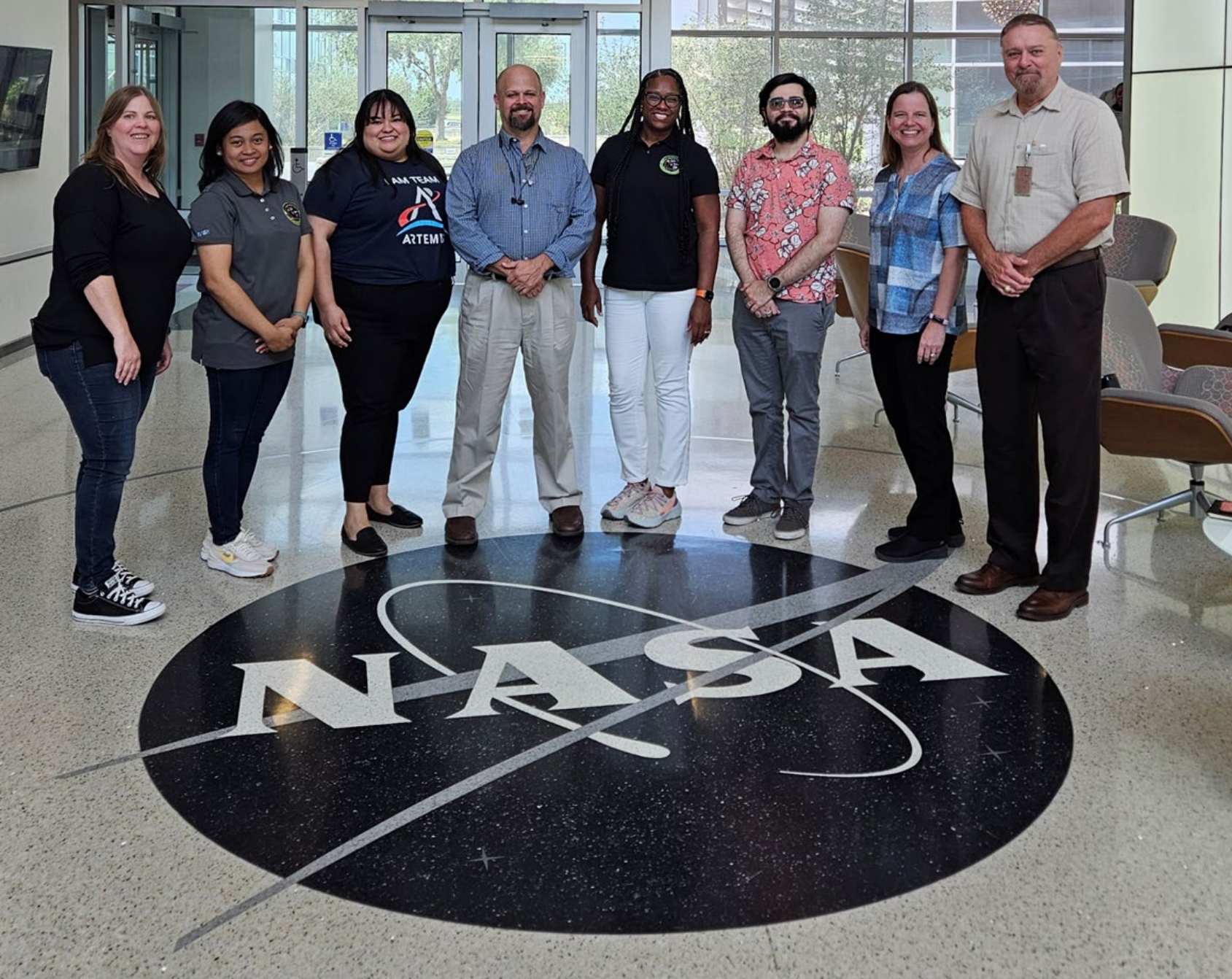


# Spaceflight Toxicology

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valerie.e.ryder@nasa.gov





## Toxicology and Risk Assessment at JSC

Support Occupational Safety for Astronauts by:

- Setting safe limits for chemicals in air and water

- Providing hazard assessments for hardware development (design/containment)

- Providing operational support during off-nominal events

# Setting Limits

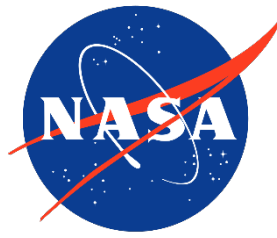
- Spacecraft Maximum Allowable Concentrations (SMACs)
- Spacecraft Water Exposure Guidelines (SWEGs)



Spacecraft Maximum  
Allowable Concentrations  
for Selected Airborne  
Contaminants  
*Volume 5*

NATIONAL RESEARCH COUNCIL  
OF THE NATIONAL ACADEMIES





# Ethanol (Vapor) Limits

Literature Review – Select most sensitive endpoint in most sensitive species

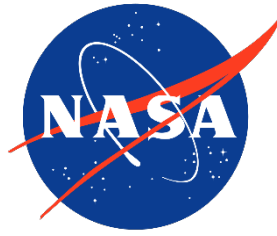
| End Point          | Data                         | Species |
|--------------------|------------------------------|---------|
| Neurotoxicity      | estimated NOAEL 15,000 mg/m3 | Human   |
| Sensory Irritation | NOAEL 10,000 mg/m3           | Human   |
| Flush Response     | NOAEL 2,000 mg/m3            | Human   |
| Hepatotoxicity     | NOAEL 20,000 mg/m3           | Rat     |

Apply uncertainty factors

| Species | Database | Spaceflight | Vulnerable Humans |
|---------|----------|-------------|-------------------|
| 1       | 1        | 1           | NA                |

Apply duration adjustment (as necessary)

| 7-day | 30-day | 180-day | 1000-day |
|-------|--------|---------|----------|
| 2000  | 2000   | 2000    | 2000     |



# Unique Occupational Scenario

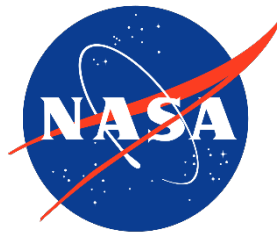
## ■ Traditional Occupational Setting

- Working adults (~16-70 y.o.) with diverse health status
- Exposure scenario
  - 8-10 h/d, 5 d/wk, 40 years



## ■ Spaceflight Setting

- Active, healthy adults (~35-55 y.o.)
- Exposure scenario
  - 24-hr/d, 7-d/wk, 6-12 months
- Physical and physiological differences



# Unique Aspects of Spaceflight

## ■ MICROGRAVITY

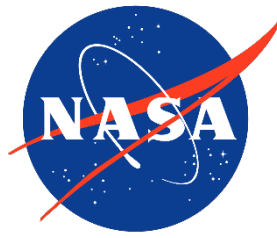
- Things float!
- Limited (near zero) data

## ■ Sensitivities

- Bone and Muscle
- Cardiovascular
- Renal
- Reduced RBC mass
- Immune dysregulation
- Organoleptic



| Spaceflight Factor     | Chemical(s)                                                                                                                                                   |
|------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Reduced BMD            | Cadmium                                                                                                                                                       |
| Renal effects          | barium, chloroform, dichloroacetylene, methylene chloride, octamethyltrisiloxane, tert-butanol, trichloroethylene, ethylene glycol, and mercury               |
| Cardiovascular effects | barium, freon 11, 12, 21, and 113                                                                                                                             |
| Blood cells/volume     | benzene, bromotrifluoromethane, di-n-butyl phthalate, unsymmetrical dimethylhydrazine, 2-ethoxyethanol, isoprene, indole, nitromethane, and trichloroethylene |
| Immune effects         | nickel, 2-mercaptobenzothiazole                                                                                                                               |
| Organoleptic effects   | C1-C4 mono-, di-, and tri-alkylamines, ammonia, antimony, barium, cadmium, dichloromethane, and silver                                                        |



# Unique Vulnerability – CO<sub>2</sub>

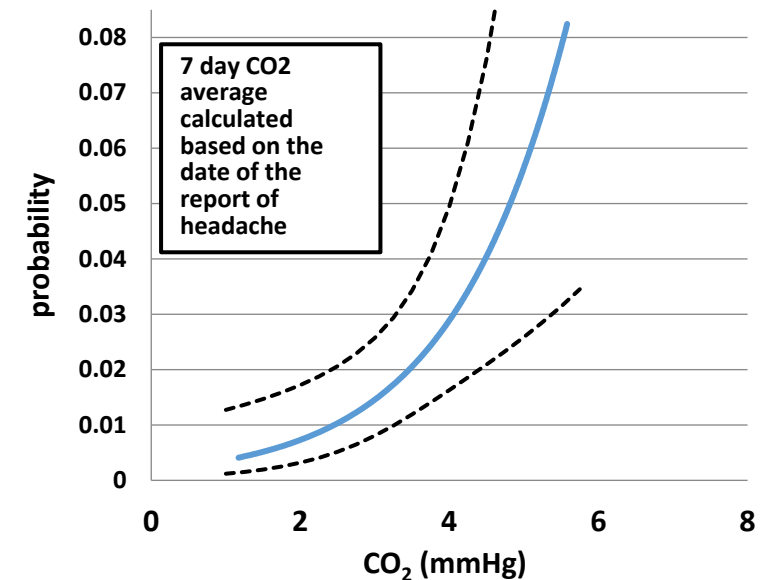
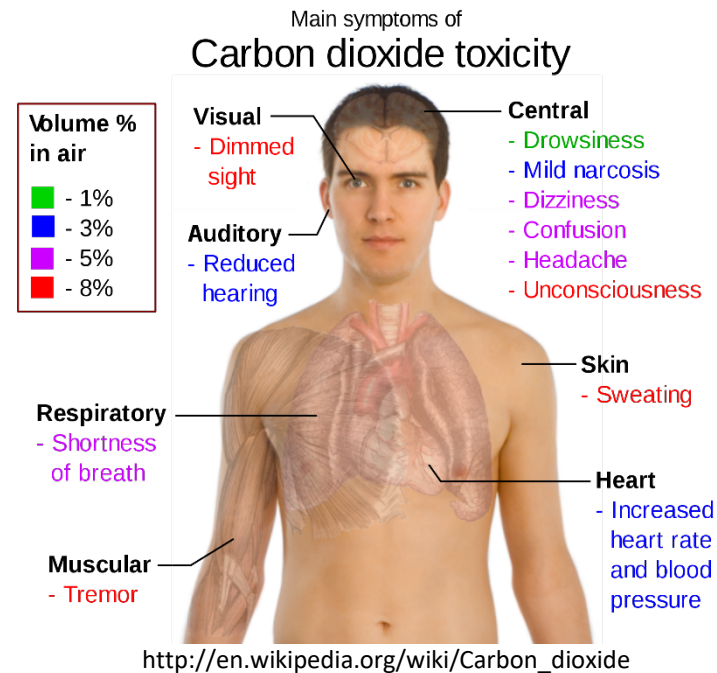
Outdoor ambient ~**0.04%** (0.3 mmHg)

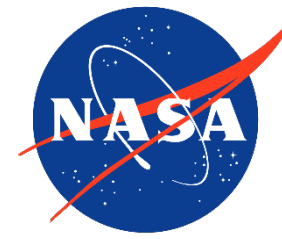
Indoor ~**0.06-0.1%** (0.4-0.8 mmHg)

OSHA PEL/NIOSH REL = **0.5%** (3.8 mmHg)

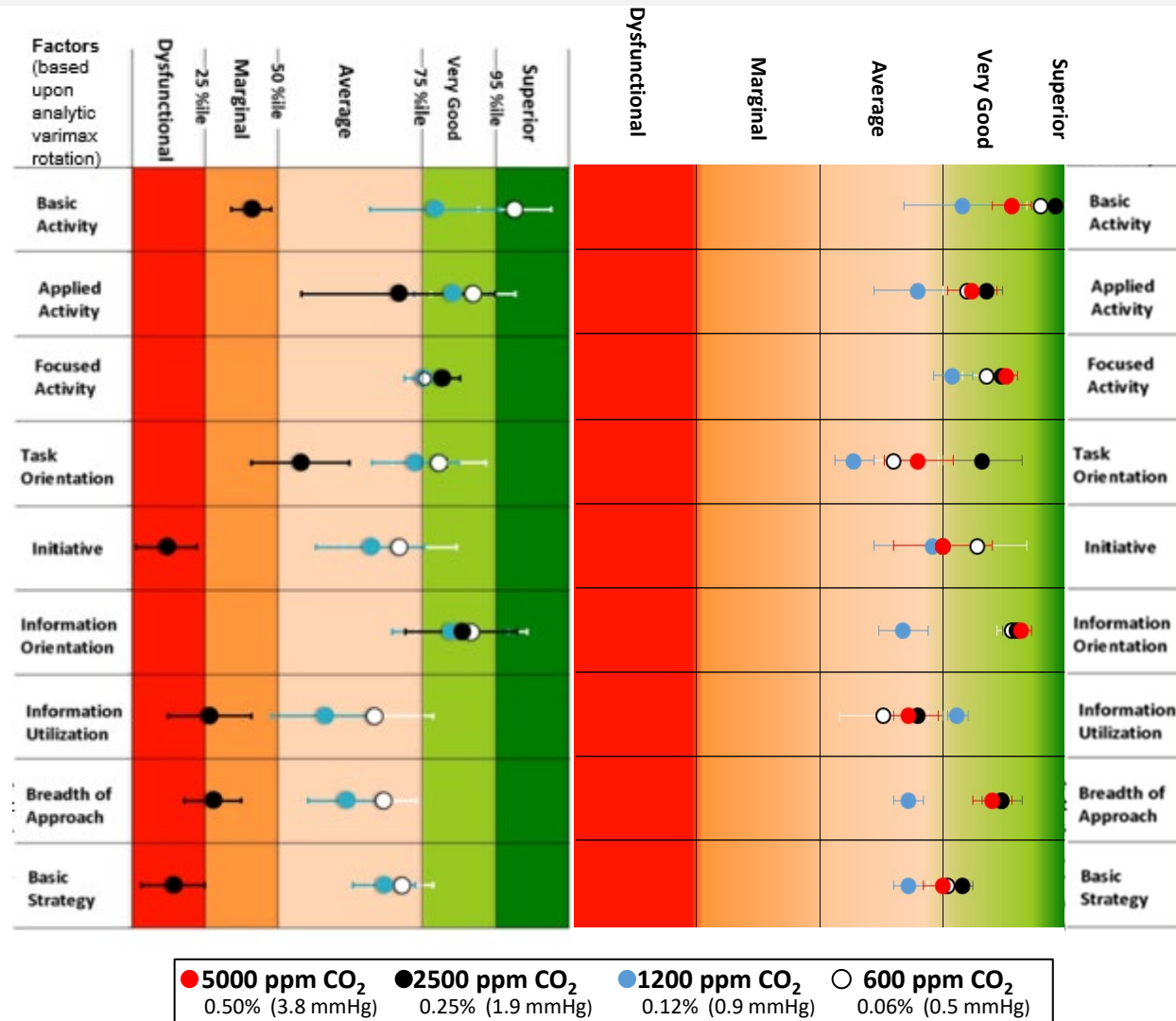
ISS levels **0.3 -0.7%** (2.3 - 5.3 mmHg)

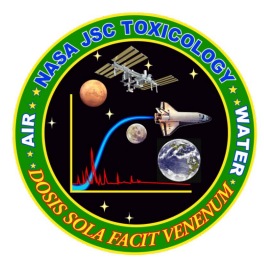
Highest U.S. spacecraft level = **2%** (15 mmHg) on Apollo 13



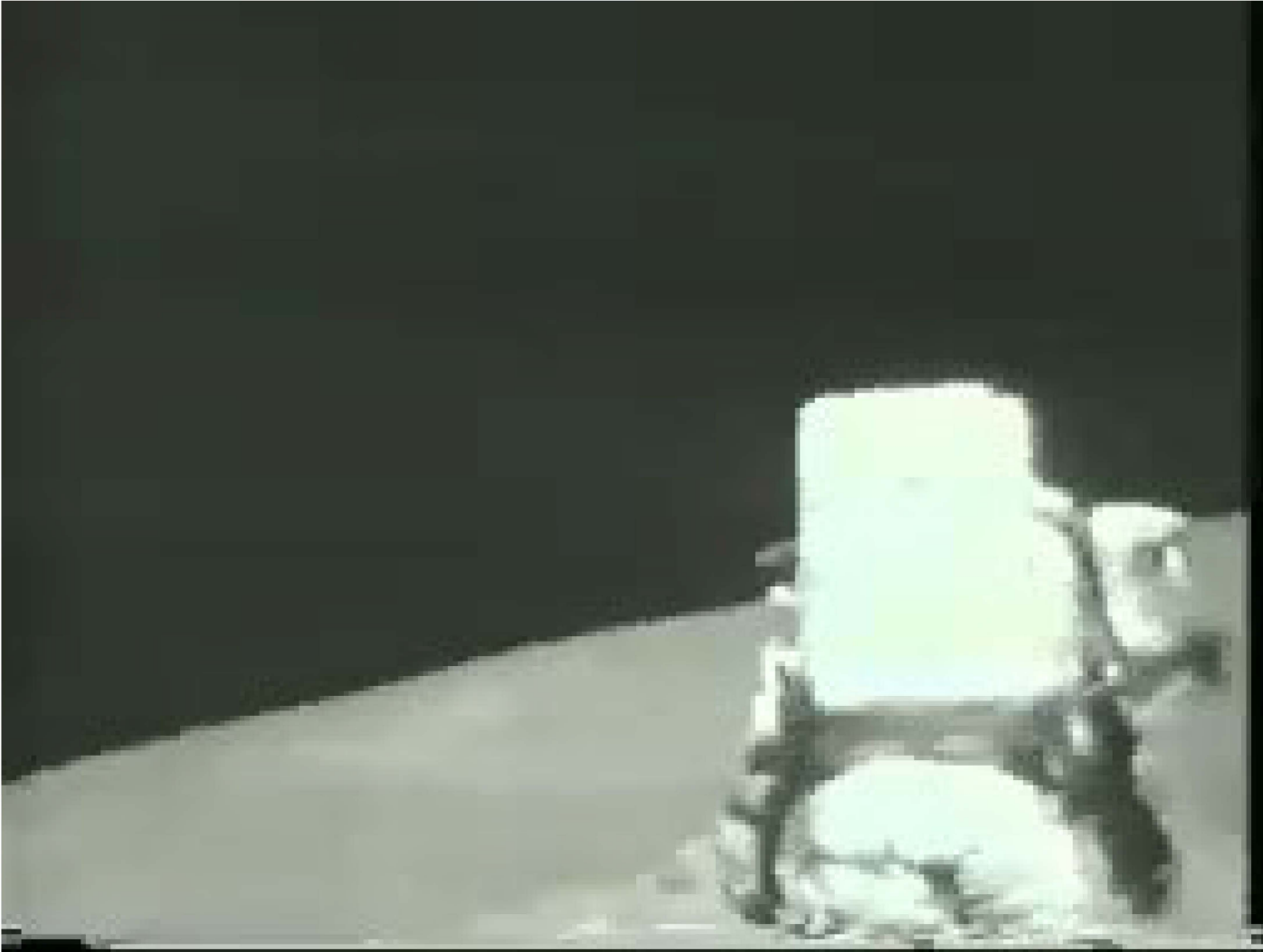
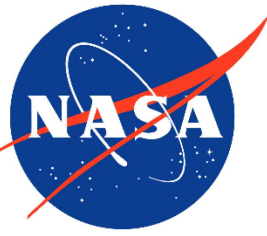


# SMS Results (Satish 2012 and Scully 2016)



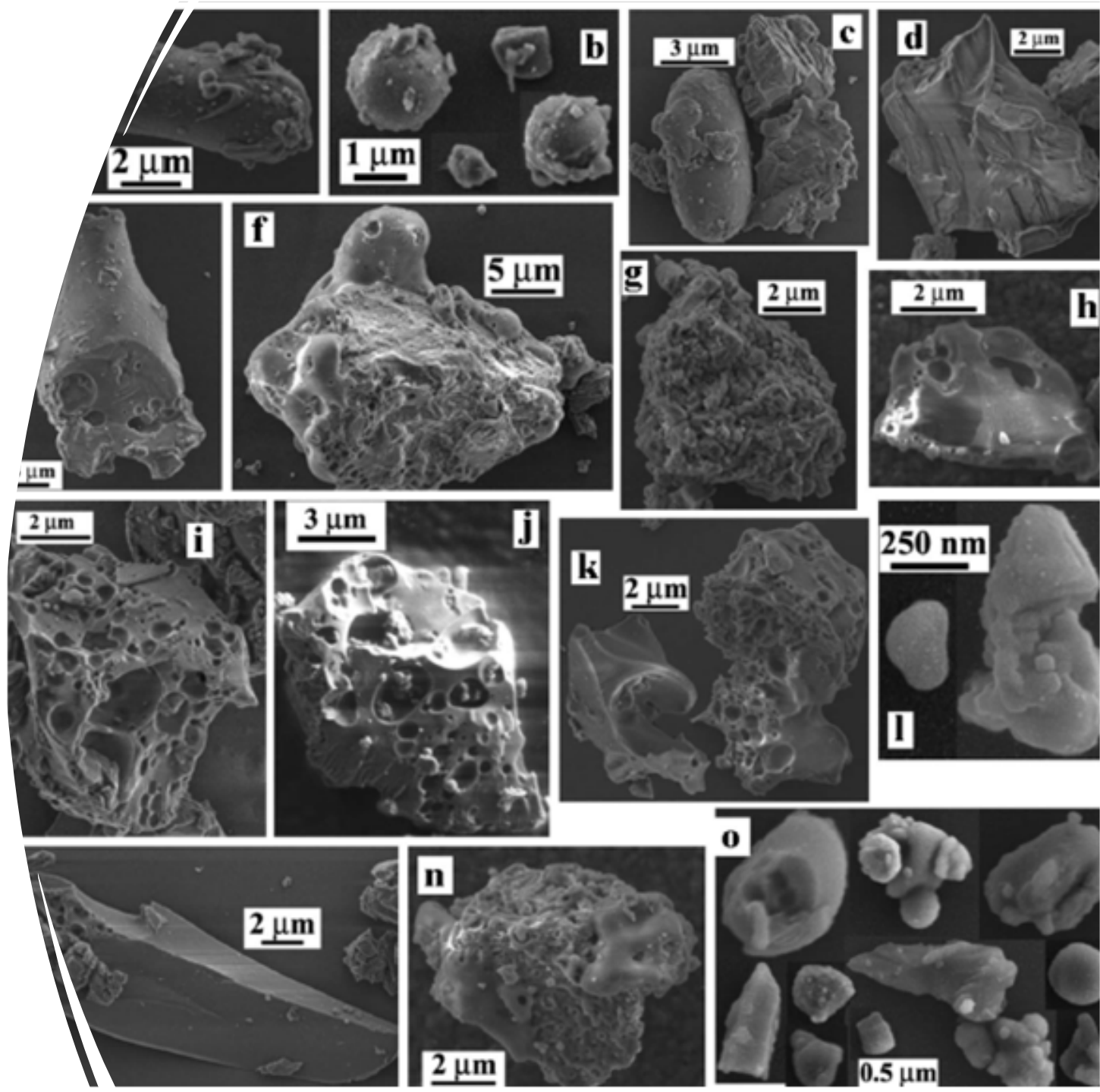


# Unique Exposures – Lunar Dust



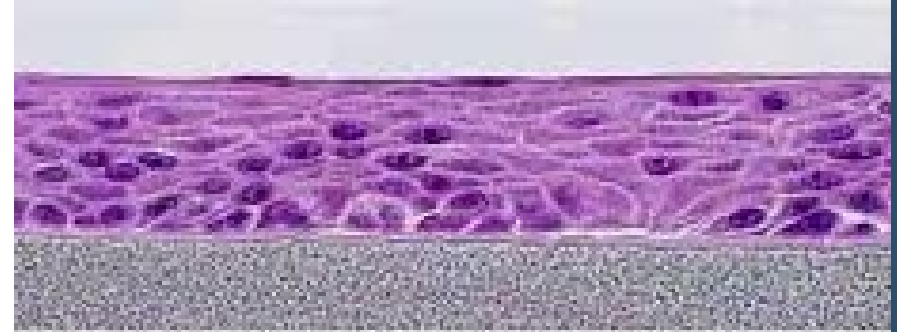
# Lunar Dust Particle Size

- Enriched in fine/ultrafine particles relative to earth
  - 95% <2 microns in diameter;  
40% <0.1 microns.

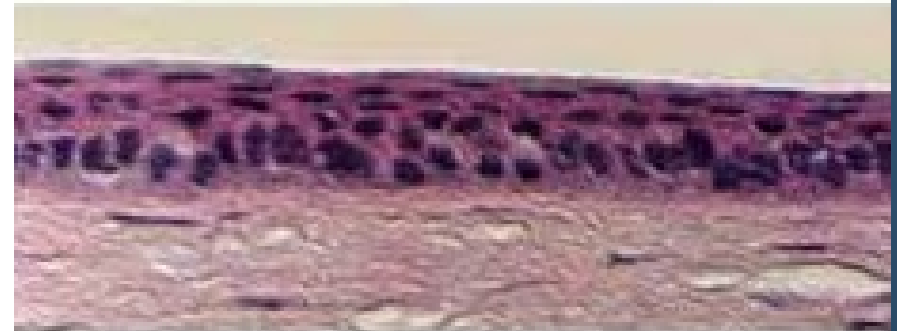


# Ocular Studies

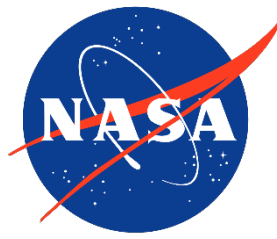
- Chemical and abrasive effects evaluated by Stillmeadow Inc.
- Rated as minimally irritating in EpiOcular *in vitro* test and Draize test in rabbits performed
- Slight redness and swelling of conjunctiva at 1-hour that resolved by 24-hours



EpiOcular™; Magnification 360x



Rabbit Cornea; Magnification 360x



# Respiratory Studies

## Dose finding

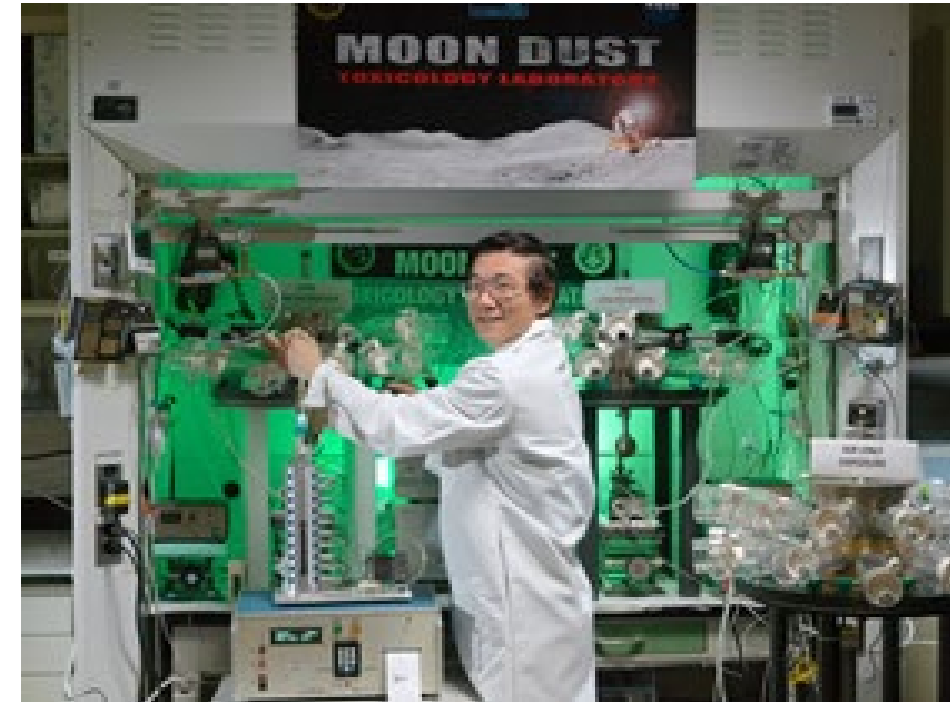
Intratracheal instillation (ITI) study in rats conducted at NIOSH  
Lung lavage and histopathology evaluation  
Predicted dose of 20 mg/animal = NOAEL and 60 mg/animal = LOAEL

## Phase 1 (with different grinding methods)

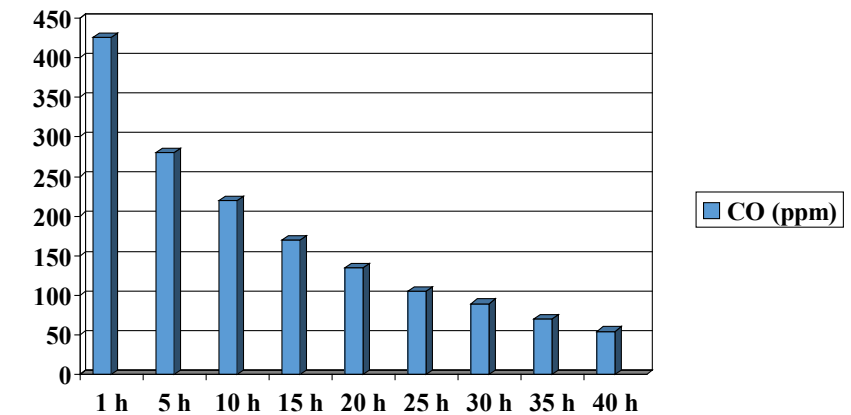
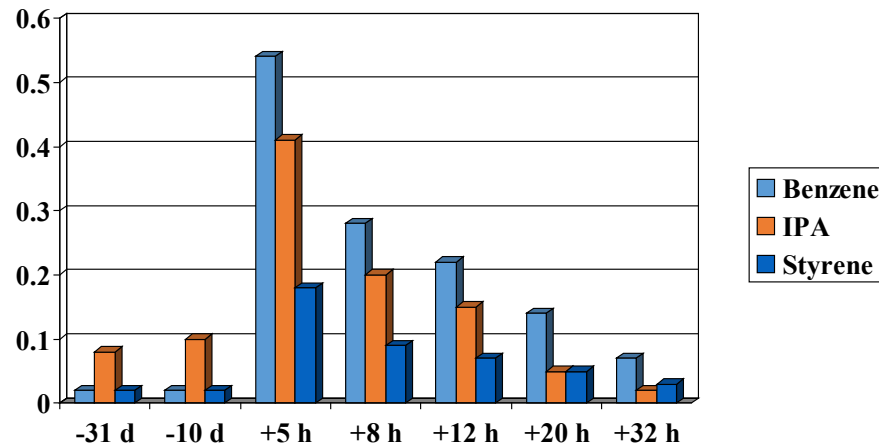
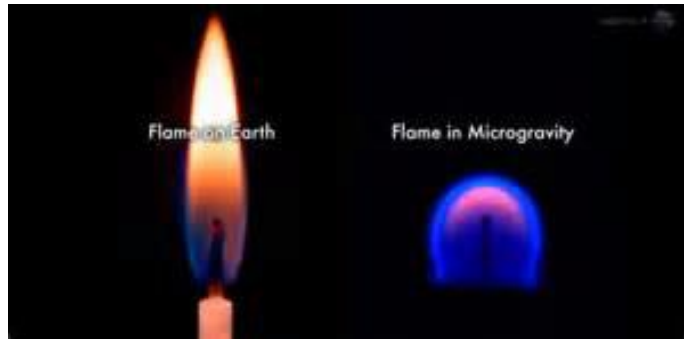
Nose-only inhalation study in rats conducted at NASA JSC  
Exposed to lunar dust (ground and unground), quartz, and  $\text{TiO}_2$  for 6 hr/d, 5 d/wk for 4 wk  
Lung lavage and histopathology at 1 day, 1 week, 4-weeks, and 13-weeks post exposure  
20 mg/m<sup>3</sup> was LOAEL

## Phase 2

Nose-only inhalation study in rats conducted at NASA JSC  
1 year after initial study at lower dose range  
Target dose of 6 mg/m<sup>3</sup> (actual = 6.8 mg/m<sup>3</sup>) was NOAEL

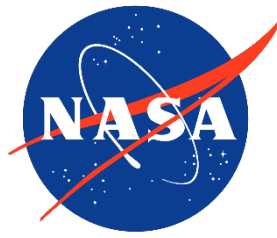


# Off-nominal/Emergency Scenarios

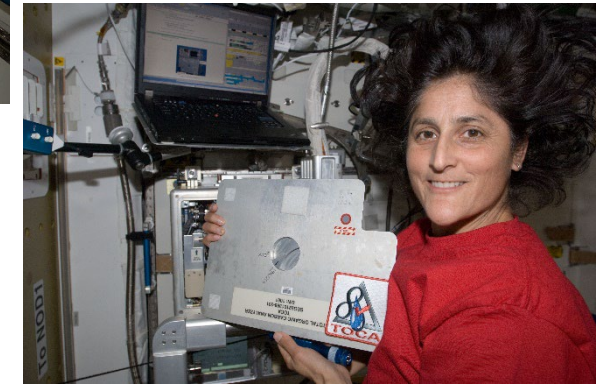
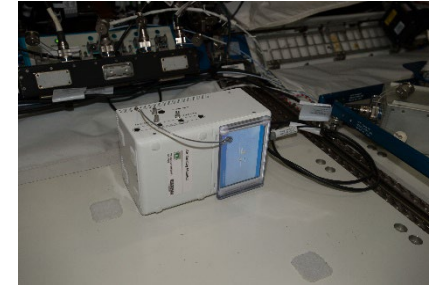


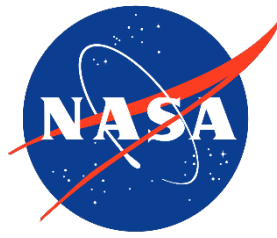


# Monitoring



- Real-time
  - Air Quality monitor (AQM)
  - CO<sub>2</sub>
  - Compound specific analyzer for combustion products (CSA-CP)
  - Total Organic Carbon (TOC) Analyzer
- Post-flight
  - Grab sample containers (GSCs)
  - Formaldehyde badges



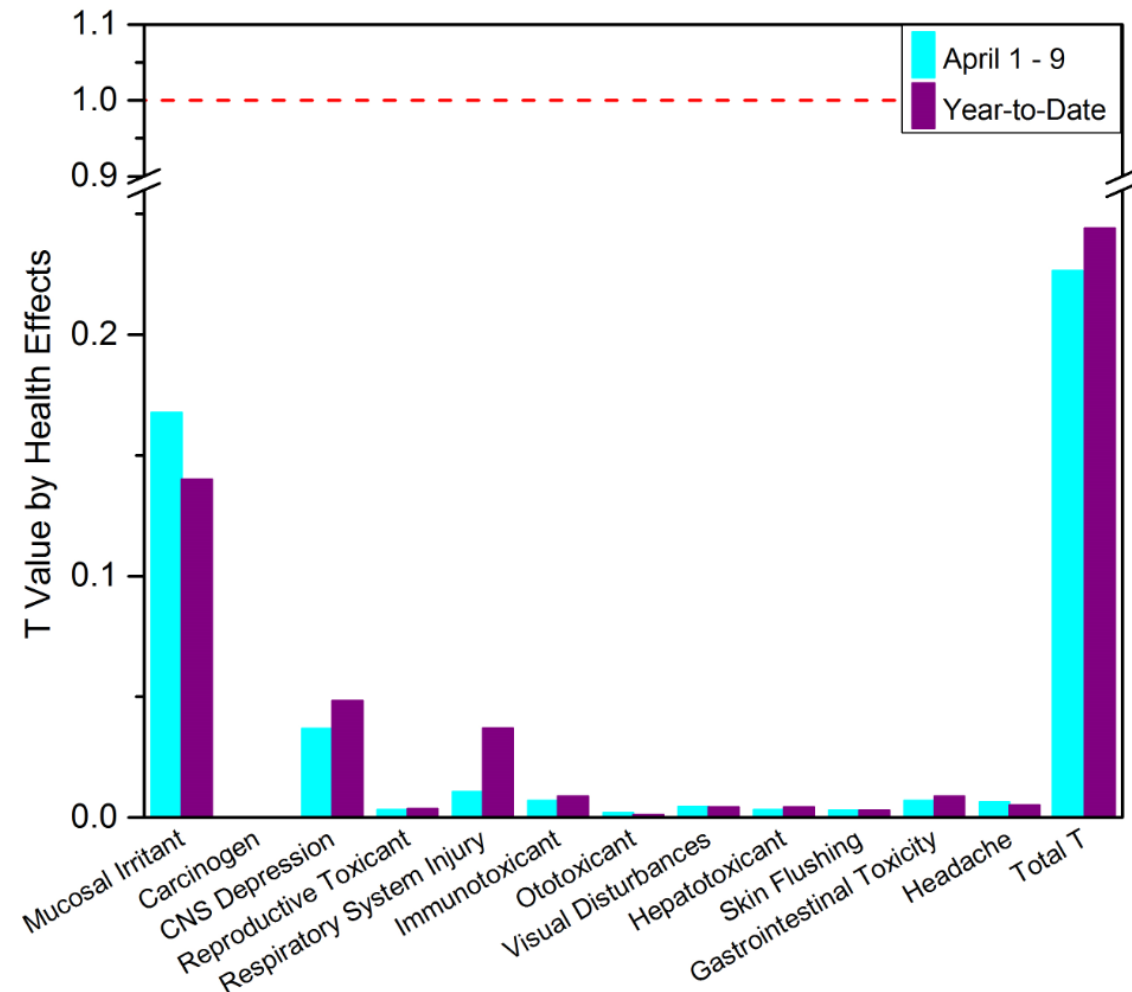


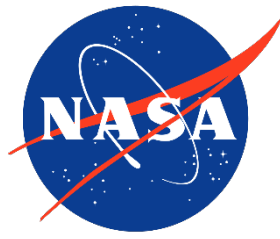
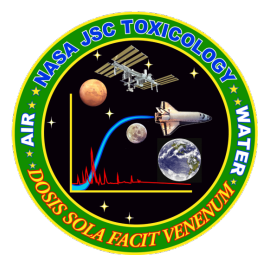
# Application of T-value to Air Monitoring Data

$$T = C_1/SMAC_1 + \dots C_n/SMAC_n$$

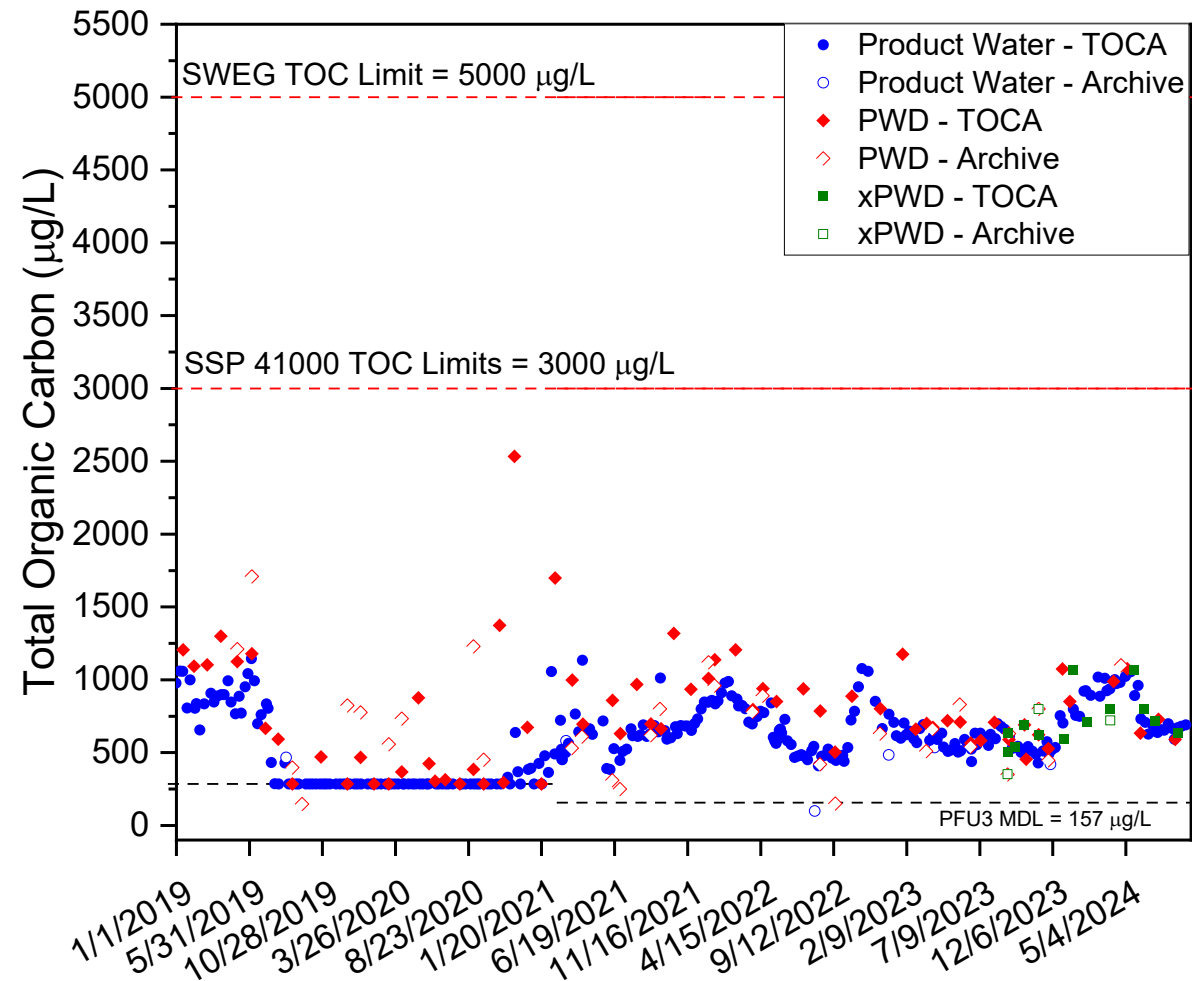
C = measured concentrations

SMACs = appropriate to exposure time



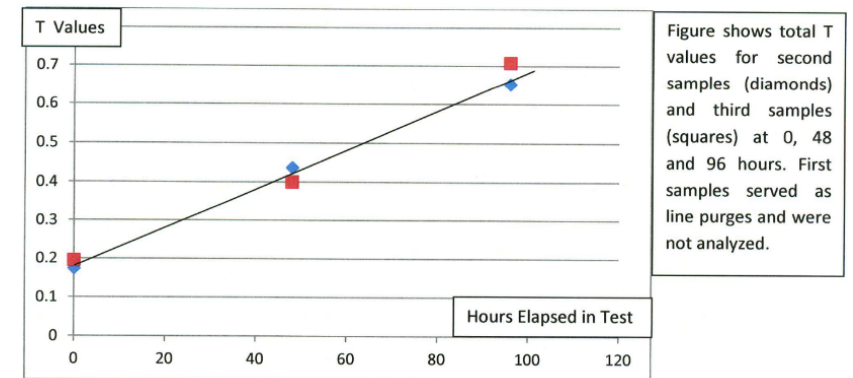


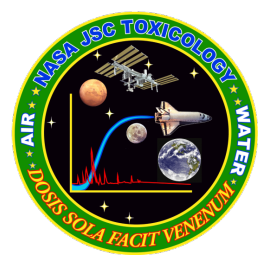
# Total Organic Carbon (TOC) Trending in ISS Potable Water



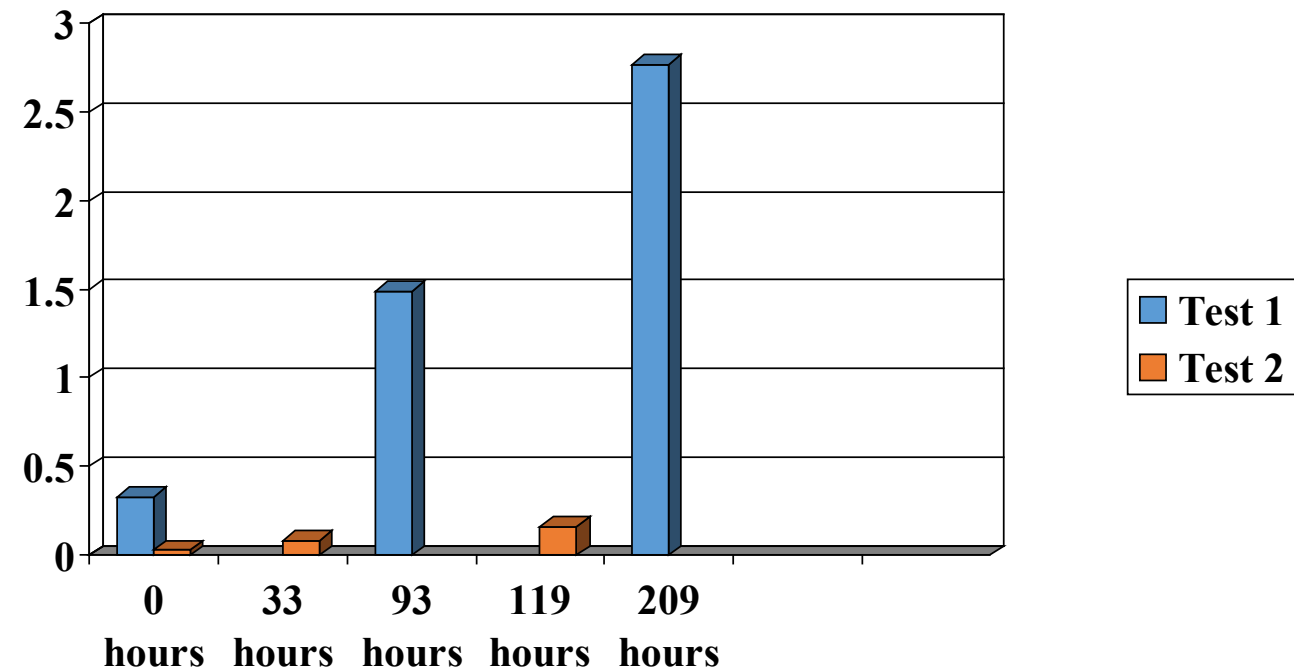
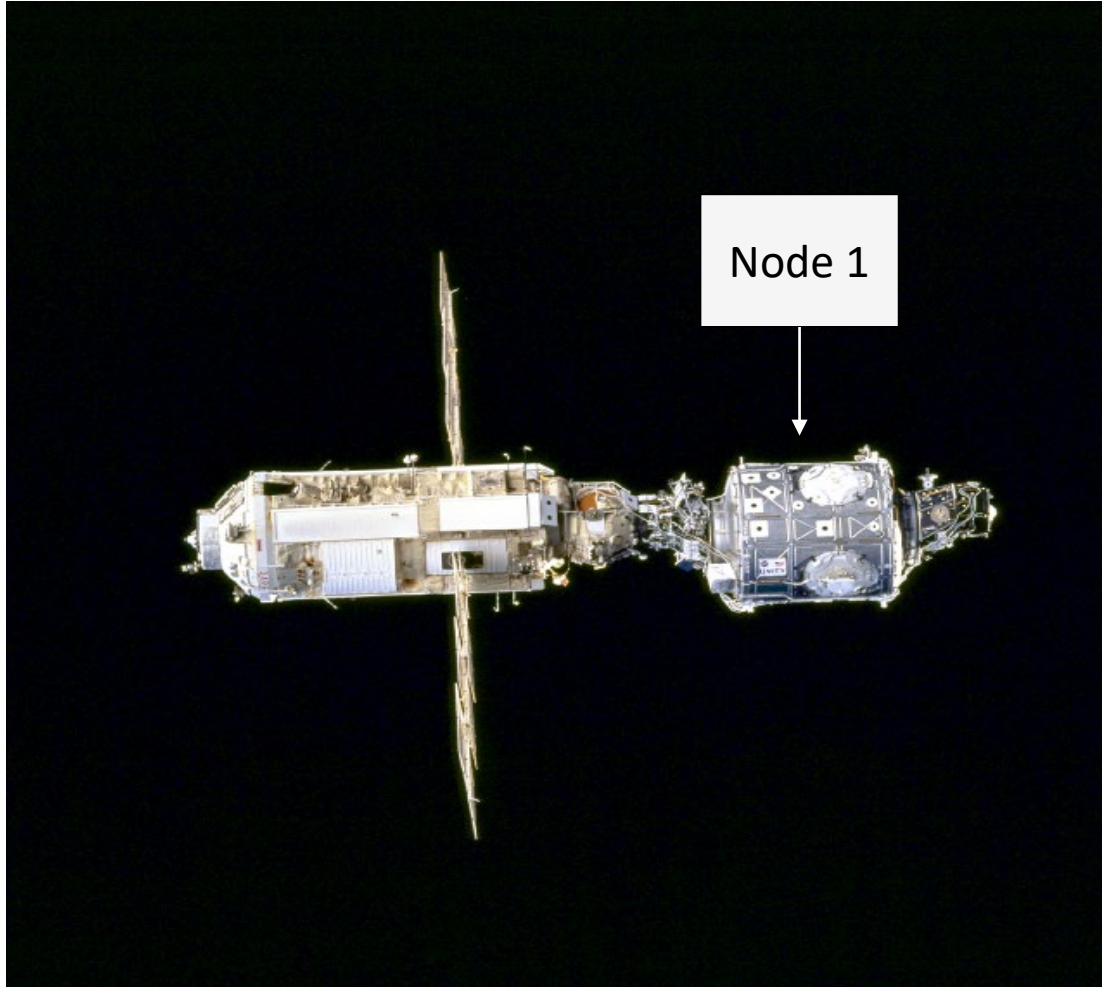
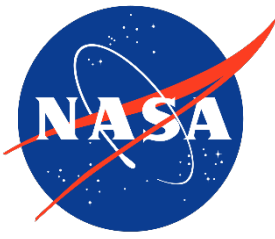
# OGT and First Entry

- Ground-based off-gas test data are used to predict the concentration of pollutants crew members will encounter at first entry
- Predicted values are compared to samples collected during first entry





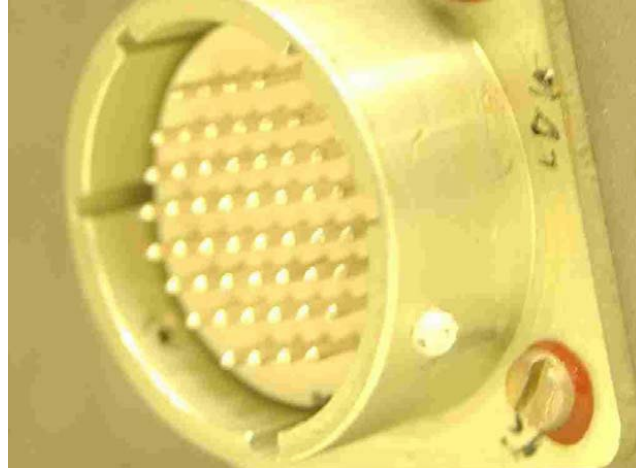
# Offgassing Tests of Node 1 at KSC (T units)



## *Additional Issues Resolved as a Results of Off-gas Testing/First Entry Results*

- HTV elevated CO
  - Source was identified as foam packing material
  - Baking procedure instituted that reduced concentrations
- Dragon coolant leak
  - Small increase detected during OGT
  - MUCH larger increase noted in first entry sample





# Toxicological Risks to Spacecraft Air and Water

- Vehicle system, payload, and utility chemicals
- Offgassed products
- Batteries (leak or fire)
- Products of corrosion
- External contaminants
- Human metabolites
- Microbial metabolites
- Operational anomalies/hardware failures & repair
- Thermal degradation of electronic components
- Pollution in the source water



## Assessing Hazards

- Payload/system chemicals
  - Composition
  - Volume
  - Concentration
- Irritancy Potential (eye, skin, respiratory)
- Systemic Toxicity

# Toxicity Hazard Levels

| Hazard Level  | Irritancy                                                                                                                                                     | Systemic Effects                                                                                                                                                                  | Containability                                            |
|---------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------|
| 0<br>(green)  | Slight irritation that lasts <30 minutes and will not require therapy                                                                                         | None                                                                                                                                                                              | Gas, solid, or liquid (may or may not be containable)     |
| 1<br>(blue)   | Slight to moderate irritation that lasts >30 min and will require therapy                                                                                     | Minimal effects, no potential for lasting internal tissue damage                                                                                                                  | Gas, solid, or liquid (may or may not be containable)     |
| 2<br>(yellow) | Moderate to severe irritation that has the potential for long-term performance decrement and will require therapy.<br>Eye Hazards: May cause permanent damage | None                                                                                                                                                                              | Either a solid or nonvolatile liquid (containable)        |
| 3<br>(orange) | Irritancy alone does not constitute a level 3 hazard                                                                                                          | Appreciable effects on coordination, perception, memory, etc., or has the potential for long-term (delayed) serious injury (e.g. cancer), or may result in internal tissue damage | Either a solid or nonvolatile liquid (containable)        |
| 4<br>(red)    | Moderate to severe irritation that has the potential for long-term performance decrement and will require therapy.<br>Eye Hazards: May cause permanent damage | Appreciable effects on coordination, perception, memory, etc., or has the potential for long-term (delayed) serious injury (e.g. cancer), or may result in internal tissue damage | Gas, volatile liquid, or fumes ( <b>NOT containable</b> ) |

# Combine Hazard Response Level



|              | HRL (COLOR OF LABEL) |          |            |            |         |
|--------------|----------------------|----------|------------|------------|---------|
|              | 0 (GREEN)            | 1 (BLUE) | 2 (YELLOW) | 3 (ORANGE) | 4 (RED) |
| TOXICITY     | 0                    | 1        | 2          | 3          | 4       |
| BIO-SAFETY   | 1                    | 2M       | 2H         |            |         |
| FLAMMABILITY | 0, 1                 | 2, 3, 4  |            |            |         |

critical

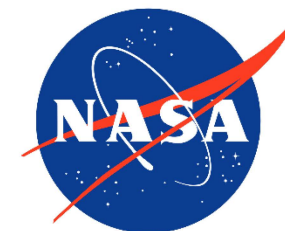
catastrophic



# FINAL HAZARDOUS MATERIALS SUMMARY TABLE

## ASCENT to ISS Increment ALL

Verification Status  
V-1: Previously Flown  
V-2: N/A



Expt /Hdwr/Item: Common Batteries

Expt/HW Acronym: NA

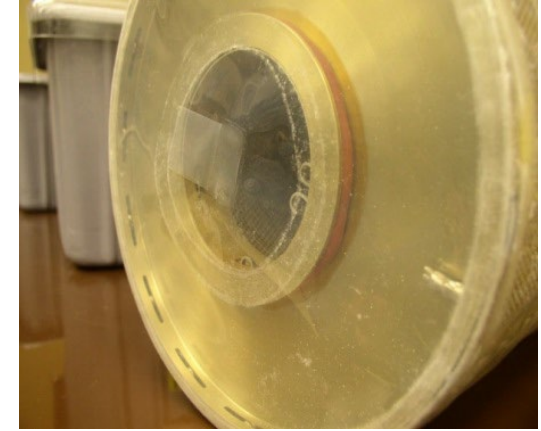
OpNom:

| Record #                 |                | Common.Bat |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | PAYLOAD CHEMICAL or BIOLOGICAL INFORMATION |                                |         |                  |                         | HAZARD RESPONSE LEVEL (HRL) = 2                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                 |              |
|--------------------------|----------------|------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------|--------------------------------|---------|------------------|-------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|--------------|
| Last Modified<br>4/26/21 |                |            | Chemicals or<br>Biological Materials                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | Maximum<br>Concentration                   | Maximum<br>Volume or<br>Amount | Tox Lvl | BioSafety<br>Lvl | Flammability<br>Haz Lvl | SPECIFIC HAZARD LEVELS                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                 |              |
| Part<br>#                | Sub-<br>System | Label      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                            |                                |         |                  |                         | Toxicity (THL)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | BioSafety (BSL) | Flammability |
|                          |                |            | Commonly Flown Battery Chemistries<br>Alkaline<br>Zn/MnO <sub>2</sub> /KOH<br>Zinc Carbon<br>Zn/carbon rod/NH <sub>4</sub> Cl (ZnCl <sub>2</sub> )<br>Lead Acid<br>Metallic Pb/PbO <sub>2</sub> /H <sub>2</sub> SO <sub>4</sub><br>Lithium Ion<br>LiCoO <sub>2</sub> , LiNMC, LiNCA<br>LiMO <sub>2</sub> , LiFePO <sub>4</sub> , LiMO <sub>x</sub><br>LiTi <sub>4</sub> O <sub>5</sub> or lithium alloys of Si or Sn<br>LiPF <sub>6</sub> , LiBOB, LiBF <sub>4</sub> or other<br>Lithium Primary<br>Li-MnO <sub>2</sub> ; LiFeS <sub>2</sub> ; LiCF <sub>x</sub><br><b>EXCLUDING: Li-SOCl<sub>2</sub>, Li-SO<sub>2</sub><br/>Li-SO<sub>2</sub>Cl<sub>2</sub>, and Li-BCX</b><br>Nickel-Cadmium<br>NiOOH/Cd(OH) <sub>2</sub> /KOH<br>Nickel-Hydrogen<br>H <sub>2</sub> /Ni(OH) <sub>2</sub> /KOH<br>Nickel Metal Hydride<br>NiOOH/metal alloy/KOH<br>Silver-Zinc<br>ZnO/Ag/KOH<br>Silver Oxide<br>Ag <sub>2</sub> O/Zn/KOH or NaOH<br>Zinc Air<br>Zn/Air/KOH | NA                                         | NA                             | 2       | NA               | 0                       | <b>Target Organ(s):</b> Eye, Skin<br><b>Principal Adverse Effects:</b><br>Electrolytes contained in batteries may cause severe eye irritation and possible permanent eye damage when they come into contact with the eyes.<br><br><b>SPECIAL NOTE: THIS RECORD DOES NOT COVER BATTERIES WITH THL &gt; 2, WHICH ARE GENERALLY NOT ALLOWED IN THE HABITABLE VOLUME OF SPACECRAFT. Batteries containing sulfur dioxide and/or thionyl chloride may be THL 4 and MUST be assessed separately. Toxic vapors from batteries with THL 4 chemistry can be life threatening to crew (reference memo SF23-07-073).</b><br><br><b>Contact:</b> David Delafuente, david.a.delafuente@nasa.gov, 281-244-8268<br><br><b>Comments:</b> Most batteries contain electrolytes that are rated THL 2. It is therefore prudent to assume that all batteries contain irritating or corrosive electrolytes. <b>NOTE:</b> As of May 21, 2019, specific battery information will now be contained within the battery/capacitor spreadsheet located in IHS record #48243.<br><br>ECLS Environmental Rating = NA ECLS Hardware Rating = NA |                 |              |

# *Examples of Toxic Release*



STS-40  
Orbiter  
Refrigerator  
Freezer Fan  
Motor



LiOH dust release



Odor from microbial  
metabolites (methyl  
sulfides) on STS-55



Iodine biocide

# Significant toxicological Events in Spaceflight

