# Laboratory-Generated Aerosols as Transfer Standards to Characterize Smoke Detector Performance

Xiaoliang Wang[a], Judith C. Chow[a], and John G. Watson[a],
Marit E. Meyer[b], Gary Ruff[b], and David L. Urban[b],
John Easton[c], Gordon Berger[d], Paul D. Mudgett[e]

**[a]Desert Research Institute**
**[b]NASA Glenn Research Center**
**[c]Case Western Reserve University**
**[d]Universities Space Research Association**
**[e]NASA Johnson Space Center**

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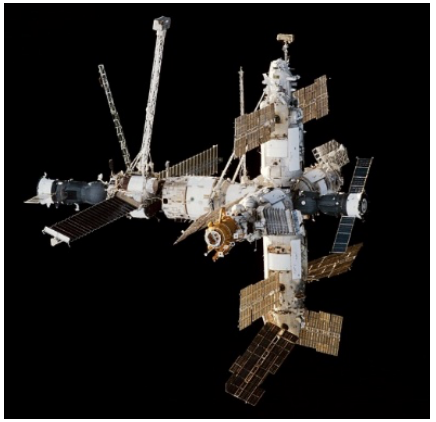
# Background

- Spacecraft fire is a catastrophic threat
  - Causes component and system failure
  - Releases toxic compounds
  - Consumes oxygen
  - Increases temperature and pressure in closed space
  - Limited options to fight fires
- Smoke detection is critical, requiring
  - Early detection
  - Sensitivity and selectivity
  - Low false alarms





Mir space station fire on 2/23/97

# Motivation

- Underwriters Laboratories Standard for Smoke Alarms (UL217)
  - Specific test facilities
  - Smoldering and flaming tests with different fuels
  - Time and labor intensive
  - Limited repeatability in smoke conditions
- Alternative: Laboratory Aerosols
  - Known composition and optical properties
  - Controllable size distributions and concentrations

# Study Objectives

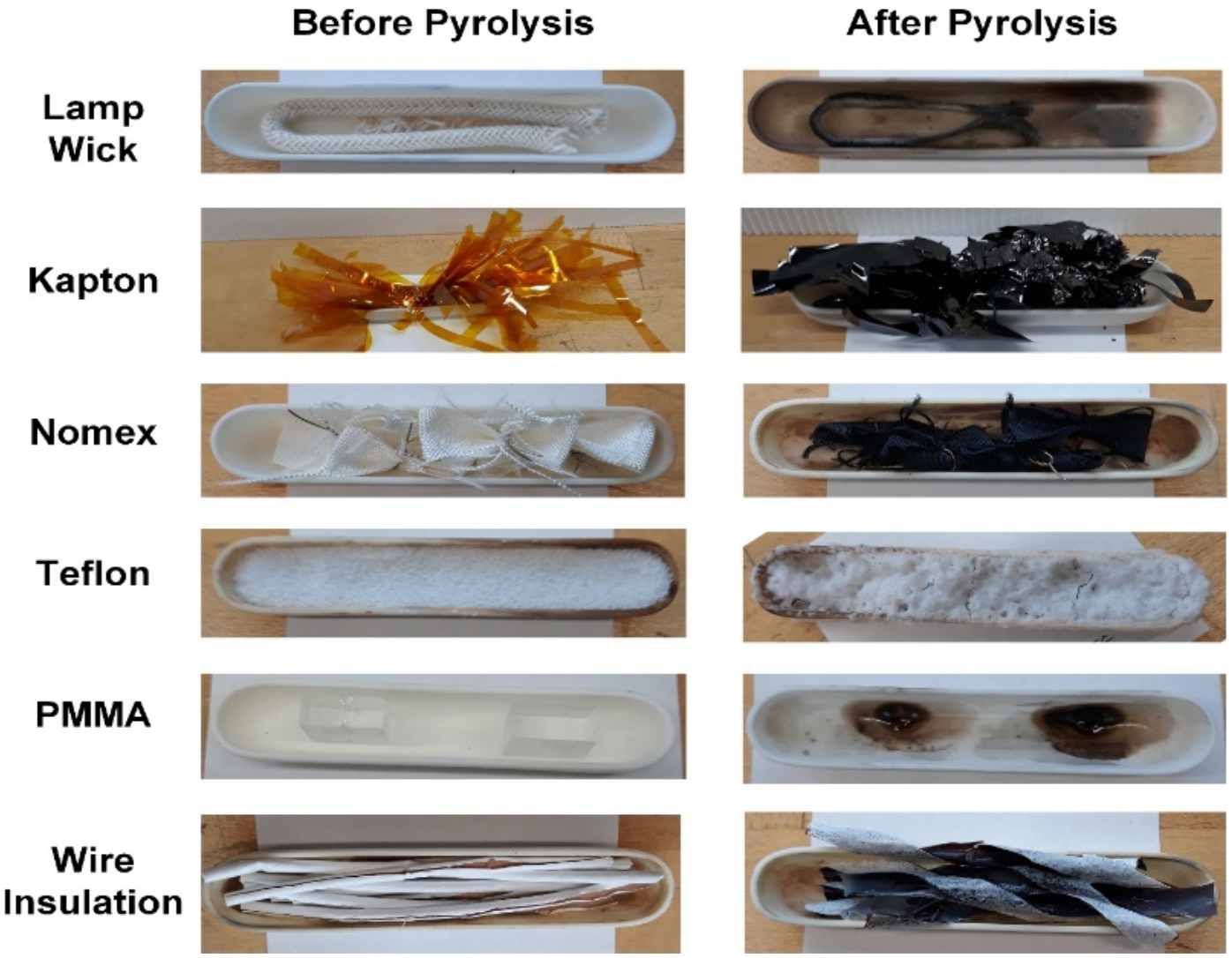
- Evaluate a method to test smoke detectors using reference aerosols
- Characterize smoke detector responses to reference and combustion aerosols
- Determine the feasibility of using reference aerosols to predict smoke detector responses to different smoke aerosols

# Reference Aerosols

| Material | Density ($g/cm^3$) | Refractive index (@589 nm) | Size | Generator |
|---|---|---|---|---|
| PSL | 1.05 | 1.590 | 300, 500, and 900 nm | TSI 3076 and 9306 |
| DOS | 0.915 | 1.448 | 100, 200, 300, 400, 500, and 700; polydisperse distributions (1.5%, 5%, 40%, and 100% solutions) | TSI 3076 |
| Rudol® mineral oil | 0.861 | 1.470 | 100, 300, and 500 nm; polydisperse distributions | Gemini 501B |

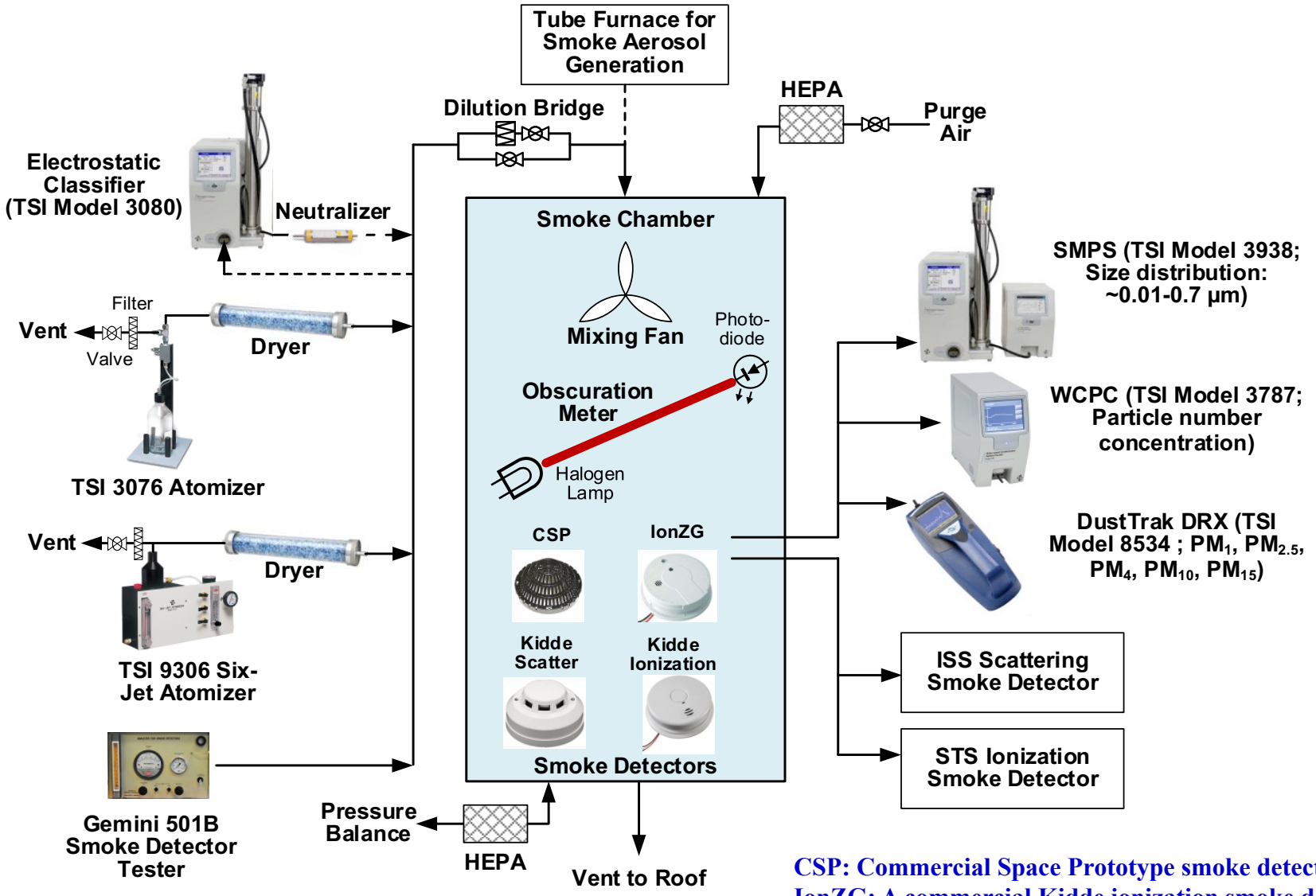
**PSL: Polystyrene latex sphere**
**DOS: Dioctyl sebacate**

# Smoke Aerosols



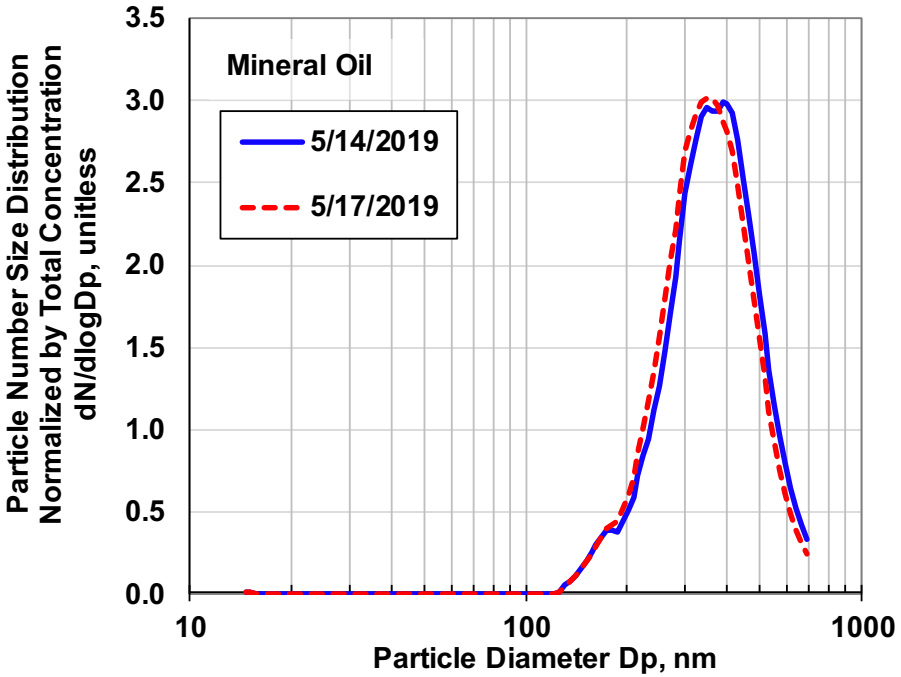

PMMA: Poly(methyl methacrylate)

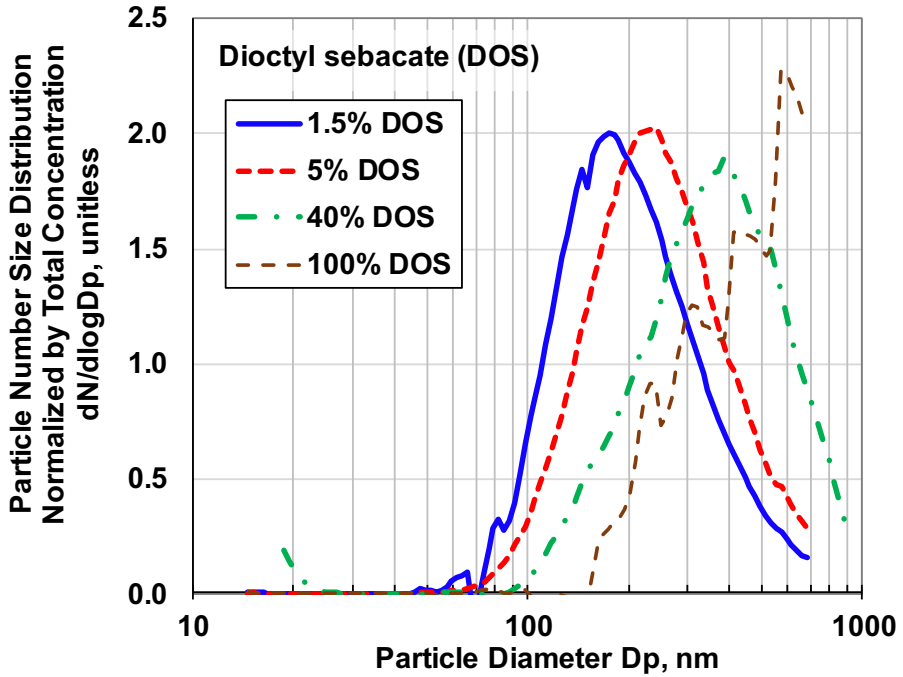
# Experimental Setup




CSP: Commercial Space Prototype smoke detector
IonZG: A commercial Kidde ionization smoke detector
ISS: International Space Station
STS: Space Transport System

# Reference Aerosol Size Distributions

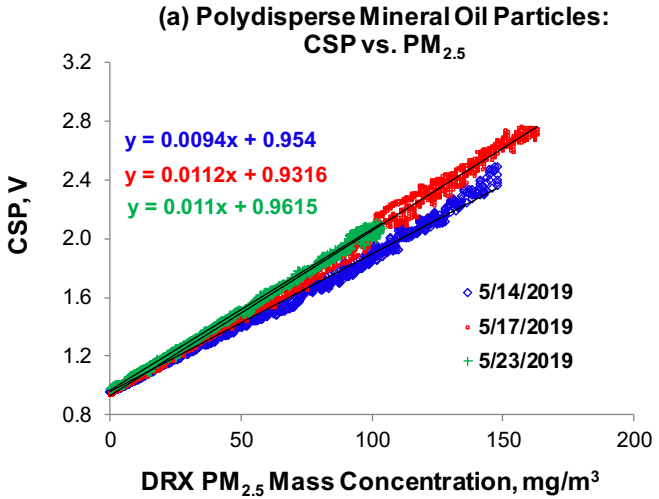


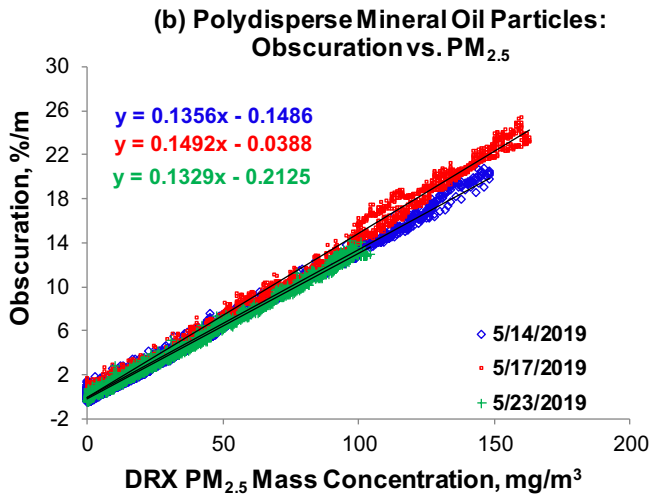



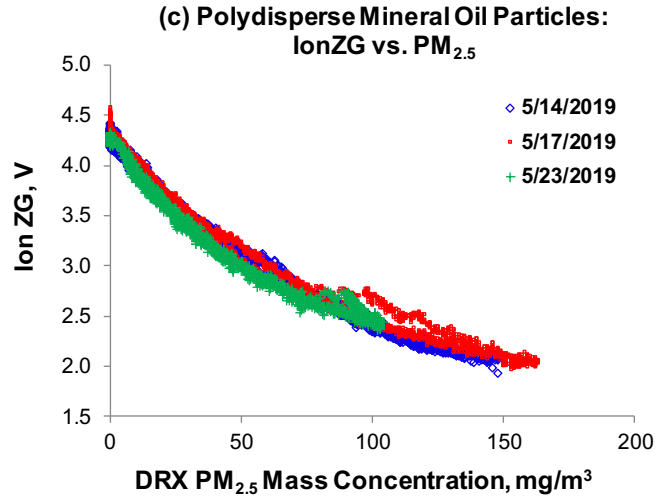

Mineral oil particles generated by the smoke tester on two separate days had similar size distributions.

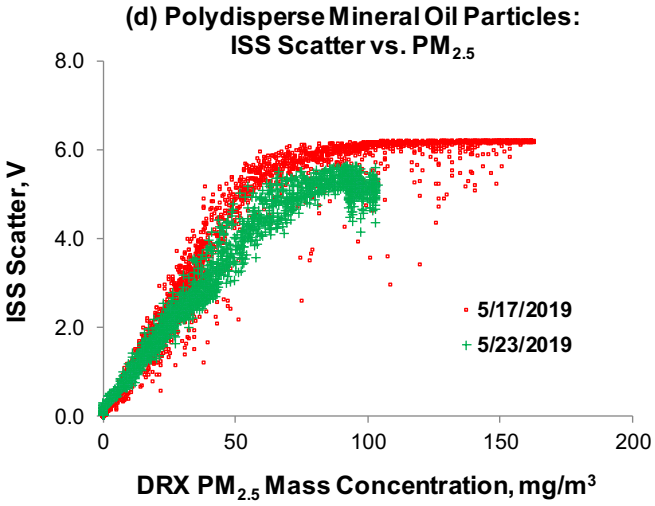
Atomizing DOS solutions by the TSI 3076 atomizer allowed adjusting particle size distribution.

# Smoke Detector Responses to Mineral Oil Particles



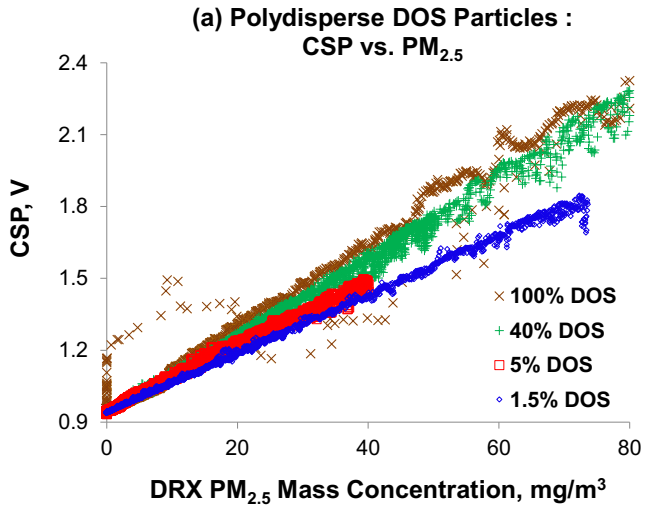



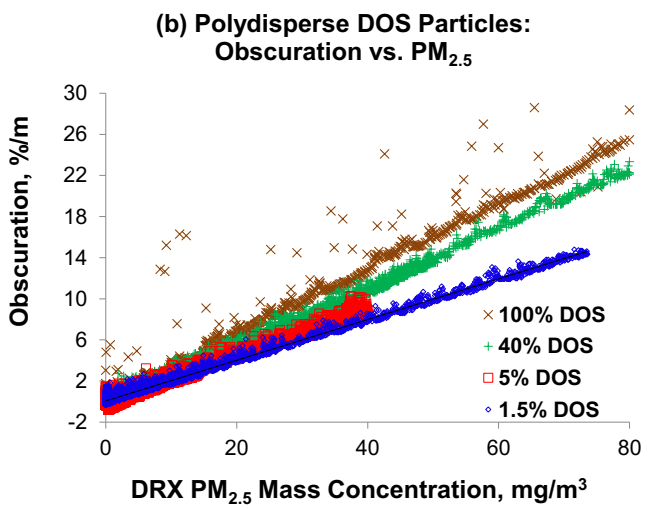



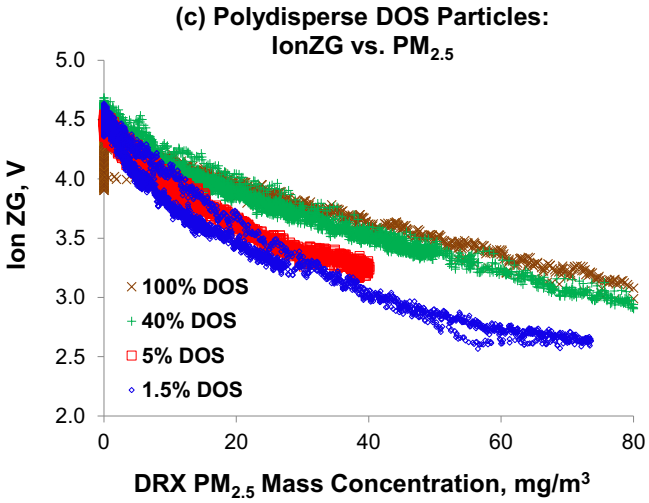




Scattering detectors (CSP, obscuration meter, and ISS scatter detector) signals increased with DRX concentration (before saturation). Ionization detector (IonZG) signal decreased with DRX concentration. Responses were repeatable on three test days.

# Smoke Detector Responses to DOS Particles

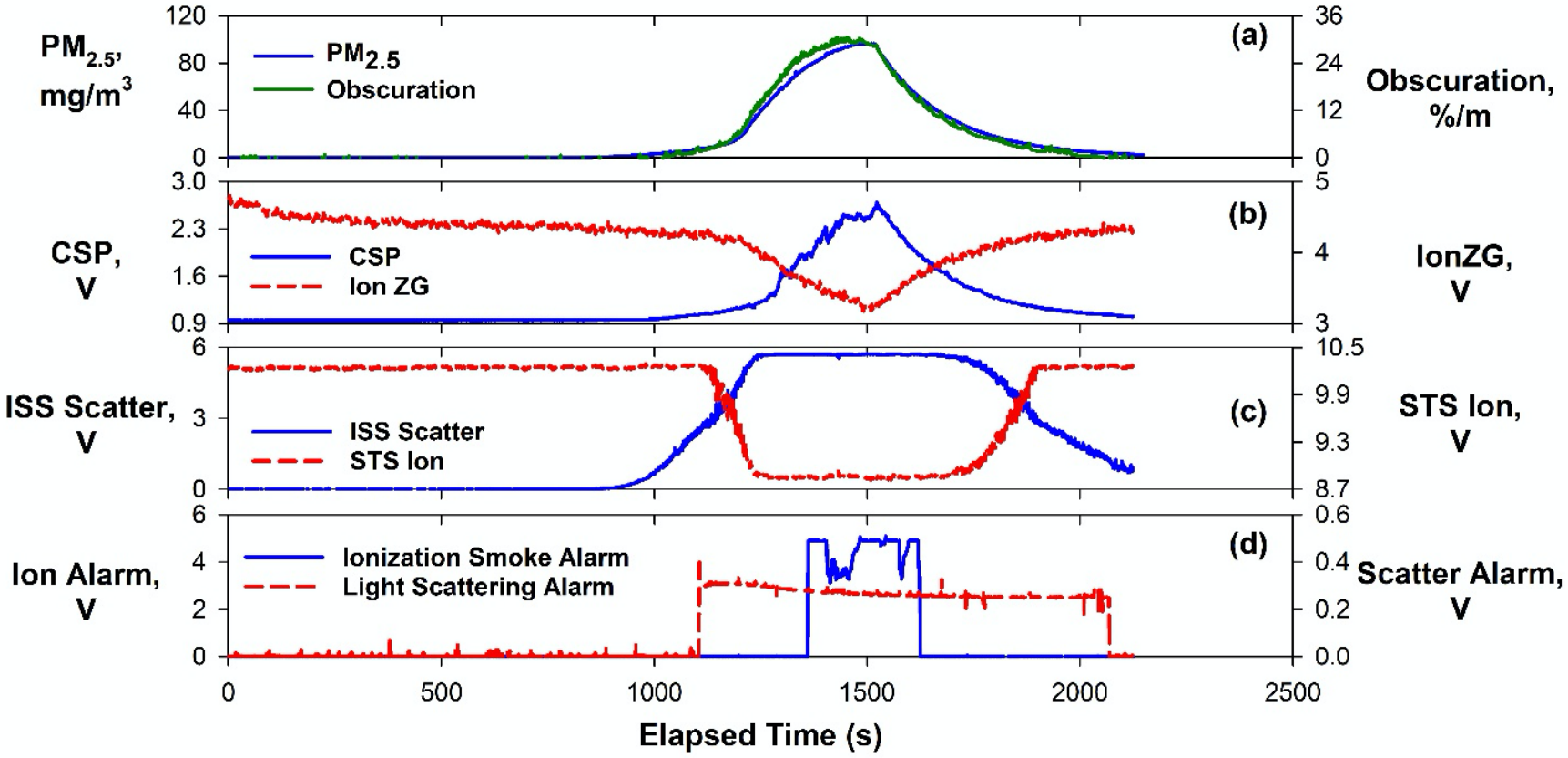



The smoke detector vs. DRX linear regression slope increased slightly with particle size for CSP and obscuration meter. The IonZG is more sensitive to smaller particles.

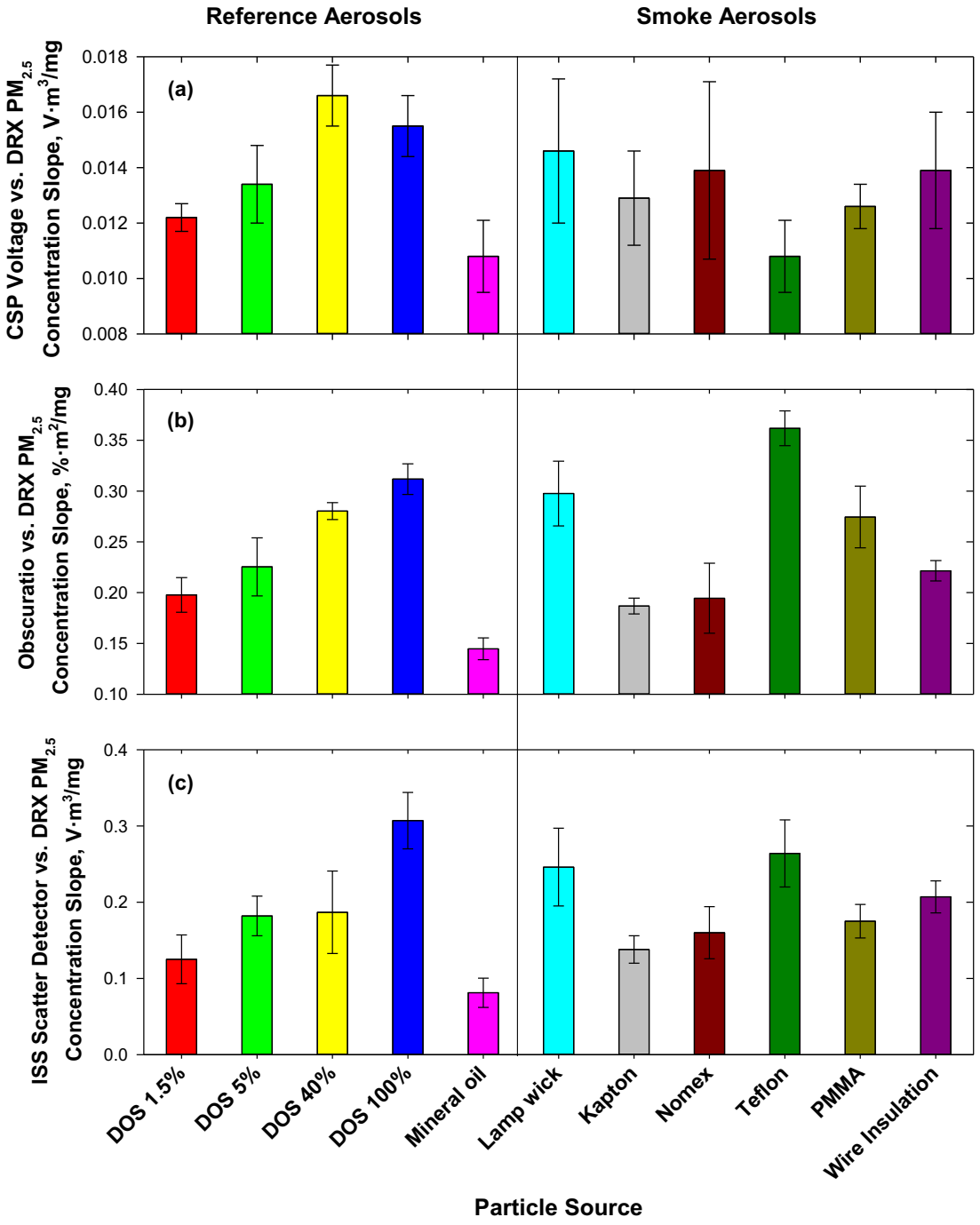
# Smoke Evolution




Example time series of a lamp wick test. One gram of lamp wick was added to the tube furnace heated to 200 °C. All instruments responded to the smoke concentration changes. The fuel boat was taken out at ~1500 s and the smoke chamber was purged slowly starting from ~1560 s.

# Smoke Detector vs. DRX Linear Regression Slopes

- Mineral oil particles had the lowest slopes among all tests;
- DOS particles from the 4 solution concentrations covered the slope range for most tested smoke aerosols;
- No single reference aerosol predicted all detector responses to smoke aerosols within ±10% error.




**Error bars represents the linear regression slope uncertainty (standard deviation).**

# Regression Slope Ratios of Smoke over Reference Aerosols (Green indicates differences within ±10%)

| (a) CSP vs. DRX | Lamp Wick | Kapton | Nomex | Teflon | PMMA | Wire Insulation |
|---|---|---|---|---|---|---|
| DOS 1.5% | 1.20 | 1.06 | 1.14 | 0.89 | 1.03 | 1.14 |
| DOS 5% | 1.09 | 0.96 | 1.04 | 0.81 | 0.94 | 1.04 |
| DOS 40% | 0.88 | 0.78 | 0.84 | 0.65 | 0.76 | 0.84 |
| DOS 100% | 0.94 | 0.83 | 0.90 | 0.70 | 0.81 | 0.90 |
| Mineral Oil | 1.35 | 1.19 | 1.29 | 1.00 | 1.17 | 1.29 |
| | | | | | | |
| (b) Obscuration vs. DRX | Lamp Wick | Kapton | Nomex | Teflon | PMMA | Wire Insulation |
| DOS 1.5% | 1.51 | 0.94 | 0.98 | 1.83 | 1.39 | 1.12 |
| DOS 5% | 1.32 | 0.83 | 0.86 | 1.61 | 1.22 | 0.98 |
| DOS 40% | 1.06 | 0.67 | 0.69 | 1.29 | 0.98 | 0.79 |
| DOS 100% | 0.95 | 0.60 | 0.62 | 1.16 | 0.88 | 0.71 |
| Mineral Oil | 2.06 | 1.29 | 1.34 | 2.50 | 1.90 | 1.53 |
| | | | | | | |
| (c) ISS Scatter vs. DRX | Lamp Wick | Kapton | Nomex | Teflon | PMMA | Wire Insulation |
| DOS 1.5% | 1.97 | 1.10 | 1.28 | 2.11 | 1.40 | 1.66 |
| DOS 5% | 1.35 | 0.76 | 0.88 | 1.45 | 0.96 | 1.14 |
| DOS 40% | 1.32 | 0.74 | 0.86 | 1.41 | 0.94 | 1.11 |
| DOS 100% | 0.80 | 0.45 | 0.52 | 0.86 | 0.57 | 0.67 |
| Mineral Oil | 3.03 | 1.70 | 1.97 | 3.26 | 2.16 | 2.55 |

# Summary

- Mineral oil particles had reproducible size distributions, but underestimated smoke aerosol responses.
- Different DOS particle sizes covered the slope range for most tested smoke aerosols.
- No single reference aerosol predicted all detector responses to smoke aerosols within ±10% error.
- Conversion factors can be developed to predict smoke aerosol responses by reference aerosols

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**Reference:**


Wang et al. (2020). "Spacecraft Smoke Detector Characterization with Reference and Smoke Aerosols." 50th International Conference on Environmental Systems, July 12-16, 2020. https://ttu-ir.tdl.org/handle/2346/86366