Air Quality Monitoring: Risk-Based Choices

John T. James, Ph.D.
Habitability and Environmental Factors Division
January 15, 2009
Roadmap

• Controlling risk of toxic events
• Learning from adverse events
• Archival air sampling
• On-board, real-time analyzers
• Commercial vs. one-of-a-kind monitors
• Constraints on spaceflight hardware
• A dusty future-living on a distant celestial body
• Recap
Controlling Risk of Toxic Exposure

- Use non-toxic systems chemicals
- Use materials that do not offgas much
- Contain toxicants in payloads
- Use non-toxic utility compounds
- Operationally limit access to toxic compounds
- Provide robust air scrubbing capability
- Personal protective equipment available
- Ability to escape spacecraft
Learning from Adverse Events

- Toxic propellants
- Fires
- Pyrolysis events
- Leaky thermal control systems
- Excess carbon dioxide
- Formaldehyde accumulation
- Unpredictable events
- Dust
Apollo-Soyuz: Nitrogen Tetroxide Exposures-1975

- RCS disabled (55:08 GET)
- 700 p/m
- Average exposure 250 p/m or 510 mg/m³, for 4 min 40 s
- Suit compressor off (57:58 GET)
- RCS isolation valves closed (54:44 GET)
- Oxygen masks on (59:24 GET)
Selected Pollutants in Mir Air after the SFOG Fire (mg/m³)

FIRE!
Carbon Monoxide and Carboxyhemoglobin Profiles after the SMALL BMP Filter Burn (CPA data)

A Little Smoke…
Ethylene Glycol in Mir Air after Leak from the Thermal Control System: Kvant and Core Module
CO2 Survey During Exercise

I--------Exercise Session-------------------I

CO2 Concentration (ppm)

GMT

S/N 1003 - Lab Wall
S/N 1007 - Crew Worn
Formaldehyde

Date of Sample

Concentration (ug/m3)

SM

Lab

Dust bunnies

Removed from IMV
Unpredictable Event

METOX SYSTEM SCHEMATIC DIAGRAM

FROM THC

MUFFLER

AIR BEARING FAN

MUFFLER

FILTER

DIVERTER VALVE

HEAT EXCHANGER

TEMPERATURE SENSOR MANIFOLD

TO THC

ELECTRIC HEATER

CANISTERS

OVEN

HEATING MODE

COOL DOWN MODE

TO THC
Impact of Metox Regeneration on T Values [index of toxicity]

<table>
<thead>
<tr>
<th></th>
<th>SM</th>
<th>FGB</th>
<th>US Lab</th>
<th>Regen</th>
</tr>
</thead>
<tbody>
<tr>
<td>MetoxReg</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>PostScrub</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Mar</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>PreReg</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>PostReg</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Odor intensity:
- Strong odor
- Faint odor
Archival Samplers

- 3 surrogate standards
- Sample is aspirated by vacuum in <5 seconds
- Analysis in Lab by GC and GC/MS
- Reactive compounds are lost
- Problem-valve not sealed well after sampling

- Formaldehyde trapped in badge matrix by diffusion
- Typical sample time is 24 h (in pairs)
- Formaldehyde eluted from badge and analyzed by spectrophotometry
- Limitations: must have sufficient face velocity of air
Hand-held air monitors

**CSA-CP**
- Commercial unit using electrochemical sensors
- First alert and source finding capability
- Zero capability
- Combustion tested and certified at 10.2 psia
- Carbon Monoxide-slight drift with closed storage
- Hydrogen Chloride sensor not specific
- Hydrogen Cyanide-depleted in use
- Oxygen-back up to the MCA
- Masking criteria after fire

**Carbon Dioxide Monitor**
- Commercial unit
- 6 % upper limit
- 18 h battery life (sample is pumped)
- Water & particle filter
- Infrared absorption used to measure CO₂ in air
- Robust/stable device
Dräger Chip Measurement System

- Flown by Russian partners
- Two-year shelf life
- One analyte at time
- Up to 10 sequential measurements
- Less than 2 minute response time
- Few interferences
- Wide collection of analytes
- Lacks sensitivity to meet nominal monitoring requirement
- Effective in contingency
Major On-Board Instruments

• Major Constituents Analyzer
• Mass spectrometer
• \( \text{O}_2, \text{N}_2, \text{H}_2\text{O}, \text{CH}_4, \text{CO}_2, \text{H}_2 \)

• Volatile Organics Analyzer
• GC-Ion mobility spectrometer
• Many trace organics
Other Air Quality Instruments

- ANITA-Trained system to deconvolute FTIR spectrum
- Electronic Nose-trained sensor array for target compounds
- VCAM-GC/MS system
- Air Quality Analyzer-GC/differential mobility spectrometer
Data Presentation to the Crew

- Acetaldehyde: 0.258
- Ethanol (M): 0.958
- Acetone: 0.540
- 2-Propanol: 0.565
- Hexane: 2.174
- Ethyl Acetate: 0.493
- Benzene: 0.577
- n-Butanol: 0.451
- Toluene: 0.520
- m,p-Xylenes: 0.564
- o-Xylene: 0.273
- OMCTS: 0.962

Concentration (mg/m3)
Commercial vs. One-of-a-kind Instruments

• Commercial
  • Inexpensive
  • Small
  • Experience history
  • Established support
  • Adapt to requirements
  • Easy sustainability

• One of a kind
  • Expensive
  • Large
  • Performance uncertain
  • Support may vanish
  • Build to requirements
  • Pain to sustain
Constraints on Spaceflight Hardware

- Small and low mass
- Use minimal resources
- Little or no crew time
- Infrequent calibration
- Reliable performance for 2 years
- Follow cleanup in a contingency
- Perform after a combustion event
- Proper information conveyed to the crew
DUST
Lunar Dust Properties

PSD of lunar dust particles (10084)

Larry Taylor, U of Tennessee

Courtesy – Dave McKay
A Dusty Future

Phobos

Martian Dust Devils

Ida and Dactyl
Recap

- Air monitoring is secondary to rigid control of risks to air quality
- Air quality monitoring requires us to target the credible residual risks
- Constraints on monitoring devices are severe
- Must transition from archival to real-time, on-board monitoring
- Must provide data to crew in a way that they can interpret findings
- Dust management and monitoring may be a major concern for exploration class missions