# False Alarm Smoke Detection and Smoke Generators

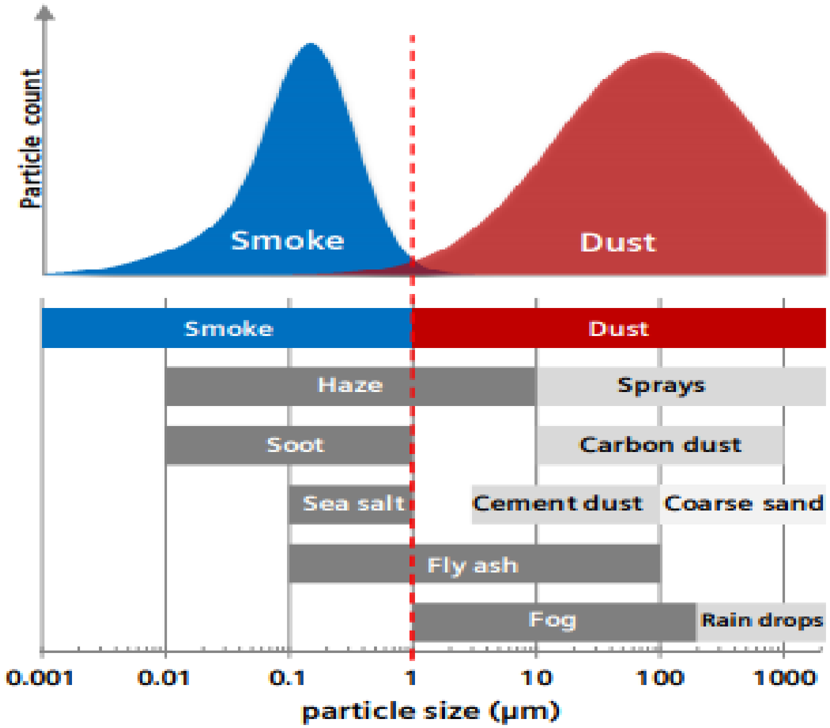
Presented to: International Aircraft Systems Fire Protection Working Group

By: Matthew Karp

Date: November 1, 2017

# Particles Sizing

- False alarm resistant smoke detectors can use size discrimination as a means of rejecting nuisances
  - Smoke is typically less than 1 µm
  - Dust is typically greater than 1 µm




Particle size by substance [1]

# Smoke Particle Size

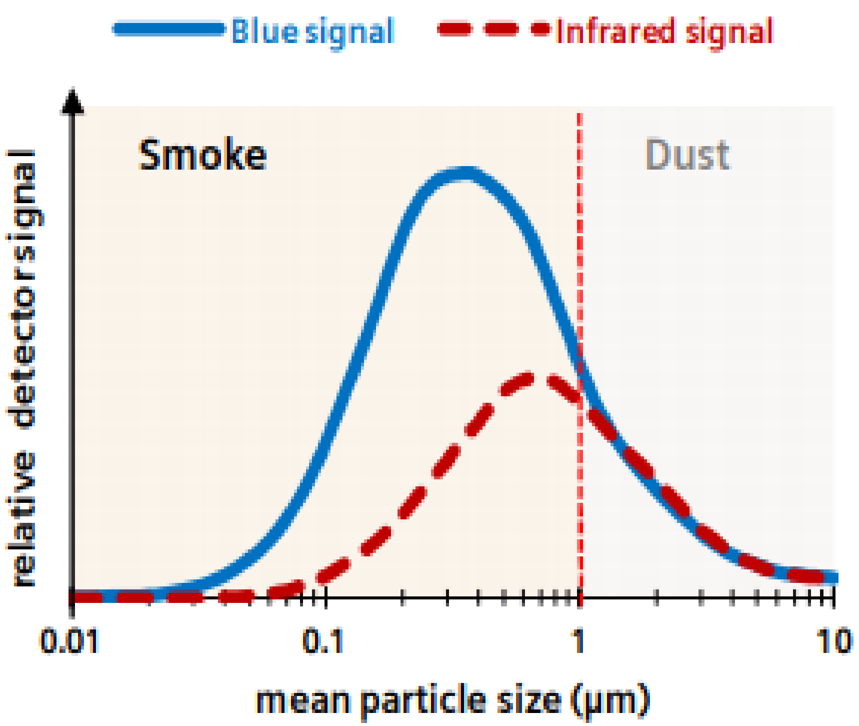
- Material smoke diameters vary with researcher and particle sizing instrument
- Research shows average particle diameter ranging from 46nm to 800nm

| Material | Smoke Production and Properties $D_{32}$ (optical measurements), µm [2] | Online determination of the refractive index of test fires $D_{pg}$ (SMPS), µm [3] | Smoke Characterization Project $D_s$ (WPS), µm [4] | U. S. Environmental Protection Agency (ELPI and SMPS data), µm [5] |
|---|---|---|---|---|
| Douglas Fir (flaming) | 0.47-0.52 | | 0.040-0.073 | 0.054-0.077 |
| Douglas Fir (smoldering) | 0.75-0.8 | | 0.136-0.141 | |
| Flaming Wood | | 0.16 | | 0.046-0.077 |
| Smoldering Wood | | 0.19 | | |
| Smoldering Cotton | | 0.17 | 0.086-0.105 | |
| Heptane Flaming | | 0.16 | 0.195-0.199 | |
| PVC Smoldering | 0.8-1.1 | 0.135-0.138 | | |

# Blue and IR Signal

- **Blue and IR light scattering are utilized in some smoke detectors**
- **Why use blue and infrared light scattering?**
  - To discriminate between smoke and other airborne particles
  - Blue scattered signal is better at detecting particles less than 1 µm than IR scattered signal
  - Smoke particles are typically less than 1 µm

- **Blue Light 450-490 nm**
- **IR Light 700-1000 nm**




Blue and Infrared signal [1]

# Light Scattering

- Light scattering by sub-micron particles is governed by the Mie scattering theory
- The general solution is found through the application of Maxwell's equation
- A simplified approximation of Mie scattering is given by van de Hulst [6]

- Where Q is the efficiency $Q = 2 - \frac{4}{p}\sin p + \frac{4}{p^2}(1 - \cos p),$

$$p = 4\pi a(n - 1)/\lambda$$

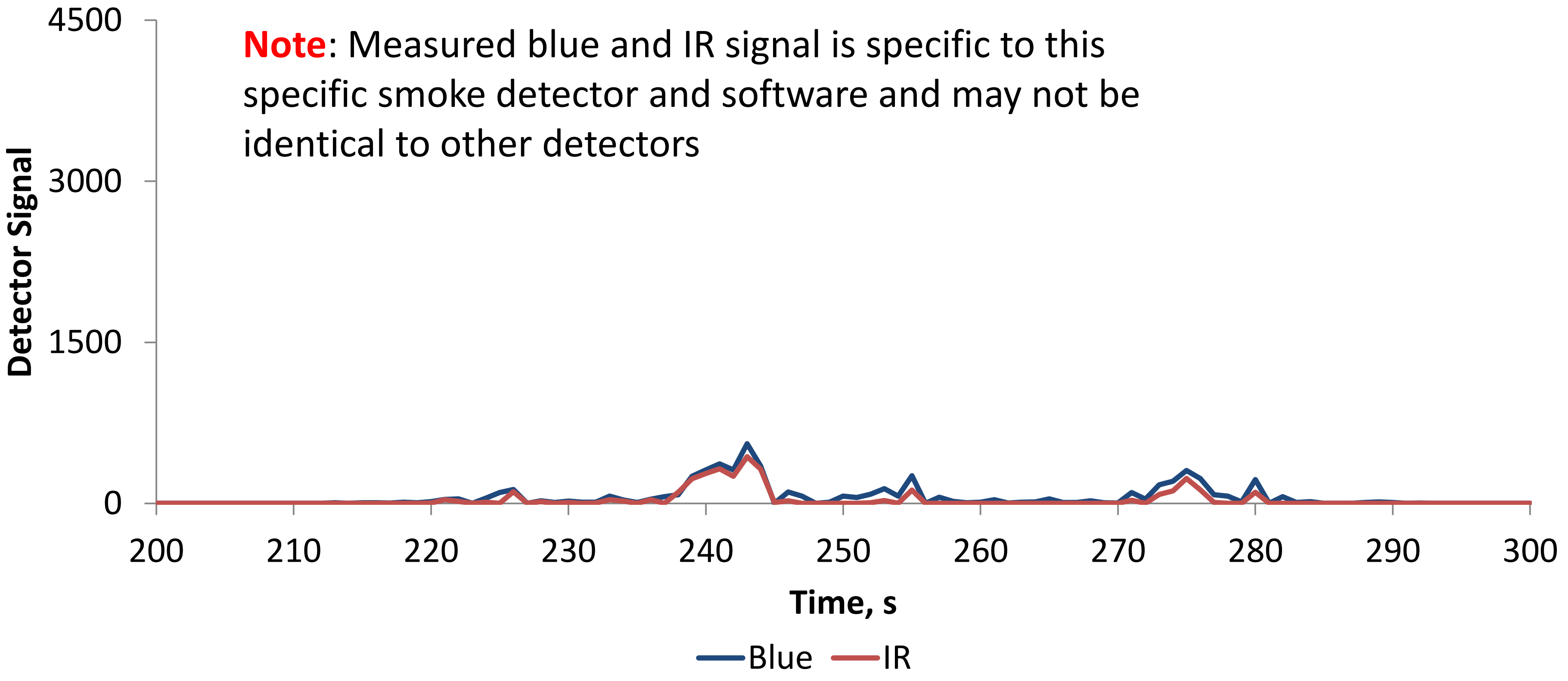
- This shows that the scattering intensity is a function of
  - *n*, Refractive index of the particle
  - a, radius of the particle
  - λ, Wavelength of the incident light

# Test Apparatus

- **Testing is conducted with**
  - Kidde smoke detector
  - Optical density meter
  - Various combustibles (paper, cardboard, incense)
  - Smoke detection nuisances (aerosol can smoke, talc powder, steam)
  - Concept Aviator 440 UL Variant (Ultra Low)
    - Smoke Fluid 135
    - Nitrogen, carbon dioxide or helium as propellant

# Steam Smoke Detector

- Tested by placing boiling water in an open electric water kettle under the detector
- Blue signal is mostly greater than IR signal
  - Indicates the average particle size is mostly less than 1 µm
- Weak signal detected and detector is not alarmed



# Can Smoke Detector Tester


**SECTION 3: Composition/information on ingredients**

**3.1. Substance**

Not applicable.

**3.2. Mixture**

| Name | Product identifier | % | GHS-US classification |
|---|---|---|---|
| Isobutane | (CAS No) 75-28-5 | 40 - 70 | Flam. Gas 1<br>Liquefied gas |
| Propane | (CAS No) 74-98-6 | 15 - 40 | Flam. Gas 1<br>Liquefied gas |
| Siloxane | Proprietary | 1 - 5 | Skin Irrit. 2<br>Eye Irrit. 2A<br>STOT SE 3 |
| Butane | (CAS No) 106-97-8 | 0.5 - 1.5 | Flam. Gas 1<br>Liquefied gas |

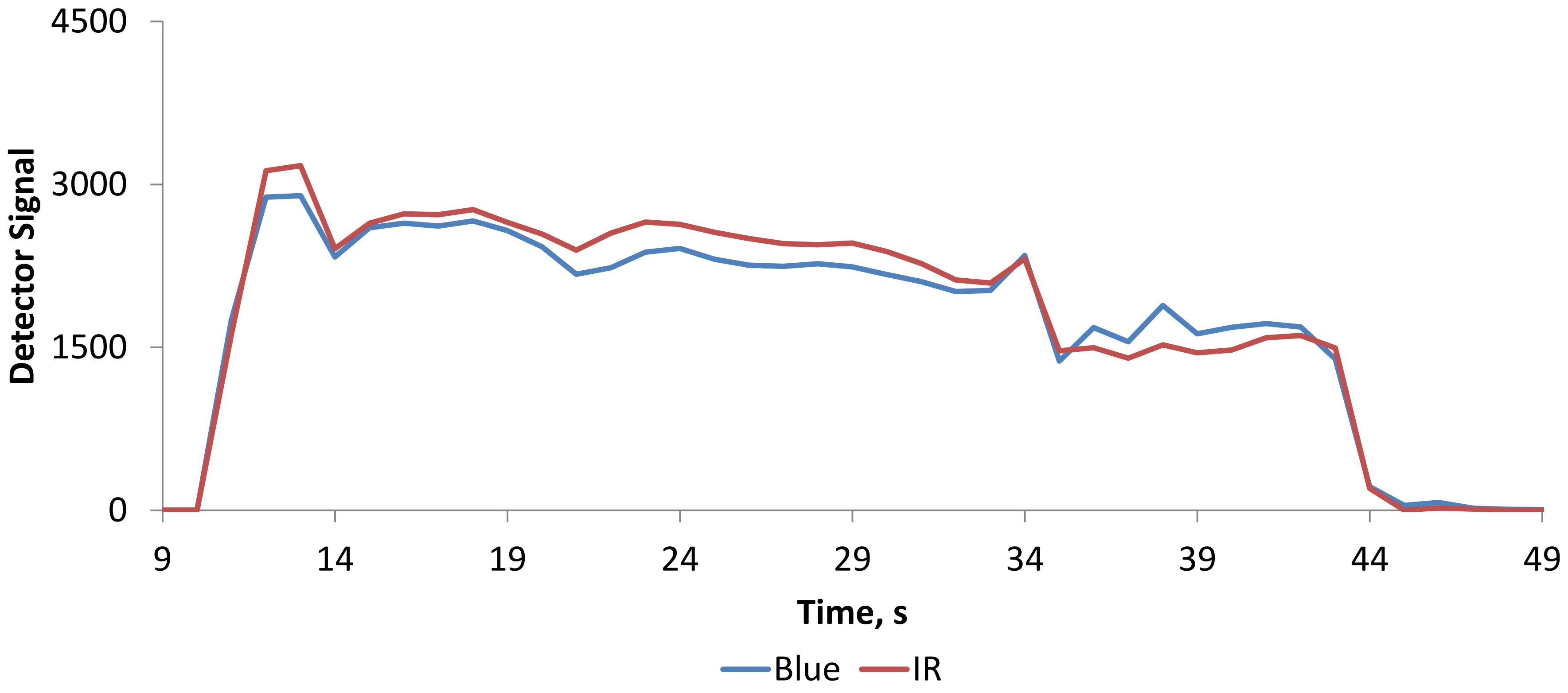
* The specific chemical identity and/or exact percentage (concentration) of composition has been withheld as a trade secret in accordance with paragraph (i) of §1910.1200.



[7]

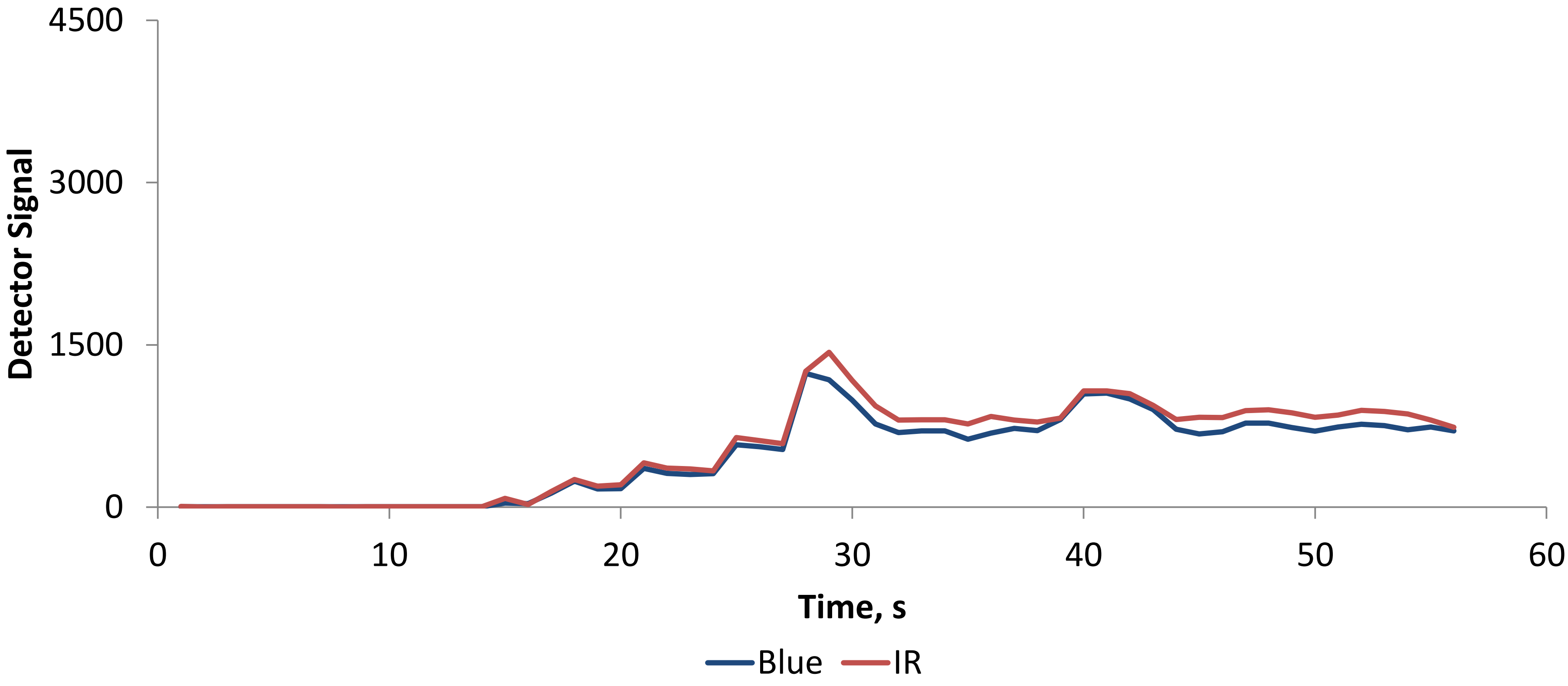
# Can Smoke Detector Tester

- The blue signal is mostly less than the IR signal
  - Indicates the average particle size is mostly greater than 1 µm
- Both the IR and the Blue sensor detect a high amount of particles
- Very strong signal detected and detector is alarmed



# Talc Powder

- Talc powder came from extra strength body powder sprayed onto detector
- The blue signal is mostly less than the IR signal
  - Indicates the average particle size is mostly greater than 1 µm
- Strong signal detected and detector is alarmed



# Incense

- Incense smoke is measured by electrical aerosol analyzer [2]
- $d_{gn}$= 0.072μm
- $\sigma_g$= 1.75

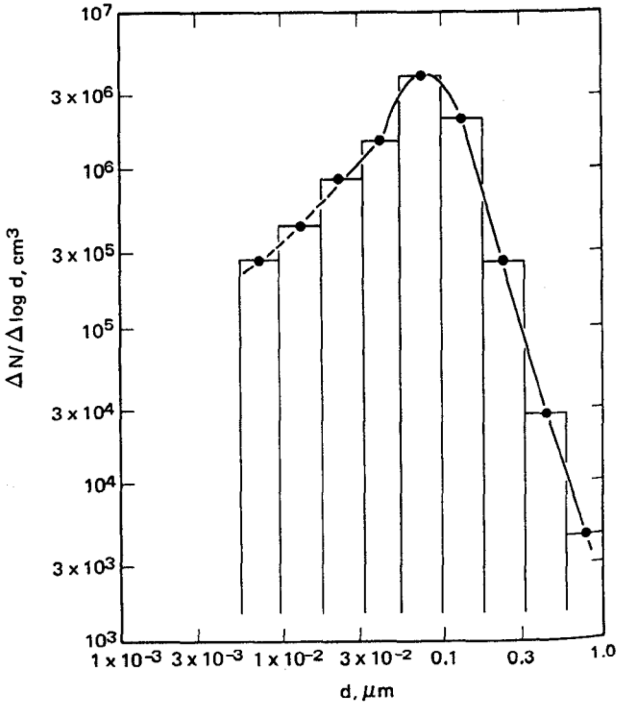
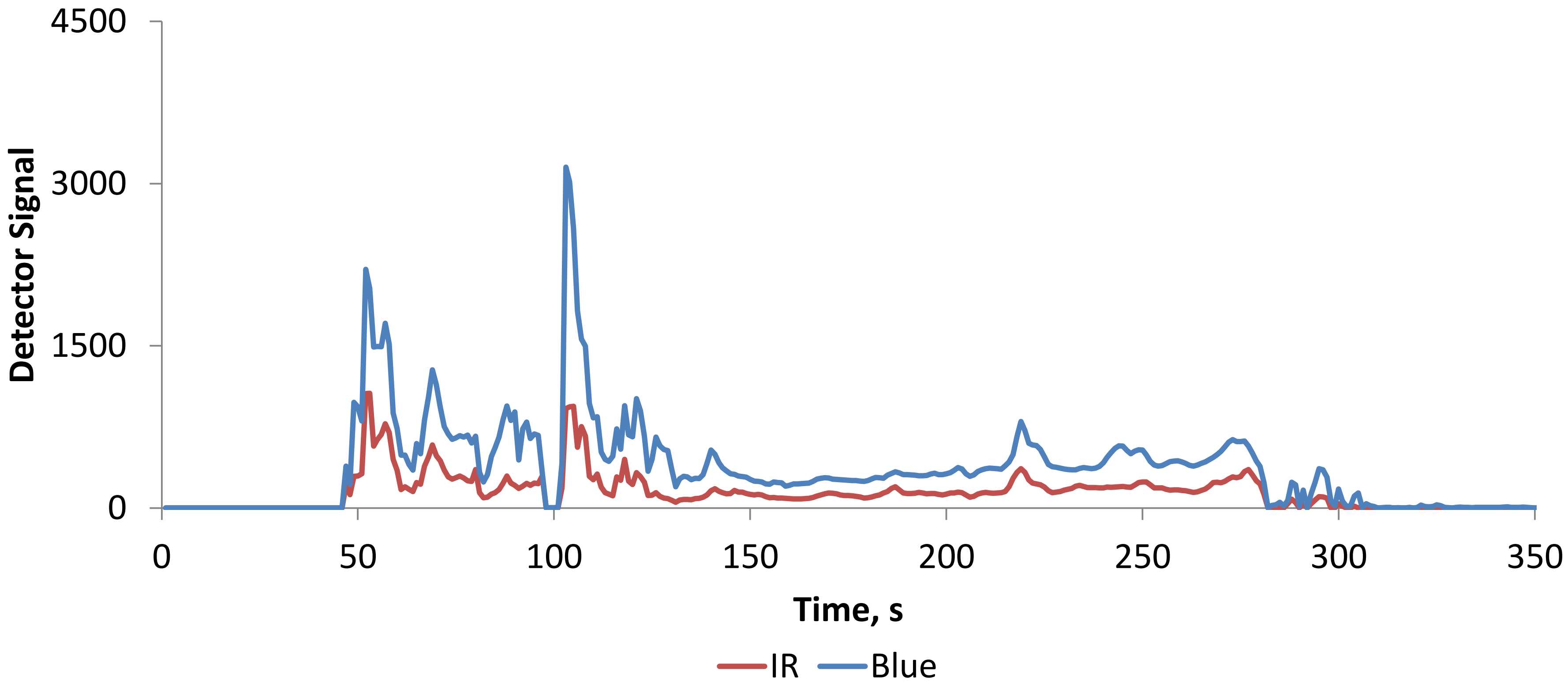



*Fig. 2-15.1. Size distribution of incense smoke as measured by an electrical aerosol analyzer. There is a large uncertainty in the dashed portion of the curve.*

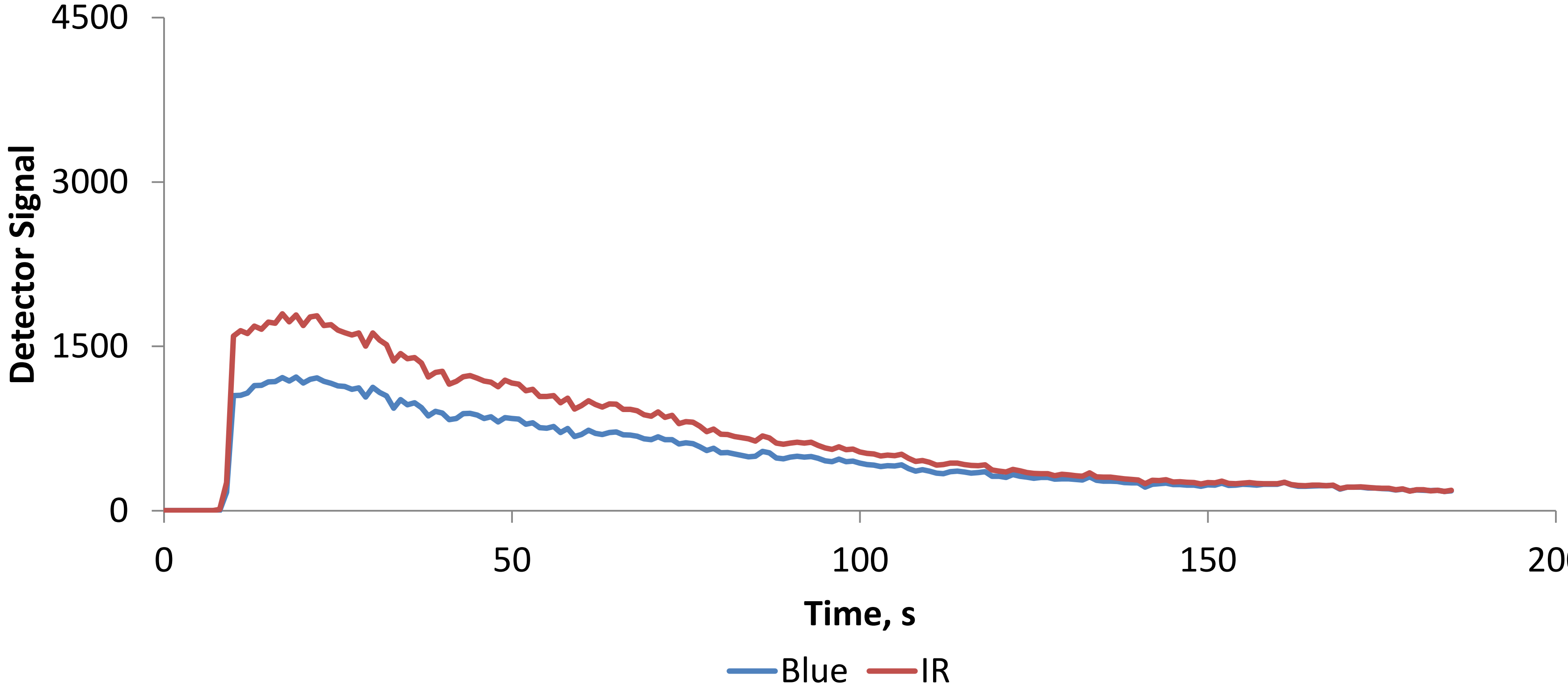
# Incense

- The blue signal is significantly greater than the IR signal
  - Indicates the average particle size is mostly less than 1 µm (measured 0.072µm)
- Very strong signal detected and detector is alarmed



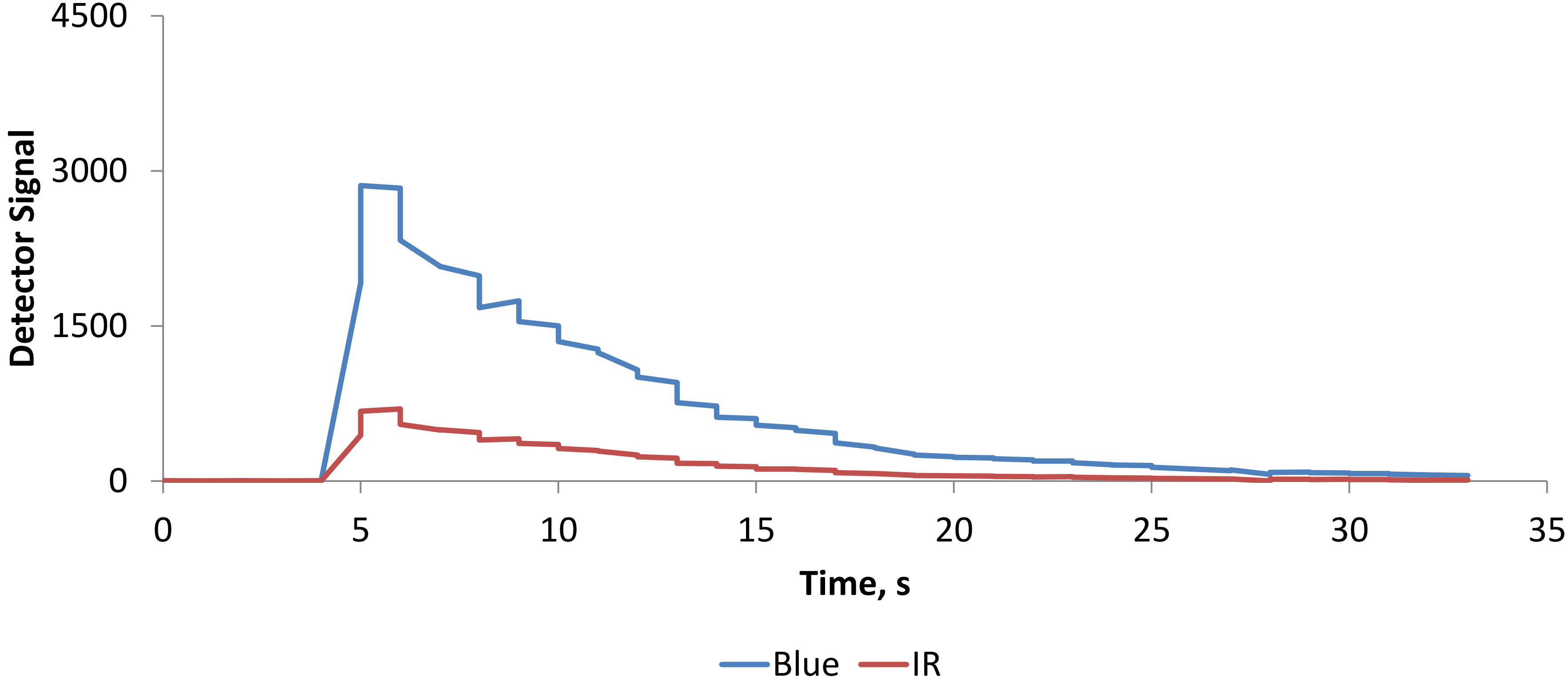
# Rosco Smoke Generator

- The blue signal is significantly less than the IR signal
  - Indicates the average particle size is mostly greater than 1 µm
- Strong signal detected and detector is not alarmed
- The measured average D10 is 2.2 µm.
  - Minimum measurement is 0.5µm due to measurement limitations, therefore actual D10 is likely smaller [8]



# Aviator UL Smoke Generator

- The blue signal is significantly greater than the IR signal and indicates the average particle size is mostly less than 1 µm
- Very strong signal detected and detector is alarmed
- The measured average D10 is 1.5µm.
  - Minimum measurement is 0.5µm due to measurement limitations, therefore actual D10 is likely smaller [8]

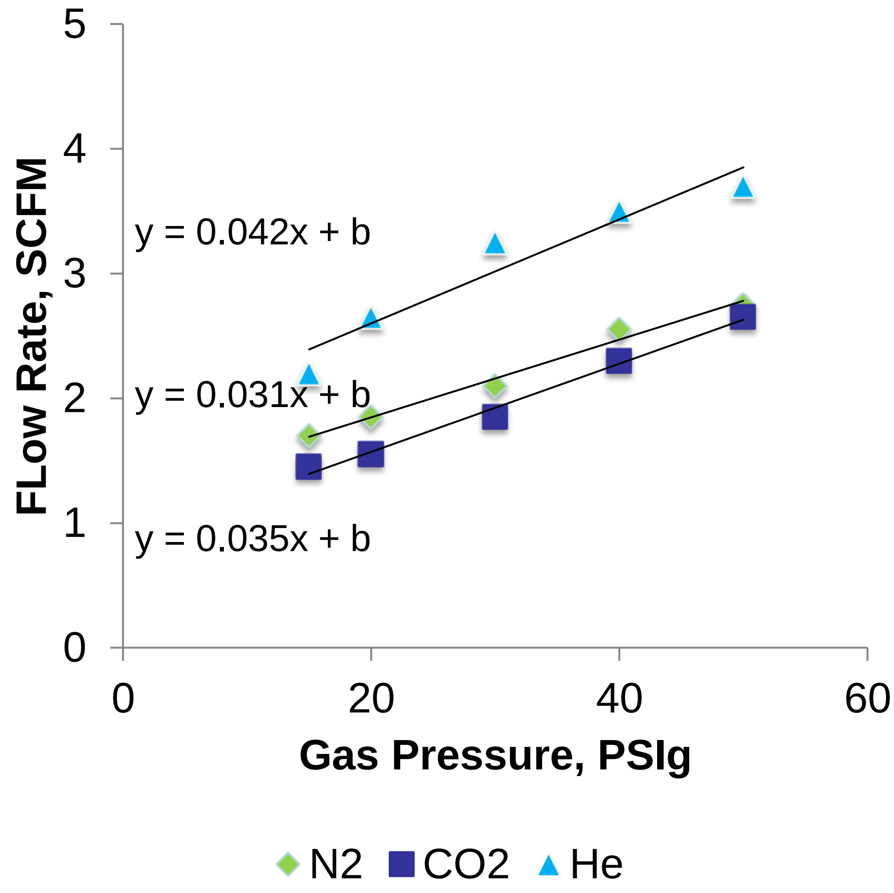


# Variability of Aviator UL

- **Aviator UL has some variability**
  - Fluid, propellant, gas pressure and built in smoke density valve
- **The smoke generator utilizes smoke fluid 135**
- **The Aviator UL can use inert gases as a propellant**
  - Tests were conducted with nitrogen, carbon dioxide and helium
- **Smoke volume can be varied**
  - Adjusting the gas pressure using the regulator valve
  - The recommended pressure range is between 15 and 50psig
- **Smoke density can be varied**
  - Adjusting the precision micrometer valve
  - 0 turns being closed
  - 4 turns being fully opened
  - 8 turns being the maximum recommended range

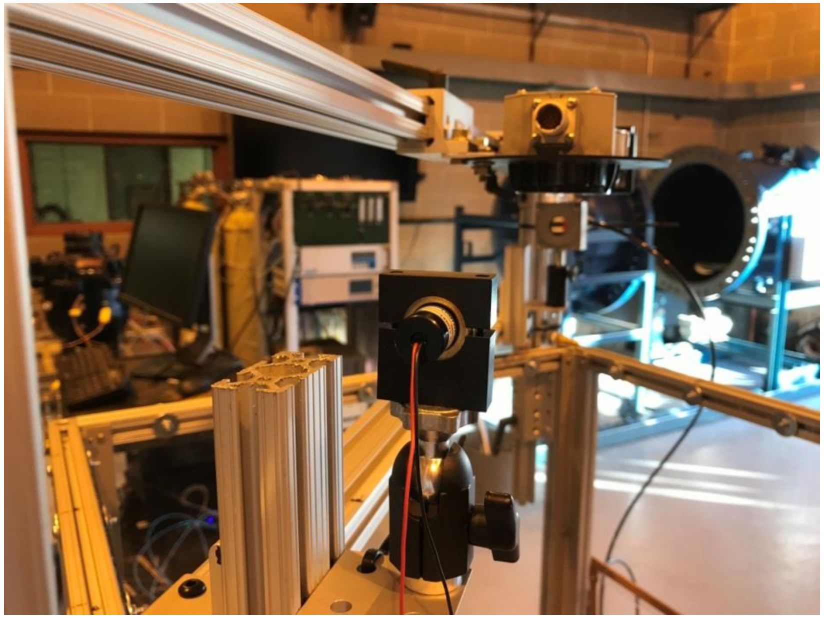
# Variability of Aviator UL

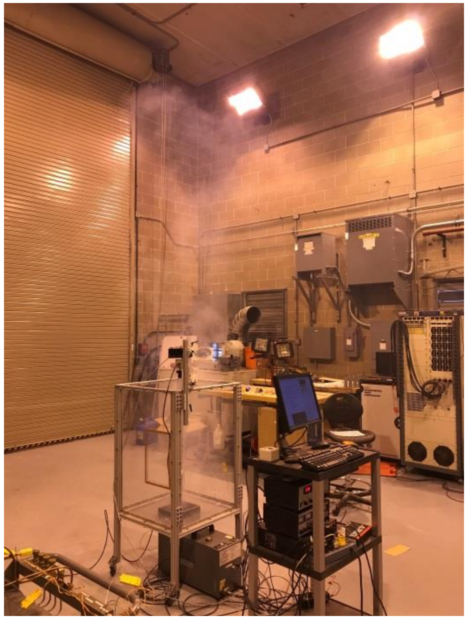
- **The flow rate is dependent on the propellant and the pressure**
  – Helium has the fastest flow rate compared to nitrogen and carbon dioxide
  – Nitrogen has the least variability of flow rate
- **The flow rate is *not* dependent on the smoke density microneedle adjustments.**



# Test Setup

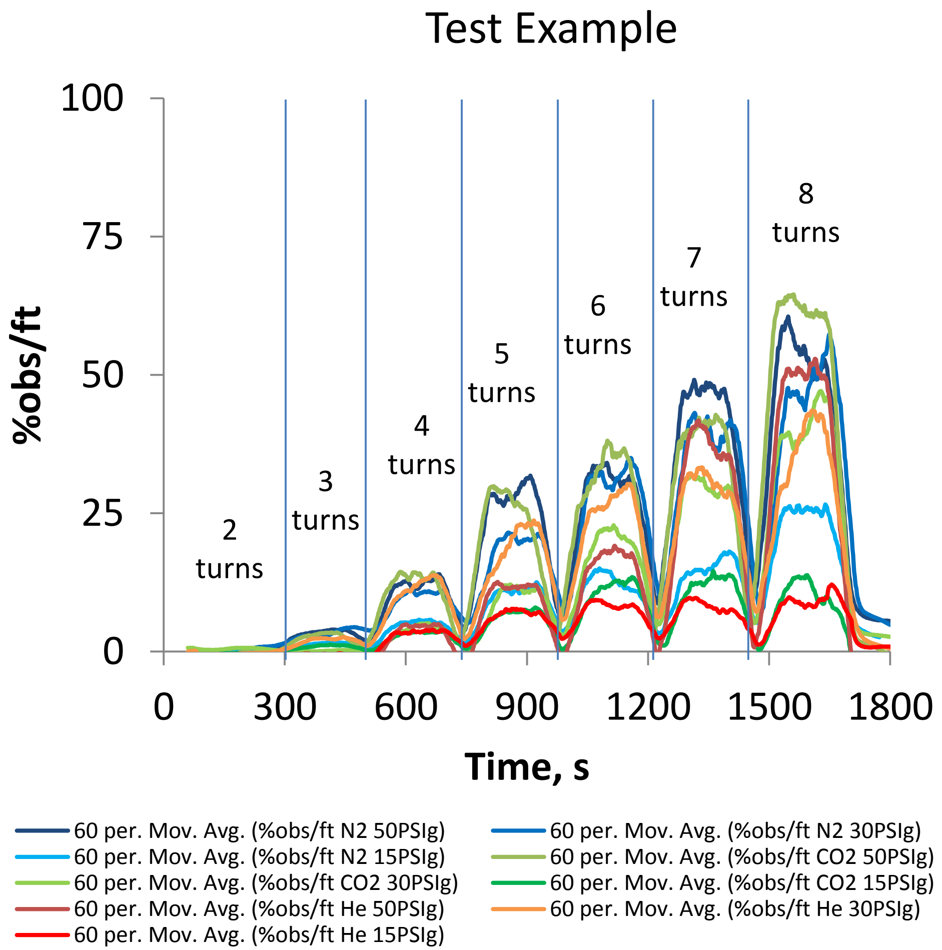
- **Optical density meter**
  - 23” between laser and smoke obscuration detector
- **Smoke detector**
  - 2” between optical density meter and smoke detector
- **Carbon Dioxide, nitrogen and helium were tested at 15psig, 30psig and 50psig**





# Test Procedure

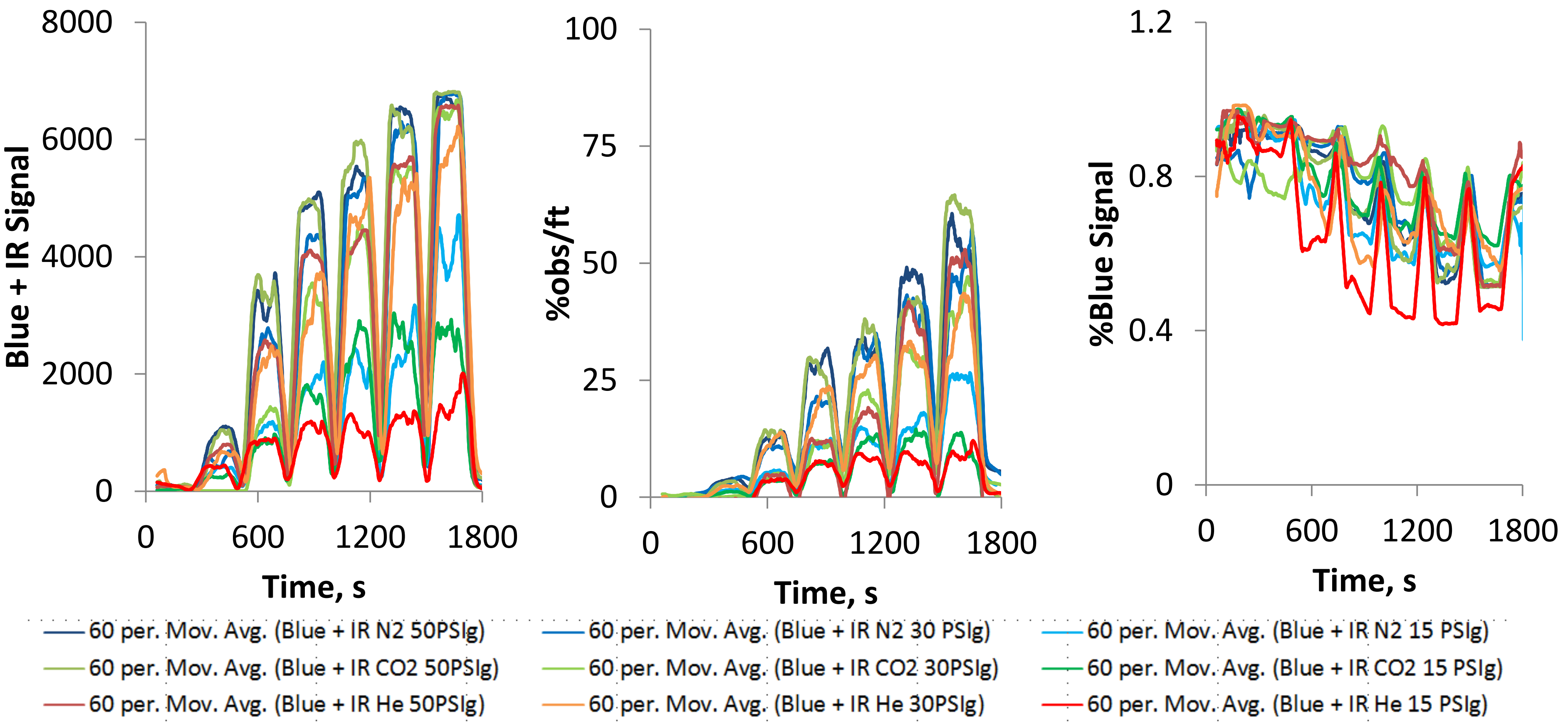
- Test starts with the precision micrometer valve open two turns
- After three minutes the generator is turned off and the valve is open another one full turn
- The generator turned back on after a one minute rest period
- This is repeated until the micrometer valve is open to eight full turns




**Note**: Smoke density can be controlled by adjusting the precision micrometer valve

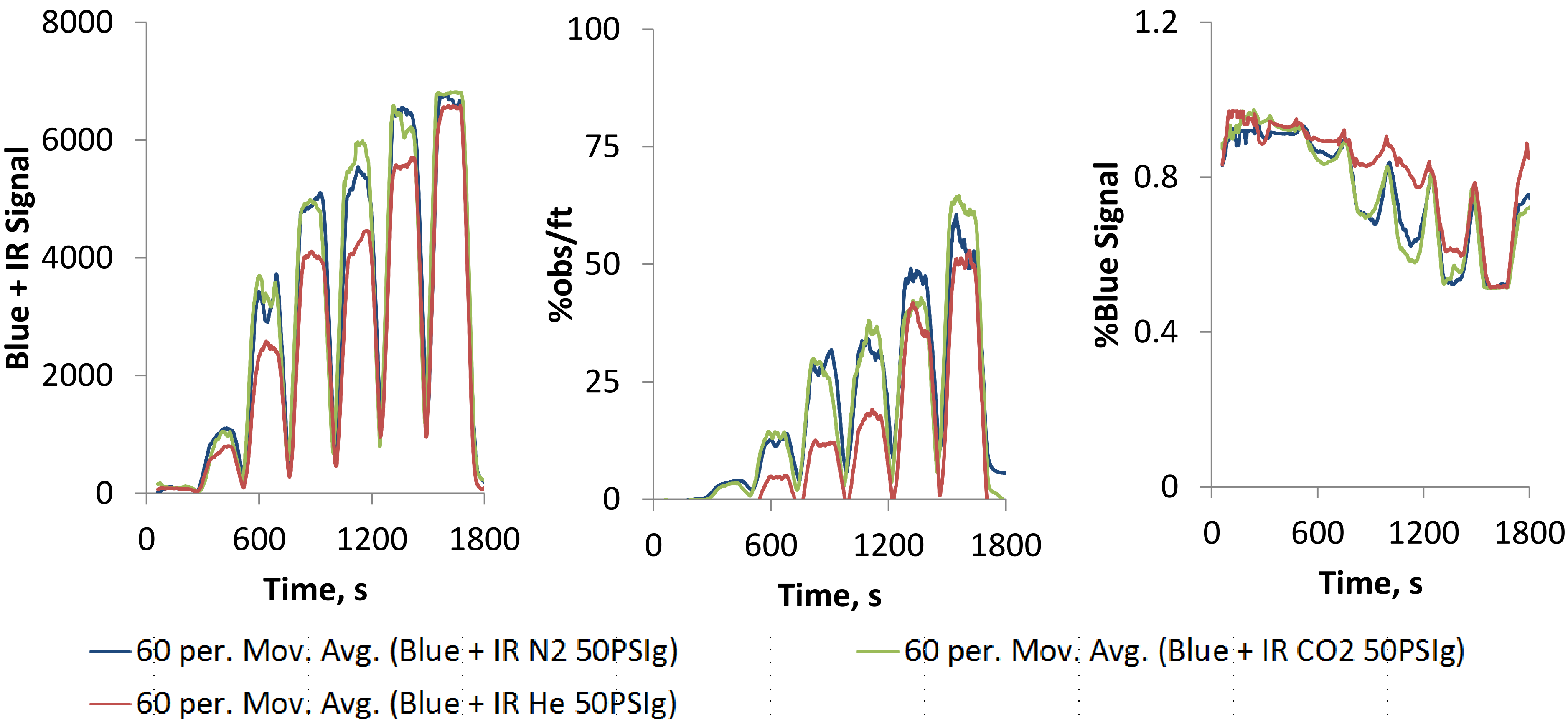
# Obscuration, Blue + IR Signal and %Blue

- The Blue + IR signal is proportional to the percent obscuration per foot
- The %Blue signal is inversely proportional percent obscuration per foot



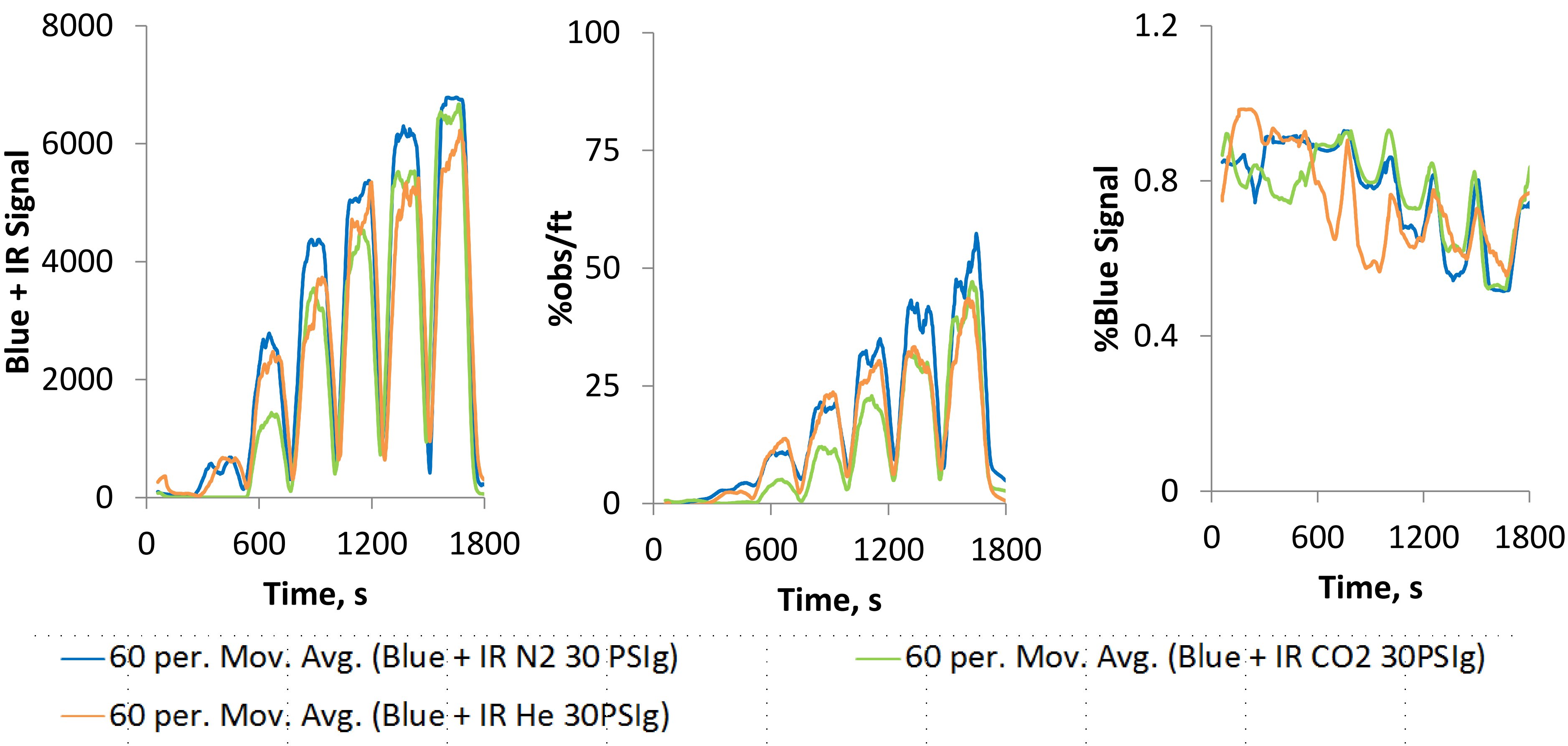
# Obscuration, Blue + IR Signal and %Blue: 50psi

- The Blue + IR signal is proportional to the percent obscuration per foot
- The %Blue signal is inversely proportional percent obscuration per foot
- Note: ~50%obs/ft causes the blue + IR signal to max out around 7000



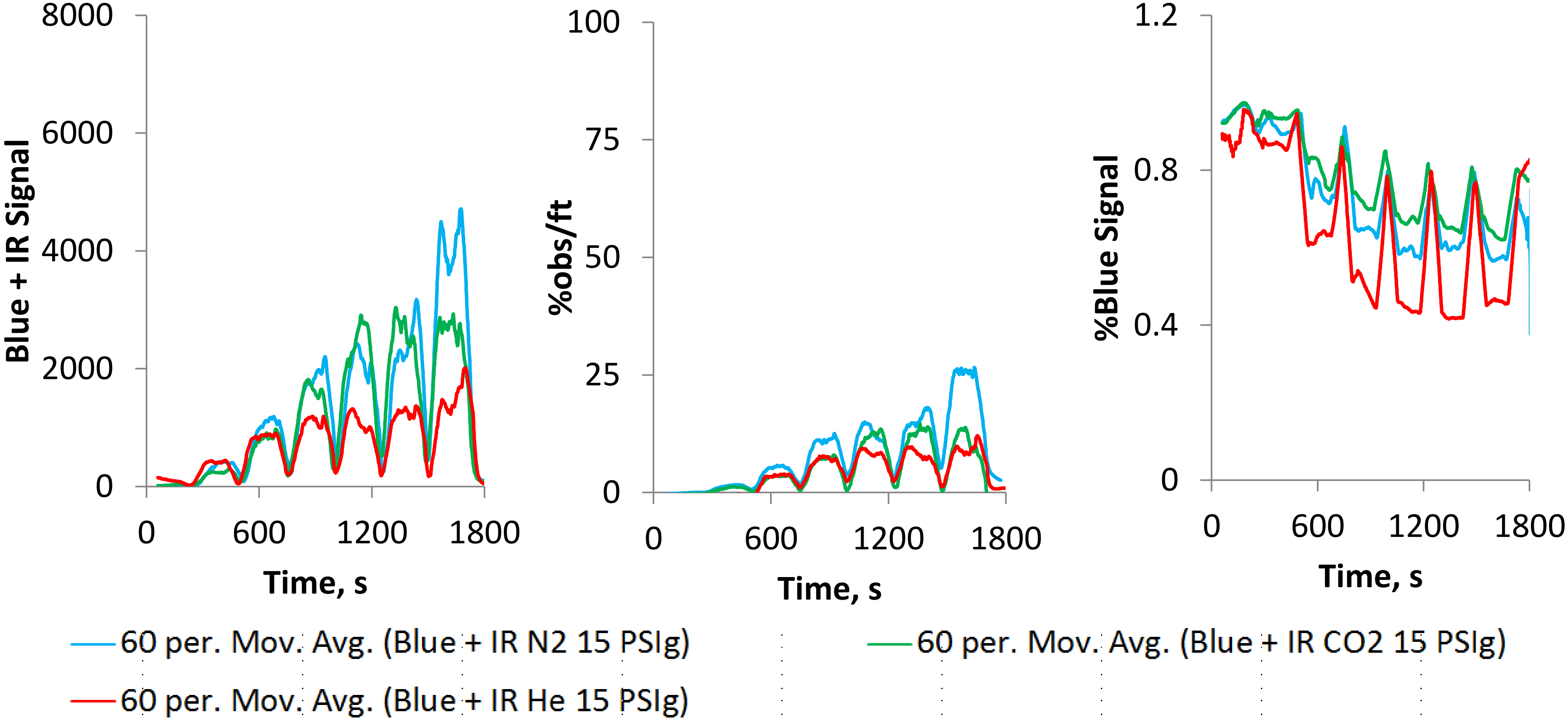
# Obscuration, Blue + IR Signal and %Blue: 30psi

- The Blue + IR signal is proportional to the percent obscuration per foot
- The %Blue signal is inversely proportional percent obscuration per foot
- Note: ~50%obs/ft causes the blue + IR signal to max out around 7000



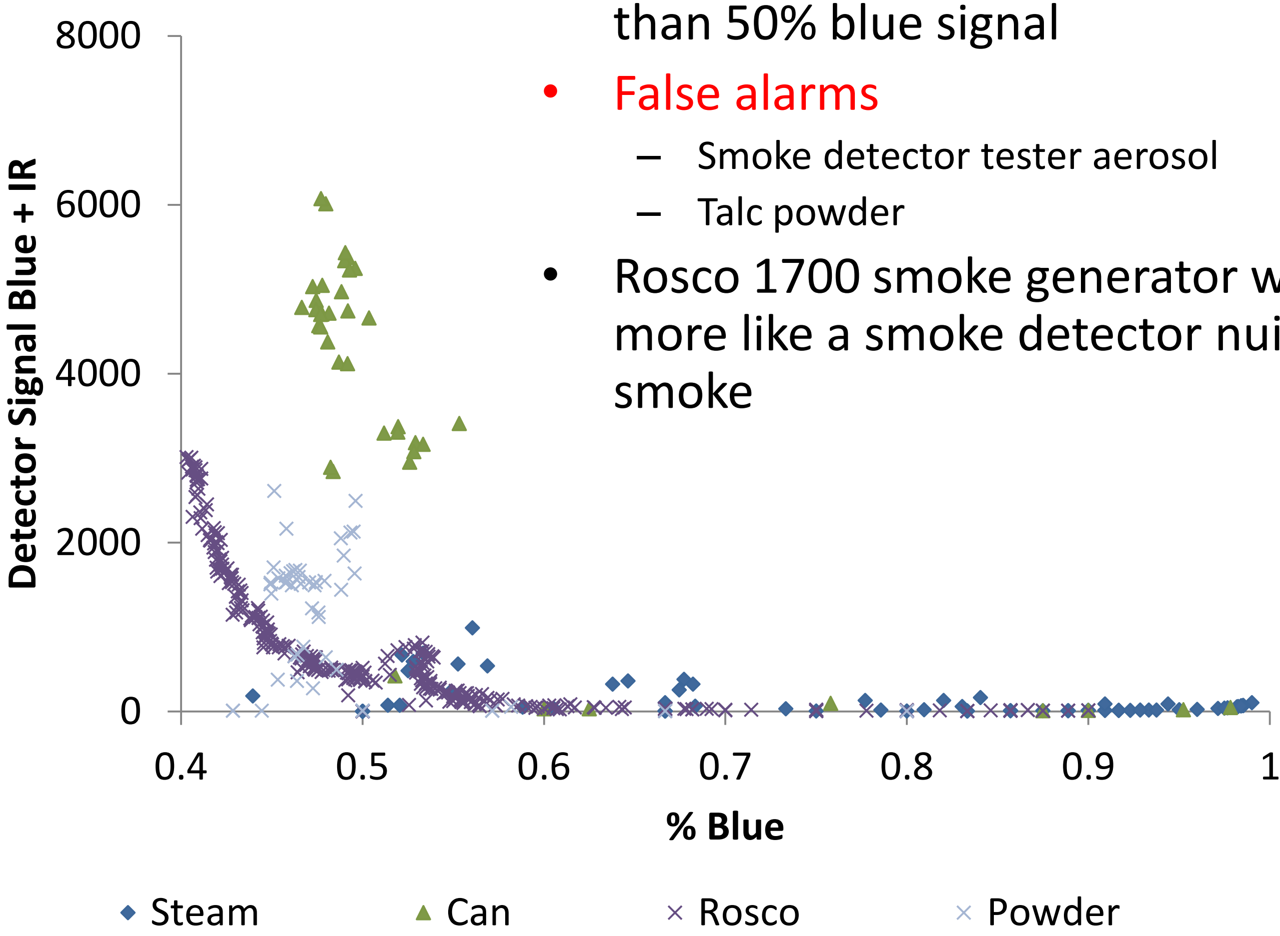
# Obscuration, Blue + IR Signal and %Blue: 15psi

- The Blue + IR signal is proportional to the percent obscuration per foot
- The %Blue signal is inversely proportional percent obscuration per foot



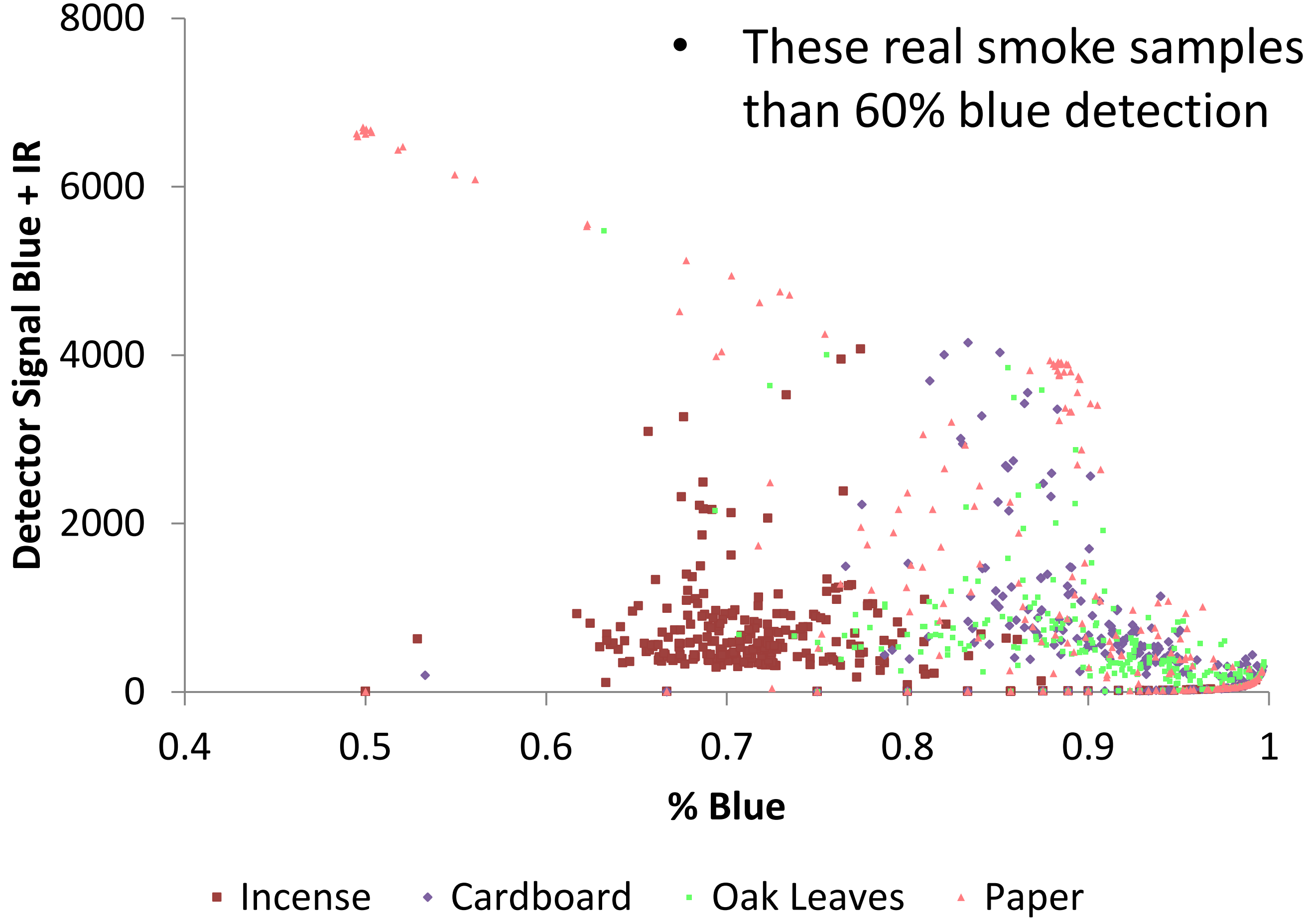
# Smoke Detector Nuisances

- Smoke detector nuisances are mostly low in blue and IR signal detection
- When significant signal is detected, they are mostly less than 50% blue signal
- False alarms
  - Smoke detector tester aerosol
  - Talc powder
- Rosco 1700 smoke generator with water based fluid acts more like a smoke detector nuisance than as actual smoke



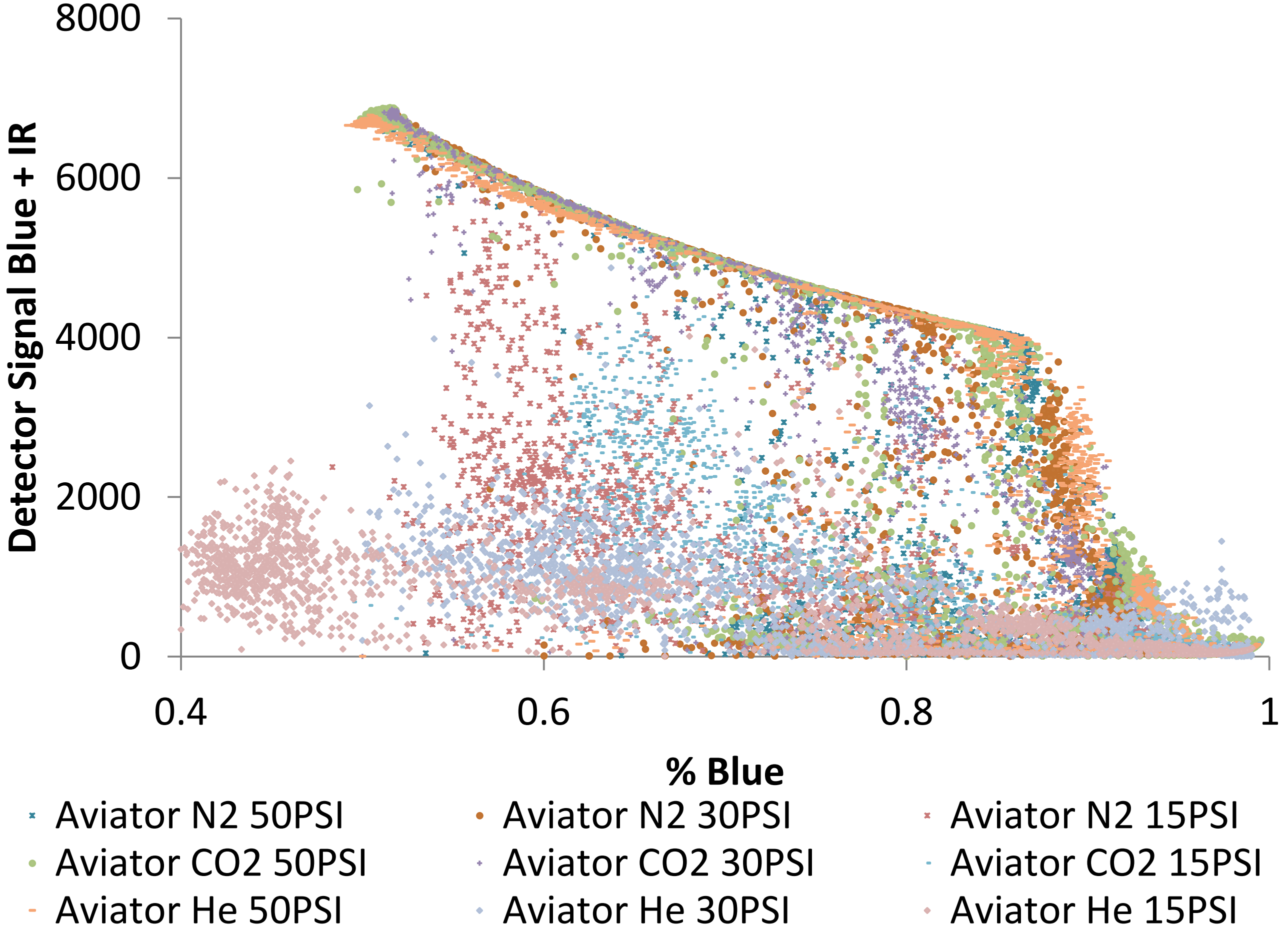
# Real Smoke

- Real smoke is mostly high in blue and IR signal detection
- These real smoke samples have mostly more than 60% blue detection



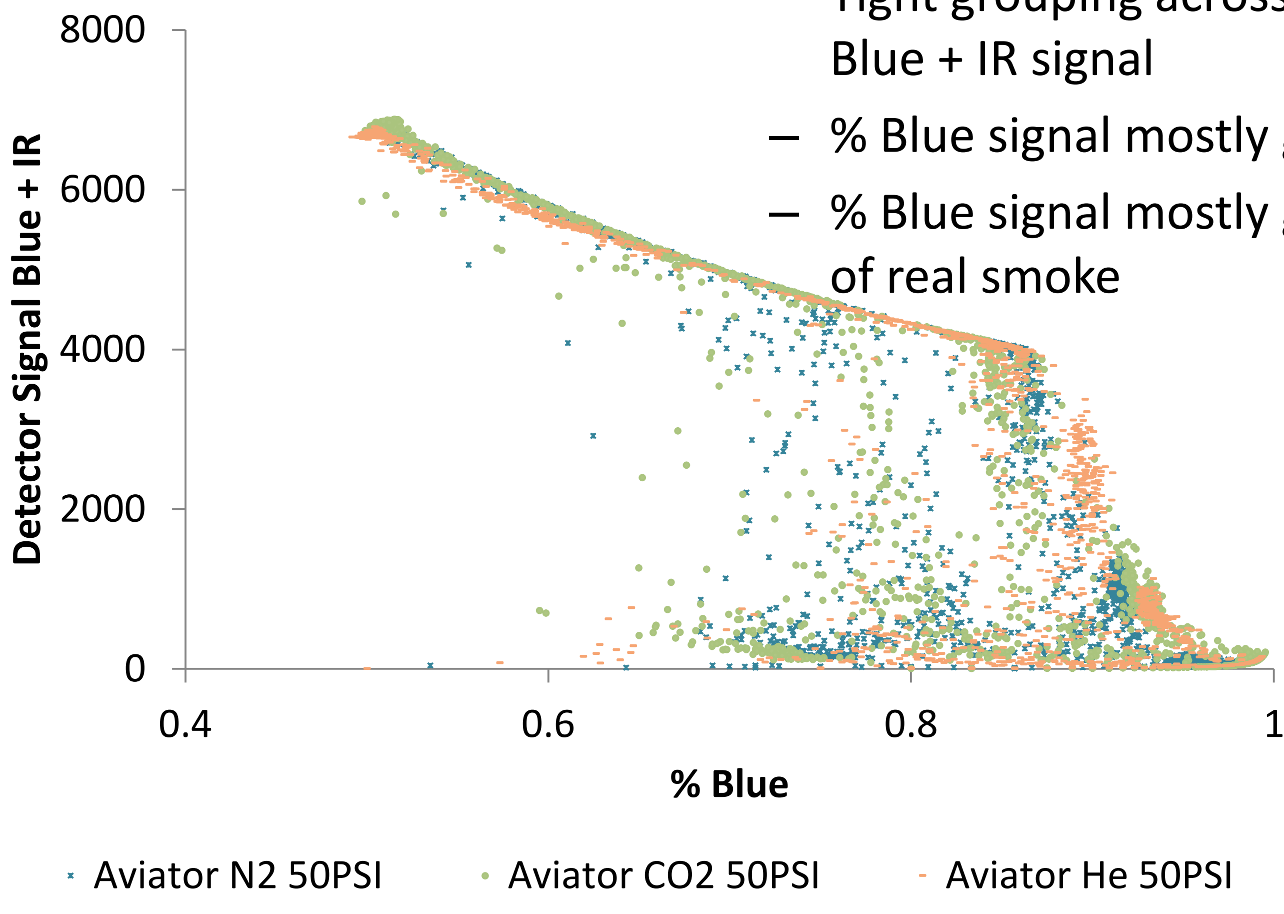
# Aviator UL Variations

- The blue and IR signal varies depending on the gas propellant and the pressure



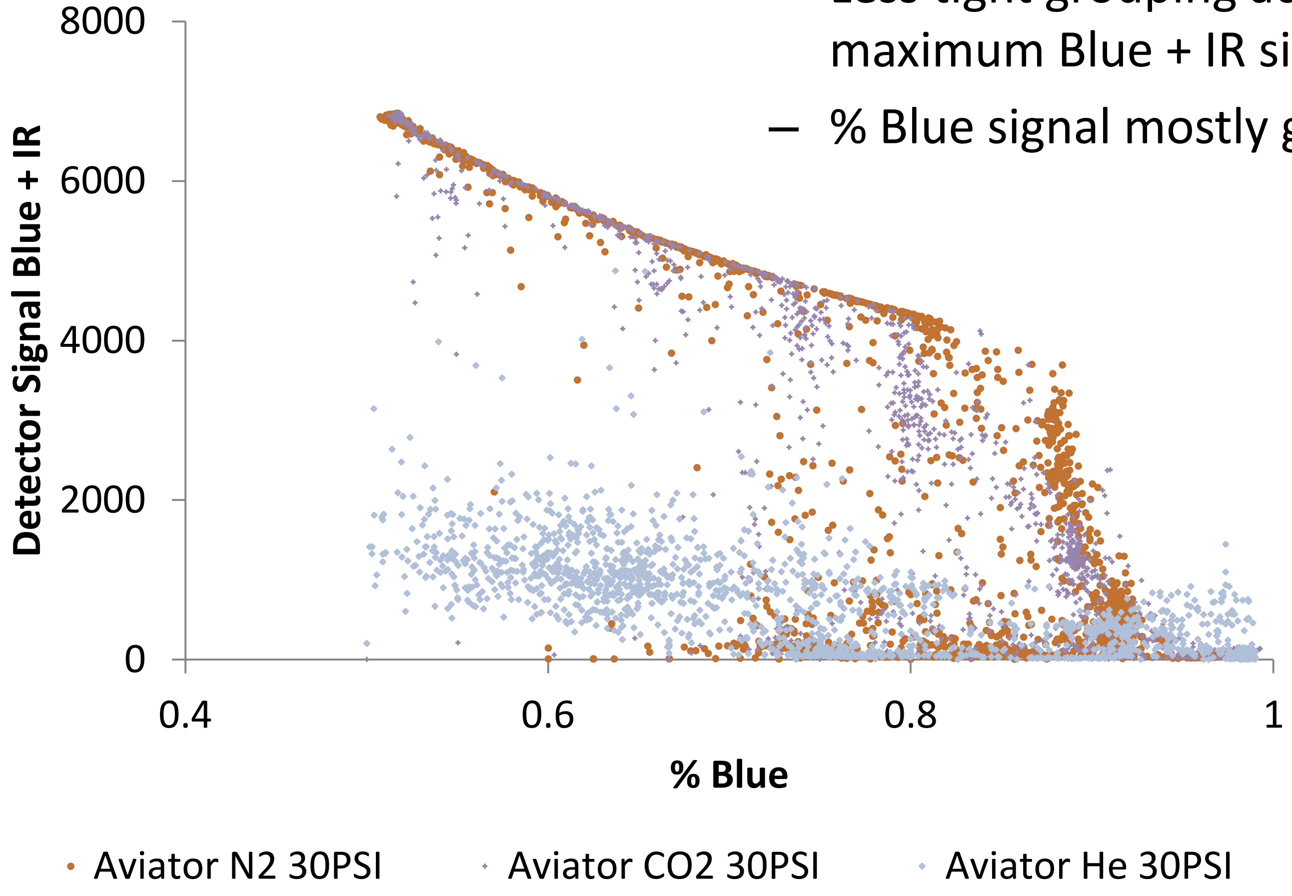
# Aviator UL Variations 50psig

- Note:
  - Tight grouping across the apparent maximum Blue + IR signal
  - % Blue signal mostly greater than 60%
  - % Blue signal mostly greater than 60% is typical of real smoke

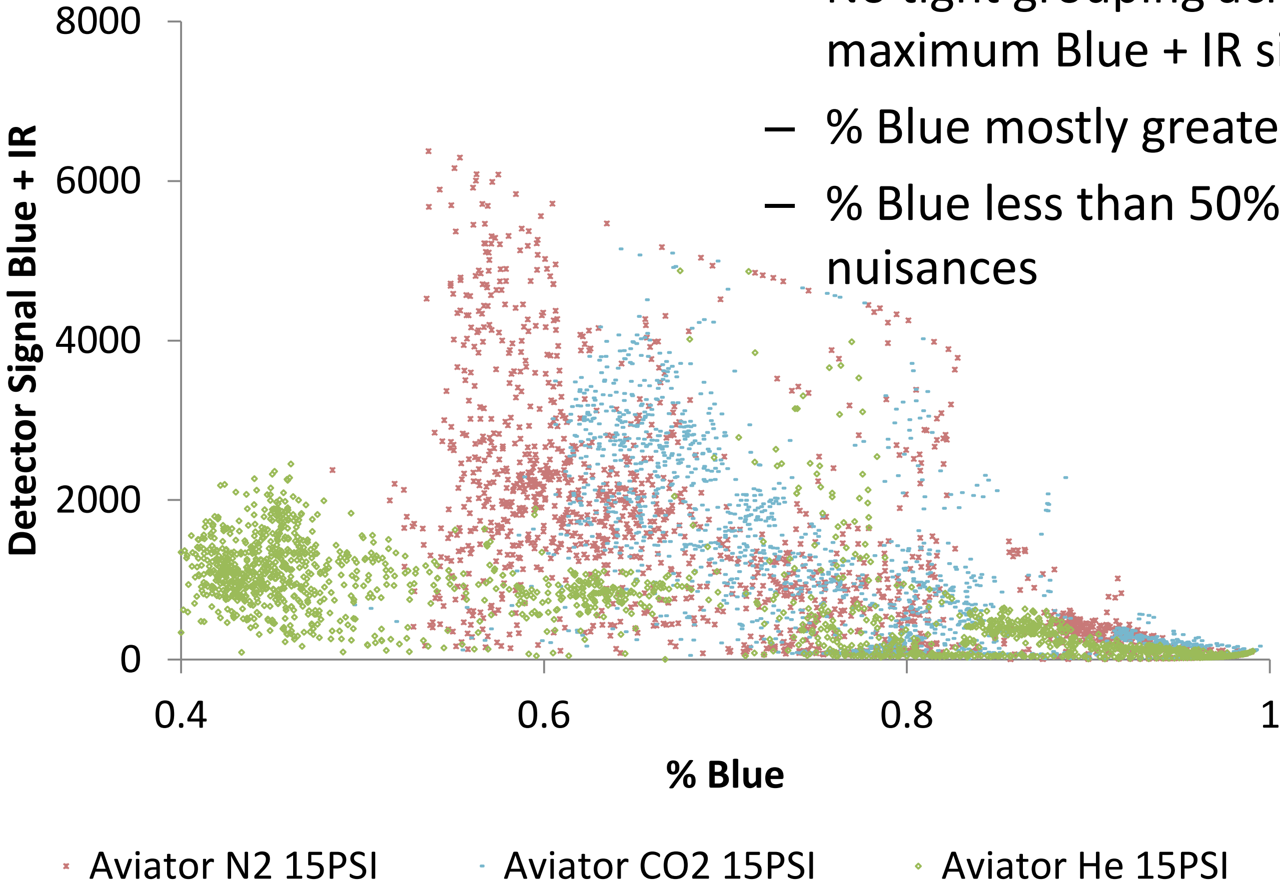


# Aviator UL Variations 30psig

- Note:
  - Less tight grouping across the apparent maximum Blue + IR signal
  - % Blue signal mostly greater than 50%



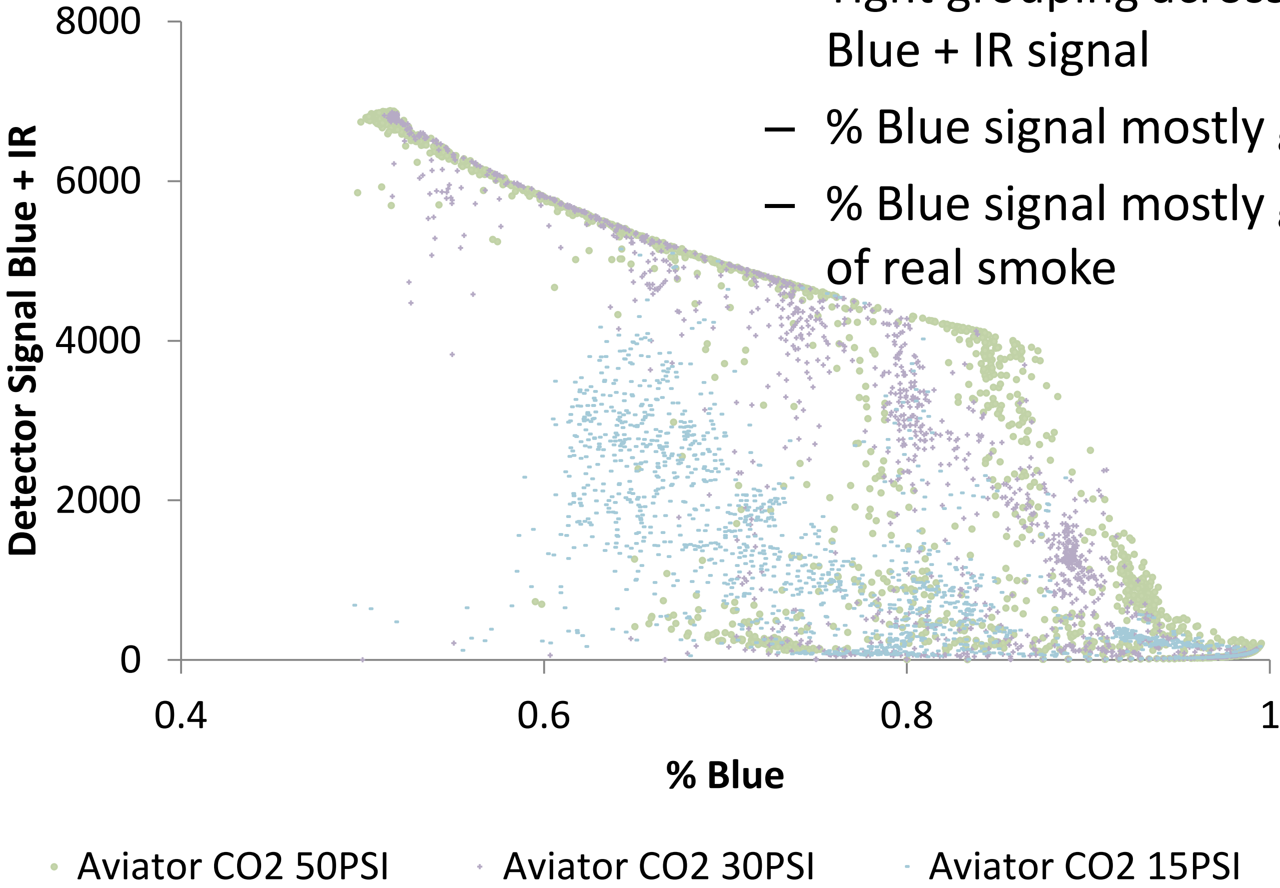
# Aviator UL Variations 15psig




- Note:
  - No tight grouping across the apparent maximum Blue + IR signal
  - % Blue mostly greater than 40%
  - % Blue less than 50% is typical of smoke alarm nuisances

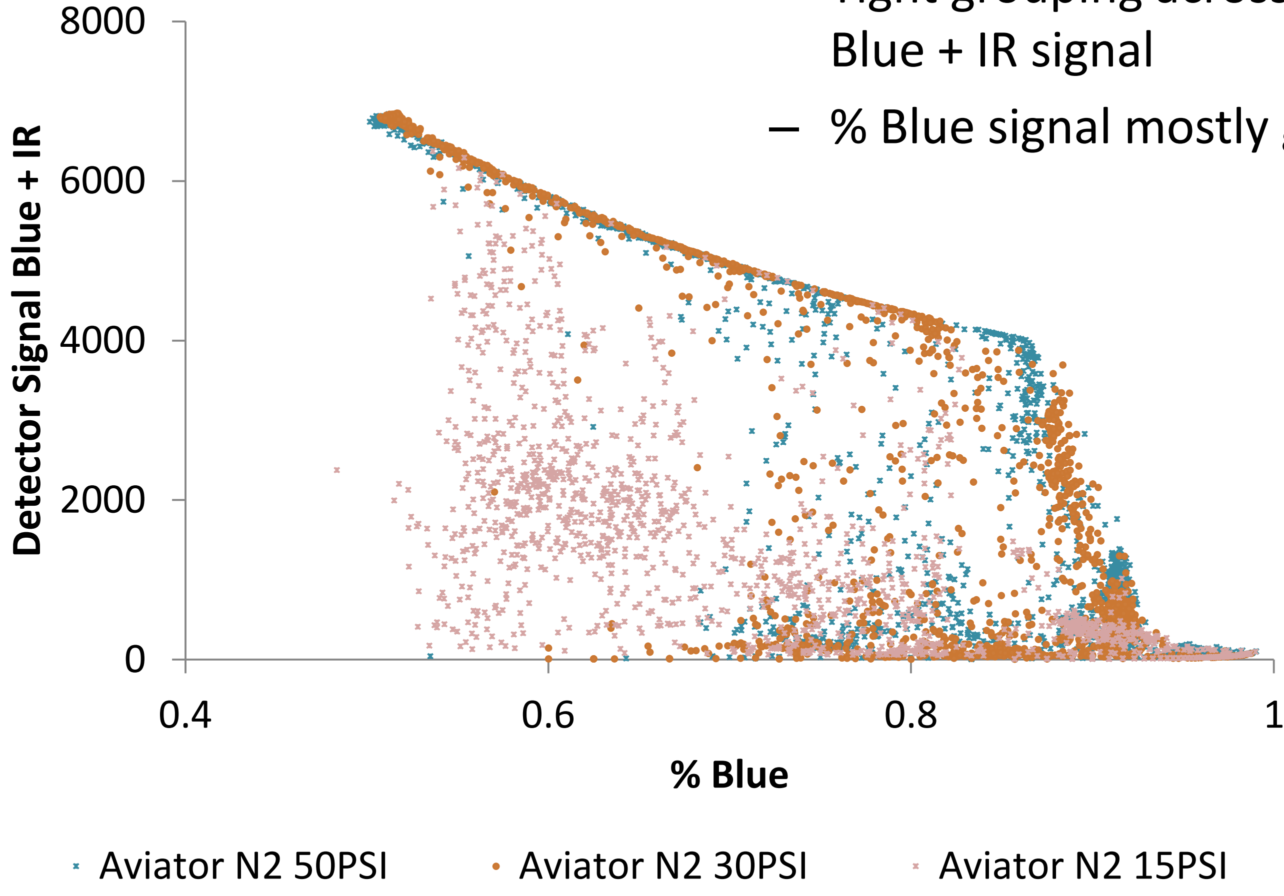
# Aviator UL Variations CO2

- Note:
  - Tight grouping across the apparent maximum Blue + IR signal
  - % Blue signal mostly greater than 60%
  - % Blue signal mostly greater than 60% is typical of real smoke



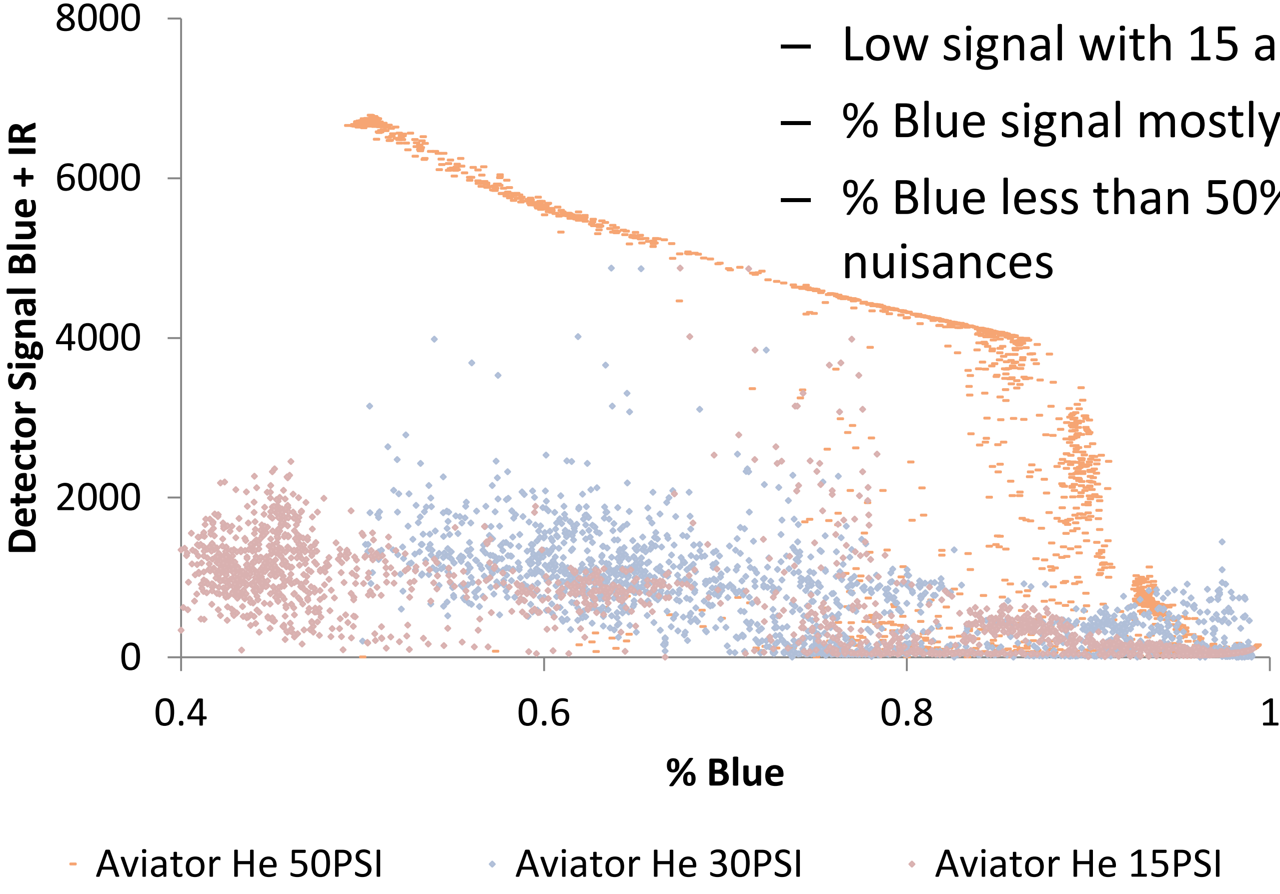
# Aviator UL Variations N2

- Note:
  - Tight grouping across the apparent maximum Blue + IR signal
  - % Blue signal mostly greater than 50%



# Aviator UL Variations He

- Note:
  - Tight grouping across the apparent maximum Blue + IR signal with 50psig
  - Low signal with 15 and 30psig
  - % Blue signal mostly greater than 40%
  - % Blue less than 50% is typical of smoke alarm nuisances



# Conclusions

- **The blue and IR signal can be used to characterize smoke detector nuisances, actual and generator smoke**
- **The smoke generator particle size, smoke density and/or refractive index varies with**
  - Gas propellant
  - Precision micrometer valve adjustments
  - Gas propellant regulator adjustments (varies the flow rate)
- **Smoke obscuration is related to the blue and IR signal**
- **Smoke detector nuisances are**
  - Mostly low in blue and IR signal detection
  - Mostly less than 50% blue signal
- **Real smoke is**
  - Mostly high in blue and IR signal detection
  - Mostly more than 60% blue detection

**Note**: Measured blue and IR signal is specific to this specific smoke detector and software and may not be identical to other detectors

# References


- [1] Siemens. *Aspirating Smoke Detection*. *Aspirating Smoke Detection*, 2015.
- [2] Mulholland, G., 2002. Smoke Production and Properties, in "SFPE Handbook of Fire Protection Engineering", 3rded. Society of Fire Protection Engineers, Boston, pp. 2-258.
- [3] eller, Alejandro & Loepfe, Markus & Nebiker, P & Pleisch, R & Burtscher, Heinz. (2006). On-line determination of the optical properties of particles produced by test fires. Fire Safety Journal. 44. 266–273. 10.1016/j.firesaf.2005.10.001.
- [4] Newman J.S., Yee G.G., Su P. (2016) Smoke Characterization and Damage Potentials. In: Hurley M.J. et al. (eds) SFPE Handbook of Fire Protection Engineering. Springer, New York, NY
- [5] KINSEY, J. S., P. KARIHER, AND Y. DONG. Evaluation of Methods for Physical Characterization of the Fine Particle Emissions from Two Residential Wood Combustion Appliances. ATMOSPHERIC ENVIRONMENT. Elsevier Science Ltd, New York, NY, 43(32):4959-4967, (2009).
- [6] van de Hulst, H. C. (1957). *Light scattering by small particles*. New York: John Wiley and Sons. ISBN 9780486139753.
- [7] SmokeCheck 25S (Smoke Alarm Tester) Safety Data Sheet. "According to the Hazard Communication Standard (CFR29 1910.1200) HazCom 2012." 17 Mar. 2015.
- [8] Emami, T. (2017). *CHARACTERIZATION OF SMOKE GENERATORS IN TESTING AIRCRAFT SMOKE DETECTORS* (Unpublished master's thesis). Rutgers, The State University of New Jersey.

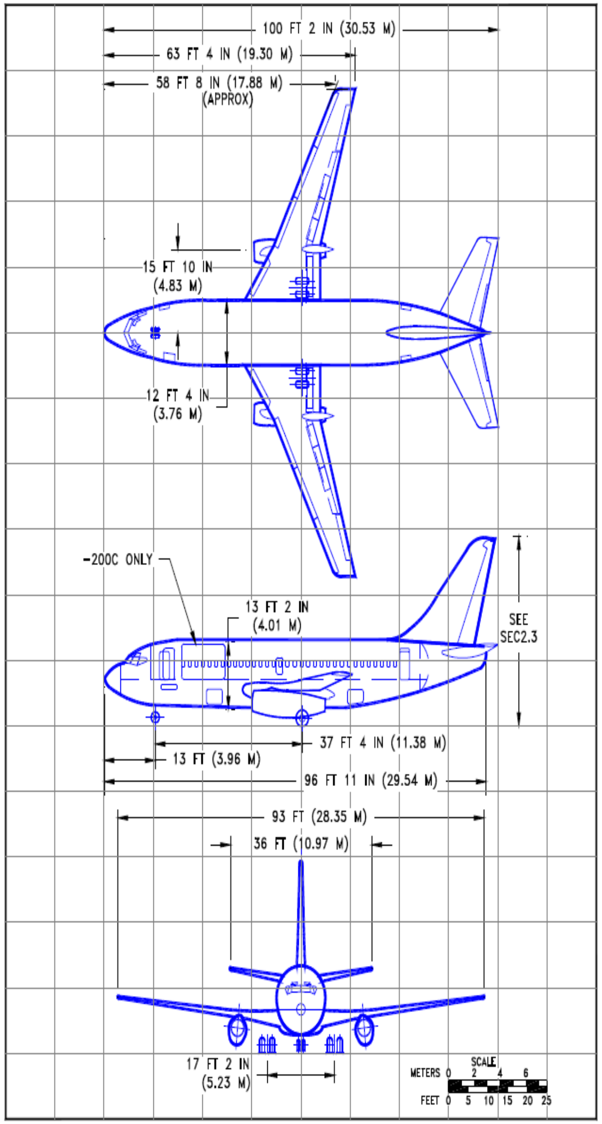
# Test Aircraft

## Cargo Compartments

Federal Aviation Administration

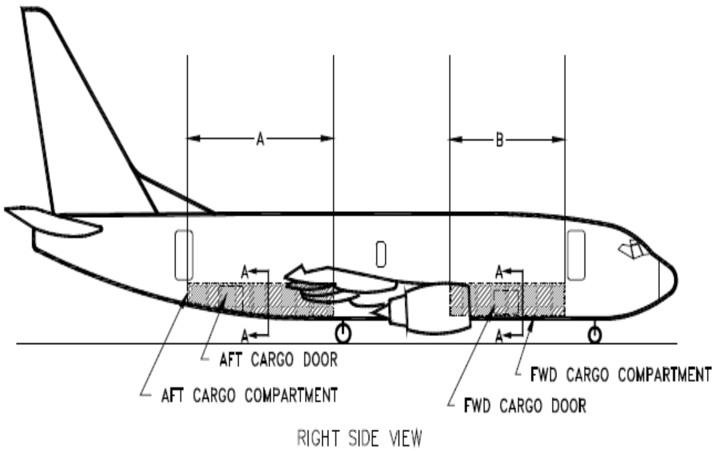
# Boeing 737-200

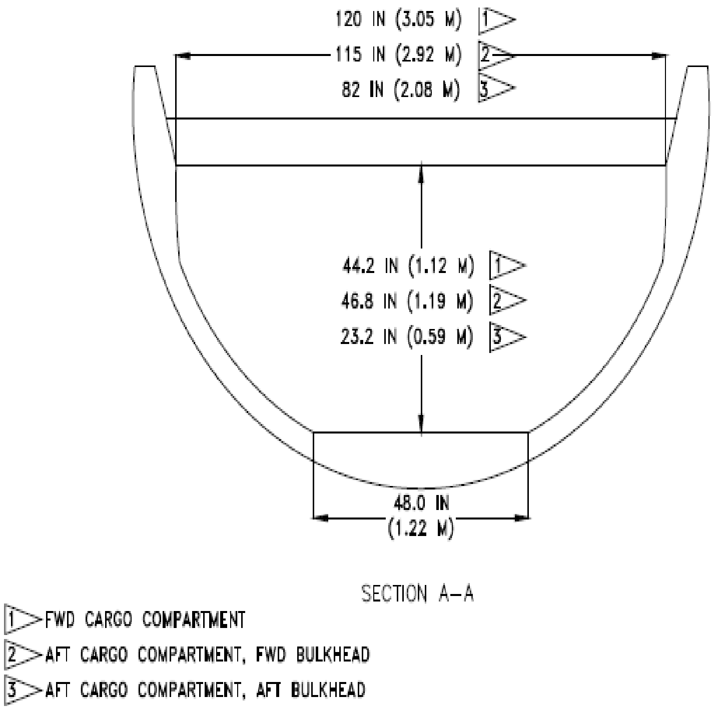
- Short to medium range
- Twinjet
- Narrow-body



# Boeing 737-200

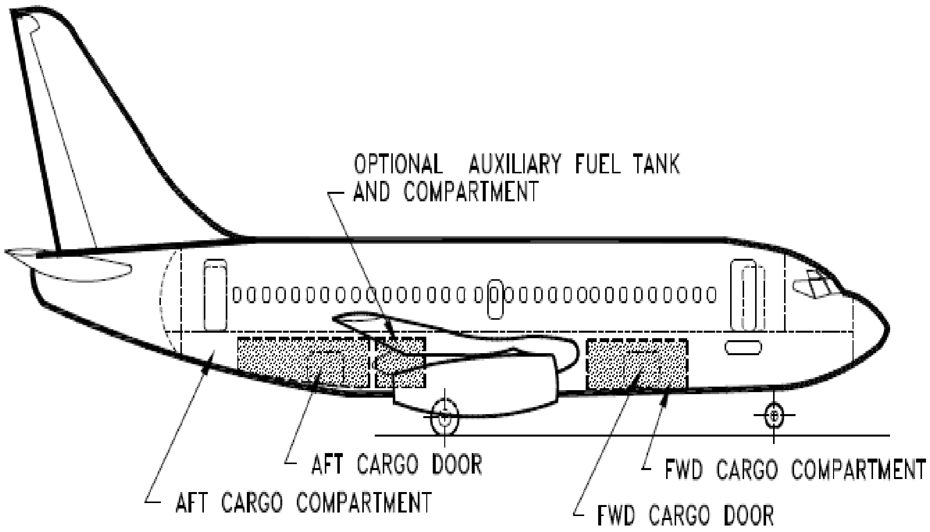
- **Aft cargo**
  - Dimension A 21’5” long [1]
- **Fwd cargo**
  - Dimension B 14’7” long



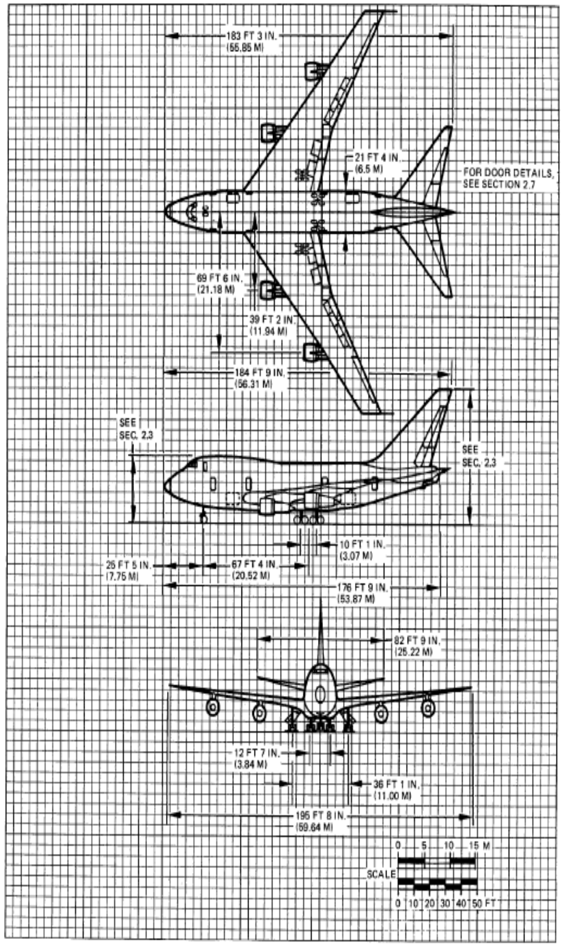
# Boeing 737-200

| Aft Cargo Compartment [1] | Forward Cargo Compartment | Total Bulk Cargo |
|---|---|---|
| 370 CU FT | 370 CU FT | 740 CU FT |



# Boeing 747 SP

- Short to ultra long range [2]
- Four-engine
- Wide-body

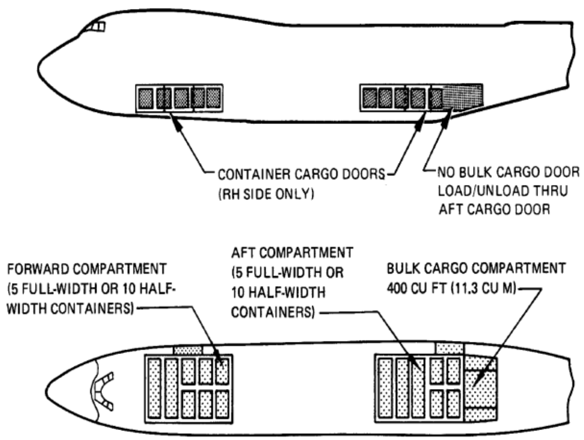


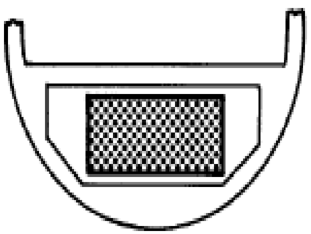

**2.2.2 GENERAL DIMENSIONS**
*MODEL 747SP*

Federal Aviation Administration

# Boeing 747-SP

| Aft Cargo Compartment [2] | Forward Cargo Compartment |
|---|---|
| 2150 CU FT | 1750 CU FT |



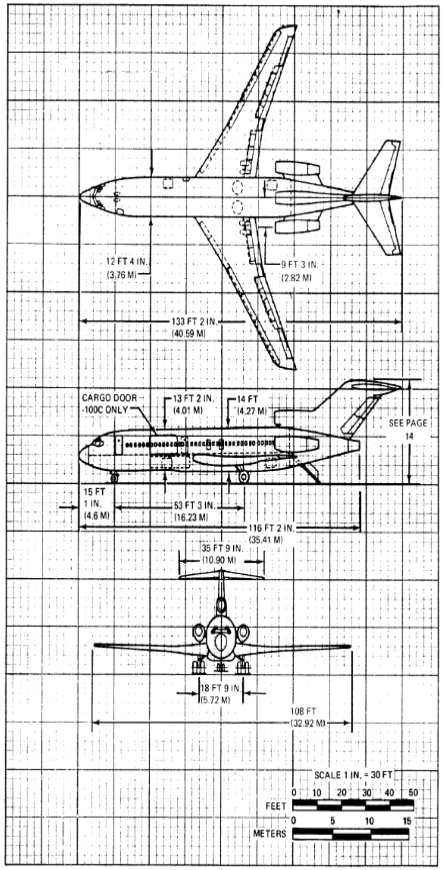
CONTAINER DATA:

SIZE: 38 IN. (0.97M) WIDE, 125 IN. (3.2M) LONG, 64 IN. (1.6M) HIGH

| | |
|---|---|
| INTERNAL VOLUME: | 162 CU FT (4.6 CU M) |
| CONTAINER WEIGHT: | 380 LB (172 KG) |
| WEIGHT LIMITATION: | 1,753 LB (795 KG) |
| PAYLOAD: | 1,373 LB (622 KG) |

# Boeing 727-100 C

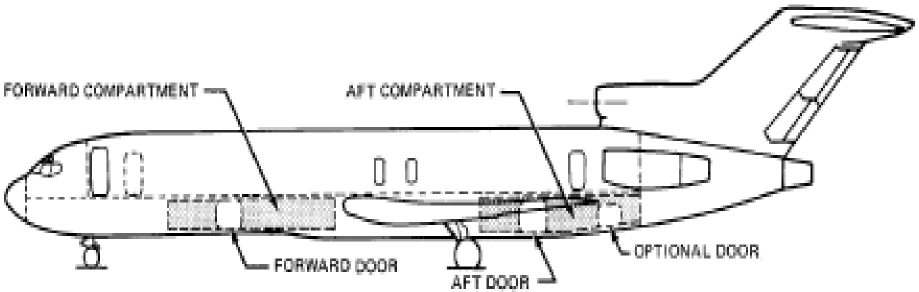
- **Short to medium range [3]**
- **Trijet**
- **Narrow-body**




2.2 GENERAL DIMENSIONS
*MODELS 727-100, -100C*

# Boeing 727-100 C

| | Aft Cargo Compartment [3] | Forward Cargo Compartment |
|---|---|---|
| Volume | 470 CU FT | 420 CU FT |
| Length | 214” | 199” |

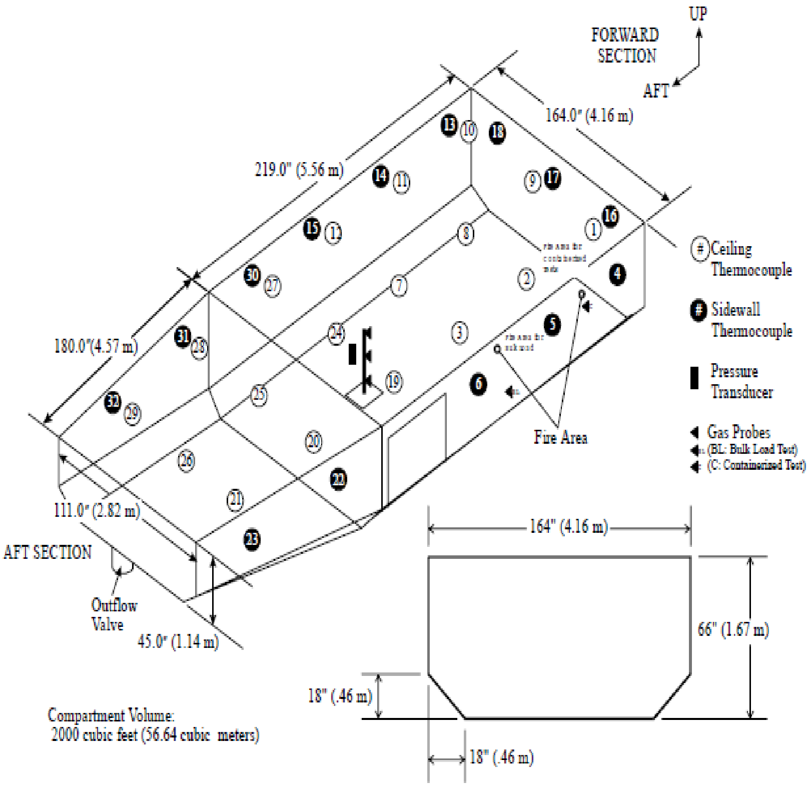



CARGO COMPARTMENT DIMENSIONS AND CAPACITIES

NOTE: SEE PAGE 23 FOR ADVANCED 727-200 BULK CAPACITIES ASSOCIATED WITH ADDITIONAL FUEL OPTIONS.

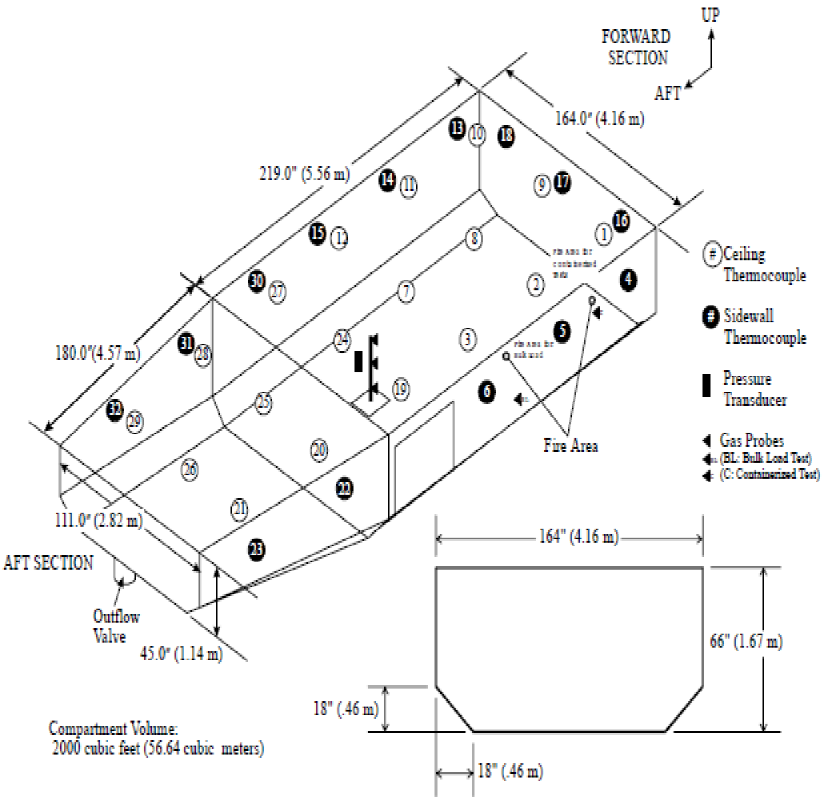
# McDonnell Douglas DC-10

- **Medium to long range**
- **Trijet**
- **Wide-body**



# McDonnell Douglas DC-10

- **Forward Cargo Compartment [4]**
- **Volume- 2000 ± 100 CU FT**
- **Leakage Rate- 50±5 CU FT/min**



# Summary

| Airplane | Aft Cargo Compartment, CU FT | Fwd Cargo Compartment, CU FT |
|---|---|---|
| 737-200 | 370 | 370 |
| 747-SP | 2150 | 1750 |
| 727-100 C | 470 | 420 |
| DC-10 | NA | 2000 |

# References


- [1] *737 Airplane Characteristics for Airport Planning, D6-58325-6*. *737 Airplane Characteristics for Airport Planning, D6-58325-6*, Boeing, 2013.
- [2] *747 Airplane Characteristics Airport Planning, D6-58326*. *747 Airplane Characteristics Airport Planning, D6-58326*, Boeing, 2011.
- *[3] 727 Airplane Characteristics Airport Planning, D6-58326*. *747 Airplane Characteristics Airport Planning, D6-58324*, Boeing, 2011.
- [4] Reinhardt, J.W., Blake D., and Marker, T., "Development of a Minimum Performance Standard for Aircraft Cargo Compartment Gaseous Fire Suppression Systems," FAA report DOT/FAA/AR-00/28, September 2000.

# Contact Information

- **Matthew Karp**
- **Email: Matthew.Karp@FAA.gov**