Results from the Vehicle Cabin Atmosphere Monitor (VCAM) Instrument On-board ISS
VCAM Operations Team

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B. J. Bornstein, J. Hofman – Software and OPs
A.P. Croonquist – Systems Engineering and OPs

Acknowledgment
D. Jan (JPL), Y. Park (JPL), and J. Joshi (NASA HQ)
T Limero (JSC), A. Macatangay (JSC), and P. Mudgett (JSC),
J. Perry (MSFC)
**Vehicle Cabin Atmosphere Monitor - VCAM**

**Salient Features**

- A gas-chromatograph/mass-spectrometer (GCMS) system for the International Space Station.
- ISS used as a flight test-bed to demonstrate reliable operations on orbit, and to simulate *human & robotic planetary* exploration environments.
- Instrument Delivery: *September 2009*
- Launched: *April 5, 2010*
- Launch Vehicle: *Shuttle STS-131*
- Commenced Measurements: *June 22, 2010*
- Operational life: 1 year
- Mass: 24.3 kg, Power(Avg): 100 W

**Science**

- Autonomously identify and quantify the presence of *trace amounts* of known potentially toxic species as well as identify unexpected threats to the human crew.
- Perform measurements of *major atmospheric constituents*. 


Lab Standard (LS): open system

compound testing and design proofing
✓ Following contamination: Very reliable workhorse.
✓ Did all the compound testing
✓ Provided all the underpinning data for science and on-board autonomous data-analysis
✓ All “lessons learned” implemented
✓ Now “retired”

Testbed: flight like closed system.
✓ Thermal environment
✓ Acoustic emission
✓ Protoflight electronics functionality
✓ Protoflight Sensor verification
✓ EMI/EMC
✓ MSFC testing
  ✓ Micro-gravity
  ✓ Usability
  ✓ Communication w/ Express Rack
✓ System SW testing
✓ System & subsystem configuration
✓ Compound testing and analysis

Protoflight: The deliverable
✓ Functionality
✓ Protoflight electronics thermal test (124 Hours)
✓ PF Mass Spectrometer (MS) vibration
✓ Conformal coating & staking (components, nuts & bolts)
✓ Running with released SW
✓ ORU vibration
✓ 500 burn-in is in process
✓ VCAM Vibration
✓ VCAM Acoustics Emission
✓ VCAM Thermal
✓ ORU HRCR and PSR
**ORU and Sample Bags**

◇ **ORU** (consumable On Orbit Replaceable Unit):

Provides He carrier gas and Calibrant gas

(fluorobenzene, acetone & Freon 218) for VCAM operation.

◇ Deliverable: One unit due on 9/25/08 for a November 08 Shuttle flight and 4 more with VCAM.

◇ **Sample Air bag**: Provides the means to present a crew collected sample of ISS air to VCAM for analysis.

◇ Deliverable: 10 bags due on 9/25/08 for a Nov. shuttle flight.
Steady progress towards operations

- Activated April 27 and SW upgraded.
- ORU gas bottles inserted by Crew April 28. Slow calibrant leak was expected and dealt with.
- Background spectra and calibration runs indicate all components working.
- Some computer resets have occurred, instrument has recovered. Cause under investigation.
- May 3 reached $7 \times 10^{-8}$ torr (goal for major constituents mode)
- First trace VOC measurements performed on June 3\textsuperscript{rd}
- TG VOC calibration being performed July 16\textsuperscript{th} – July 20\textsuperscript{th}.
Target Trace Gases

• Identified and prioritized by JSC toxicology group

• Special cases
  • HMCTS and Propylene Glycol
  • qualitative detection only – no quantification

• Validation Testing
  • > 90% identification rate  Success
  • 40% accuracy requirement  Success
  • 24 hour / 20% precision requirement  Success

<table>
<thead>
<tr>
<th><strong>Priority 1</strong></th>
<th><strong>Compound</strong></th>
<th><strong>Concentration Range (ppm)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethanol</td>
<td>1–10</td>
<td></td>
</tr>
<tr>
<td>Acetaldehyde</td>
<td>0.1–3</td>
<td></td>
</tr>
<tr>
<td>Acetone</td>
<td>0.5–5</td>
<td></td>
</tr>
<tr>
<td>Dichloromethane</td>
<td>0.03–5</td>
<td></td>
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<tr>
<td>Octamethylcyclotetrosiloxane</td>
<td>0.05–1</td>
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<tr>
<td>Hexamethylcyclotrisiloxane</td>
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<td>Propylene glycol</td>
<td>0.5–5</td>
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<tr>
<td>Perfluoropropane</td>
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<td><strong>Priority 2</strong></td>
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<tr>
<td>Benzene</td>
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<tr>
<td>C5 Alkanes (Pentane)</td>
<td>2–20</td>
<td></td>
</tr>
<tr>
<td>C7 Alkanes (Hexane)</td>
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<tr>
<td>C5 Aldehydes (Pentanal)</td>
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<td>C6 Aldehydes (Hexanal)</td>
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</tr>
<tr>
<td>Ethyl benzene</td>
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<td>Ethyl acetate</td>
<td>1–10</td>
<td></td>
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<tr>
<td>2–propanol</td>
<td>1–10</td>
<td></td>
</tr>
<tr>
<td>Freon 113</td>
<td>2–10</td>
<td></td>
</tr>
<tr>
<td>Furan</td>
<td>0.01–1</td>
<td></td>
</tr>
<tr>
<td>Toluene</td>
<td>1–10</td>
<td></td>
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<tr>
<td>Xylenes (3)</td>
<td>1–10</td>
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<tr>
<td><strong>Priority 3</strong></td>
<td><strong>Compound</strong></td>
<td><strong>Concentration Range (ppm)</strong></td>
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<tr>
<td>1,2-Dichloroethane</td>
<td>0.01–0.1</td>
<td></td>
</tr>
<tr>
<td>2–butanone</td>
<td>0.5–5</td>
<td></td>
</tr>
<tr>
<td>4–methyl–2–pentanone</td>
<td>2–10</td>
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</tr>
<tr>
<td>Carbonyl sulfide</td>
<td>0.01–1</td>
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</tr>
<tr>
<td>Chloroform</td>
<td>0.02–1</td>
<td></td>
</tr>
<tr>
<td>Freon 11</td>
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<td></td>
</tr>
<tr>
<td>Isoprene</td>
<td>0.05–1</td>
<td></td>
</tr>
<tr>
<td>Limonene</td>
<td>1–10</td>
<td></td>
</tr>
<tr>
<td>Vinyl chloride</td>
<td>0.05–1</td>
<td></td>
</tr>
</tbody>
</table>
MCA Validation: Carbon Dioxide Calibration Curve

Actual Abundance vs. Measured Abundance

Lab Air

ISS Air

[7/28/2009 11:38 "/CO2" (2455040)]
Linear Regression for WithBkgCO2_CO2: 
$Y = A + B \times X$

Weight given by WithBkgCO2_CO2E error bars.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Error</th>
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<tr>
<td>A</td>
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<tr>
<td>B</td>
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<td>0.00861</td>
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Ion Chromatograms for VCAM Trace VOC Measurements of ISS Cabin Atmosphere

1. perfluoropropane
2. isoprene
3. NVL / (carbon disulfide?)
4. acetone
5. ethyl acetate
6. 2-butanone
7. dichloromethane
8. 2-propanol
9. ethanol
10. NUI / NVL / (1,3-dioxolane?)
11. NUI / NVL
12. toluene & trimethylsilonol (NVL)
13. NVL (chloroethane?)
14. NUI / NVL
15. xylenes (m, o, p)
16. 1-butanol
17. ethyl benzene
18. NUI / NVL (DMCPS?)
19. limonene
20. NVL (cyclohexanone)
21. NUI / NVL
22. NVL (benzaldehyde?)

(NVL: Not on VCAM Requirements List)
(NUI: Not uniquely identified)
Total Ion Chromatogram for VCAM Trace VOC Measurement of ISS Cabin Atmosphere

(preconcentrator load time ~ 3x nominal level)

> 40 Chemicals detected
## VCAM TG Measurements

<table>
<thead>
<tr>
<th>Trace Chemical Species</th>
<th>VCAM Requirements Range</th>
<th>Current Capability</th>
<th>Post-IFM Capability</th>
<th>Updated Quantization Range</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>ppm</td>
<td>I = Identify</td>
<td>I = Identify</td>
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<tr>
<td>VCAM Validation Species</td>
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<td>Q = Quantify</td>
<td>Q = Quantify</td>
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<tr>
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<td></td>
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<td></td>
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<tr>
<td>1,2-dichloroethane</td>
<td>0.01 - 1</td>
<td>IQ</td>
<td>IQ</td>
<td>0.003 - 1</td>
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<tr>
<td>1-butanol</td>
<td>0.5 - 5</td>
<td>-</td>
<td>IQ</td>
<td>0.02 - 5</td>
</tr>
<tr>
<td>2-butanone</td>
<td>0.5 - 5</td>
<td>I (ok) Q (in progress)</td>
<td>IQ</td>
<td>0.01 - 5</td>
</tr>
<tr>
<td>2-propanol</td>
<td>1 - 10</td>
<td>I (ok) Q (in progress)</td>
<td>IQ</td>
<td>1 - 10</td>
</tr>
<tr>
<td>4-methyl 2-pentanone</td>
<td>2 - 10</td>
<td>-</td>
<td>IQ</td>
<td>2 - 10</td>
</tr>
<tr>
<td>Acetaldehyde</td>
<td>0.1 - 3</td>
<td>I (ok) Q (in progress)</td>
<td>IQ</td>
<td>0.1 - 3</td>
</tr>
<tr>
<td>Acetone</td>
<td>0.5 - 5</td>
<td>IQ</td>
<td>IQ</td>
<td>0.1 - 5</td>
</tr>
<tr>
<td>Benzene</td>
<td>0.01 - 1</td>
<td>I (ok) Q (in progress)</td>
<td>IQ</td>
<td>0.01 - 1</td>
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<tr>
<td>Carbonyl sulfide</td>
<td>0.01 - 1</td>
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<td>IQ</td>
<td>0.01 - 1</td>
</tr>
<tr>
<td>Chloroform</td>
<td>0.02 - 1</td>
<td>I (ok) Q (in progress)</td>
<td>IQ</td>
<td>0.002 - 1*</td>
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<tr>
<td>Dichloromethane</td>
<td>0.03 - 5</td>
<td>IQ</td>
<td>IQ</td>
<td>0.01 - 5</td>
</tr>
<tr>
<td>Ethanol</td>
<td>1 - 10</td>
<td>IQ</td>
<td>IQ</td>
<td>0.5 - 10</td>
</tr>
<tr>
<td>Ethyl acetate</td>
<td>1 - 10</td>
<td>IQ</td>
<td>IQ</td>
<td>0.05 - 10</td>
</tr>
<tr>
<td>Ethyl benzene</td>
<td>1 - 10</td>
<td>IQ</td>
<td>IQ</td>
<td>0.01 - 10</td>
</tr>
<tr>
<td>Freon 11</td>
<td>2 - 10</td>
<td>I (ok) Q (in progress)</td>
<td>IQ</td>
<td>2 - 10</td>
</tr>
<tr>
<td>Freon 113</td>
<td>2 - 10</td>
<td>I (ok) Q (in progress)</td>
<td>IQ</td>
<td>2 - 10</td>
</tr>
<tr>
<td>Furan</td>
<td>0.01 - 1</td>
<td>I (ok) Q (in progress)</td>
<td>IQ</td>
<td>0.002 - 1*</td>
</tr>
<tr>
<td>Hexanal</td>
<td>0.1 - 2</td>
<td>-</td>
<td>IQ</td>
<td>0.01 - 2*</td>
</tr>
<tr>
<td>Hexane</td>
<td>2 - 20</td>
<td>I (ok) Q (in progress)</td>
<td>IQ</td>
<td>2 - 20</td>
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<tr>
<td>HMCTS</td>
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<td>-</td>
<td>I</td>
<td>Identify only</td>
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<td>Isoprene</td>
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<td>IQ</td>
<td>IQ</td>
<td>0.05 - 1</td>
</tr>
<tr>
<td>Limonene</td>
<td>1 - 10</td>
<td>IQ</td>
<td>IQ</td>
<td>0.02 - 10</td>
</tr>
<tr>
<td>OMCITS</td>
<td>0.05 - 1</td>
<td>-</td>
<td>IQ</td>
<td>0.05 - 1</td>
</tr>
<tr>
<td>Pentanal</td>
<td>0.1 - 2</td>
<td>-</td>
<td>IQ</td>
<td>0.01 - 2*</td>
</tr>
<tr>
<td>Pentane</td>
<td>2 - 20</td>
<td>I (ok) Q (in progress)</td>
<td>IQ</td>
<td>0.05 - 20*</td>
</tr>
<tr>
<td>Perfluoropropane</td>
<td>10 - 100</td>
<td>IQ</td>
<td>IQ</td>
<td>10 - 100</td>
</tr>
<tr>
<td>Propylene glycol</td>
<td>Identify only</td>
<td>-</td>
<td>I</td>
<td>Identify only</td>
</tr>
<tr>
<td>Toluene</td>
<td>1 - 10</td>
<td>IQ</td>
<td>IQ</td>
<td>0.01 - 10</td>
</tr>
<tr>
<td>Vinyl chloride</td>
<td>0.05 - 1</td>
<td>-</td>
<td>IQ</td>
<td>0.05 - 1*</td>
</tr>
<tr>
<td>Xylenes (o, m, p)</td>
<td>1 - 10</td>
<td>IQ</td>
<td>IQ</td>
<td>0.01 - 10</td>
</tr>
</tbody>
</table>
### VCAM TG Measurements

**Additional chemicals detected by VCAM in ISS Atmosphere**

<table>
<thead>
<tr>
<th>Trace Chemical Species</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Species Detected in ISS Trace Gas Measurements</strong></td>
</tr>
<tr>
<td>1,3 dioxolane</td>
</tr>
<tr>
<td>1-butene</td>
</tr>
<tr>
<td>2-butenal</td>
</tr>
<tr>
<td>2-methyl 2-propanol</td>
</tr>
<tr>
<td>2-methyl butane</td>
</tr>
<tr>
<td>benzaldehyde</td>
</tr>
<tr>
<td>carbon disulfide</td>
</tr>
<tr>
<td>chlorobenzene</td>
</tr>
<tr>
<td>cyclohexanone</td>
</tr>
<tr>
<td>dichlorobenzene</td>
</tr>
<tr>
<td>decamethylcyclopentasiloxane</td>
</tr>
<tr>
<td>ethoxyethanol</td>
</tr>
<tr>
<td>hexanal</td>
</tr>
<tr>
<td>methyl acetate</td>
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<tr>
<td>styrene</td>
</tr>
<tr>
<td>trimethylbenzene</td>
</tr>
<tr>
<td>trimethylsilanol</td>
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</tbody>
</table>
VCAM TG Measurements

Acetone

Requirements Range = 0.5 - 5 ppm (1.2 - 11.9 mg/m³)
VCAM TG Measurements

Isoprene
Requirements Range = 0.05 - 1 ppm (0.14 - 2.78 mg/m³)
VCAM TG Measurements

dichloromethane
Requirements Range = 0.03 - 5 ppm (0.1 - 17.2 mg/m³)
Perfluoropropane
Requirements Range = 1 - 100 ppm (89 - 892 mg/m³)

Concentration (mg/m³)

Date:
- 6/15/2010
- 6/19/2010
- 7/1/2010
- 7/4/2010
- 7/11/2010
- 7/14/2010
- 7/28/2010
- 8/1/2010
- 8/11/2010
- 8/15/2010
- 8/25/2010
- 9/8/2010
- 9/11/2010
- 9/22/2010
- 10/6/2010
- 10/10/2010
- 10/13/2010
- 10/17/2010
- 11/1/2010
- 11/4/2010
- 11/10/2010
- 11/17/2010
- 12/1/2010
- 12/11/2010
- 12/15/2010
- 12/19/2010
- 12/29/2010
- 1/13/2011
- 1/16/2011
- 1/19/2011
- 1/23/2011
- 1/26/2011
- 2/2/2011
- 2/23/2011
- 3/9/2011
- 3/12/2011
- 4/6/2011
- 4/16/2011
- 5/4/2011
- 5/12/2011
- 6/1/2011
VCAM TG Measurements

Ethanol
Requirements Range = 1 - 10 ppm (1.9 - 18.8 mg/m³)

- MS Heater ON
- MS Heater OFF
- GSC/JSC Results
- AQM
VCAM TG Measurements

Toluene
Requirements Range = 1 - 10 ppm (3.8 - 37.6 mg/m³)
VCAM TG Measurements

1,2-dichloroethane
Requirements Range = 0.01 - 1 ppm (0.04 - 4 mg/m³)
VCAM TG Measurements

Xylenes
Requirements Range = 1 - 10 ppm (4.4 - 44 mg/m³)
VCAM TG Measurements

**ethyl benzene**

Requirements Range = 1 - 10 ppm (4.4 - 44 mg/m³)
VCAM TG Measurements

**Limonene**

Requirements Range = 1 - 10 ppm (5.6 - 55.6 mg/m³)
VCAM MCA Measurement Status for Nitrogen
VCAM MCA Measurement Status for Oxygen

Oxygen Partial Pressure (%) vs Date

- **O2 - VCAM**
- **O2 - ISS**

Dates:
- 9/7/2010
- 9/13/2010
- 9/24/2010
- 10/16/2010
- 10/22/2010
- 10/23/2010
- 10/25/2010
- 11/26/2010
- 11/27/2010
- 12/3/2010
- 12/8/2010
- 12/12/2010
- 1/9/2011
- 1/16/2011
- 2/20/2011
- 3/5/2011
- 3/12/2011
VCAM MCA Measurement Status for Carbon Dioxide
VCAM MCA Measurement Status for Argon

![Graph showing the Argon Partial Pressure over time from 9/7/2010 to 3/12/2011. The graph displays fluctuations in pressure with error bars indicating variability. The data shows a general trend of increasing pressure until a sharp decrease in late March 2011.](image-url)
Conclusions, Summary, and Recommendations

Jay Perry (MSFC/VCAM Referee):

1. VCAM continues to return results for targeted VOCs that meet or exceed performance requirements. Although the instrument is operating in an environment that is typically below its requirement range, for nearly all the targeted VOCs, the instrument continues to compare exceptionally well with air quality results reported via the GSC sampling/ground analysis.

2. VCAM is proving to possess operational flexibility beyond expectations for an instrument of its class.

3. VCAM is proving to be a viable part for the overall technical solution of crewed spacecraft cabin atmospheric quality analysis and monitoring.

4. Exploring further development to include combining the VCAM with Fourier transform infrared (FTIR) spectrometry and other portable methods for broad spectrum analysis and portable instruments for highly specific analytical targets is recommended to realize the most powerful analytical instrument combination for crewed spacecraft cabin atmospheric quality analysis and monitoring.
VCAM Components : Sensor (GC/MS)

Paul Ion Trap Mass Spectrometer

<table>
<thead>
<tr>
<th>Mass range</th>
<th>24 - 350 u</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
<td>10 picomoles</td>
</tr>
<tr>
<td>Mass resolution $(m / \Delta m)$</td>
<td>&gt; 250</td>
</tr>
<tr>
<td>Mass crosstalk</td>
<td>1 : 50,000</td>
</tr>
</tbody>
</table>

Pre-Concentrator / Gas Chromatograph (PCGC)

<table>
<thead>
<tr>
<th>PC performance</th>
<th>&gt; 50 x enrichment</th>
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</thead>
<tbody>
<tr>
<td>GC type</td>
<td>10m DB-Wax</td>
</tr>
<tr>
<td>Elution time for all SMAC species</td>
<td>1200 sec</td>
</tr>
<tr>
<td>Elution peak width</td>
<td>8 sec (FWHM)</td>
</tr>
</tbody>
</table>
Schematic presentation of the VCAM subassemblies. The Paul ion trap is contained in the Sensor vacuum chamber; the calibration gas and He carrier gas are part of the Consumables ORU.
1. air/promt peak
2. isoprene
3. furan
4. acetone
5. ethyl acetate
6. 2-butanone
7. dichloromethane
8. 2-propanol
9. ethanol
10. fluorobenzene
11. 2-propanol
12. toluene
13. 1-butanol
14. ethyl benzene
15. Limonene
PERFORMANCE VALIDATION

MCA Validation: Oxygen Calibration Curve

Actual Abundance vs. Measured Abundance

[7/28/2009 11:31 "O2" (2455040)]
Linear Regression for WithBkgO2_O2:
Y = A + B \cdot X
Weight given by WithBkgO2_O2E error bars.

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<tbody>
<tr>
<td>A</td>
<td>8.62246</td>
<td>0.06228</td>
</tr>
<tr>
<td>B</td>
<td>0.85286</td>
<td>0.0027</td>
</tr>
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</table>
Software (Data Analysis): Identification Using Elution Time Gating