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
Selected Pollutants in Mir Air after the SFOG Fire (mg/m³)

- Benzene
- IPA
- Styrene

30-day Benzene Limit

-31 d -10 d +5 h +8 h +12 h +20 h +32 h

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

A Little Smoke…

CO (ppm)

COHb (%X10)
Ethylene Glycol in Mir Air after Leak from the Thermal Control System: Kvant and Core Module
CO2 Survey During Exercise

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

The graph shows the CO2 concentration (ppm) over time during an exercise session. The data is represented for two sources:

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

The graph indicates fluctuations in CO2 concentration throughout the exercise period, with peaks and troughs at various times.
Formaldehyde

Concentration (ug/m³)

Date of Sample

Dust bunnies Removed from IMV

SM
Lab
Unpredictable Event
Impact of Metox Regeneration on T Values [index of toxicity]

- Dec: 0.5
- Jan: 1
- MetoxReg: 3
- PostScrub: 5 (Strong odor)
- Mar: 1 (Faint odor)
- PreReg: 0.5
- PostReg: 1

- 30 hours TCCS Scrub
- 3 hours Nominal Regeneration

Legend:
- SM
- FGB
- US Lab
- Regen
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: 0.555
- 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

Lunar Dust Properties

Larry Taylor, U of Tennessee

Milky Way of np-Fe$^0$

all white beads = Fe$^0$

PSD of lunar dust particles (10084)

Particle diameter (μm)

ΔN
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