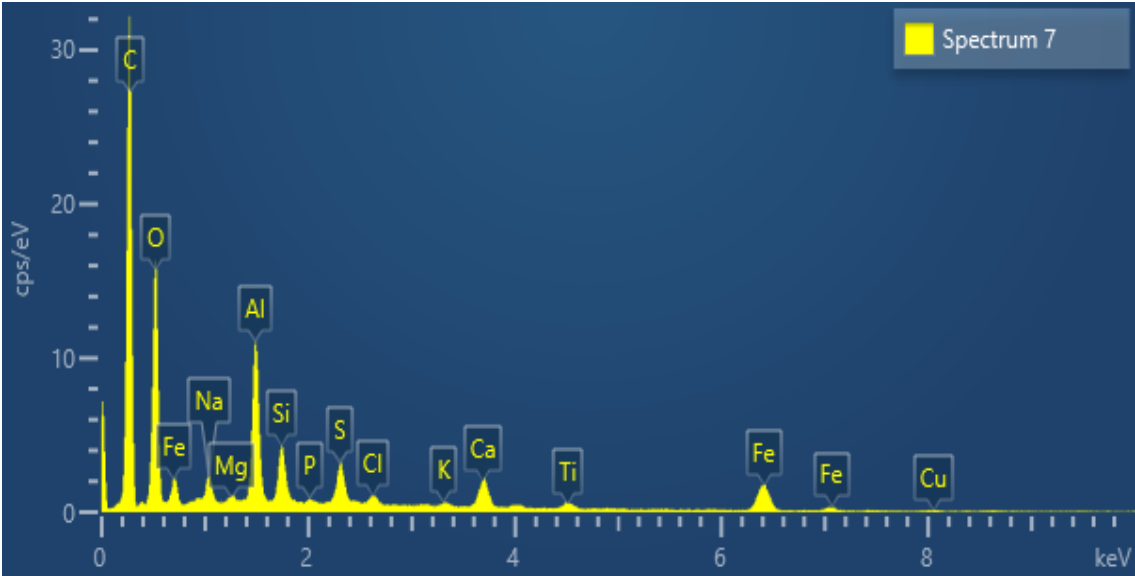
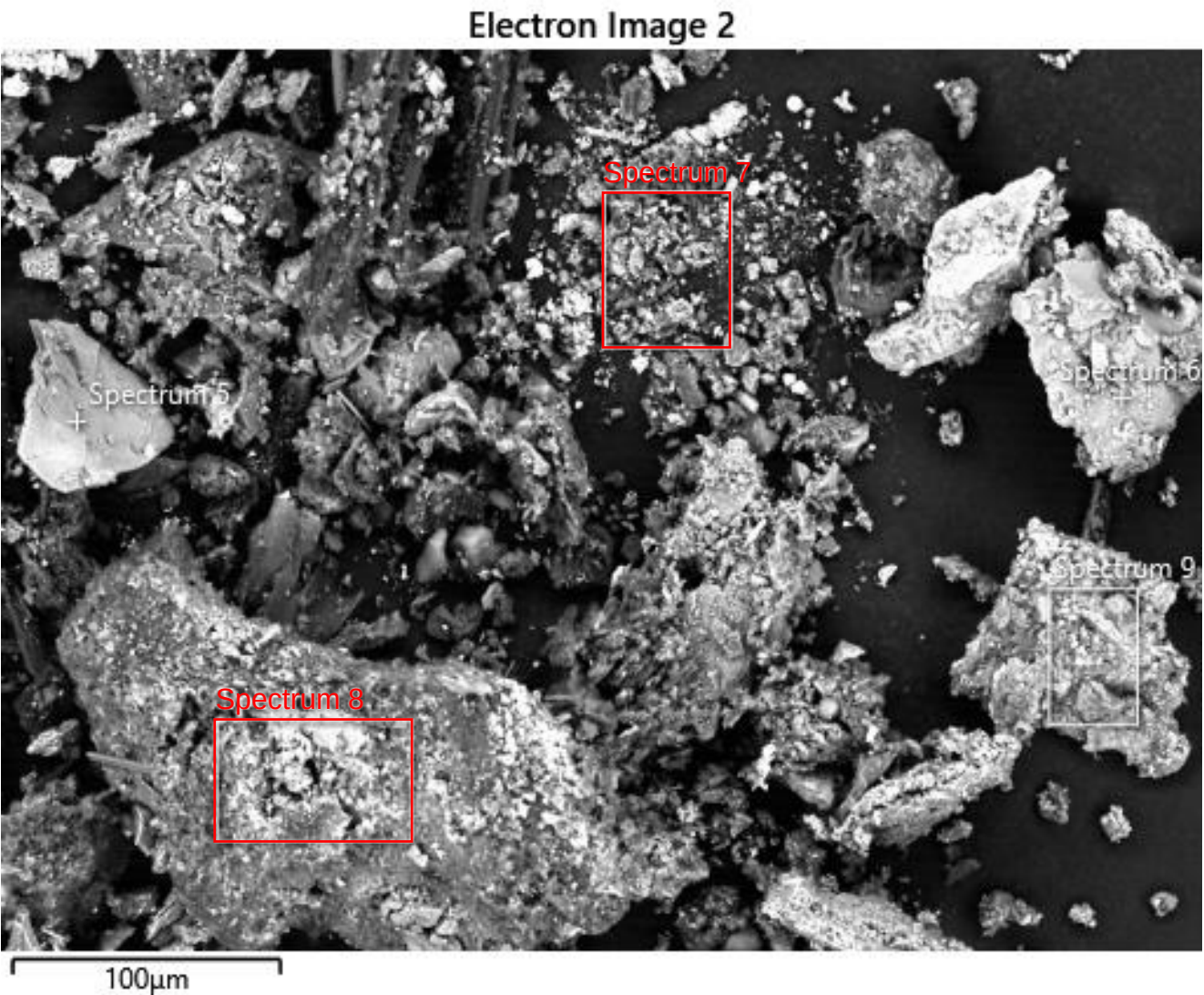
Area 1 – 100x – Backscatter - 335617 right engine heat exchanger



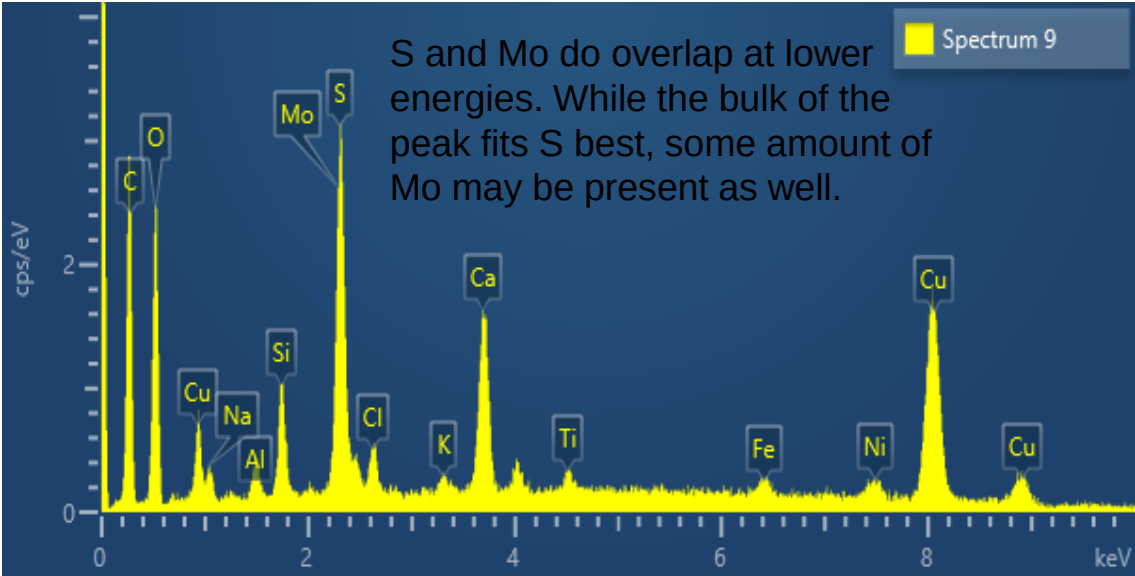
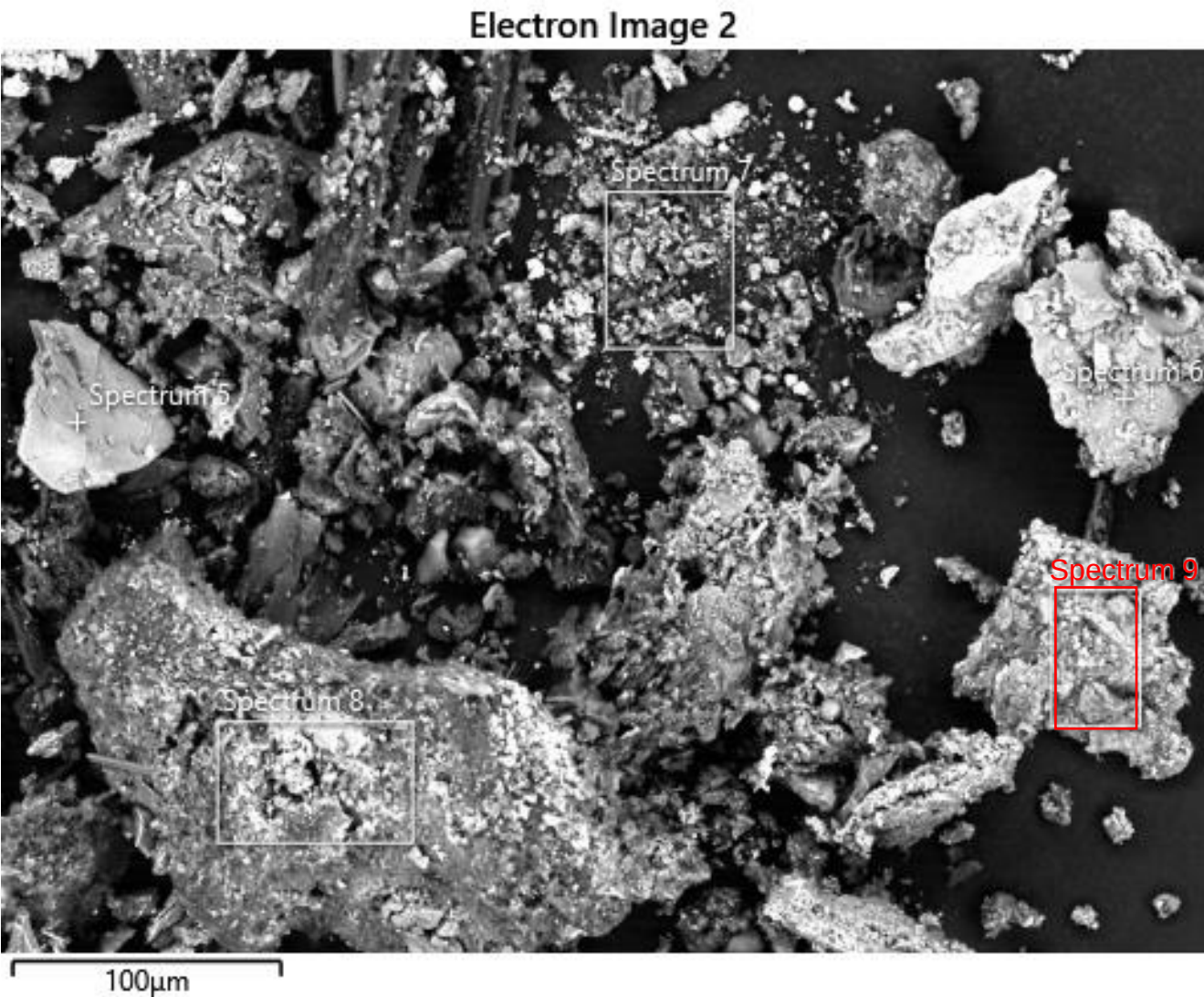
Area 1 – 250x – EDXS Point Analysis - 335617 right engine heat exchanger



Area 2 – 250x – EDXS Point Analysis - 335617 right engine heat exchanger



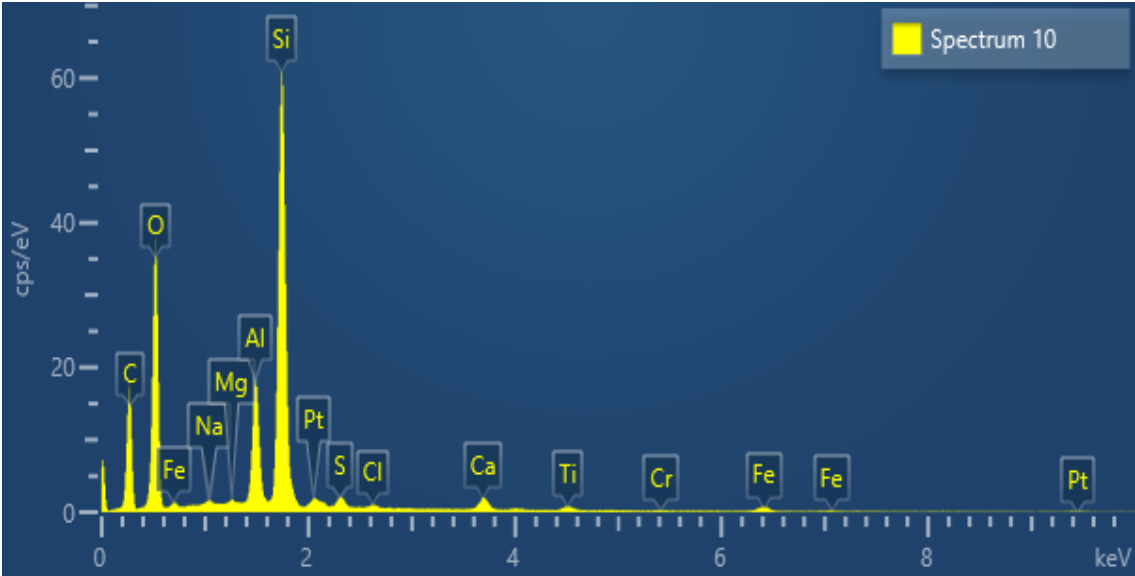
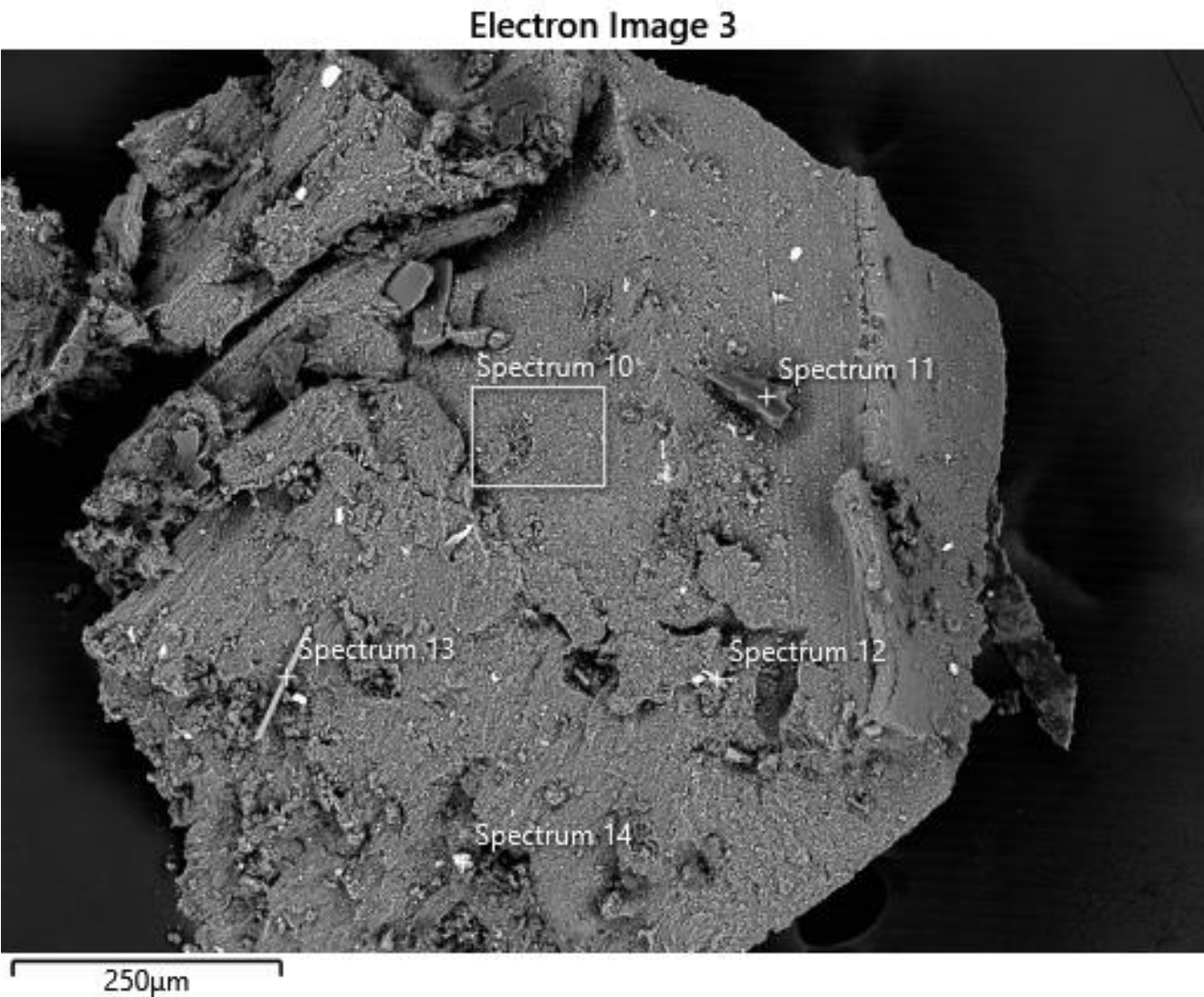
Area 2– 250x – EDXS Point Analysis - 335617 right engine heat exchanger



Area 3 – 50x – Backscatter - 335618 left main

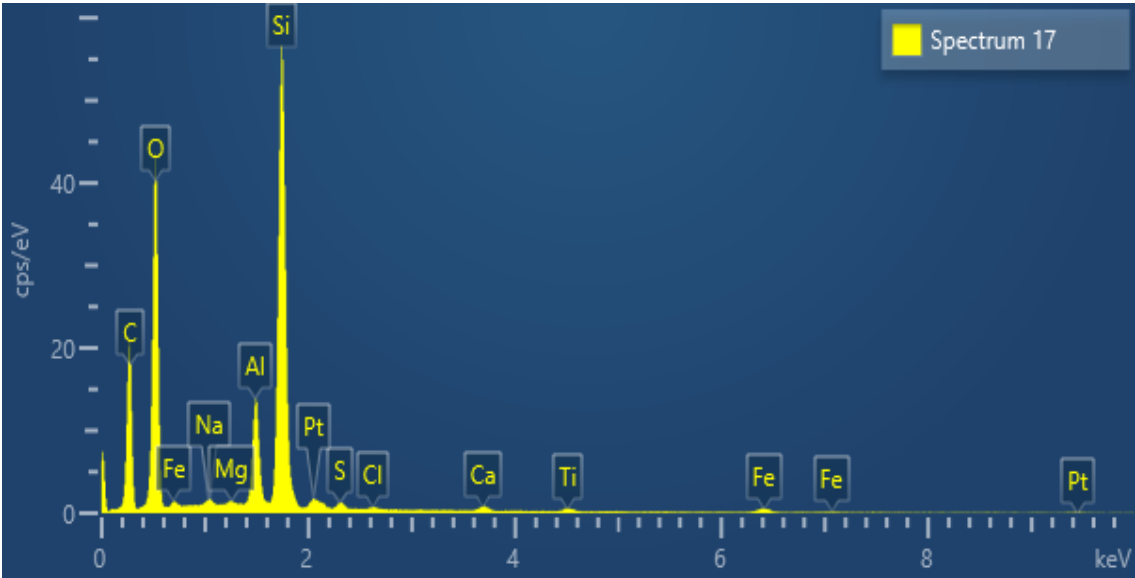
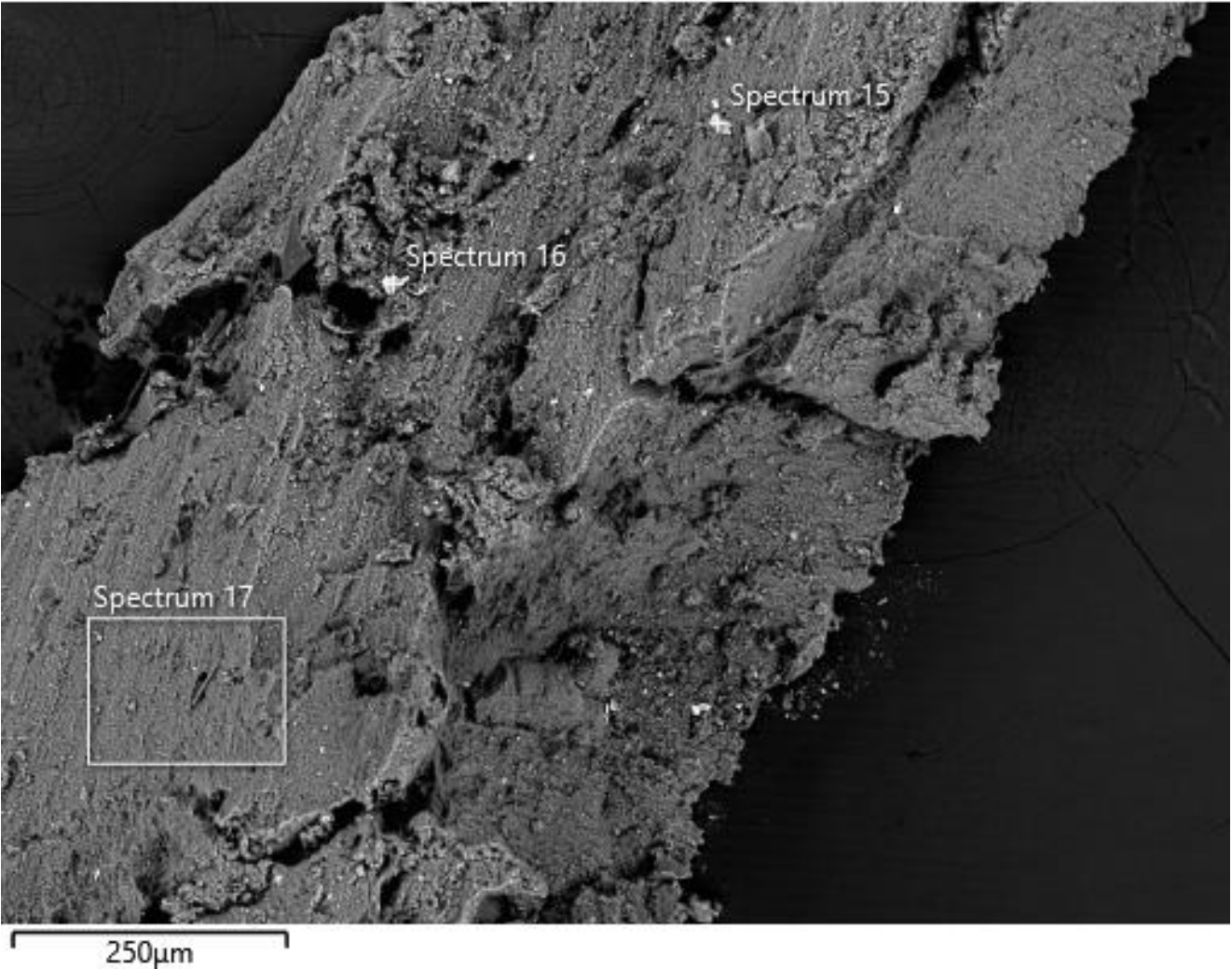


Area 1 – 100x – EDXS Point Analysis - 335618 left main

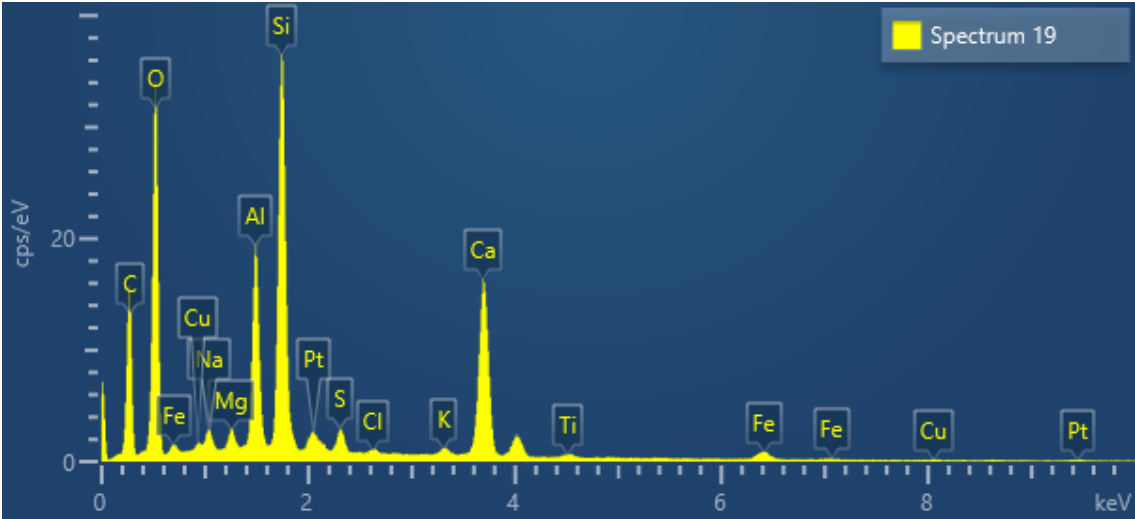
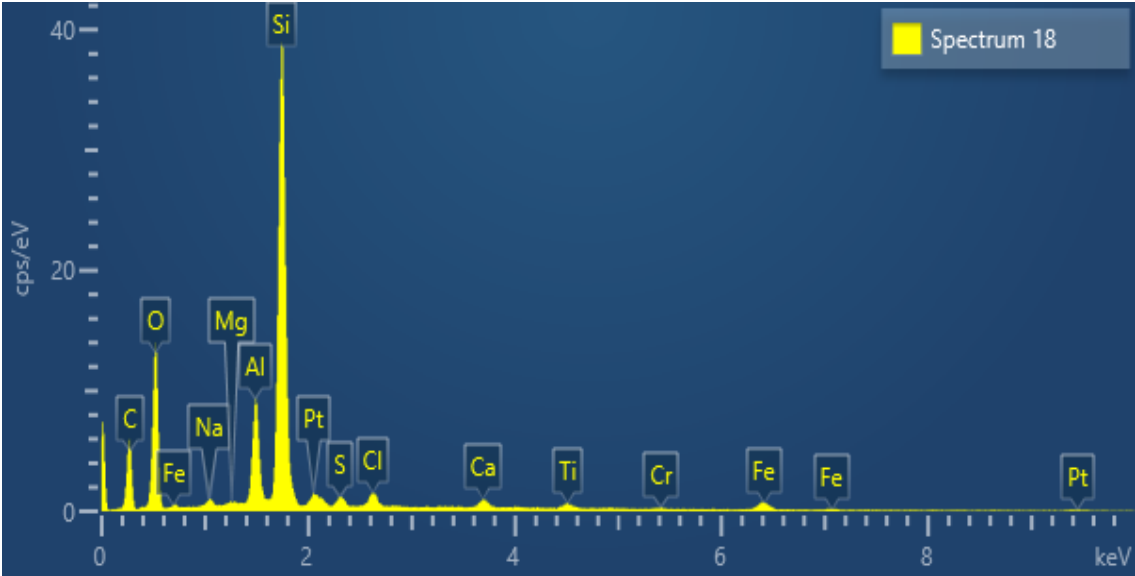
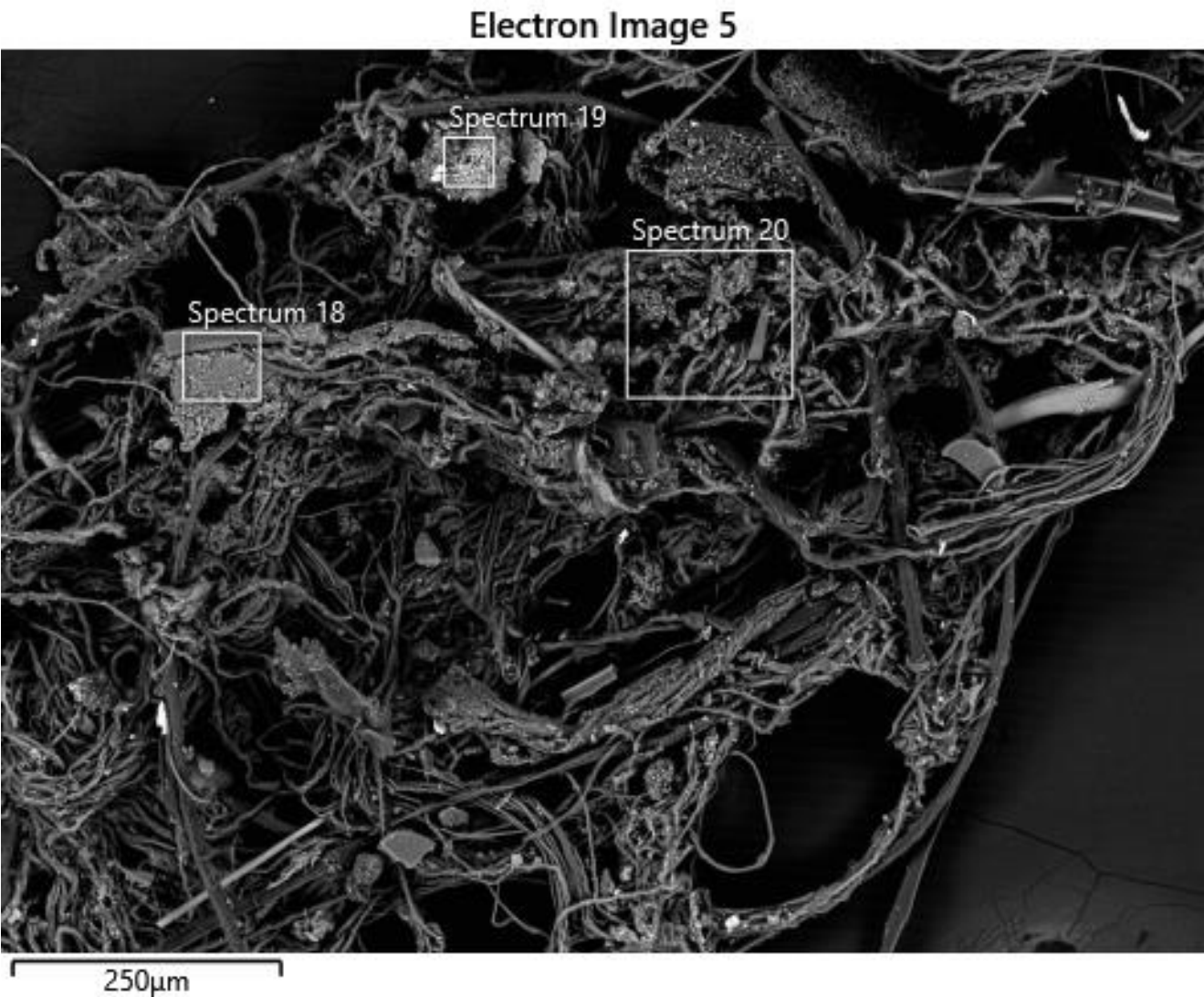


Area 2 – 100x – EDXS Point Analysis - 335618 left main

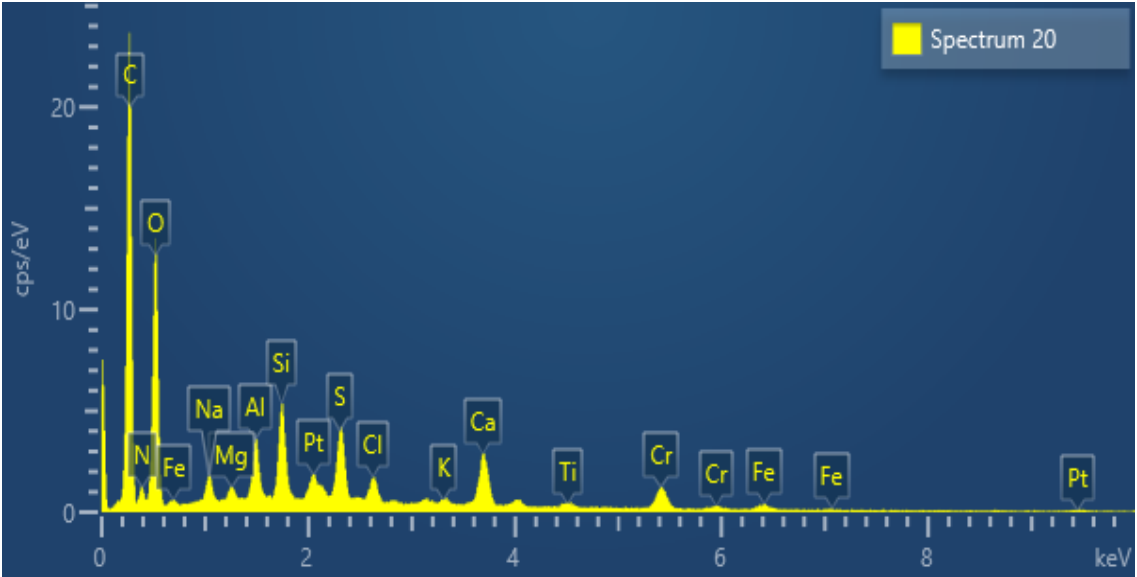
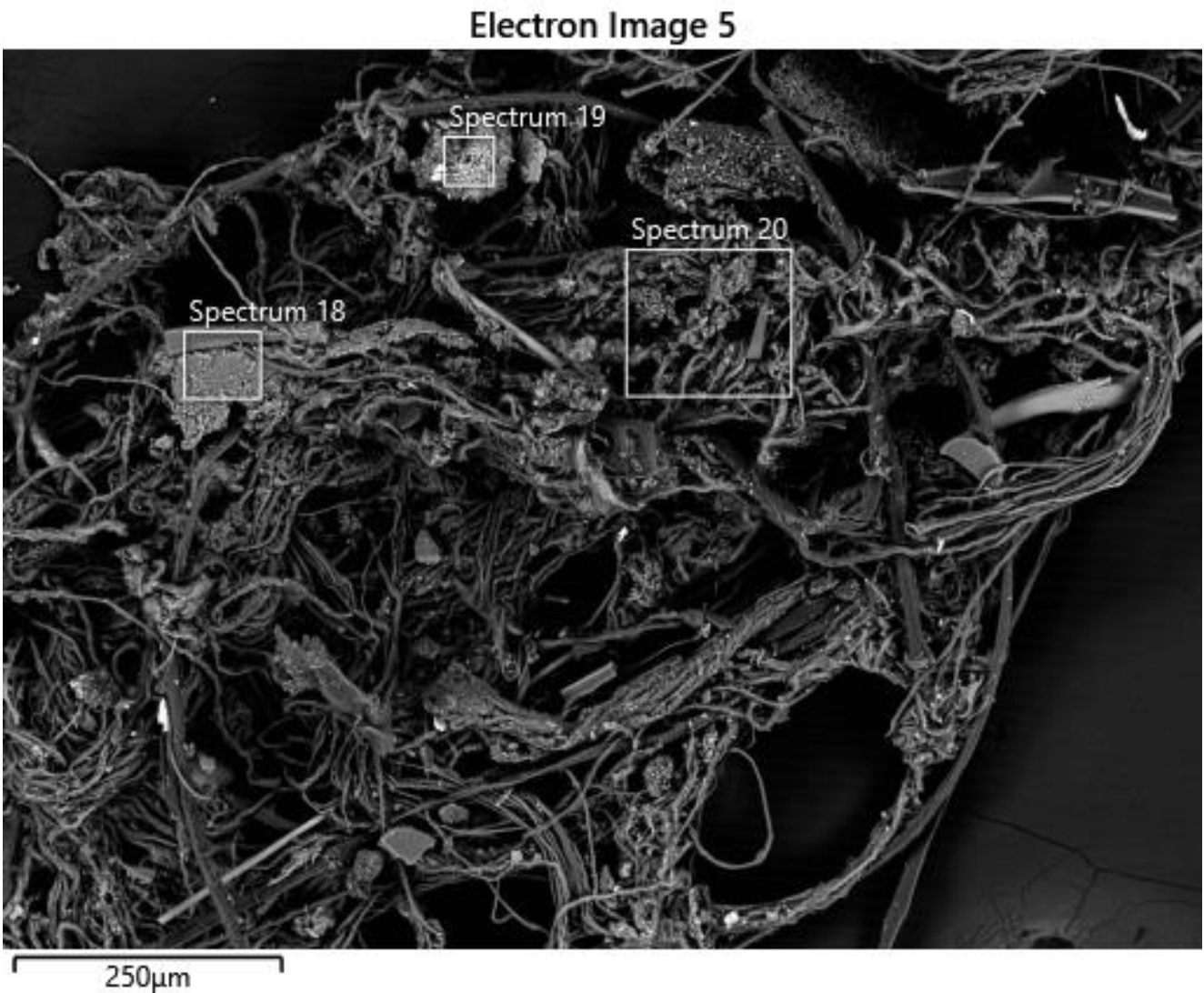
Electron Image 4



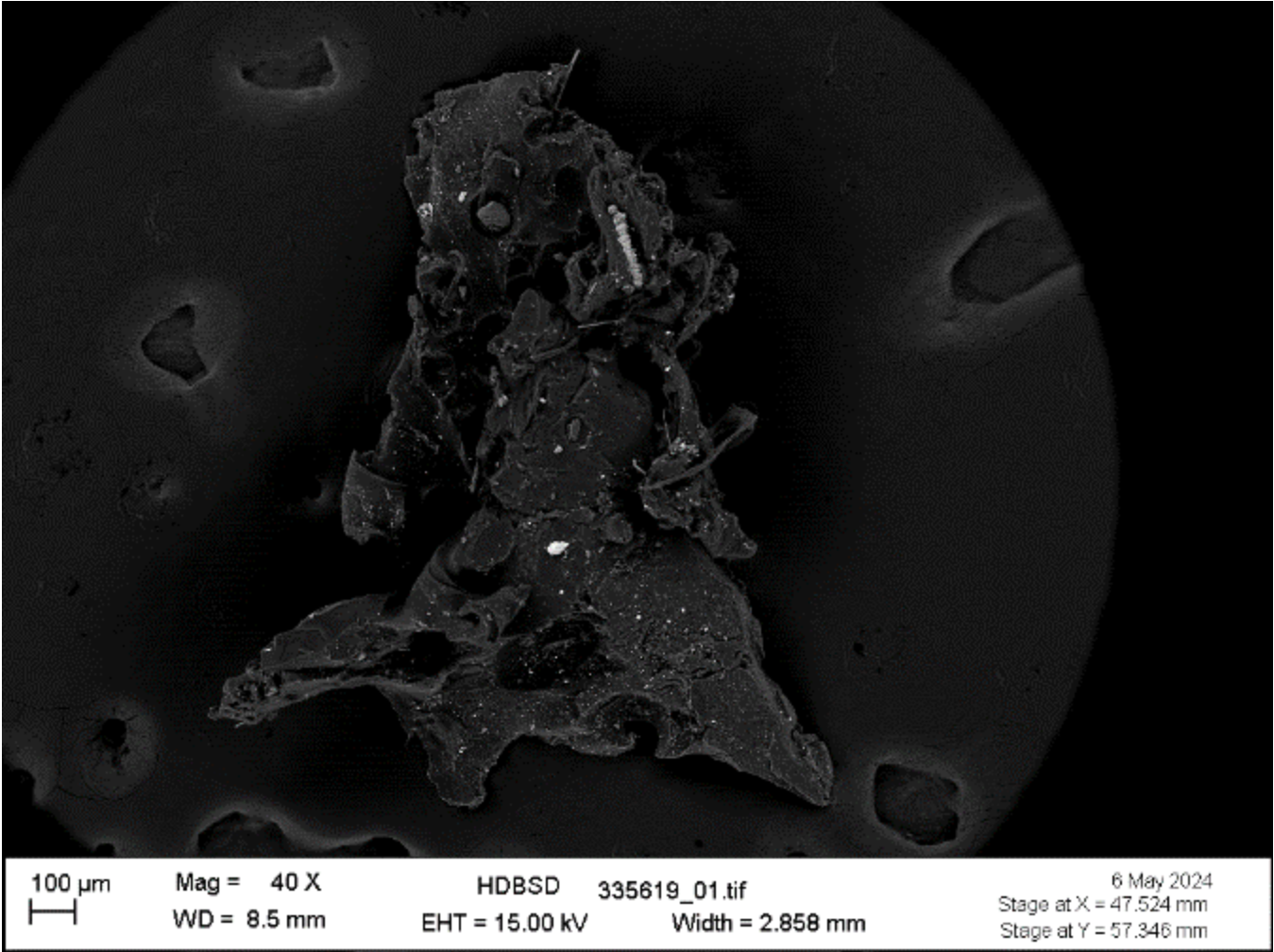
Area 3 – 100x – EDXS Point Analysis - 335618 left main



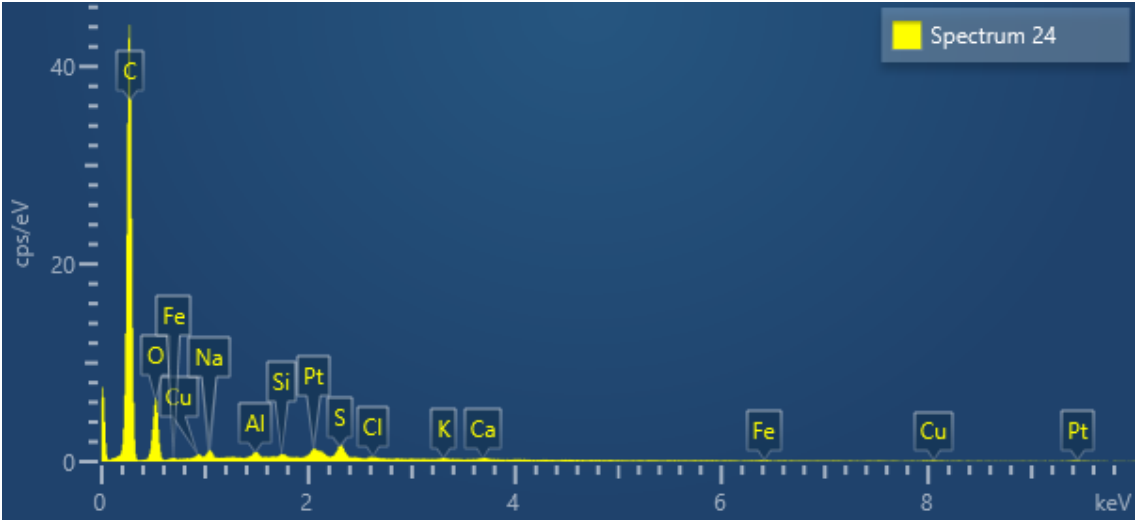
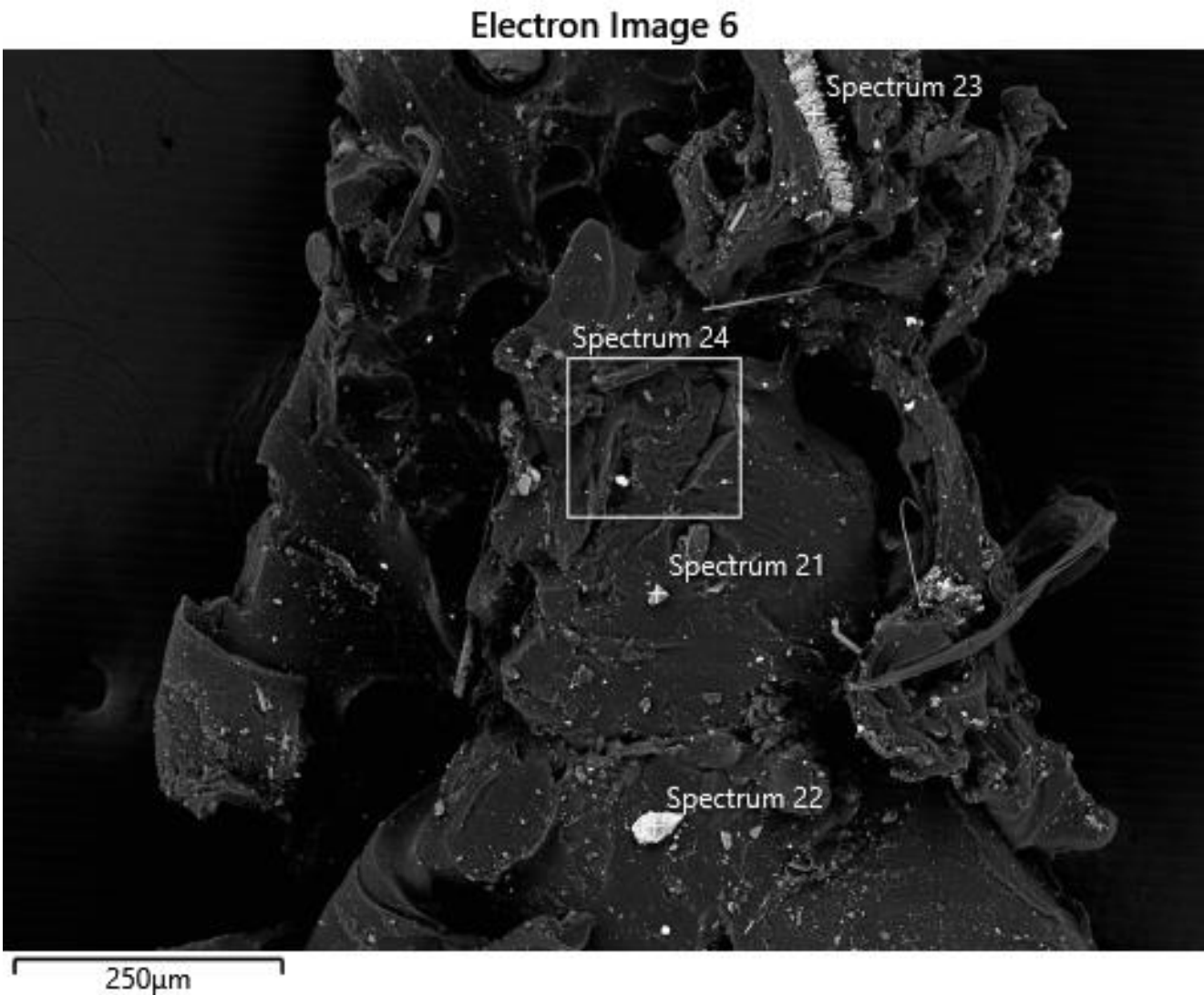
Area 3 – 100x – EDXS Point Analysis - 335618 left main



Area 1 – 40x – Backscatter - 335619 right engine fuel filter bowl



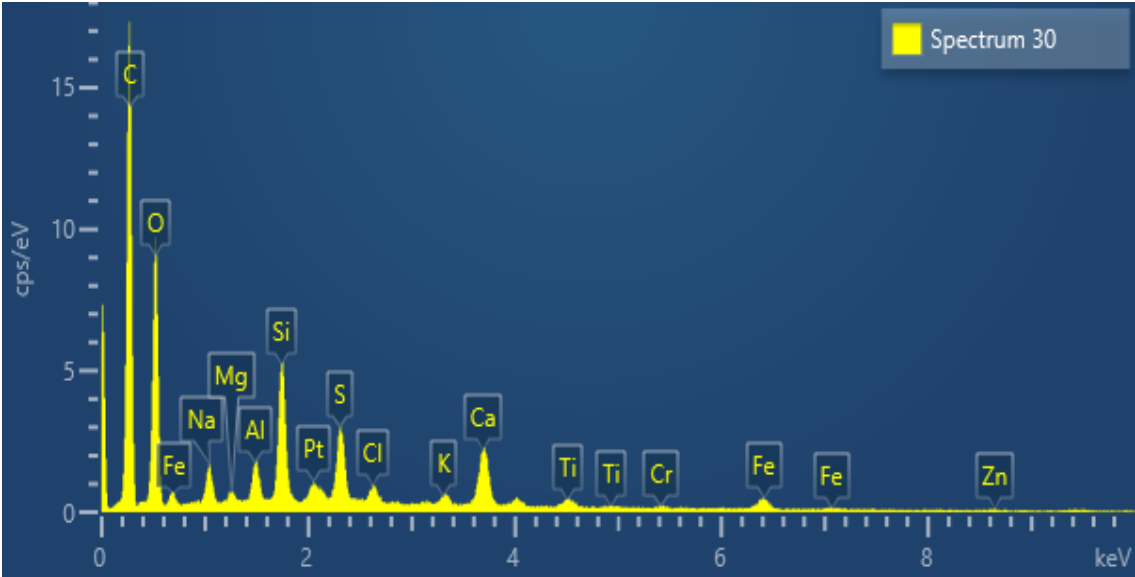
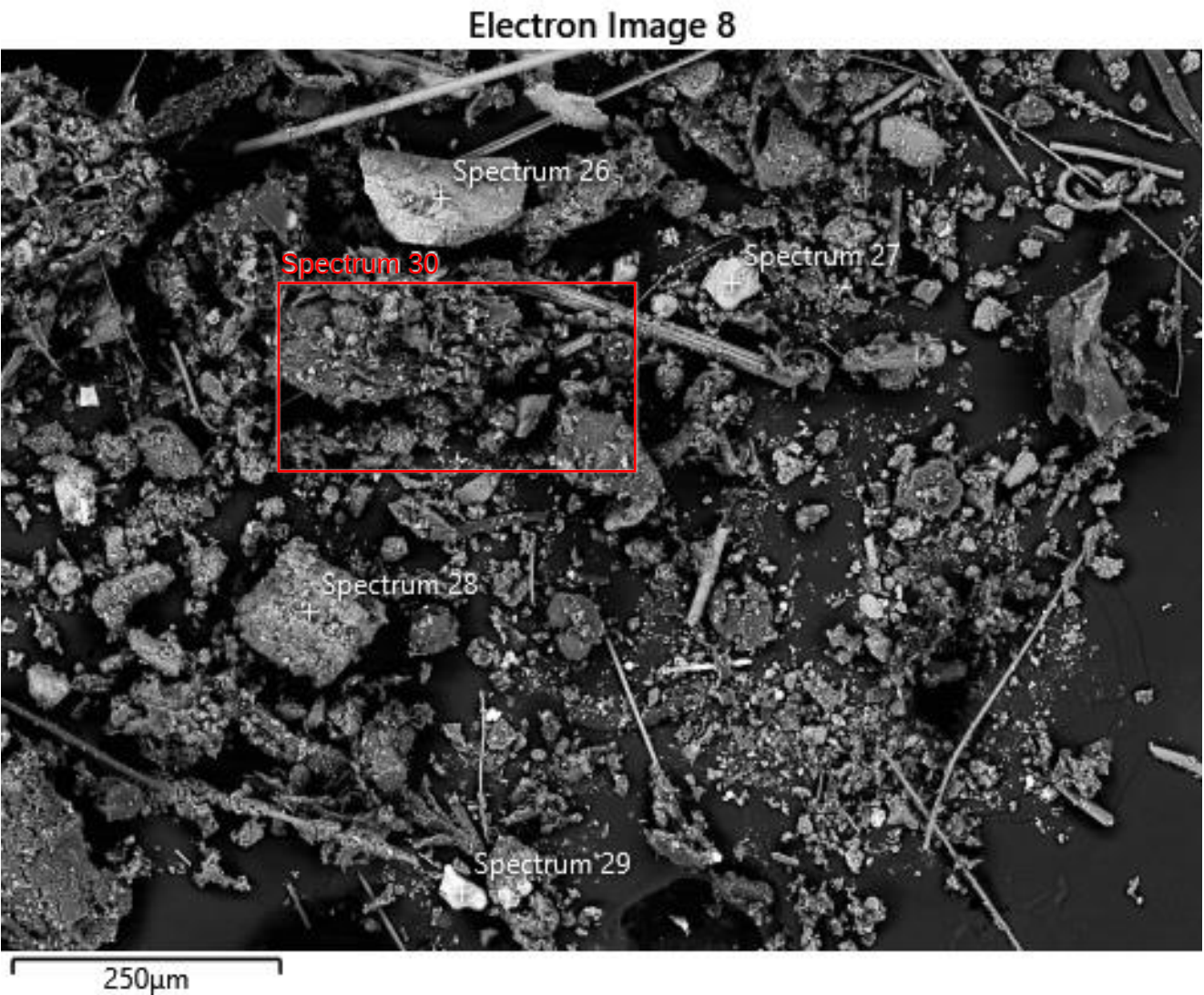
Area 1 – 100x – EDXS Point Analysis - 335619 right engine fuel filter bowl



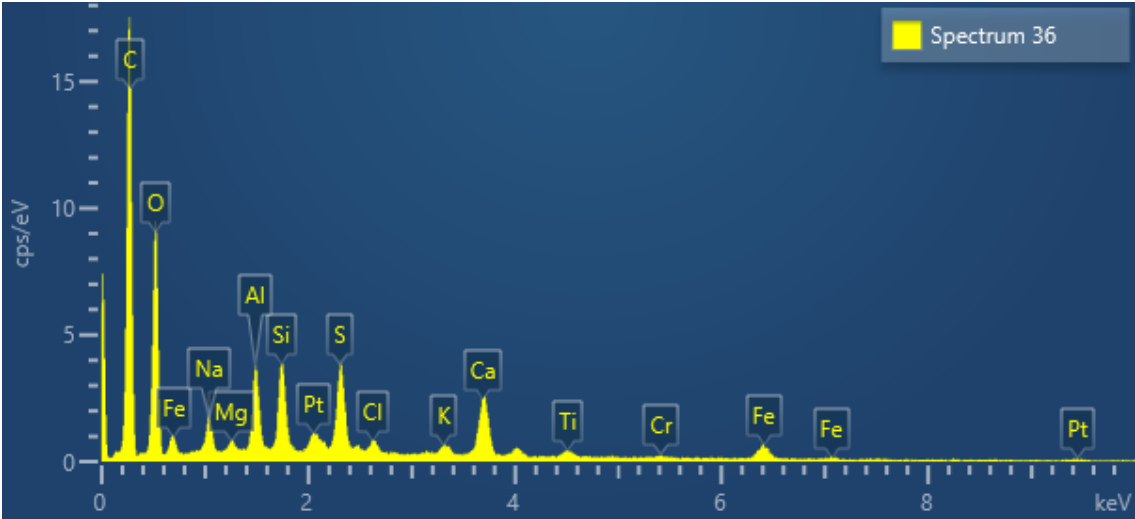
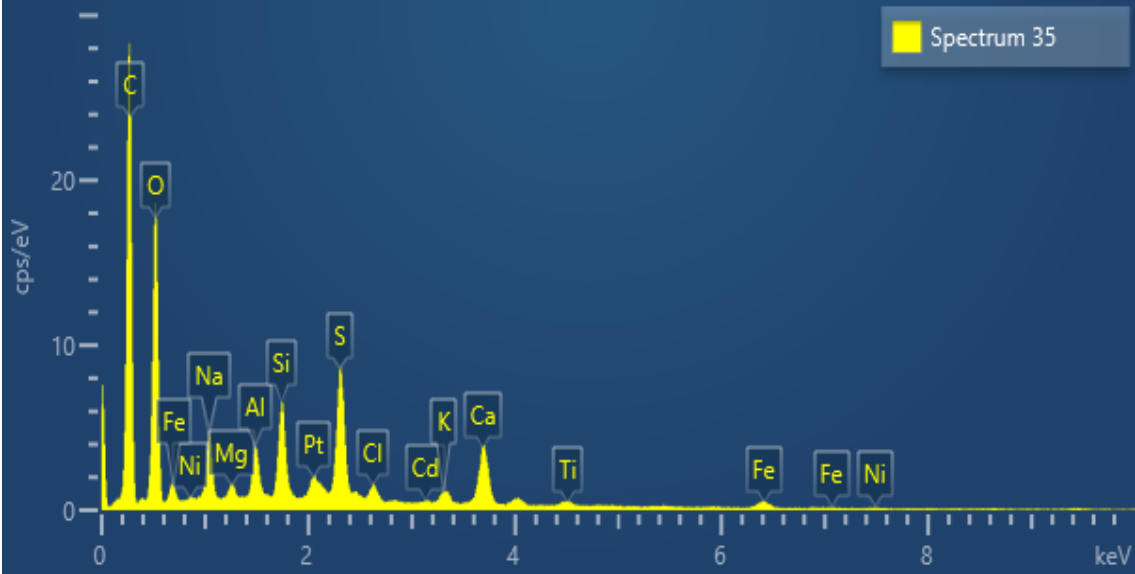
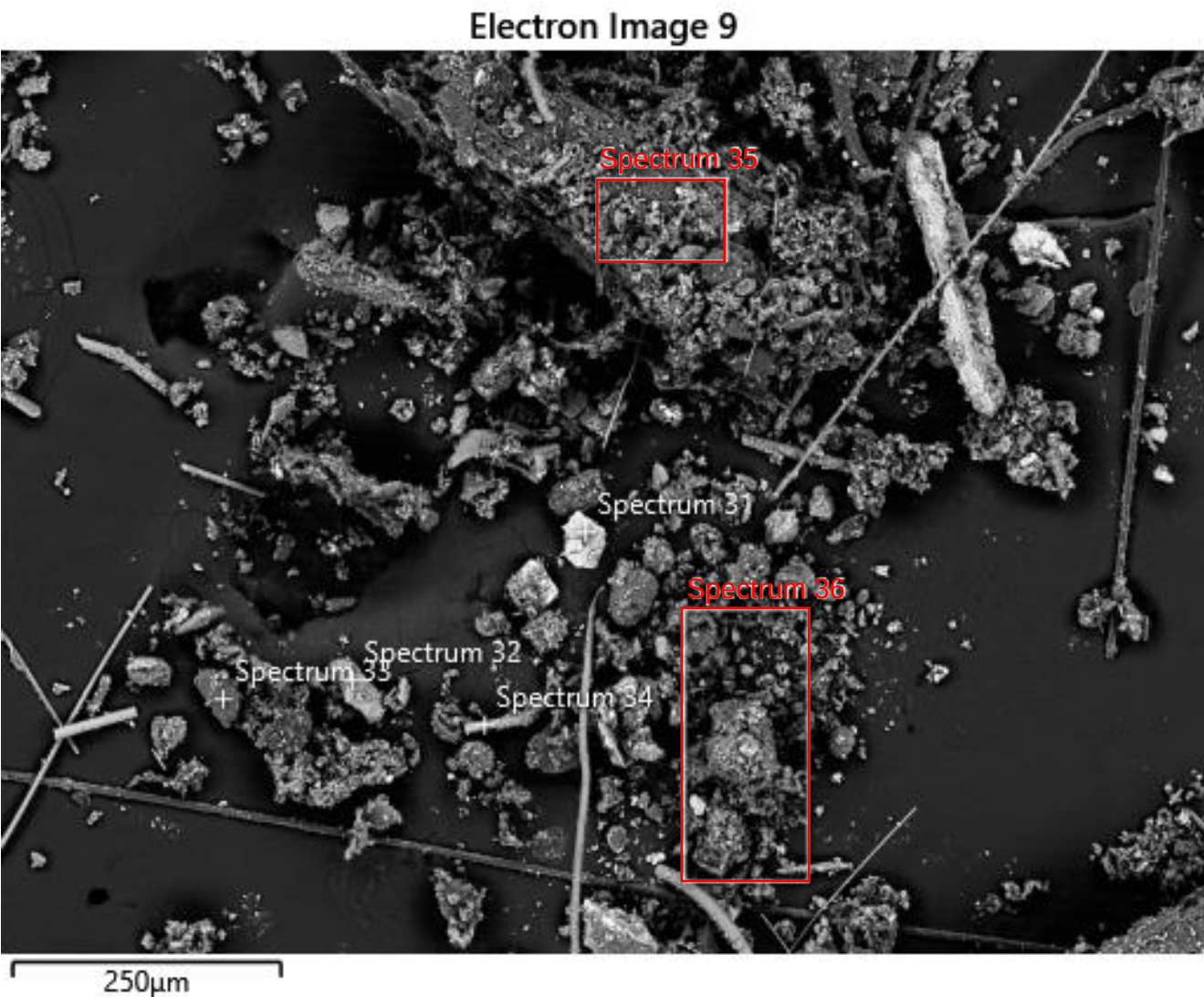
Area 1 – 50x – Backscatter - 335620 left engine heat exchanger



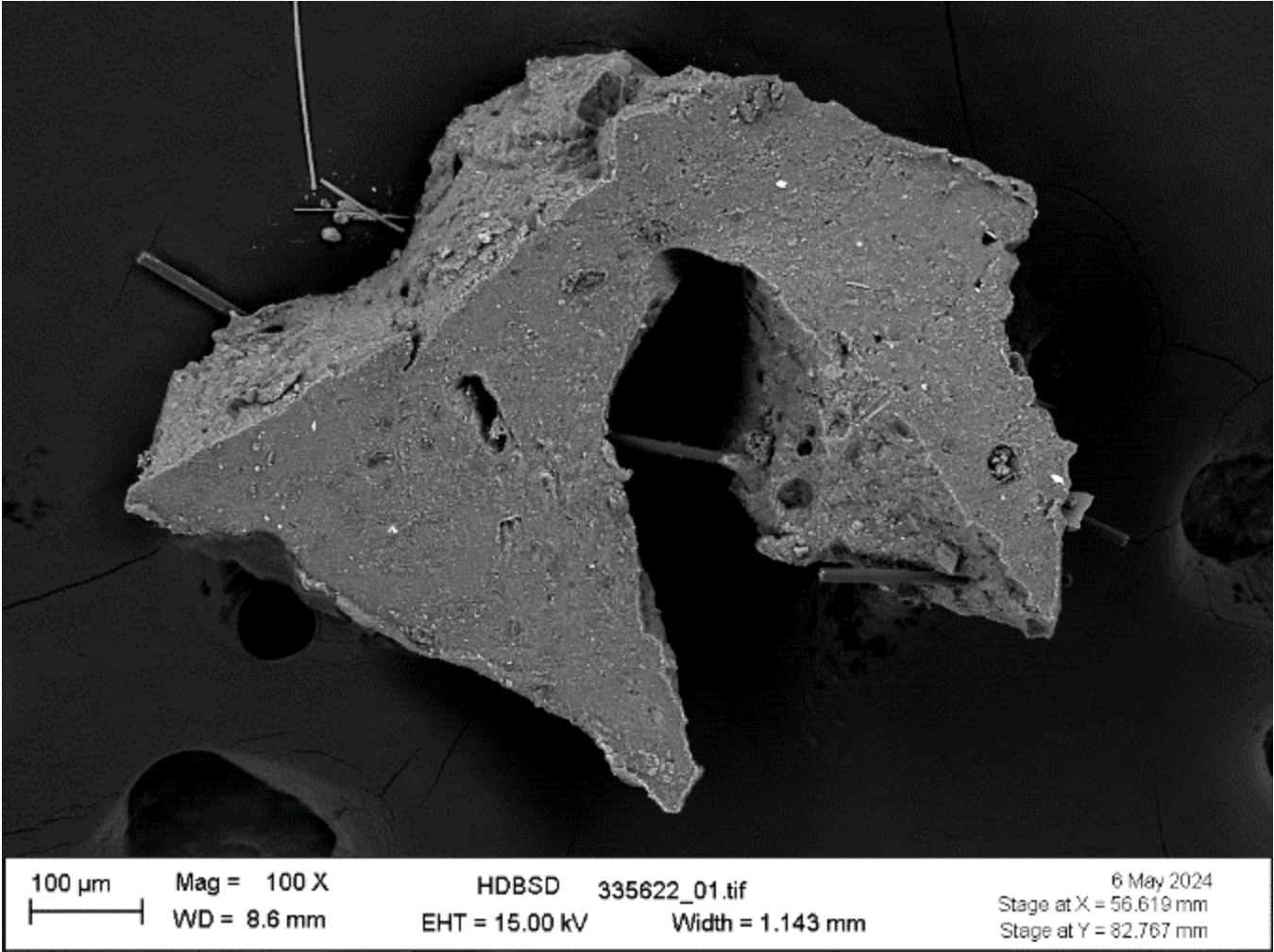
Area 1 – 100x – EDXS Point Analysis - 335620 left engine heat exchanger



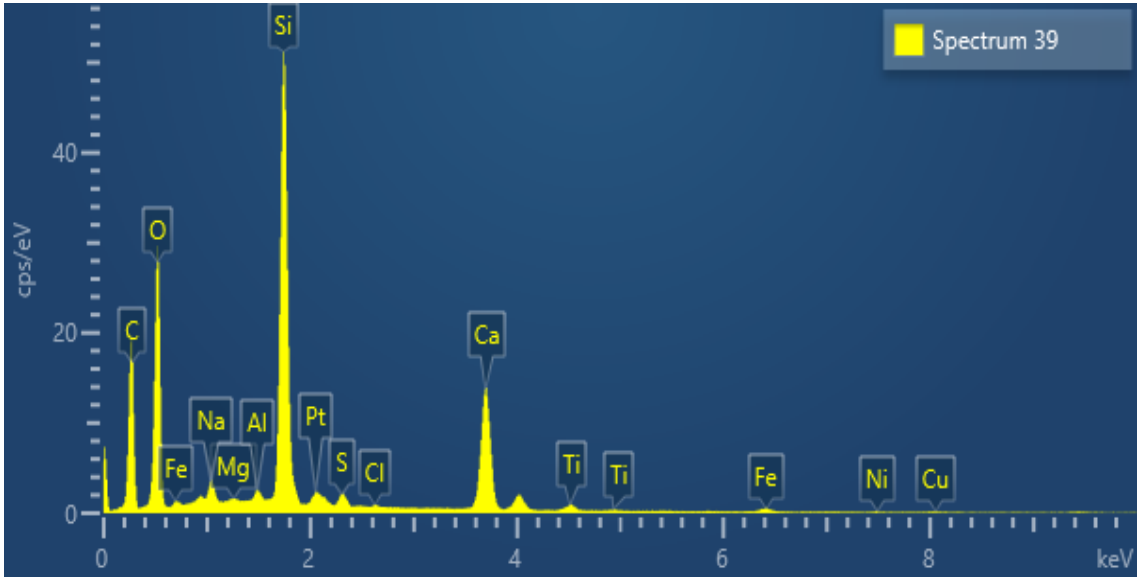
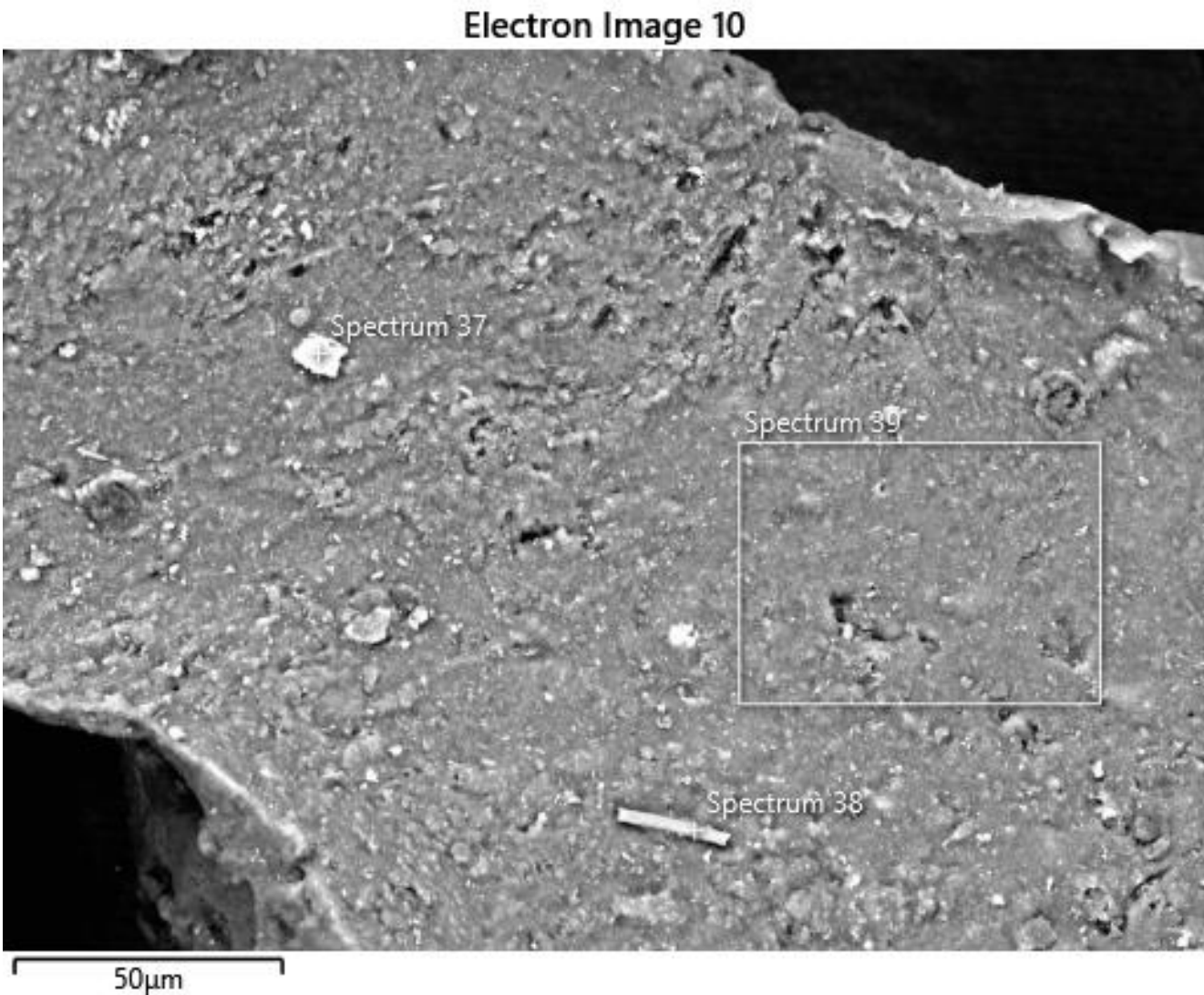
Area 2 – 100x – EDXS Point Analysis - 335620 left engine heat exchanger



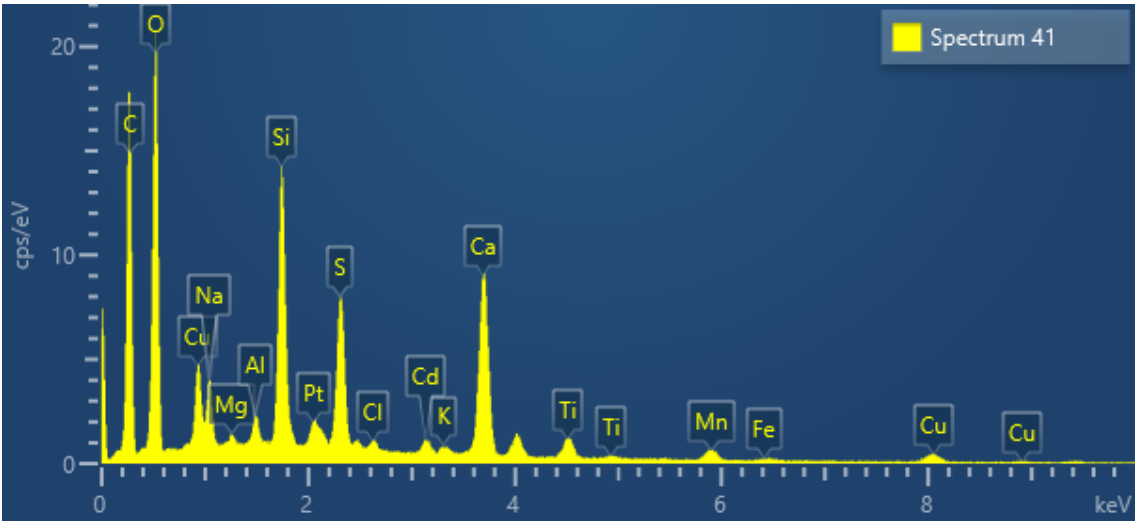
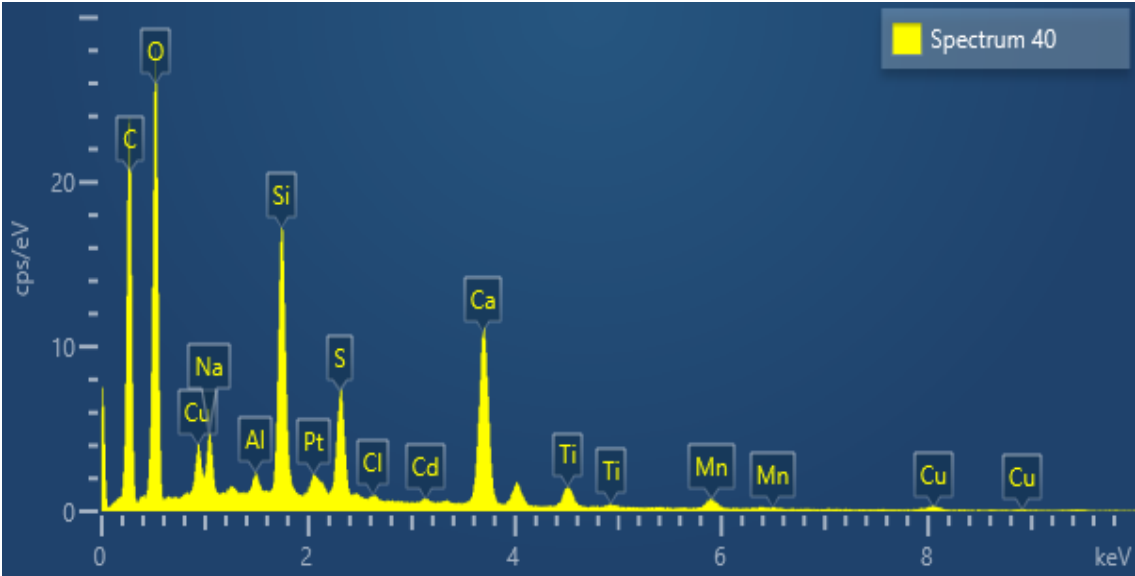
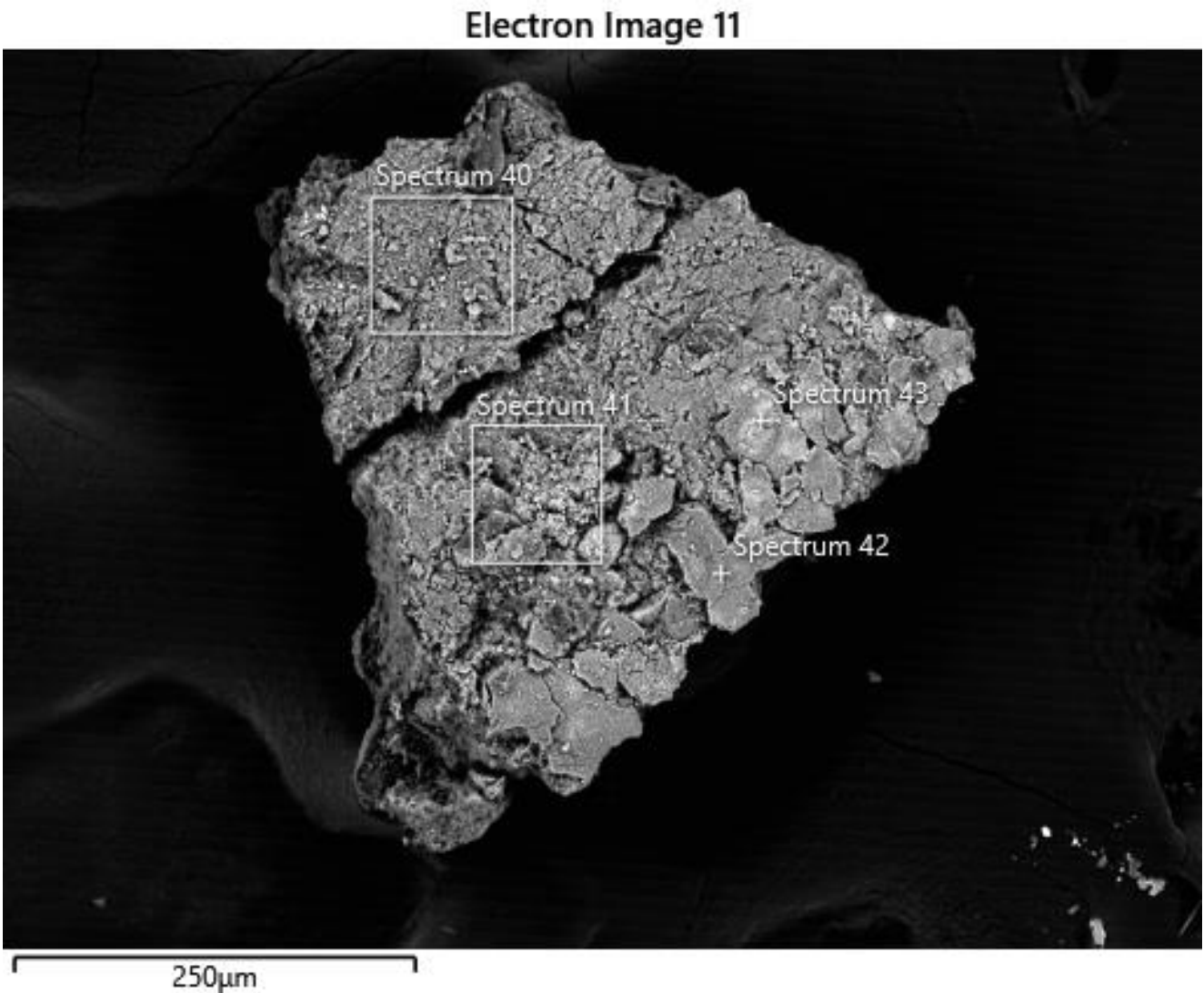
Area 1 – 100x – Backscatter - 335622 APU filter



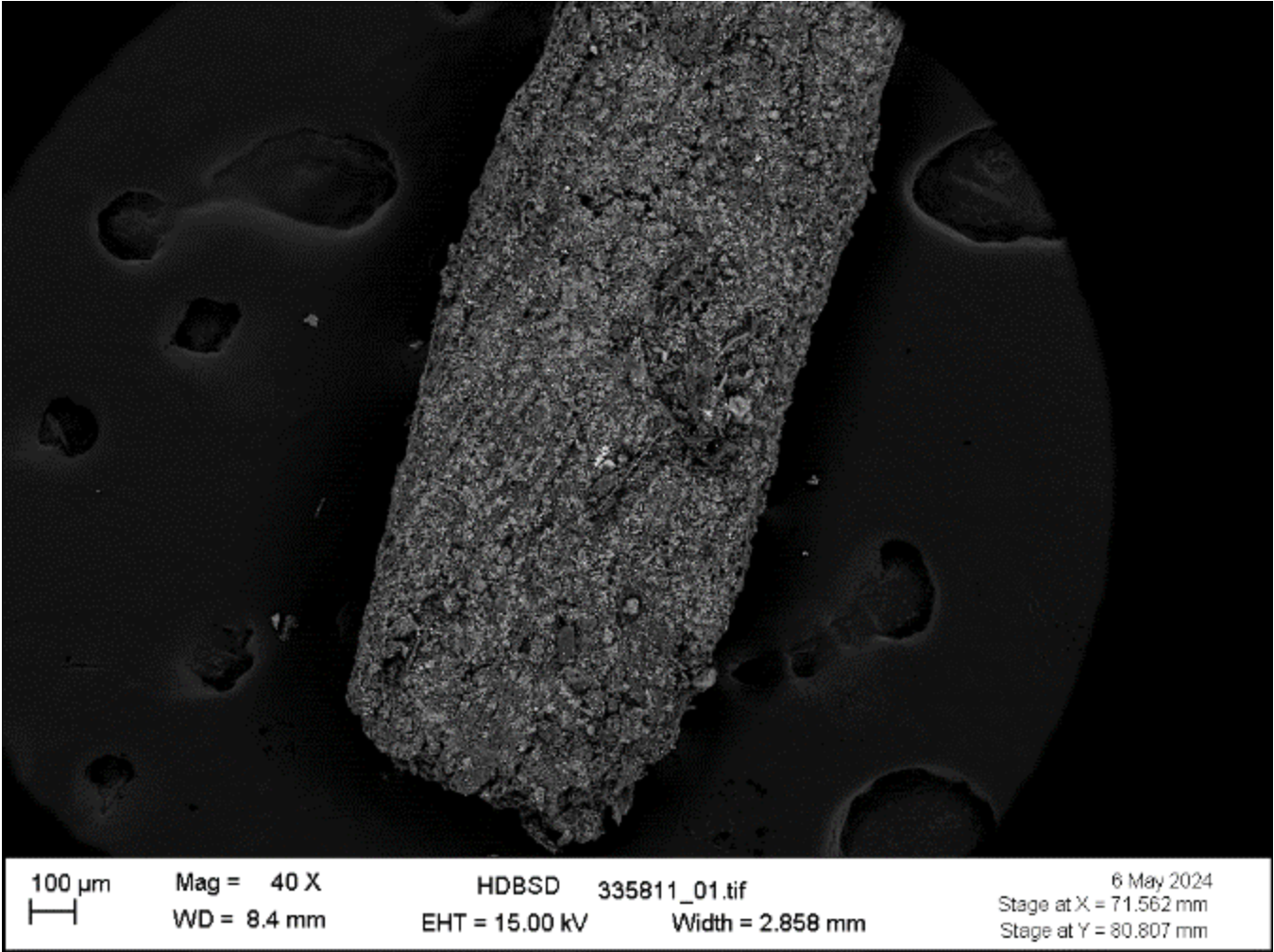
Area 1 – 500x – EDXS Point Analysis - 335622 APU filter



Area 2 – 150x – EDXS Point Analysis - 335622 APU filter

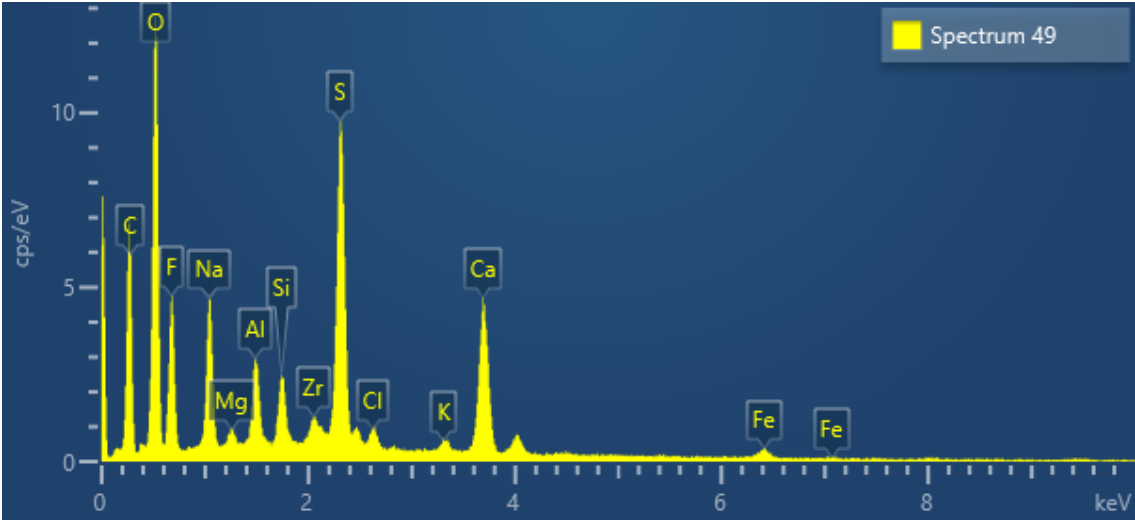


Area 1 – 40x – Backscatter - 335811 left engine fuel control unit

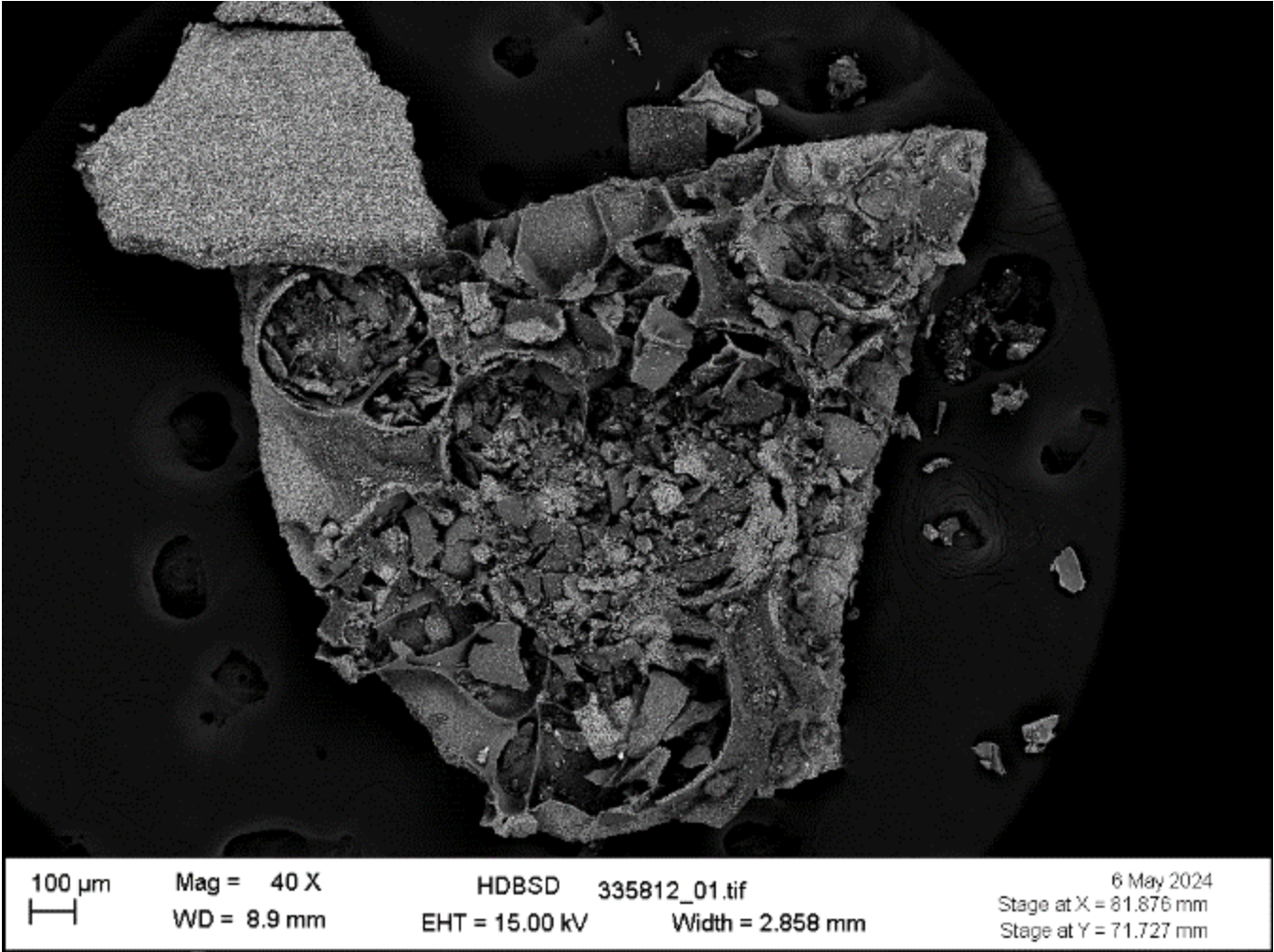


Area 1 – 250x – EDXS Point Analysis – 335811 left engine fuel control unit

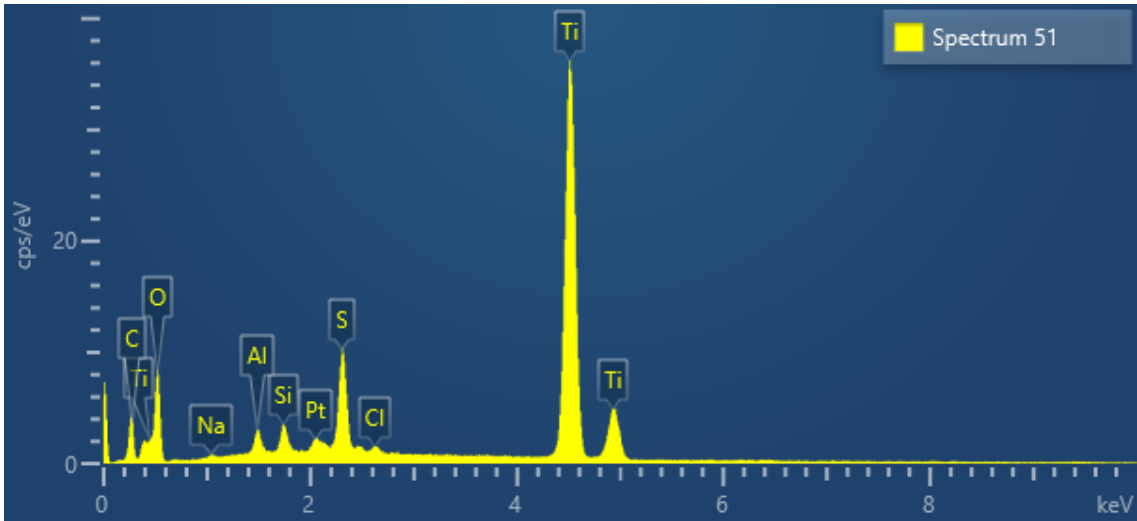
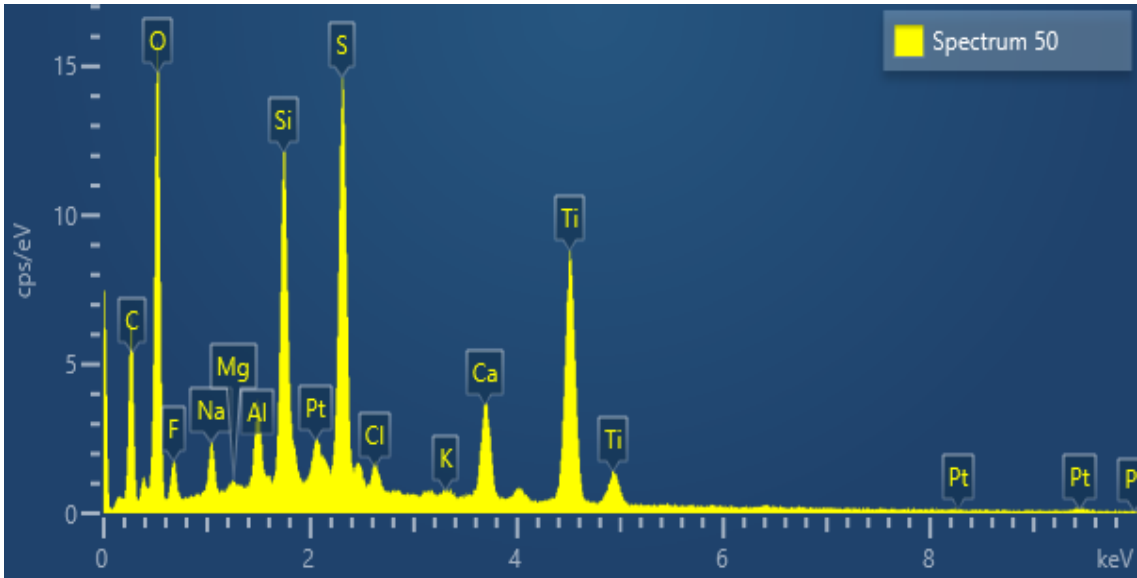
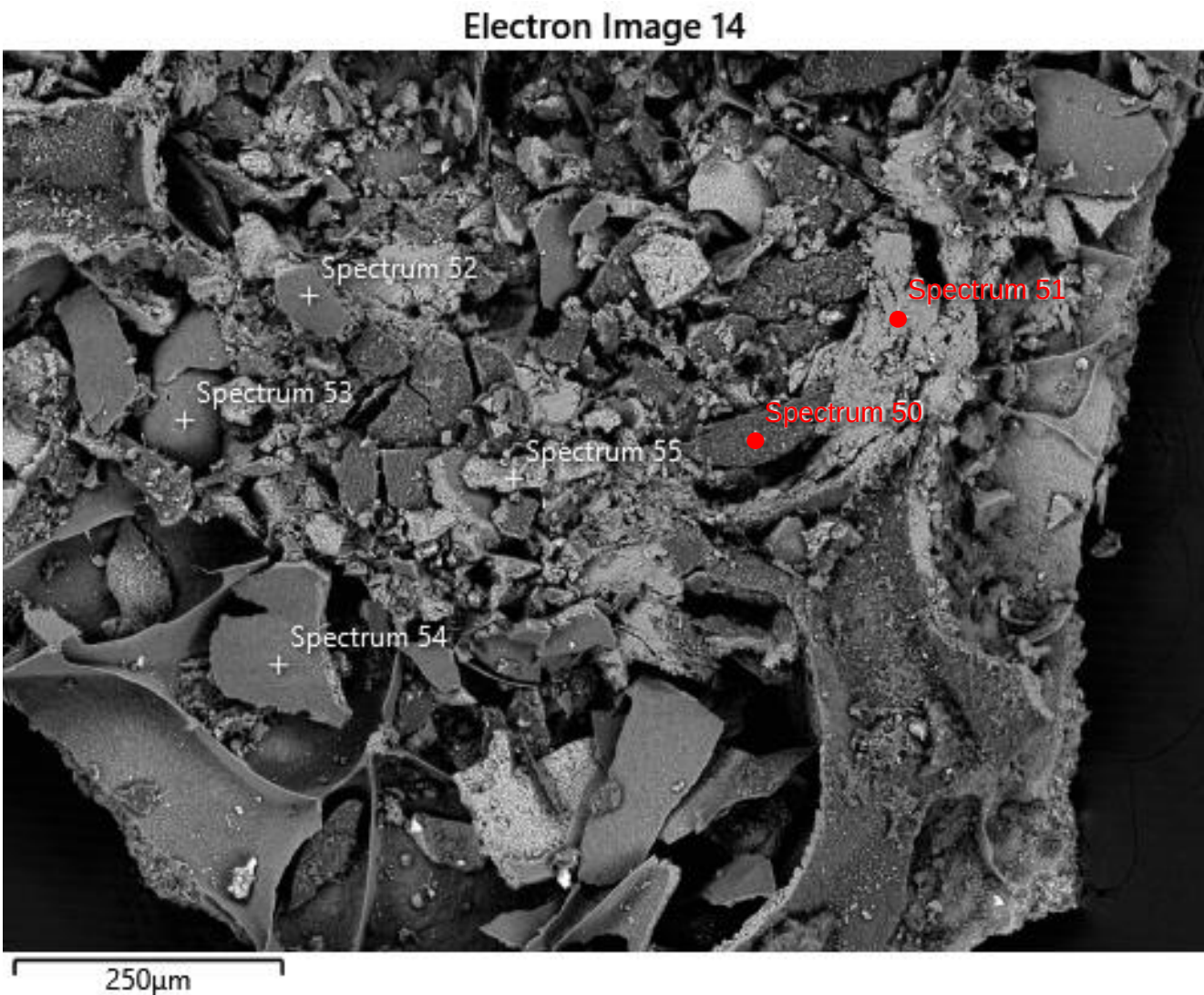
Electron Image 12



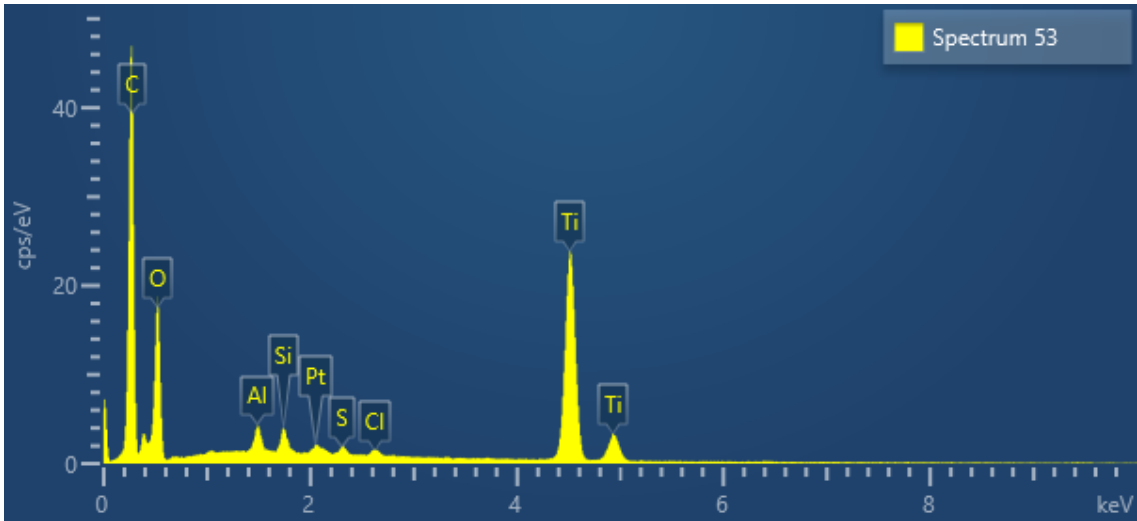
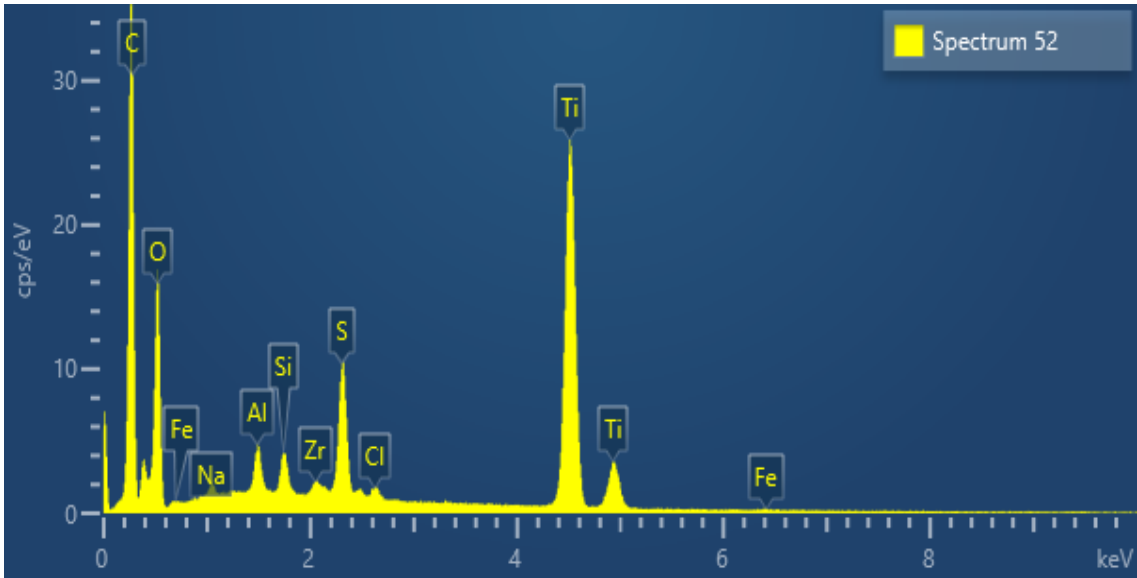
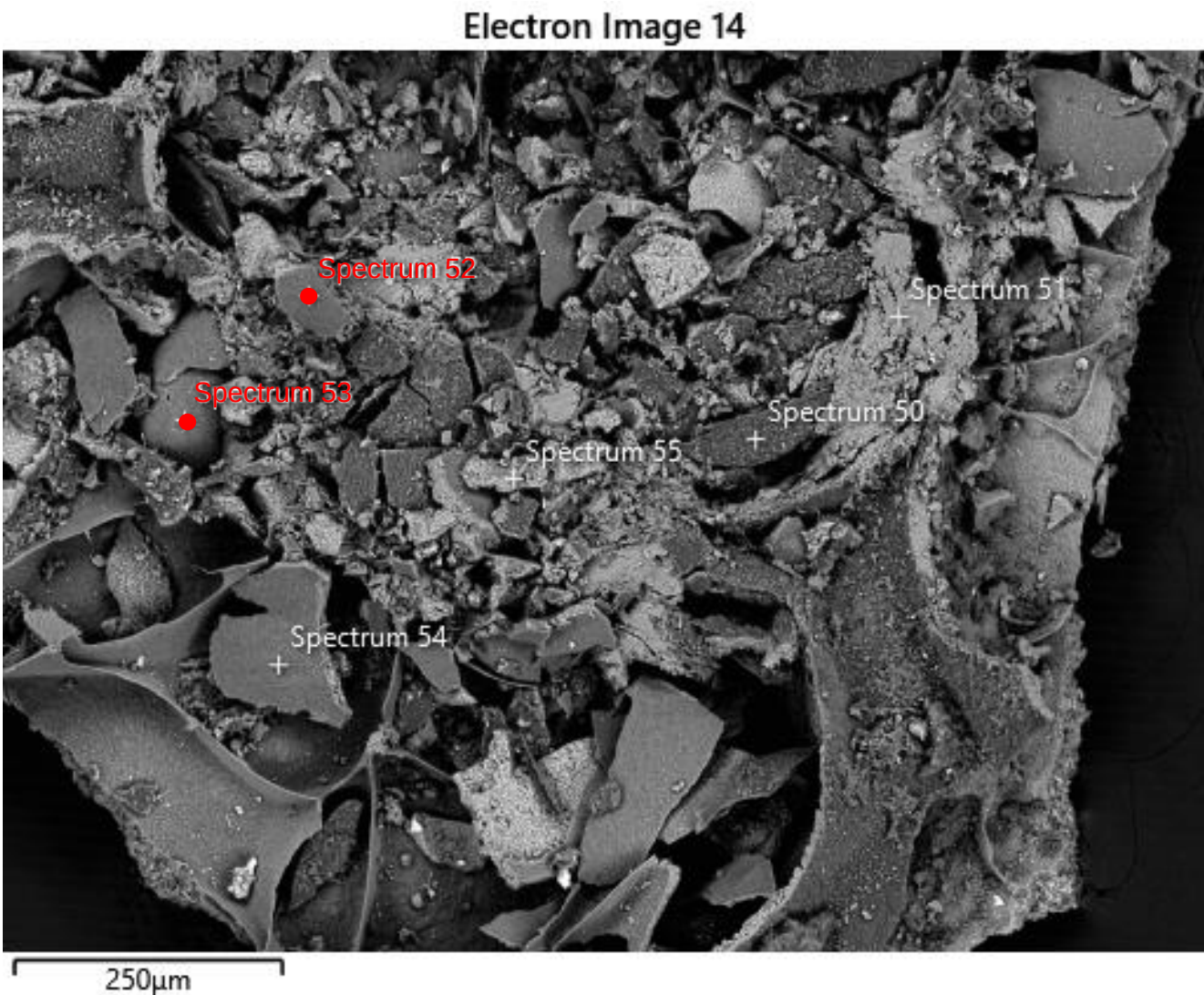
Area 1 – 40x – Backscatter - 335812 right engine fuel pump



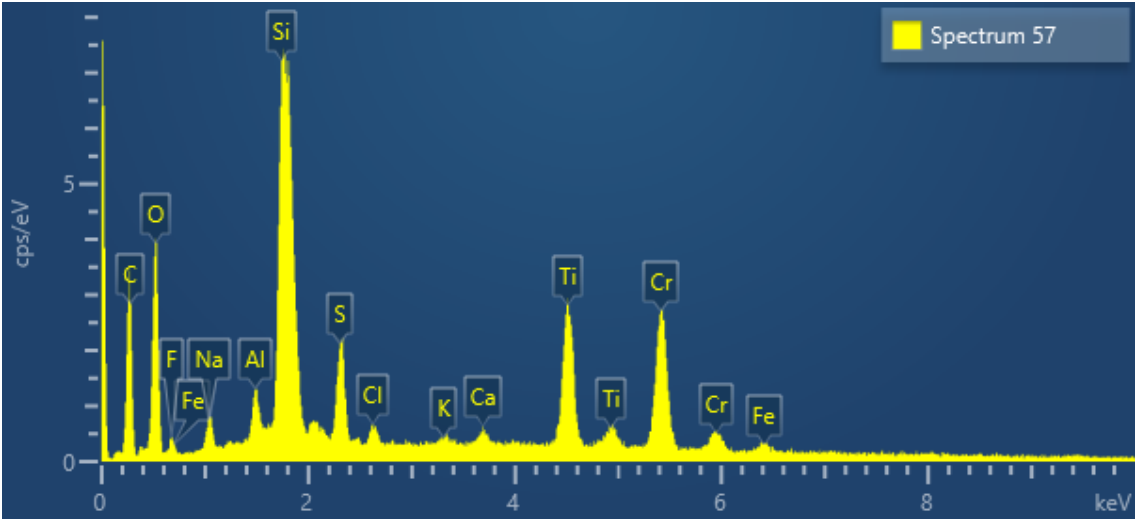
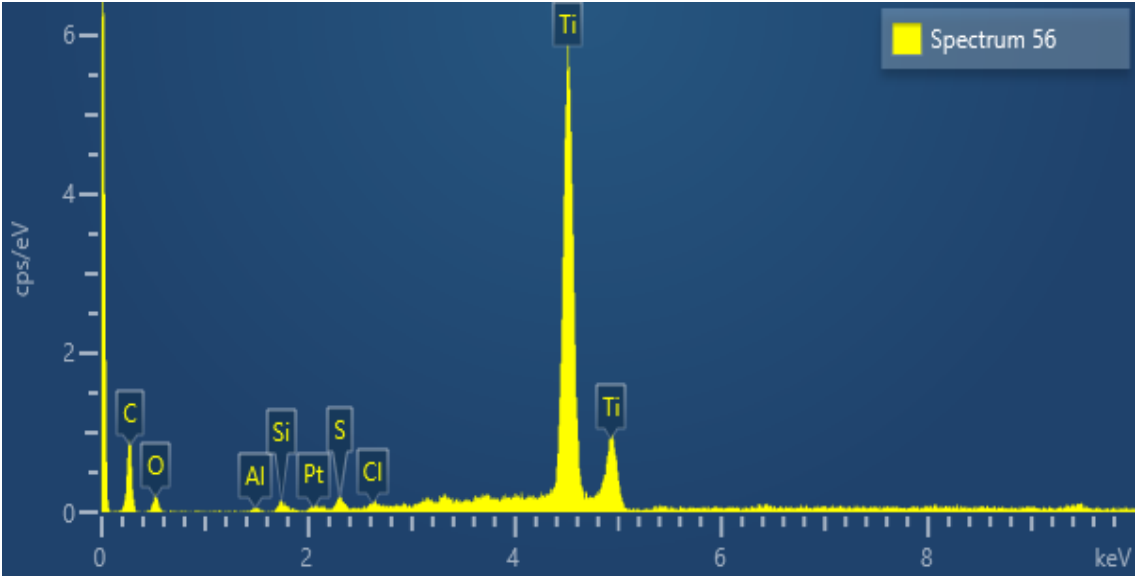
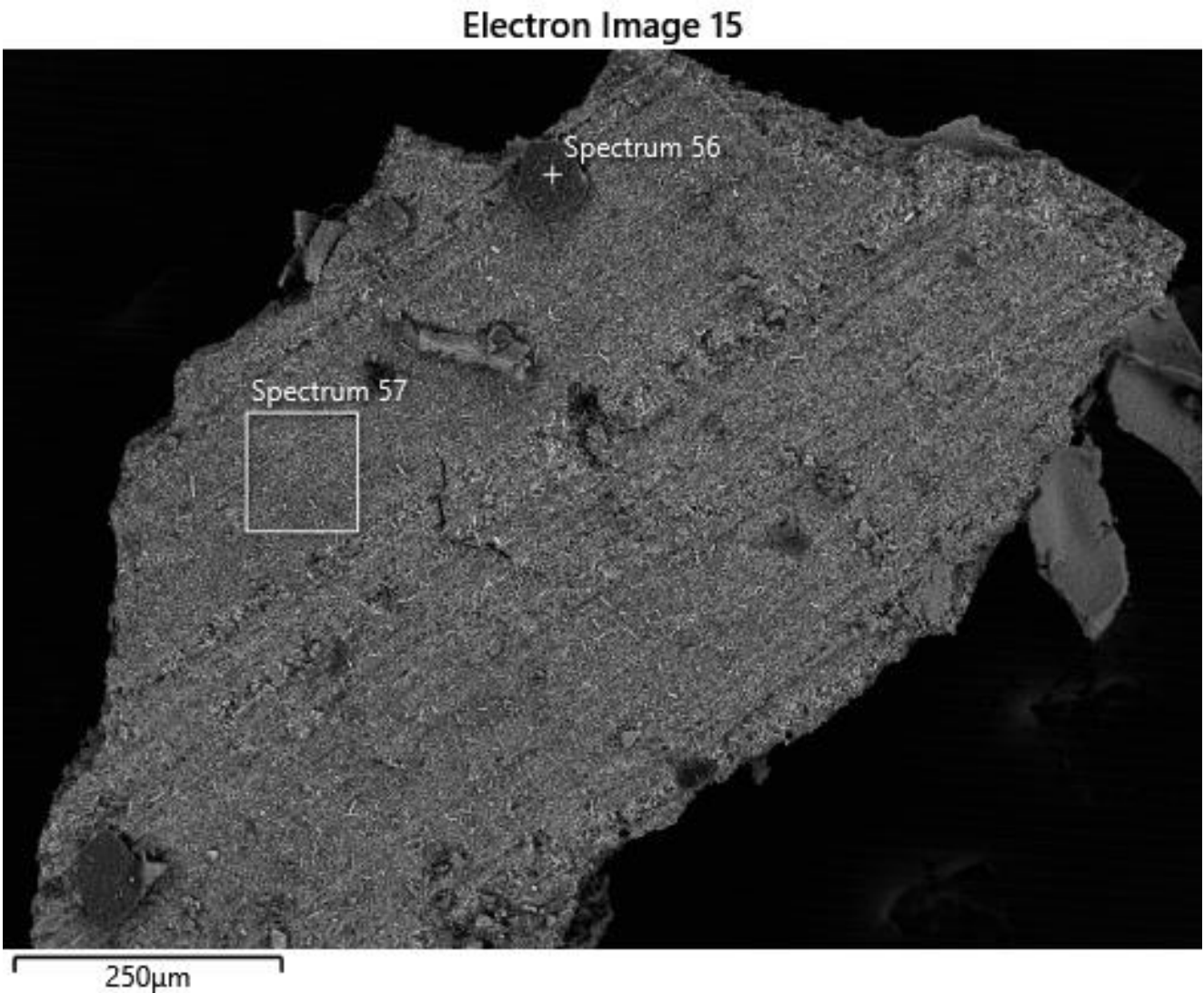
Area 1 – 100x – EDXS Point Analysis – 335812 right engine fuel pump



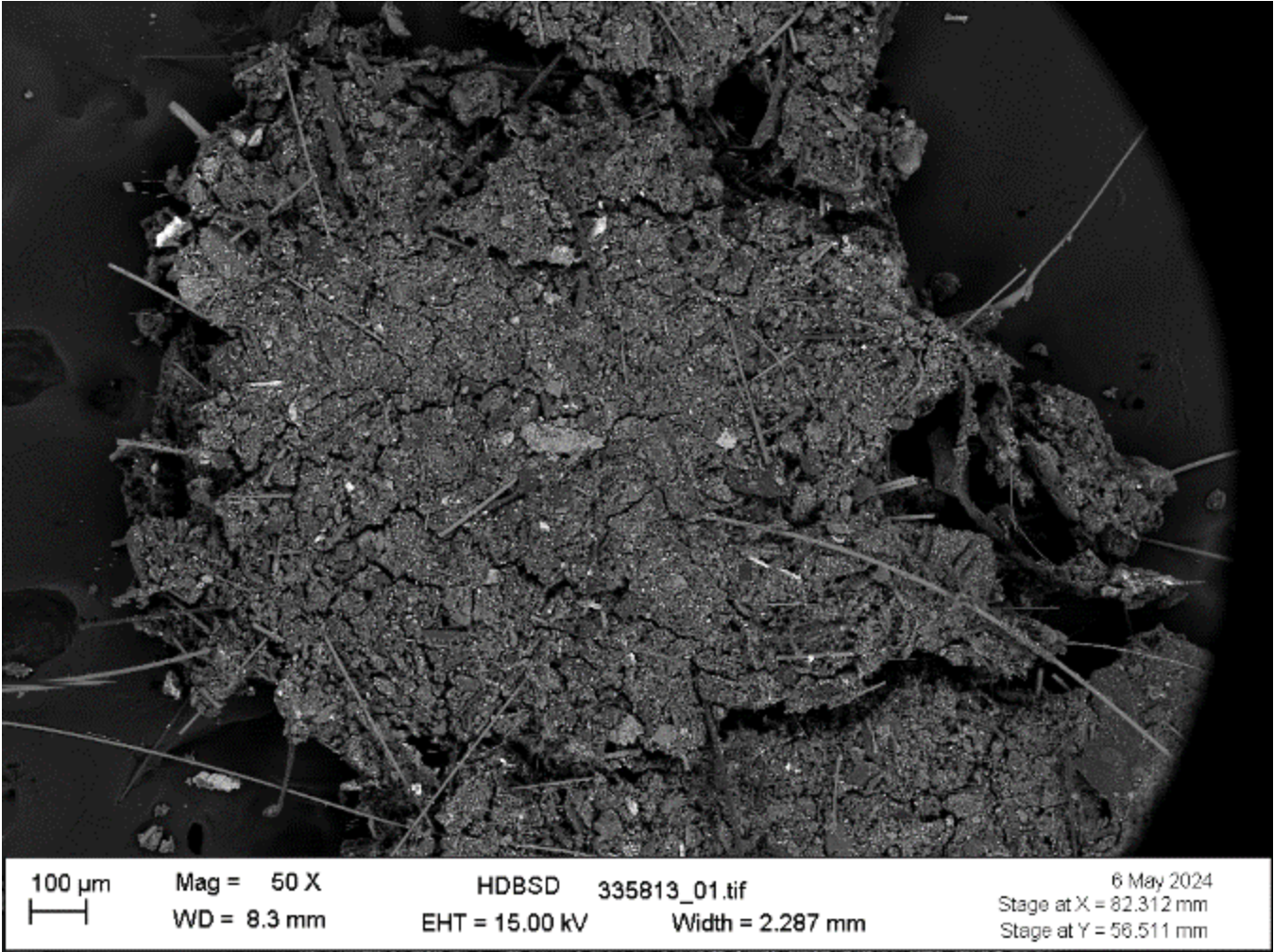
Area 1 – 100x – EDXS Point Analysis – 335812 right engine fuel pump



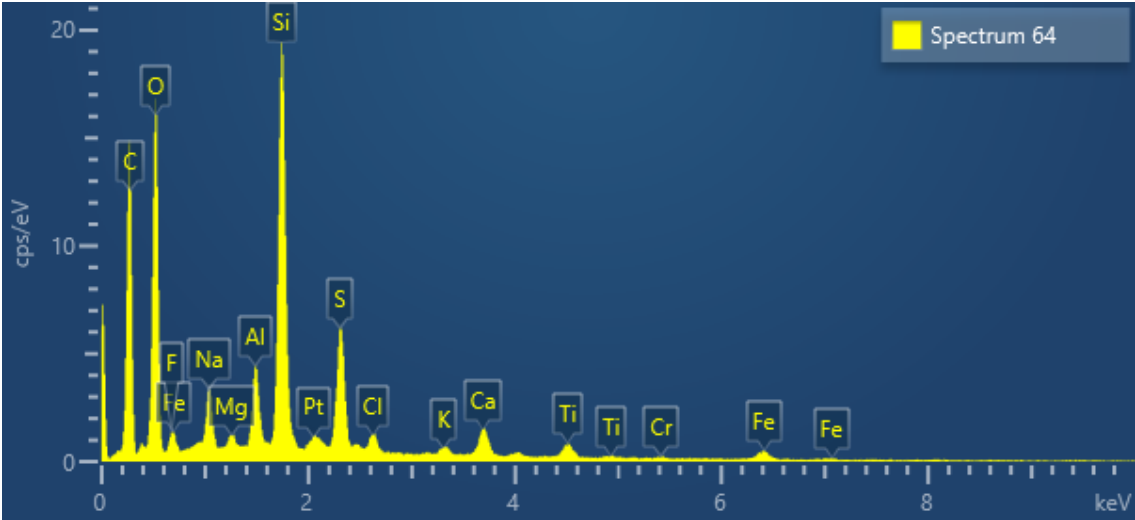
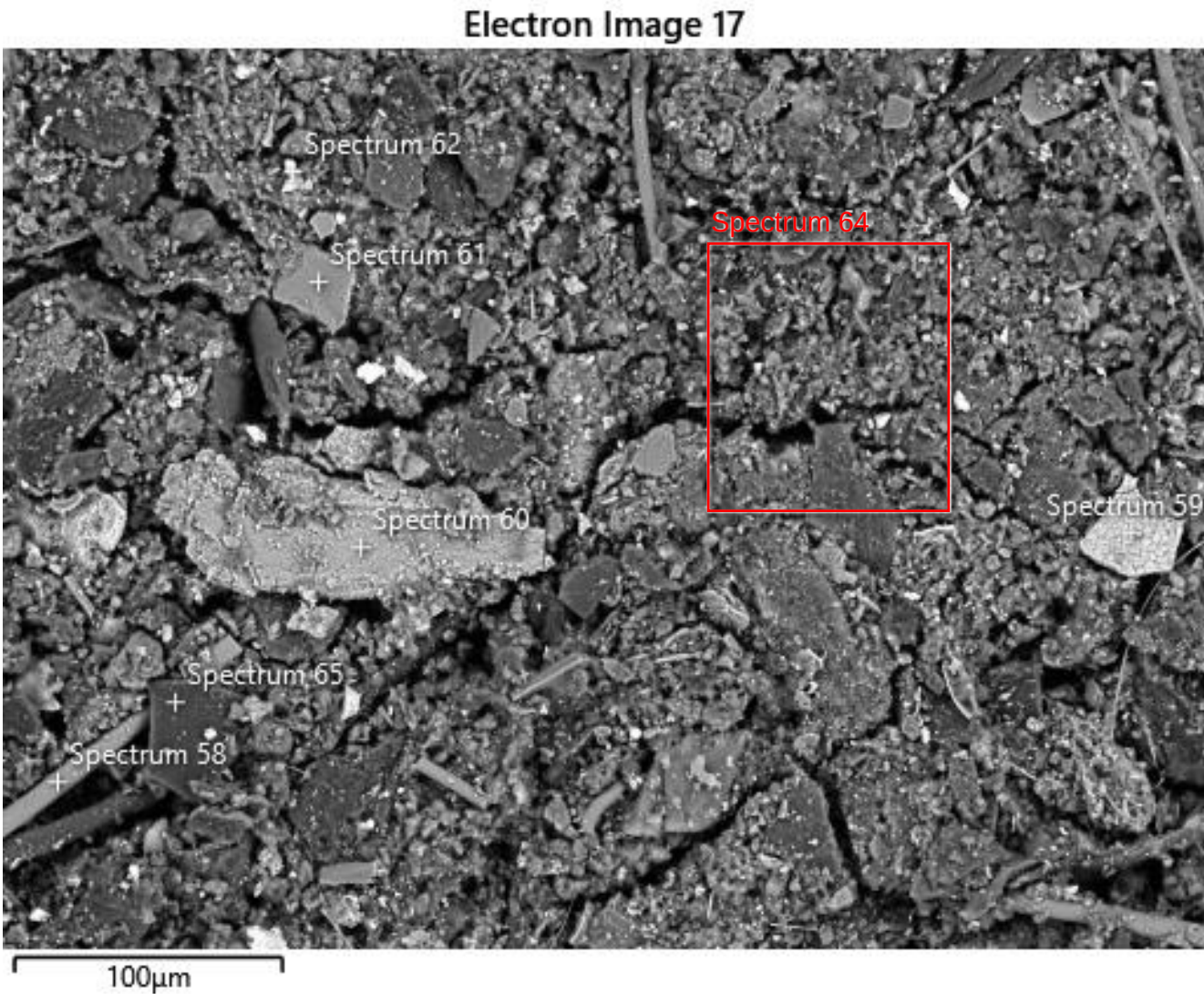
Area 2 – 100x – EDXS Point Analysis – 335812 right engine fuel pump



Area 1 – 50x – Backscatter - 335813 right engine fuel control



Area 1 – 250x – EDXS Point Analysis - 335813 right engine fuel control



Area 2 – 40x – Backscatter 335813 right engine fuel control



Area 2 – 250x – EDXS Point Analysis – 335813 right engine fuel control

