Spacecraft Water Monitoring:

Adapting to an era of emerging scientific challenges

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Presentation Overview

- Spacecraft water 101
  - Water sources as discussed by spacecraft
  - Summary of diverse challenges
- "Paradigm Shift"
  - Current water quality monitoring paradigm
  - Monitoring tools
    - Archive vs. In-flight
  - Changing landscape and emerging priorities
- Technology Needs
  - Chemicals of interest
  - Highlighted technology needs
  - Technical Resources
  - Case-Study: Colorimetric Solid Phase Extraction (C-SPE)

Spacecraft Water 101

- Ground-supplied water launched in a Russian Progress vehicle and delivered to the ISS in twin 210 Liter "Rodnik" tanks.

- Potable water transferred to the ISS from Space Shuttles via contingency water containers (CWCs); 44 liter bladders that hold water that is generated as a byproduct of the Shuttle fuel cell power system.

- Recycled humidity condensate and urine distillate from the ISS that is reclaimed as potable through elaborate processing through on-orbit reclamation systems.

Summary of Challenges to Spacecraft Water Quality

Contributors to Condensate or Urine Being Recycled

Bladder/Tank Materials

Added Biocides

WATER QUALITY

Unintended Contributions from Processors

Pollutants in Source Water

Water Quality "Anomalies" on Shuttle, Mir & ISS

Shuttle

- High iodine levels detected by crewmembers (STS-26, 27, 28, 30)
- High nickel levels in preflight samples (STS-79,84,91,98,101,104,106)
- Cadmium (STS-59) and lead (STS-108) hits in preflight samples
- Restriction in iodine consumption due to concerns about elevated thyroid hormone levels (Apr 98)

Mir

- Ethylene glycol coolant leaks led to taste issues & temporary halts in water recycling (Mir 21 Jul 96)
- High levels of chloroform in Rodnik ground-supplied water (Jan 95 – Jun 96)
- Mir oxygen canister fire led to halt in water recycling until sample returned (Feb 97)

ISS

- High cadmium level detected in SVO-ZV traced to a spring in dispenser (Exp 1 [5A] to Exp 2 [5A.1]), Again in Exp 13/14
- Caprolactam in CWC water stored long-term (Expedition 1)
- Incidents of abnormally high silver in Rodnik water from 10 P (Dec 02) and 11P (Apr 03)
- High turbidity levels in SVO-ZV water
- Lead in filter reactor effluent, although no apparent breakthrough to potable water (Expedition 1[4A] and Expedition 3 [UF-1])

“Paradigm Shift”

Current Water Monitoring Paradigm

- Archive Sampling
  - 300 ml or 1 L bags that are collected on-orbit and returned to ground for testing

Strengths:

-Allows for full microbial/chemical characterization. (250+ analytes)

Weaknesses:

-Requires crew time, upmass (bags/adapters), downmass for sample return

-Doesn't allow in-flight decision making

ISS006E08628

Current In-Flight Monitoring Capabilities

- Deployed on recent ULF2 flight
- Works to analyze organic load in water produced by U.S. water/urine processor
- Total organic carbon (TOC) data used as a health screening tool, general indicator of system performance
- Doesn't address specific organics or metals or other inorganics

Total organic carbon analyzer (TOCA)

Microbial Water Analysis Tools

- In-flight total bacterial count "enumeration"
- Serves a screening function, archive needed to fully evaluate microbial profile. Does allow in-flight decision making
- In-flight coliform testing produces color change if org. present

Factors in Changing Landscape

- Looming Shuttle Retirement and Gap between CEV
  - Upmass: Progress, HTV, ATV, etc.
    - Less upmass for consumables, etc.
  - Downmass: Reliance on Soyuz. Lots of competition for downmass.
    - 1L archive water bag weighs ~ 2 pounds!
    - Increased need for in-flight monitoring assets
- 6 crew habitation on ISS
  - New U.S. systems, competition for upmass,etc.
- Resulting preference for hardware that is small, rugged, less dependent on resupply, non-complex
- Multi-program opportunity for hardware!
  - ISS as "Constellation testbed"

Technology Needs

Comparison of Contaminants of Concern for Different Potable Waters

ISS U.S. Laboratory Condensate	Shuttle-generated fuel cell water	Ground-supplied Russian "Rodnik" water (Progress launched)
Benzyl alcohol	Nickel[2]	Chloroform
Ethanol	Ethanol[1]	Manganese
Methanol	Iodine[1]	Silver[1]
Acetate	Free gas	
Formate	Cadmium[2]	
Proprionate	Lead[2]	
Zinc[2]	Caprolactam[3]	
Nickel[2]		
Formaldehyde		
Ethylene glycol		
Propylene glycol		

1 Related to biocide addition
2 Generally resulting from releases from metallic heat-exchanger coatings, or dispenser parts
3 Resulting from leaching for bladder material

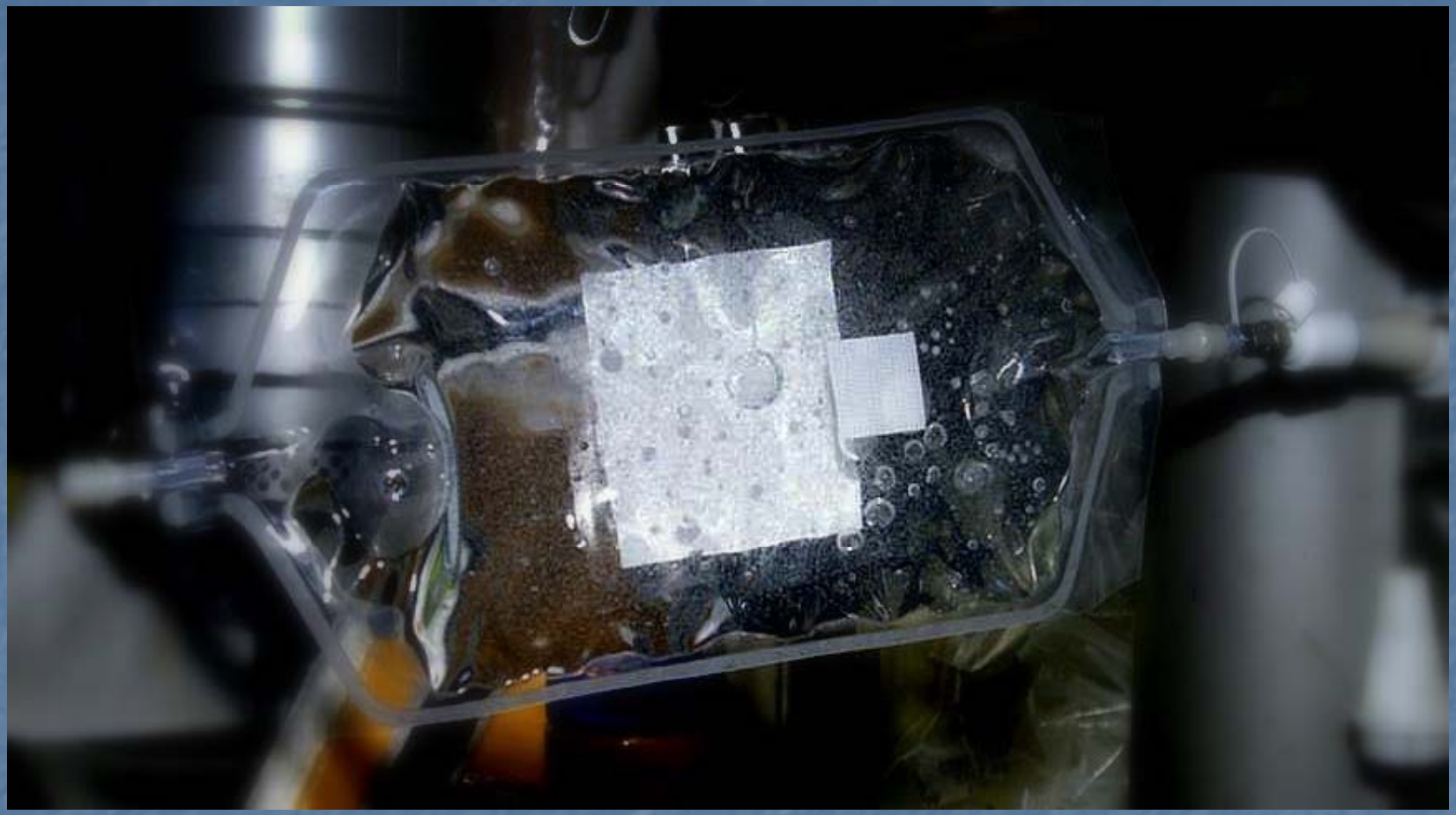
Potential Areas of Particular Interest/Need

- Total Alcohol Detector (alcohols/glycols)
  - Although not a huge priority from a crew health standpoint, alcohols are primary components of condensate and data is useful from a engineering/systems perspective.
- "Front-end" unit for water monitoring that could be compatible with already developed in-flight air monitoring tools (GC/MS, GC/DMS, etc).
  - Combined air/water capabilities would go a long way toward providing a sustainable platform for Cx; help with ISS as well
- Chemical-specific colorimetric "test strips" that could provide a general indication of water contamination (e.g., strips may be semi-quantitative in nature)

Pertinent Technology Questions to Ask

- √ Can the technology meet required analytical detection limits?
- √ Does the technology require resupply of consumables?
- √ Does the technology utilize chemicals or reagents that can pose a crew health concern in a closed-loop spacecraft environment?
- √ Does the technology have the specificity to handle mixtures of pollutants without affecting the reliability of individual results?
- √ Can the technology be adapted to the uniqueness of a zero gravity environment? Is it rugged enough to perform there?
- √ Does the technology minimize critical crew time/interaction?
- √ Are weight and power needs within practical limits?

Be prepared for unexpected challenges!



*Trapped air bubbles interfere with fluid transfers

*Trapped air bubbles can affect analytical techniques that rely on a known sample volume

Technical Resources

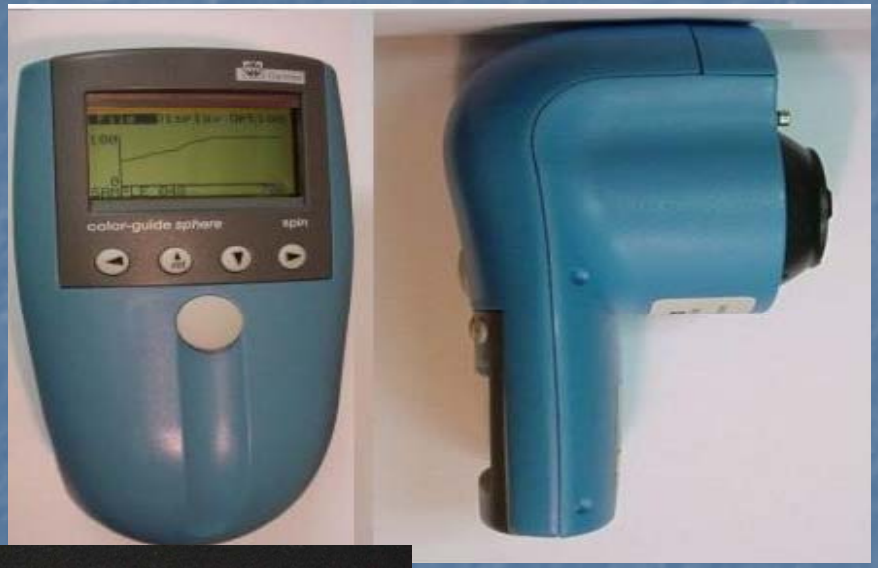
- Spacecraft Water Exposure Guidelines (SWEGs)
  - Volumes 1, 2, 3, & Guidelines Document
  - Describe chemical-specific environmental challenges
    Monitored levels, toxicological background

- JSC 63414, November 2008
  "Spacecraft Water Exposure Guidelines"

  - Health-based water quality limits for 29 chemicals/compounds that are of particular significance to spaceflight
  - Available on-line at **http://hefd.jsc.nasa.gov/tox.htm**

Case Study:
Colorimetric Solid Phase Extraction (C-SPE)

Example of an Innovation and Collaboration Success Story



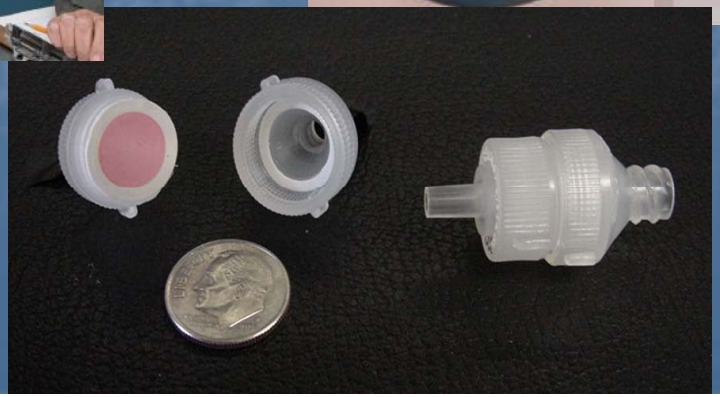
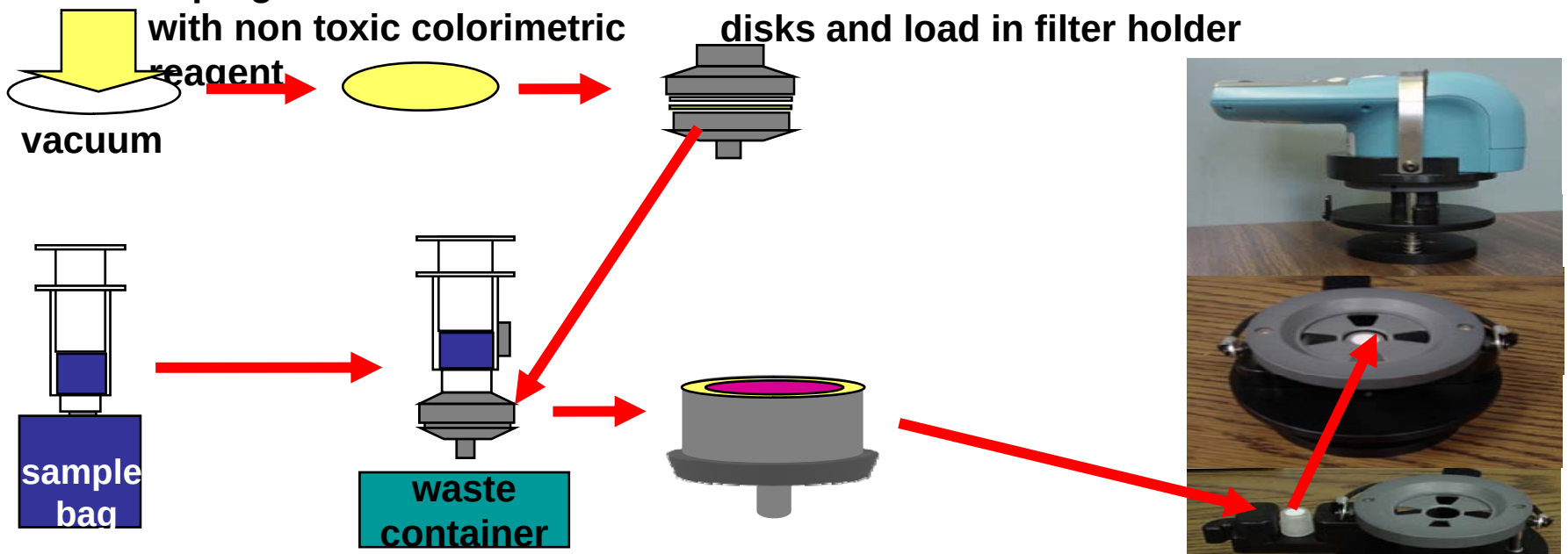


Illustration of C-SPE Technology

C-SPE utilizes solid phase extraction membranes impregnated with analyte-specific colorimetric reagents to rapidly and selectively measure low levels of key water quality indicators

***Silver and Iodine are Targets to Date**



3. Withdraw sample using syringe
4. Pass sample through disk
5. Acquire spectrum with portable reflectance spectrometer

Total analysis (steps 3-5) under 2 min

Collaborative Success Story: Adapting a "bright idea" and COTS technology to spaceflight

- **Interactive Team formed in 1999 with first proposal on C-SPE**
  - **Iowa State University and University of Utah**
  - **NASA/JSC and Wyle Laboratories**
  - **BYK Gardner**

SLSD scientists provided spaceflight expertise in adapting technology to meet specific NASA medical needs

Owners of commercial technology used in "paint color matching" and other applications. Adapted COTS spectrophotometers to allow translation of color change to analyte concentration

University researchers developed a novel technology that could concentrate water analytes on a membrane and then produce a measurable color change across a broad concentration range

C-SPE History

- Through collaborative work in peer reviews, etc. NASA and Iowa State/Utah researchers formed an initial working relationship.

- Consistent with NASA efforts to encourage University collaborations, C-SPE team was funded by AEMC (Advanced Environmental Monitoring & Control) through two three-year cycles to move C-SPE from TRL 1 to 4.

- Following ISS/AEMC Trade Study and NASA RFI in FY03-FY04, C-SPE was identified as a top technique for biocides and inorganics in water.

- C-SPE was recognized as having potential benefits for both ISS and Exploration, and agreements were put in place to encourage the technology development (e.g. AEMC Rapid Technology Development and Environmental Monitors on Station funding)
  - Extensive development and microgravity testing over several years

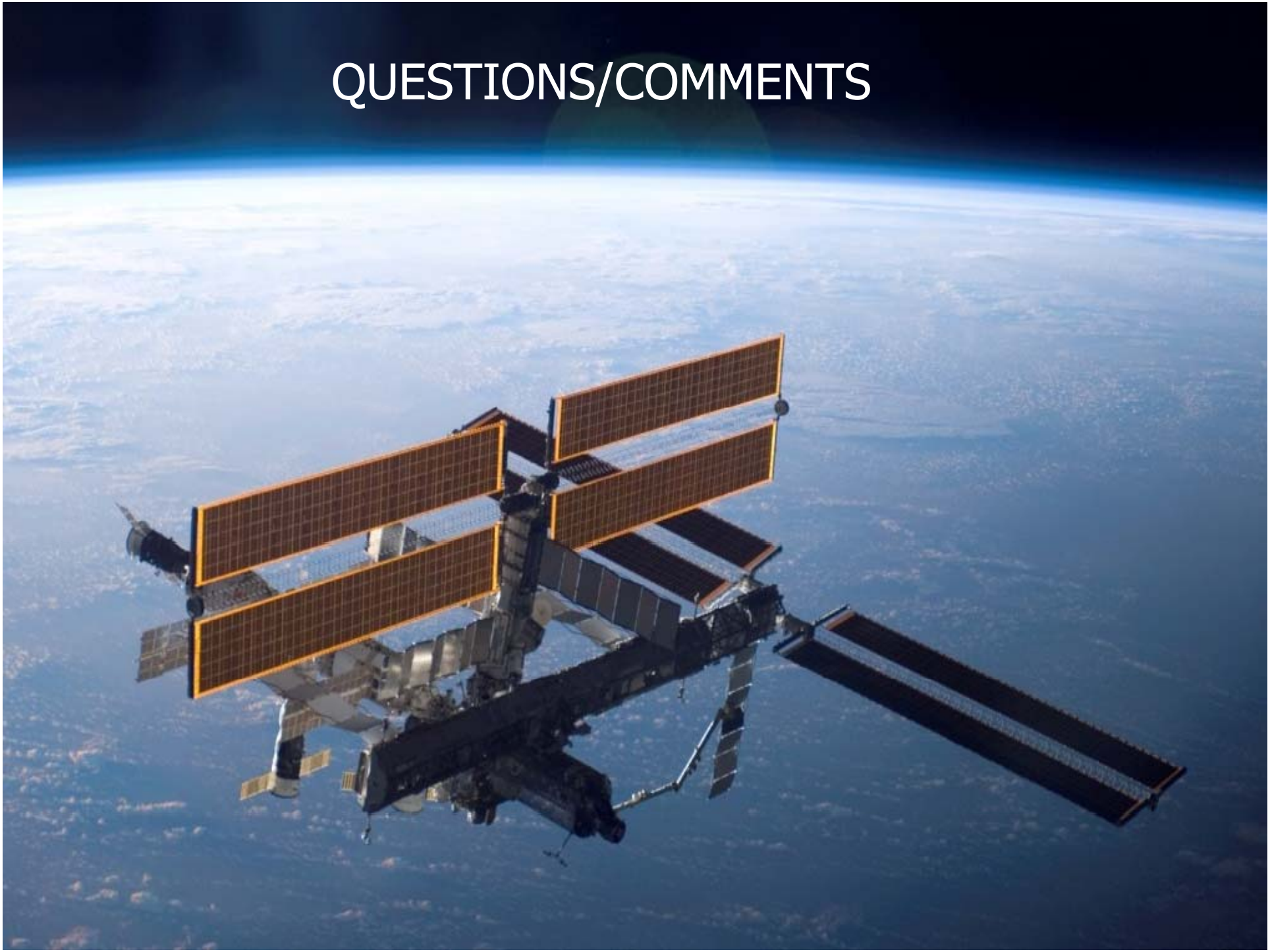
- For FY09 C-SPE was jointly funded by ISS and ESMD for a FY09 Flight Experiment on ISS.
  - Scheduled for delivery in Spring of 2009, targeted for 17A launch

What made it successful?

TECHNICAL

☑ small size,mass, power requirements
☑ limited consumables
☑ lack of complexity
☑ adaptability to other compounds of interest
☑ ability to provide in-flight data that could be used operationally
☑ broad potential applicability to more than one NASA program/spacecraft

TEAM CHARACTERISTICS

☑ patience through funding ups and downs, NASA development hurdles
☑ communication skills
☑ diverse background in academia and industrial applications of technology was a practical benefit to the project

QUESTIONS/COMMENTS