Aircraft Cargo Compartment Multi-Sensor Detector

By:
Adityanand U. Girdhari

Rutgers University Advisors:
Dr. Tobias Rossmann
Dr. Constantine Polymeropolous

Federal Aviation Administration Advisor:
Mr. David Blake

Federal Aviation Administration Fellowship
Mechanical and Aerospace Engineering Department
Rutgers University, Piscataway, New Jersey 08854

Motivation

- Current Cargo Compartment Detection Systems
  - False alarms to non-fire (nuisance) sources
  - Slow alarm response times to real fires
- 100:1 False to Real Fire Alarm Ratio
- Post Alarm Certified Procedure
  - Flight diversion/Declaration of Emergency situation
  - Compartment inspection
  - Fire extinguisher replacement
  - Passenger disappointment and panic
  - Loss of confidence in smoke detection systems

Outline

- Introduction
- Experimental Apparatus
- Experimental Results
- Multi-Sensor Algorithm Development
- Comparison with Current Detection Systems
- Comparison with Computational Fluid Dynamic Model
- Conclusions and Recommendations
- Acknowledgements

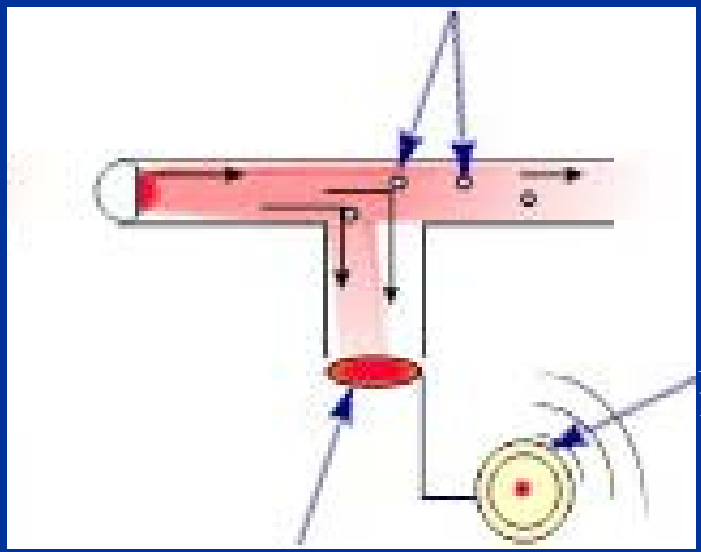
Code of Federal Regulations 14 CFR 28.858: "Cargo or Baggage Compartment Smoke or Fire Detection Systems"

- *Visual indication to the flight crew within one minute after start of fire*
- *Capable of detecting a fire at a temperature significantly below that at which the structural integrity of the airplane is substantially decreased*
- *There must be a means to allow the crew to check in flight, the functioning of each fire detector circuit.*
- *The effectiveness of the detection system must be shown for all approved operating configurations and conditions.*

Current Aircraft Cargo Compartment Smoke Detection Systems

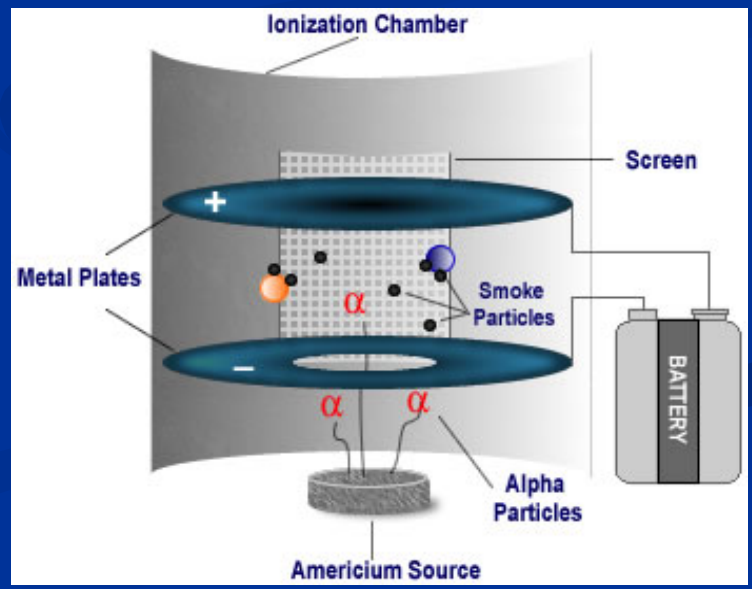
- Light Transmission Detectors
  - Primary Method
  - Light scattering by smoke particles
  - Smoldering Fires
- Ionization Detectors
  - Utilized to Lesser Extent
  - Smoke/Generated Ion Collision
  - Flaming Fires

Smoke particles in chamber deflect light rays



Activated photo cell Powers Alarm

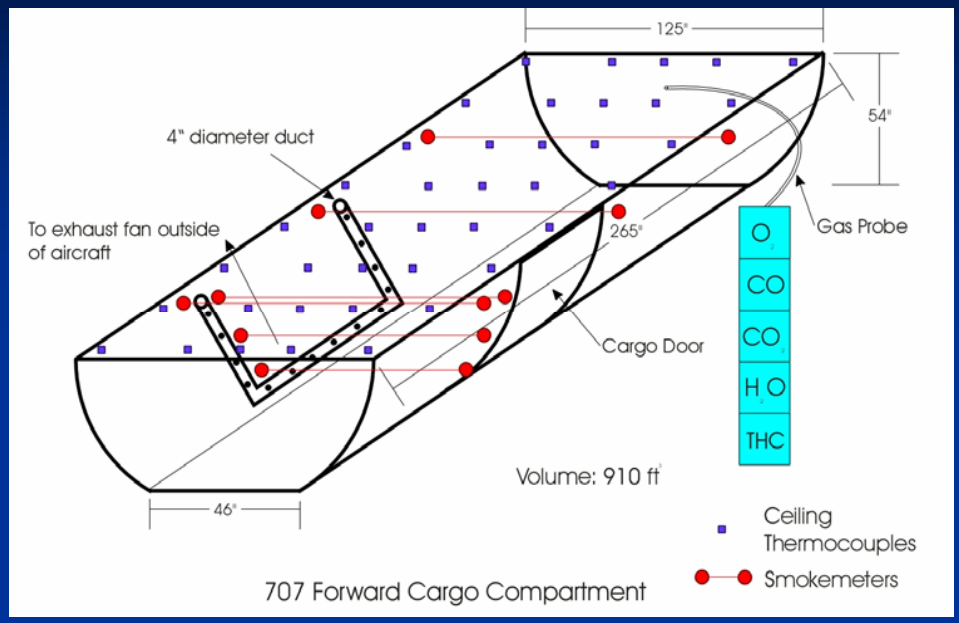
Deflected light rays activate photo cell

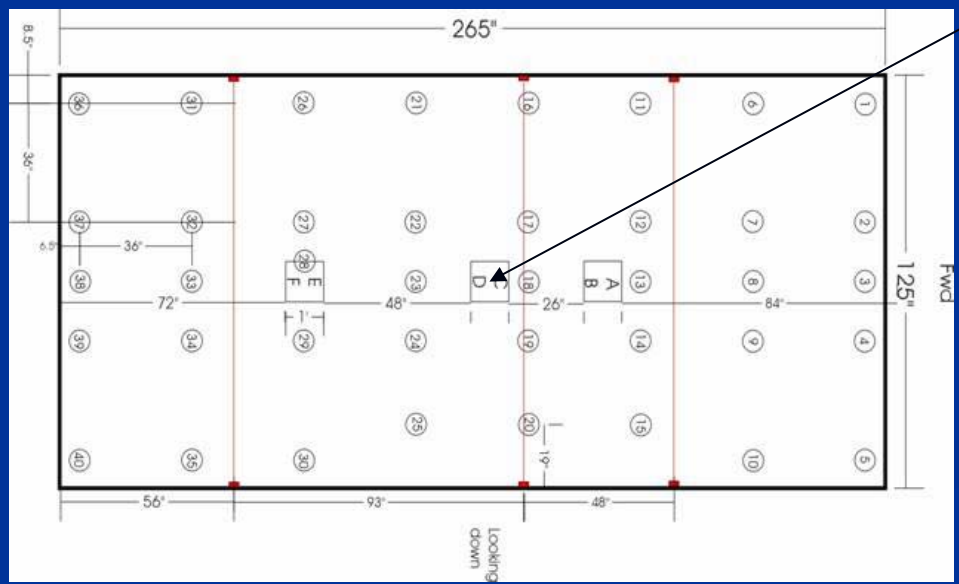


Thesis Objectives

- Reduce False Alarm Ratio
- Nuisance Immunity and Faster Alarm Response Times
- Detect Complete Fire Signature
  - Particulate levels from smoke and byproducts of combustion
  - Gas species concentrations
  - Temperature rise
- Employ a Multi-Sensor Detector
  - Optical Sensors/Smoke Meter (% Obscuration)
  - Thermal Sensors (Temperature)
  - Gas Sensors (CO and CO2)
  - Ionization Technology
- Develop an Alarm Algorithm
- Compare Experimental Results with Computational Results
  - Smoke Transport Computational Fluid Dynamic Model

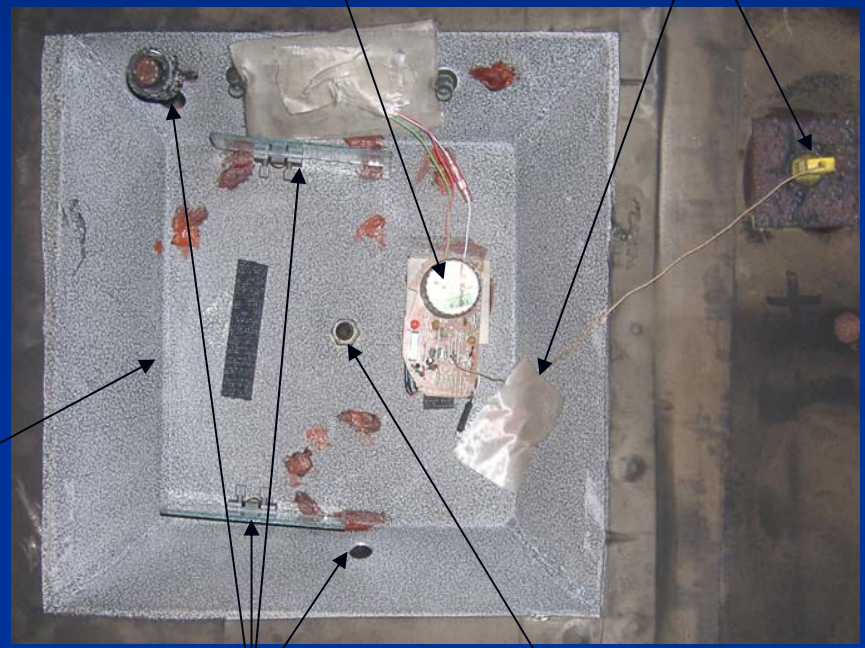
General Experimental Design





Ionization Smoke Detector

Thermocouple and Bead in Pan

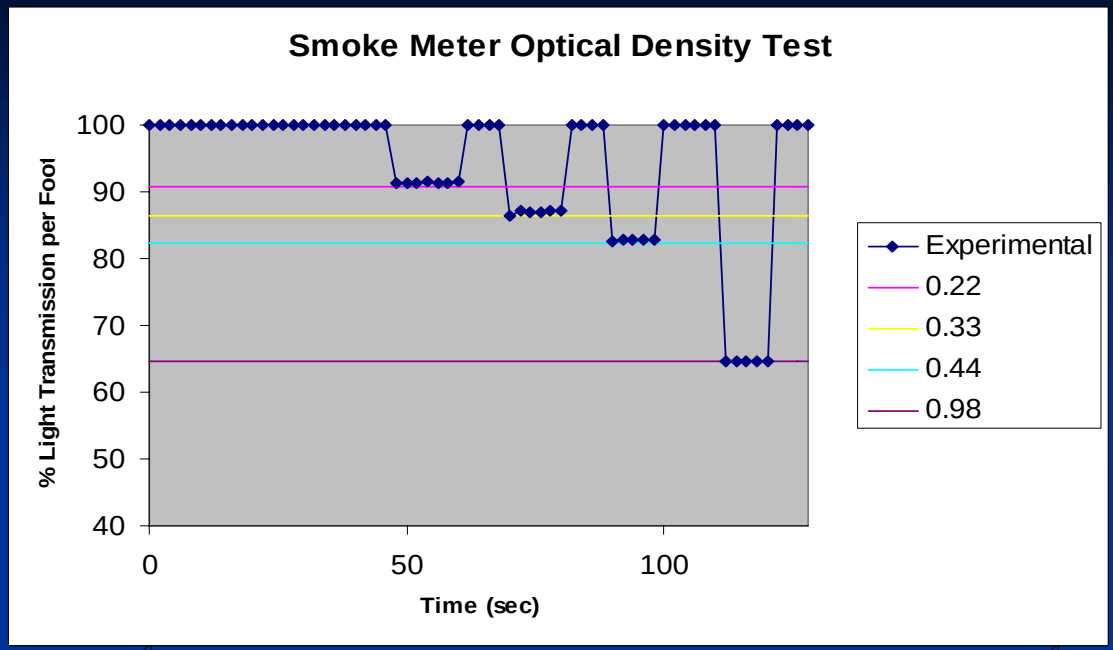


Smoke Meter (Mirrors, Laser, Detector)

Gas Probe

- Central Recessed pan

Smoke Meter

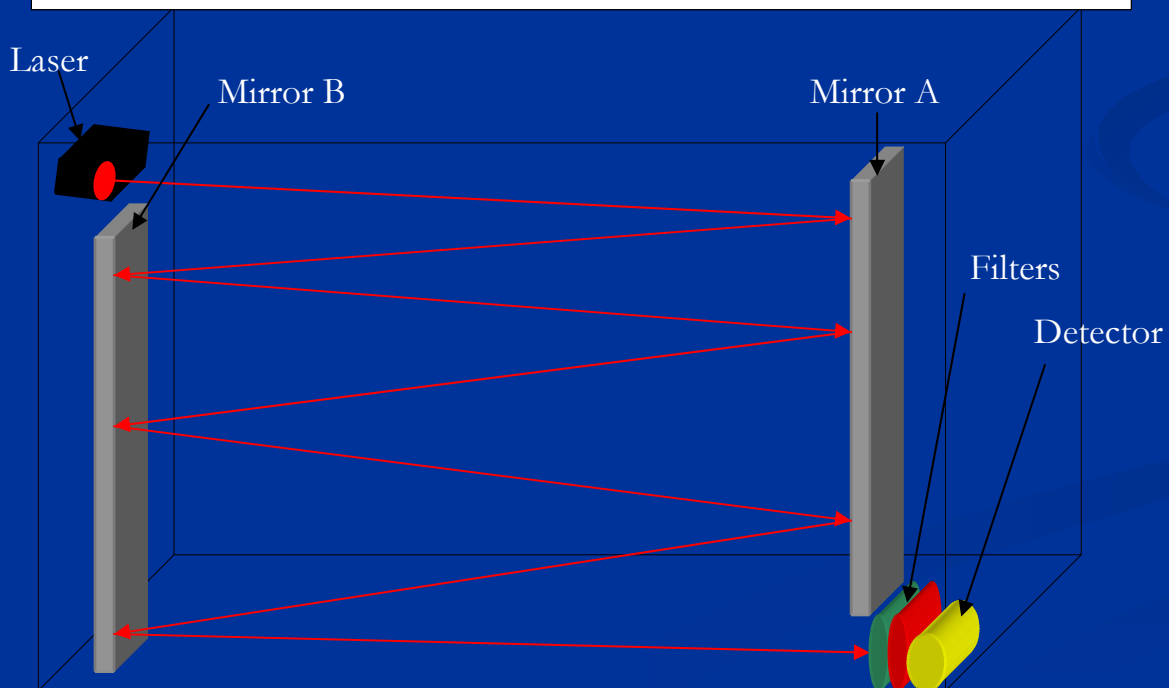


THEORETICAL

$$\frac{\%LT}{Filter} = \frac{1}{10^{X}} \times 100$$

EXPERIMENTAL

$$\frac{\%\ LT}{ft} = 100 \times \left[\frac{I}{I_0}\right]^{\frac{1}{L}}$$

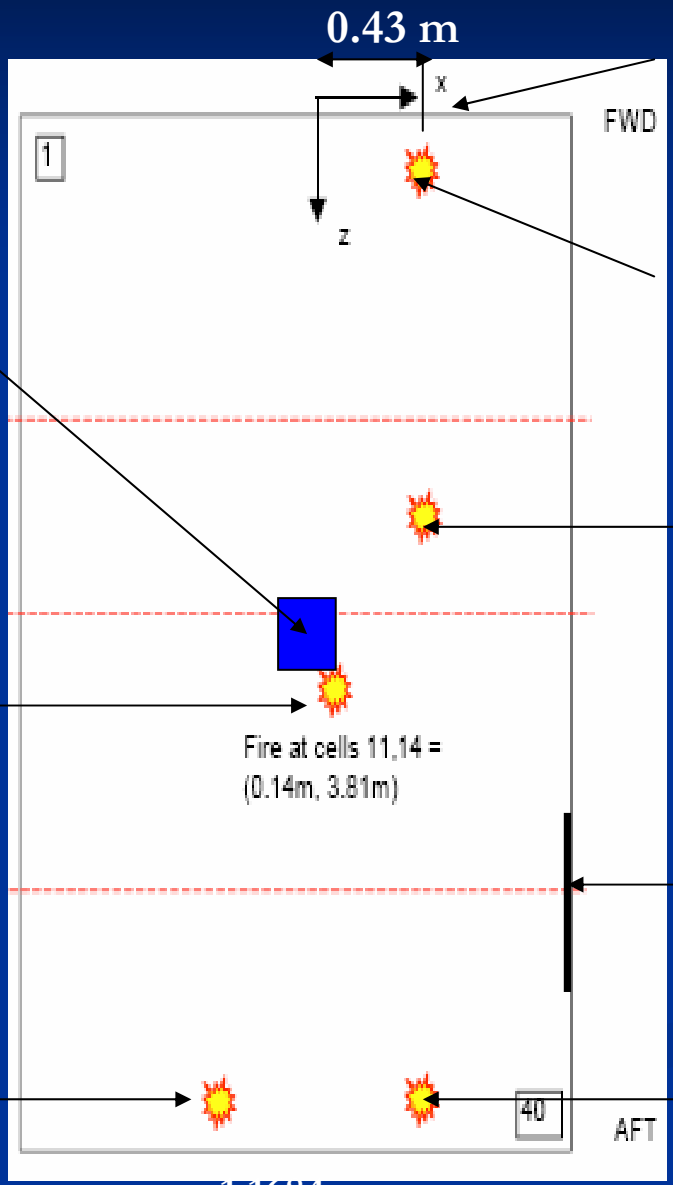


- **INSTRUMENTATION**
  - 4" x 1.5" by 0.13" First Surface Mirrors (8 ½" Gap)
  - VLM High Quality Fixed Laser Diode Module-670 nm
  - OEM Coaxial Silicon Photo Detector
  - Band Pass Filter
  - Infrared Filter
- **TECHNICAL STANDARD ORDER (TSO-C1d)**
  - Alarm 60-96 %LT/ft

Experimental Testing

Real Fire Sources	Nuisance Sources
1. Denatured Alcohol • (40 mL) • 4 minutes • Flaming	**1. Vaporizer** • Simulation of vapors from rapid pressure changes and aerosols • 1 ½ minutes
2. Polyurethane Foam • 9” x 4” x 4” foam block • 4 minutes • Flaming	**2. Arizona Test Dust** • Simulation of dust from dirty containers or cargo itself • Box set-up • 1 minute
3. Alcohol Soaked Rags • 10 mL Denatured Alcohol • 1 rag with 1 square foot area • 4 minutes • Flaming	**3. Heat Gun** • Simulation of container on hot day and thermal energy released • 2 minutes
4. Shredded Newspaper • 123 in^2 pan, 6 in. height • 2 minutes • Flaming & Smoldering	**4. Occupied Compartment** • Background CO_2 levels • 5 minutes
5. Suitcase • Assorted Fabrics • 5 minutes • Smoldering	**5. Exhaust fumes** • Loading vehicle by cargo compartment before door closes and taxiing aircraft • 4 minutes

Experimental Locations



Forward Bulkhead Wall

Recessed Pan Multi Sensor Detector

FWD Starboard Fire

Sidewall Fire

X-location Fire

Cargo Door

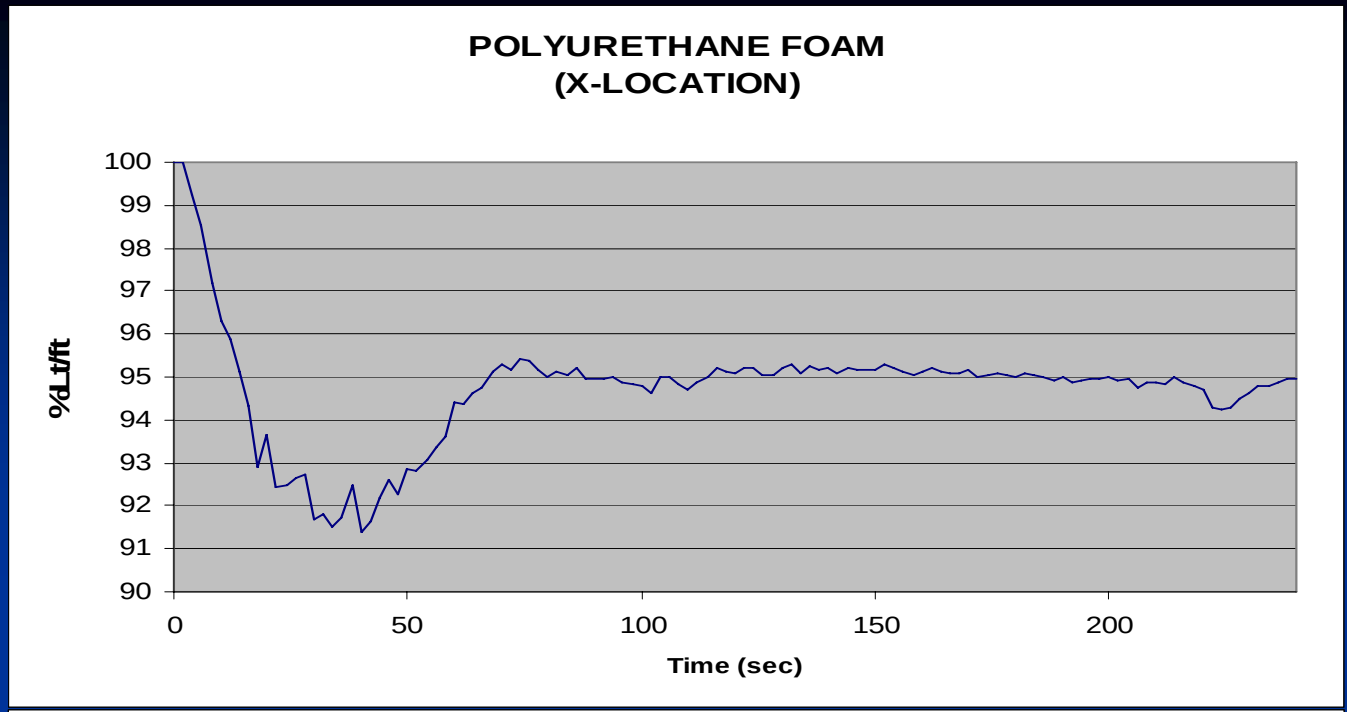
AFT Port Fire

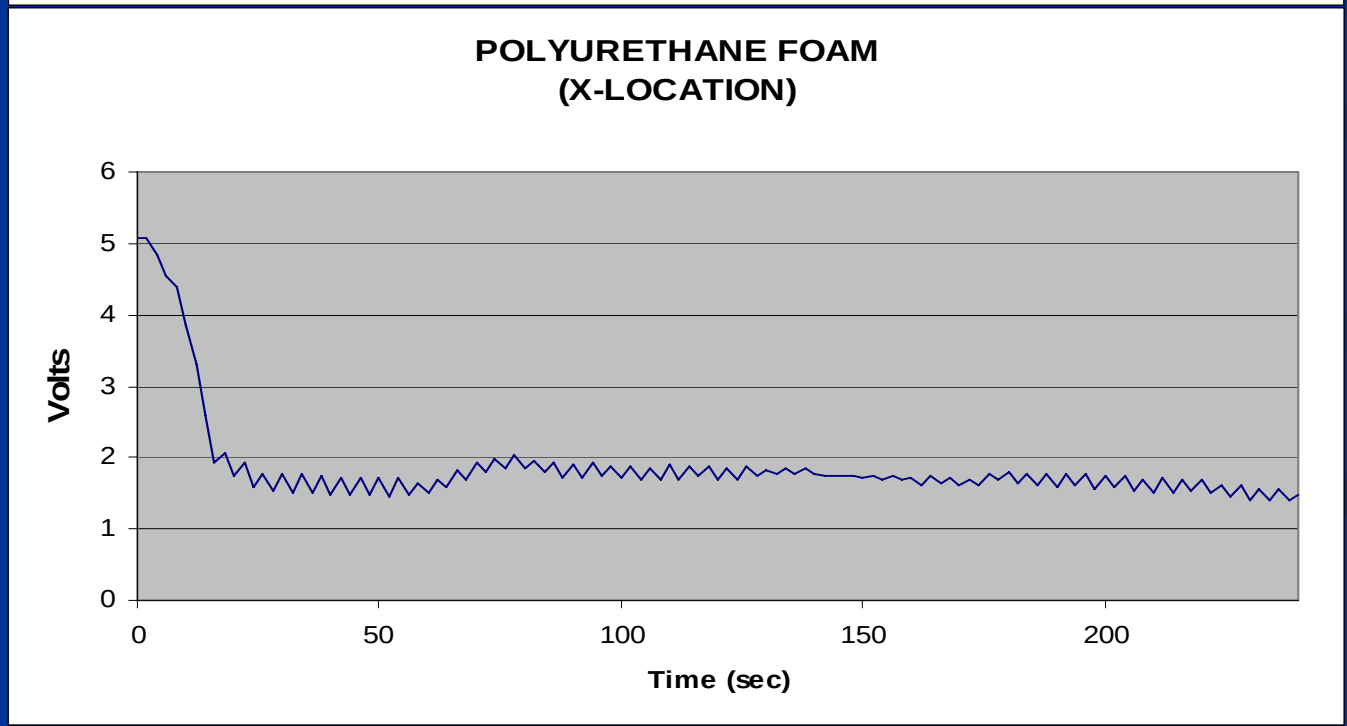
AFT Starboard Fire

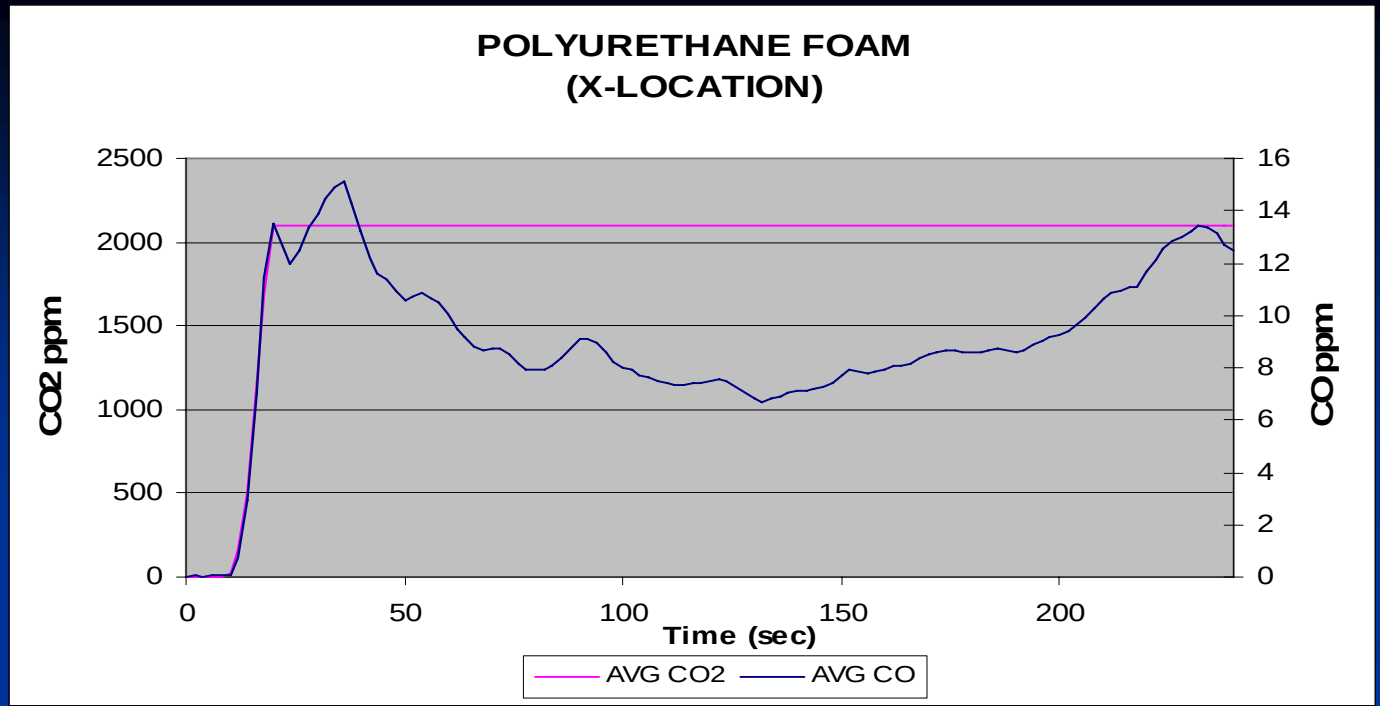
- RESIN CAKE
  - X-Location
  - FWD Starboard
  - AFT Port
  - SIDEWALL
- ALL SOURCES
  - X-Location
  - FWD Starboard
  - AFT Starboard

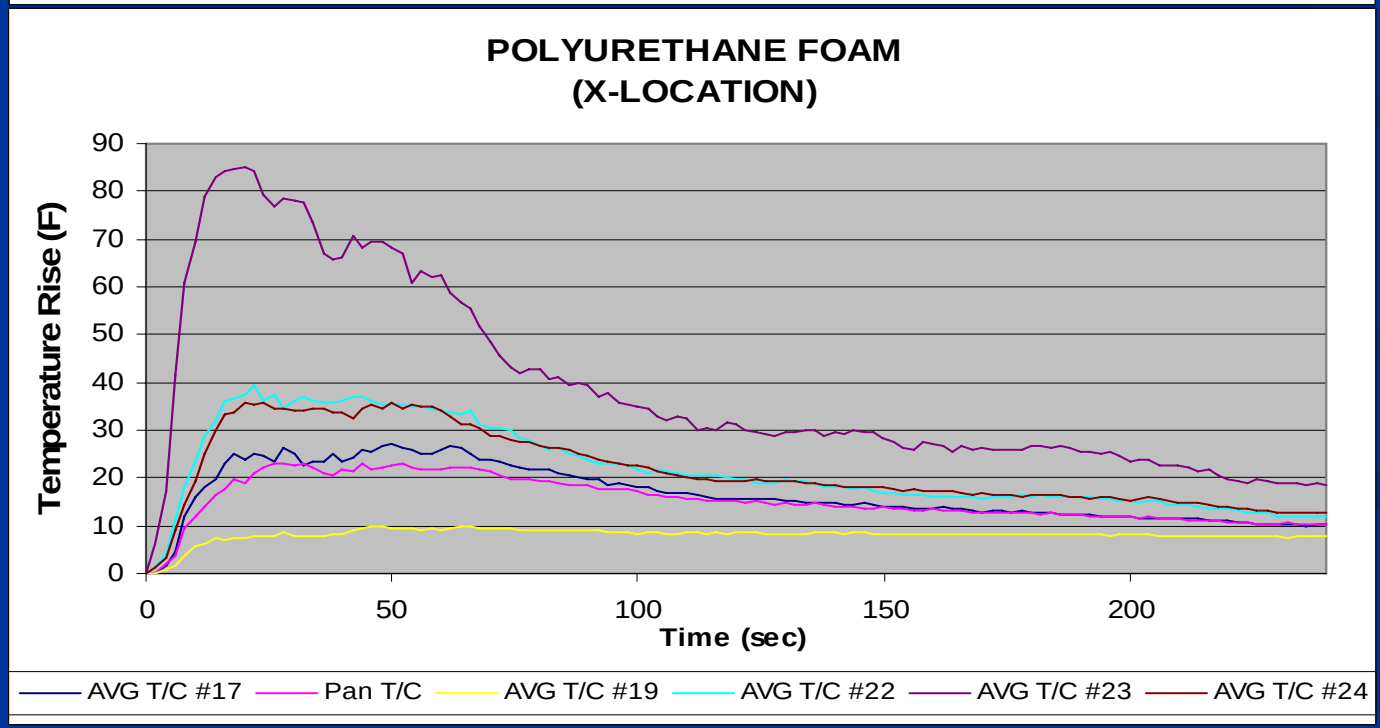
Experimental Fire Test Results

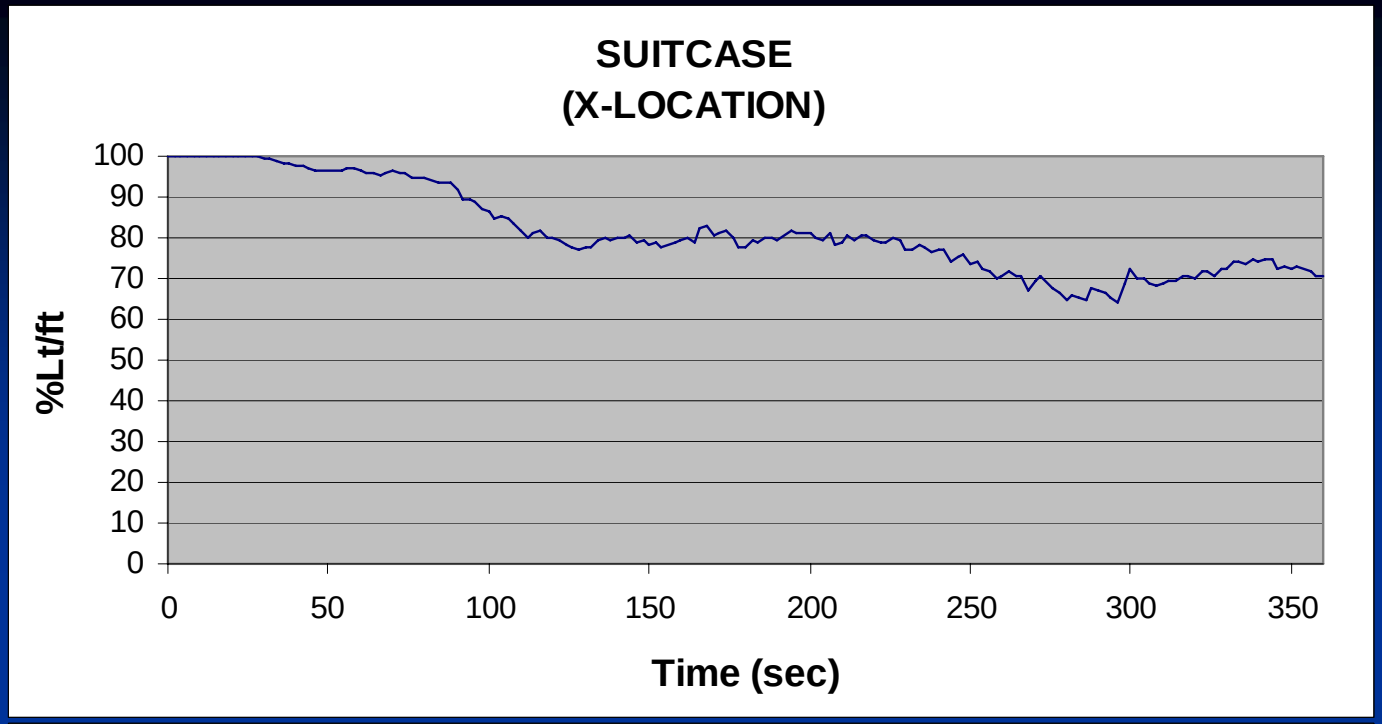
- Polyurethane Foam: Flaming Fire Source
- Suitcase: Smoldering Fire Source

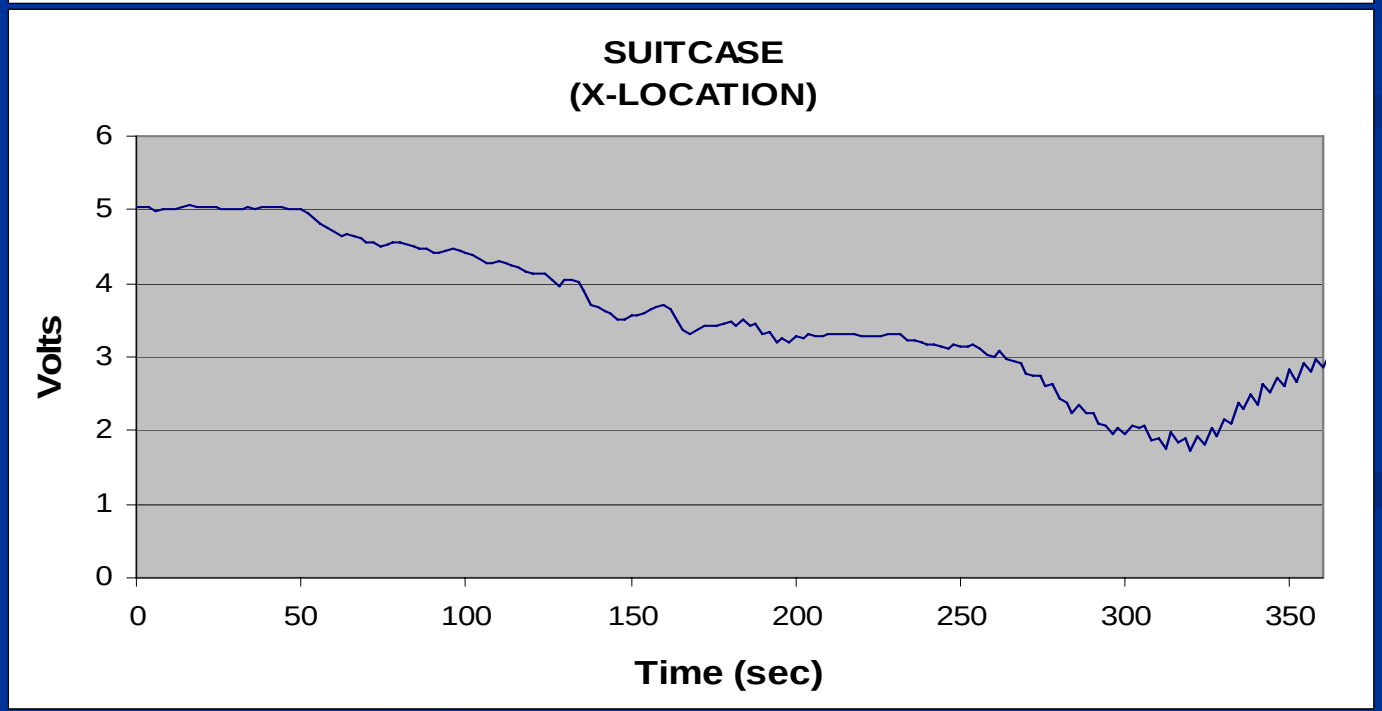

POLYURETHANE FOAM
(X-LOCATION)
%Lt/ft
100
99
98
97
96
95
94
93
92
91
90
0
50
100
150
200
Time (sec)

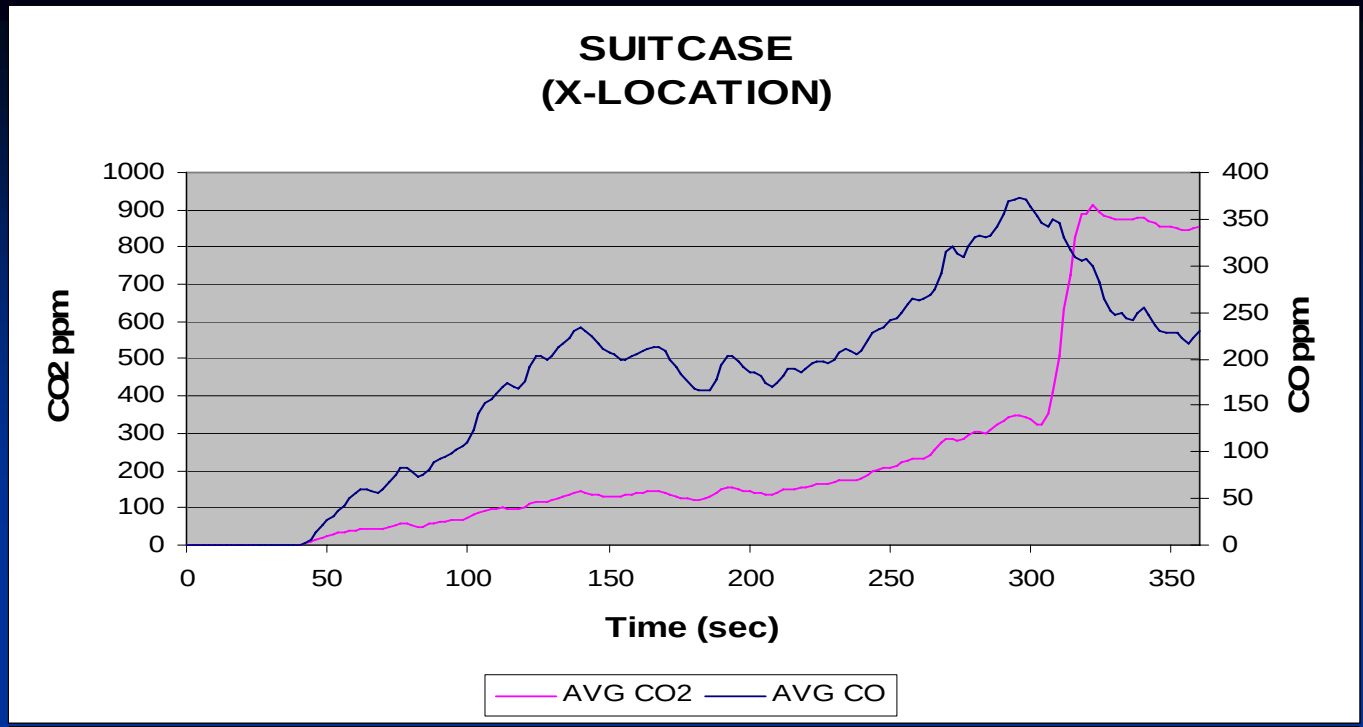

POLYURETHANE FOAM
(X-LOCATION)
Volts
6
5
4
3
2
1
0
0
50
100
150
200
Time (sec)

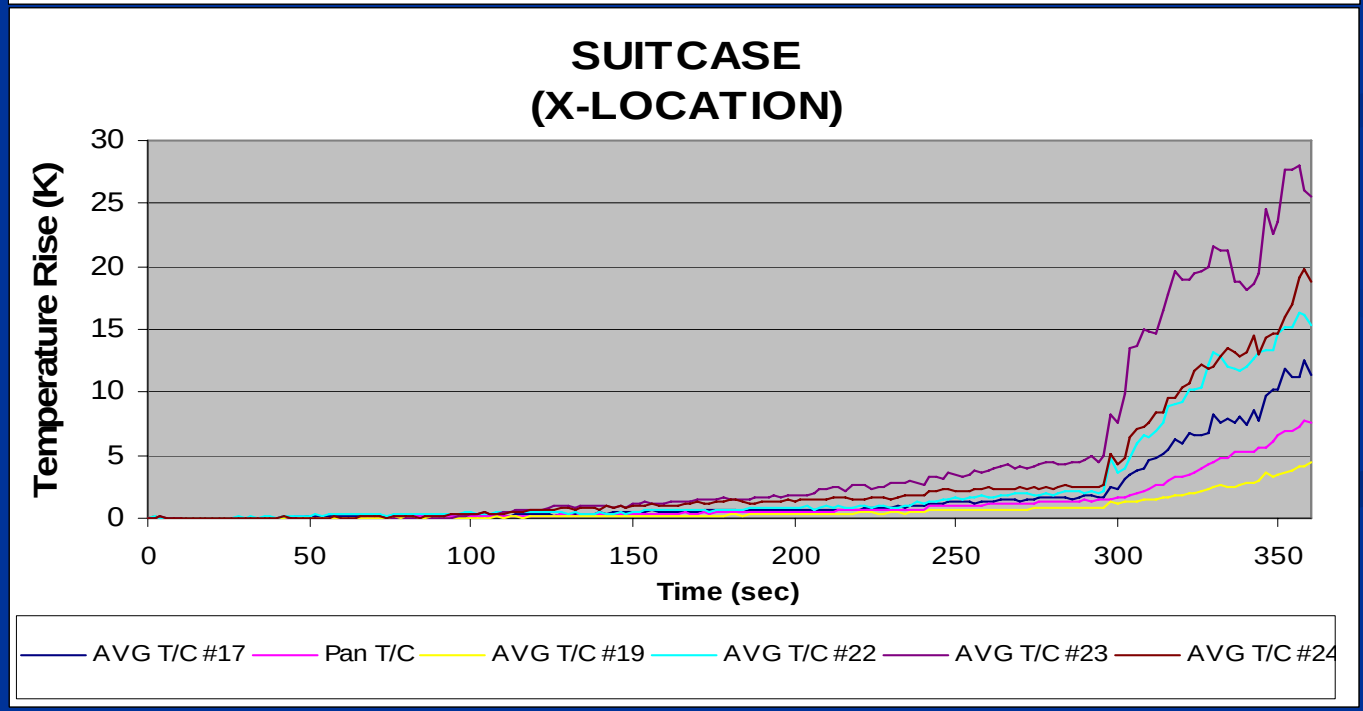

POLYURETHANE FOAM
(X-LOCATION)
CO2 ppm
CO ppm
2500
2000
1500
1000
500
0
16
14
12
10
8
6
4
2
0
0
50
100
150
200
Time (sec)
AVG CO2
AVG CO


POLYURETHANE FOAM
(X-LOCATION)
Temperature Rise (F)
90
80
70
60
50
40
30
20
10
0
0
50
100
150
200
Time (sec)
AVG T/C #17
Pan T/C
AVG T/C #19
AVG T/C #22
AVG T/C #23
AVG T/C #24


SUITCASE
(X-LOCATION)
%Lt/ft
100
90
80
70
60
50
40
30
20
10
0
0
50
100
150
200
250
300
350
Time (sec)

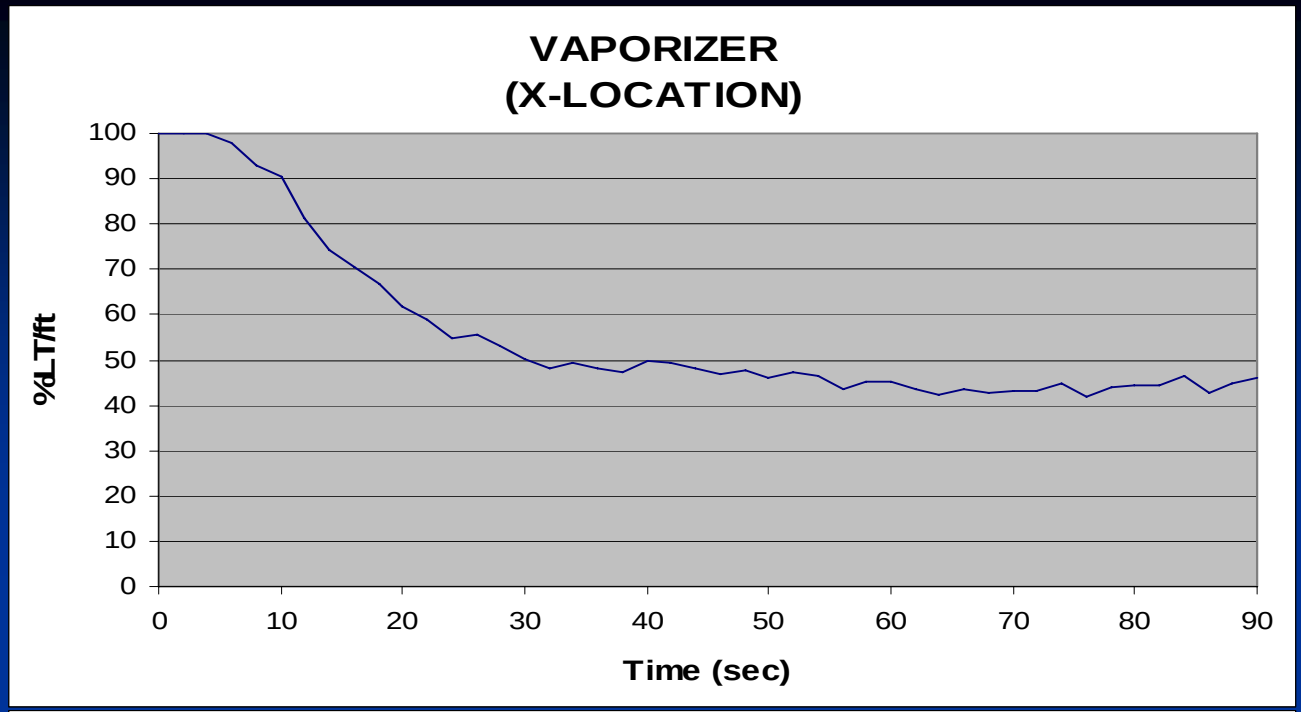

SUITCASE
(X-LOCATION)
Volts
6
5
4
3
2
1
0
0
50
100
150
200
250
300
350
Time (sec)

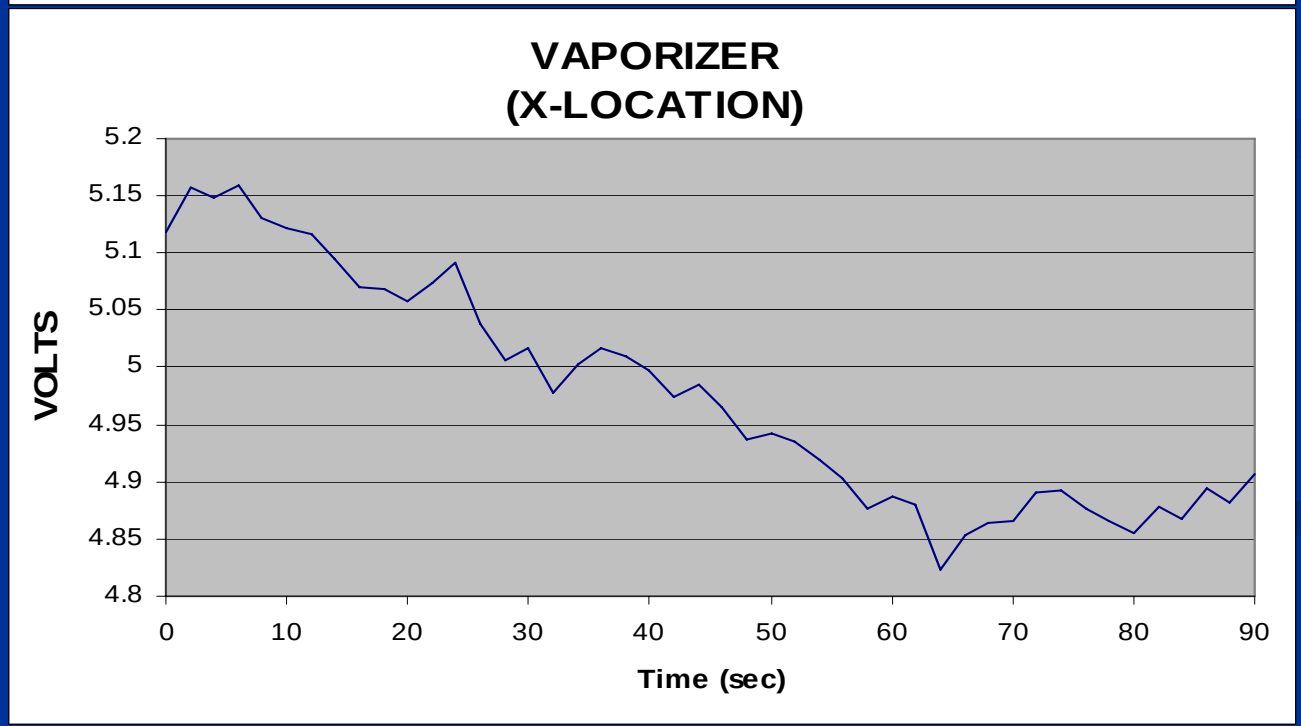

SUITCASE
(X-LOCATION)
CO2 ppm
CO ppm
Time (sec)
AVG CO2
AVG CO

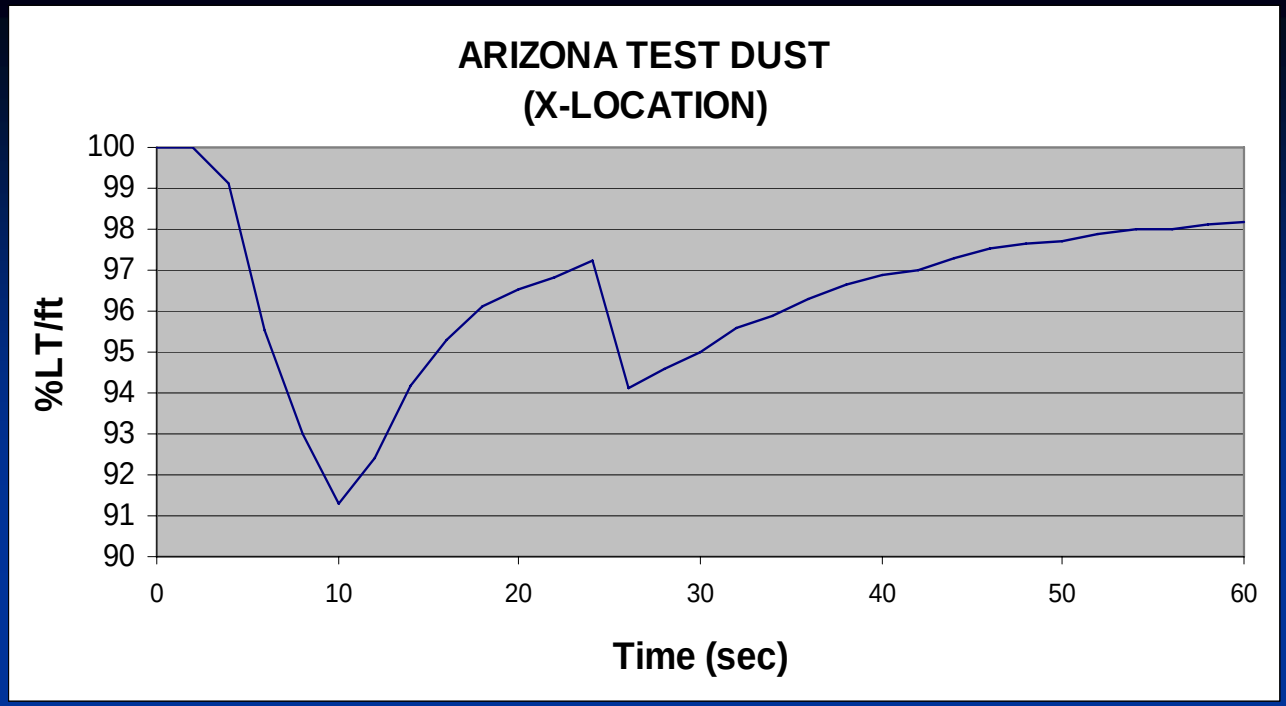

SUITCASE
(X-LOCATION)
Temperature Rise (K)
Time (sec)
AVG T/C #17
Pan T/C
AVG T/C #19
AVG T/C #22
AVG T/C #23
AVG T/C #24

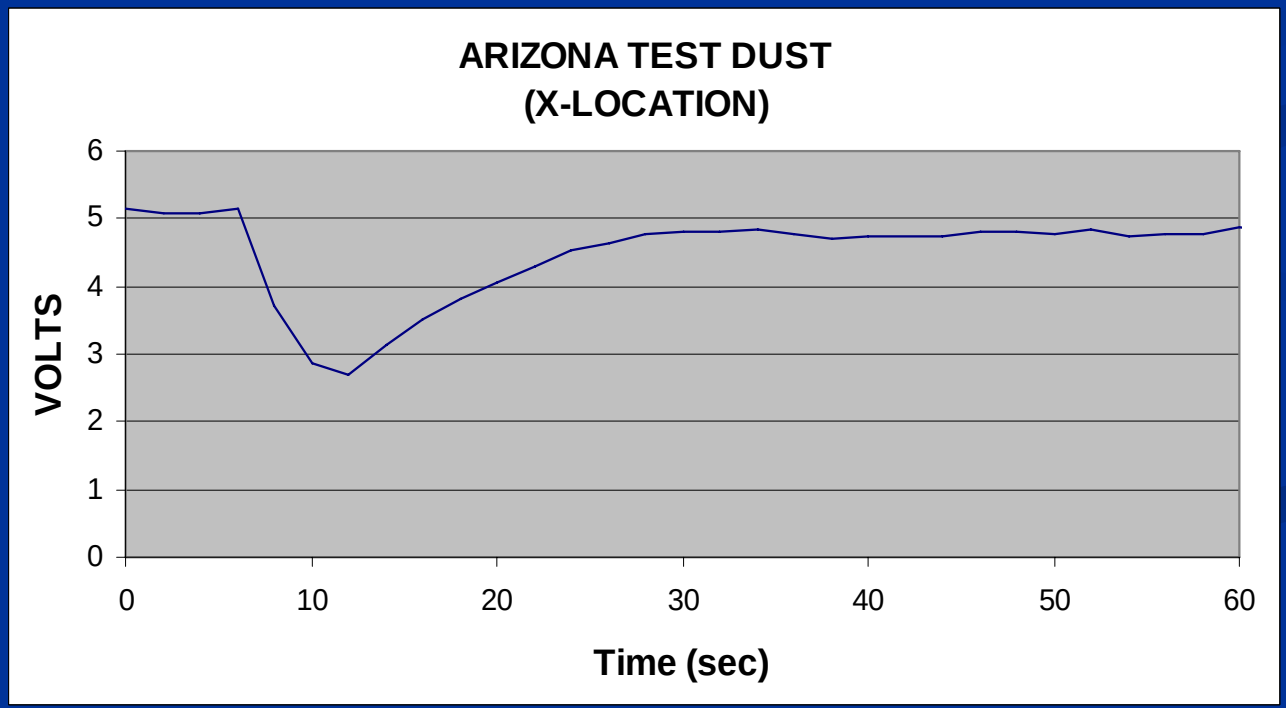
Experimental Nuisance Test Results

- Vaporizer
- Arizona Test Dust


VAPORIZER
(X-LOCATION)
%LT/ft
100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
Time (sec)


VAPORIZER
(X-LOCATION)
VOLTS
5.2
5.15
5.1
5.05
5
4.95
4.9
4.85
4.8
0
10
20
30
40
50
60
70
80
90
Time (sec)


ARIZONA TEST DUST
(X-LOCATION)
%LT/ft
100
99
98
97
96
95
94
93
92
91
90
0
10
20
30
40
50
60
Time (sec)


ARIZONA TEST DUST
(X-LOCATION)
VOLTS
6
5
4
3
2
1
0
0
10
20
30
40
50
60
Time (sec)

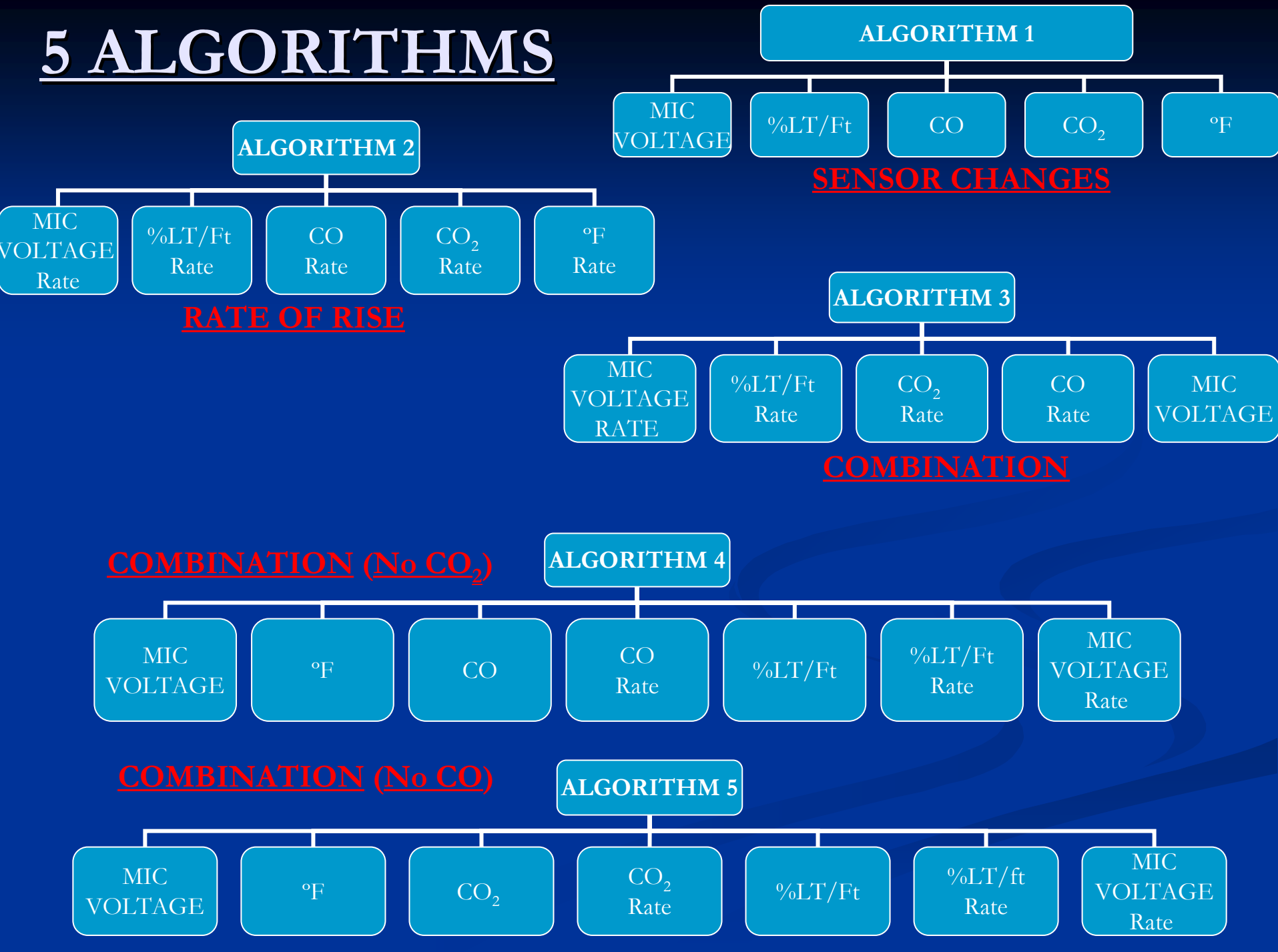
Algorithm Development

- % Light Transmission per foot
- MIC Voltage Difference
- Temperature changes from ambient
- CO Gas Concentration changes from ambient
- CO_2 Gas Concentration changes from ambient
- Rate of Decline of % Light Transmission per foot
- Rate of Decline of MIC Voltage Difference
- Rate of Rise of Temperature
- Rate of Rise of CO Gas Concentrations
- Rate of Rise of CO_2 Gas Concentrations

Algorithm Methodology

- MIC
  - Threshold voltage just below the extreme voltages for the majority of **nuisance sources**
- Smoke Meter
  - Threshold values close to 96 %LT/ft (TSO-C1d)
- Gas Probe
  - Threshold concentration just above the extreme CO and CO_2 gas concentrations for the majority of **nuisance sources**
- Thermocouple
  - Threshold temperature just above the extreme temperature levels for the majority of **nuisance sources**

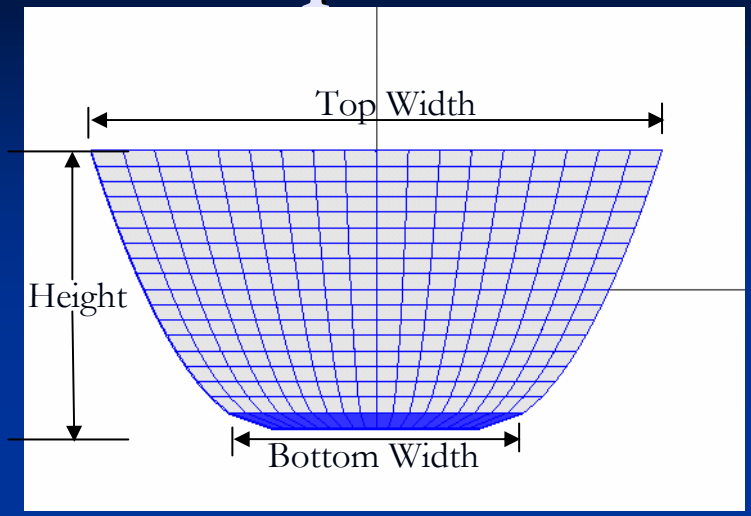
5 ALGORITHMS

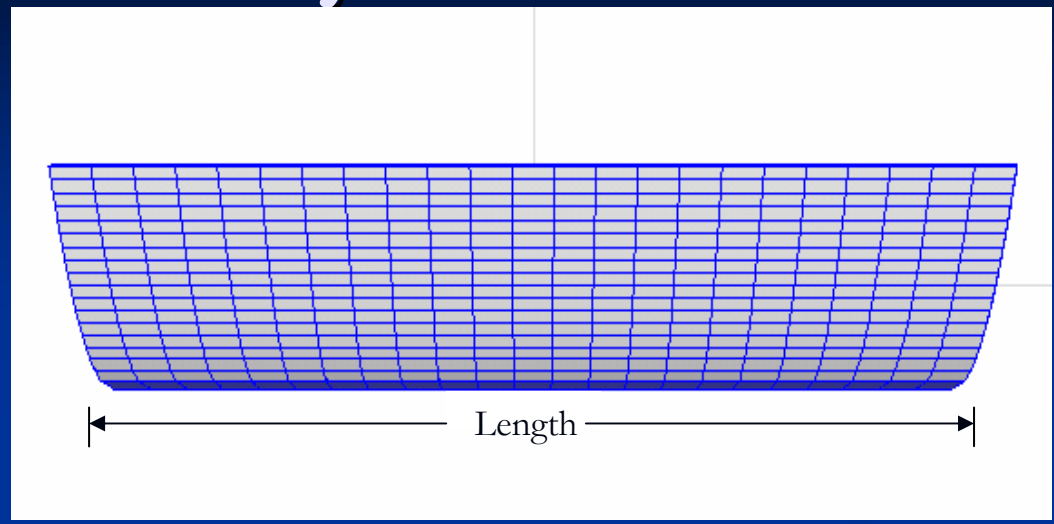


DETECTOR ANALYSIS
Multi-Sensor vs. Current Detectors

	ALGORITHMS					PHOTOELECTRIC	IONIZATION
	1	2	3	4	5		
TOTAL TESTS	30	30	30	30	30	30	30
FAILURE	4	0	1	1	0	10	8
SUCCESSFUL	26	30	29	29	30	20	22
FAILURE %	13.33	0.00	3.33	3.33	0.00	33.33	26.67
SUCCESSFUL %	86.67	100.00	96.67	96.67	100.00	66.67	73.33

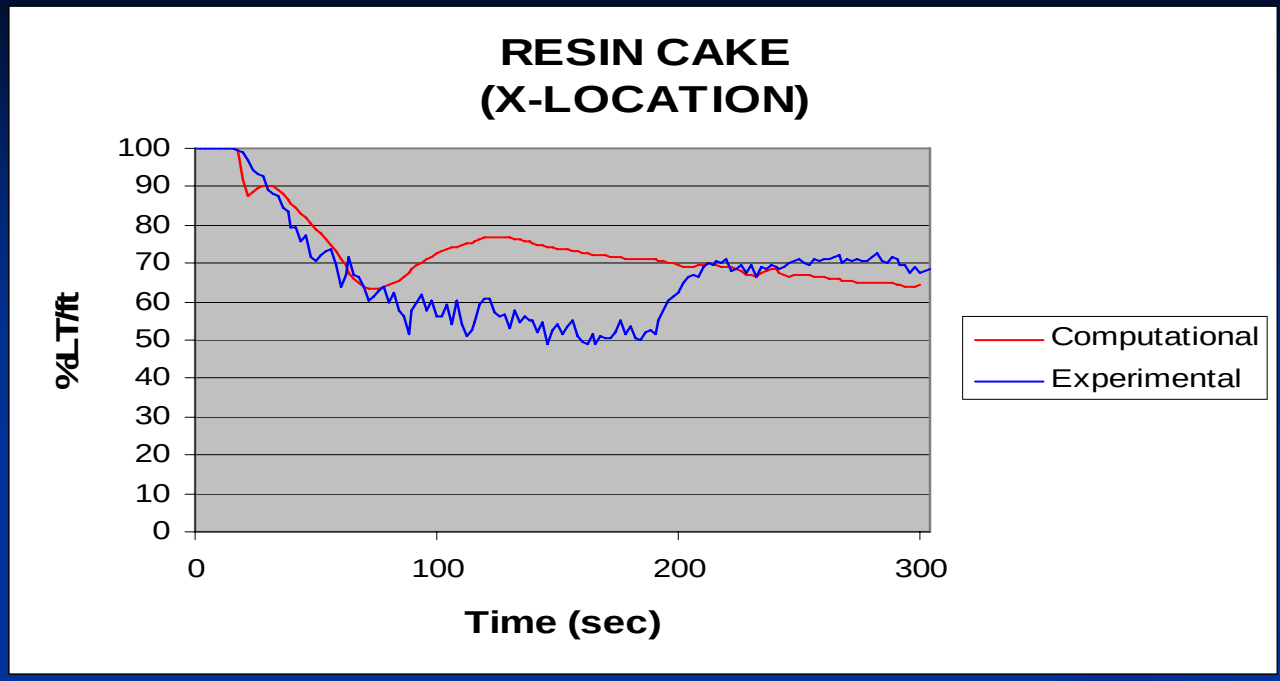
Computational Fluid Dynamic Model

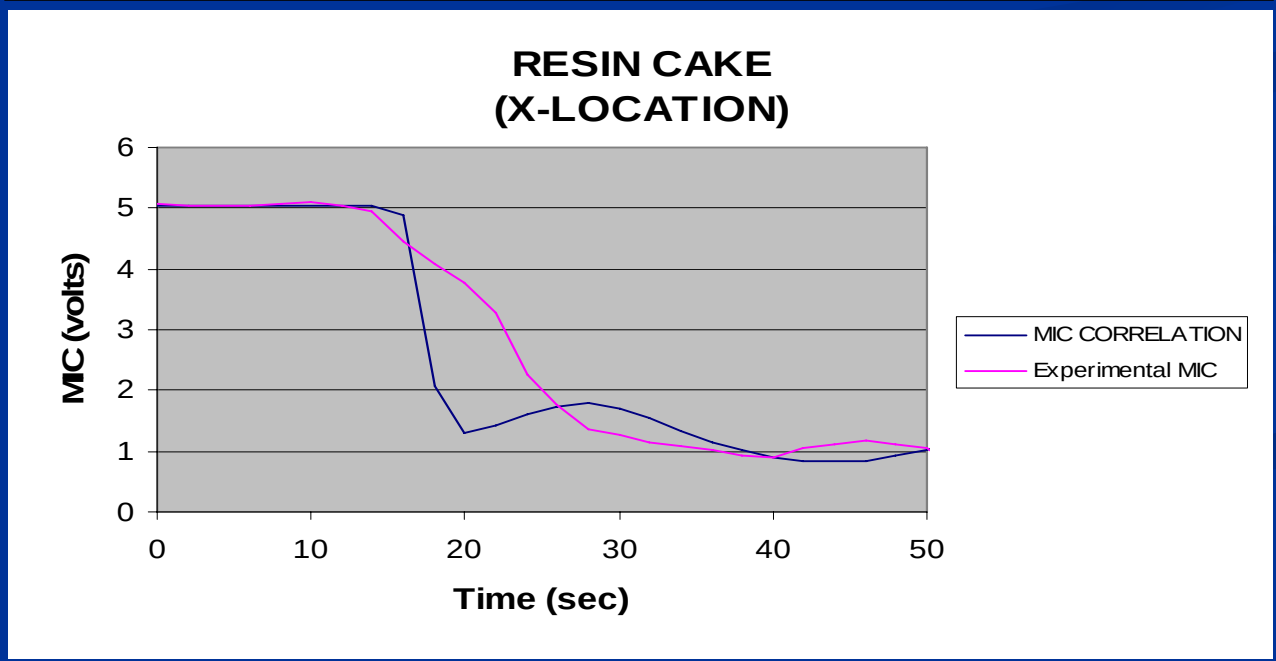




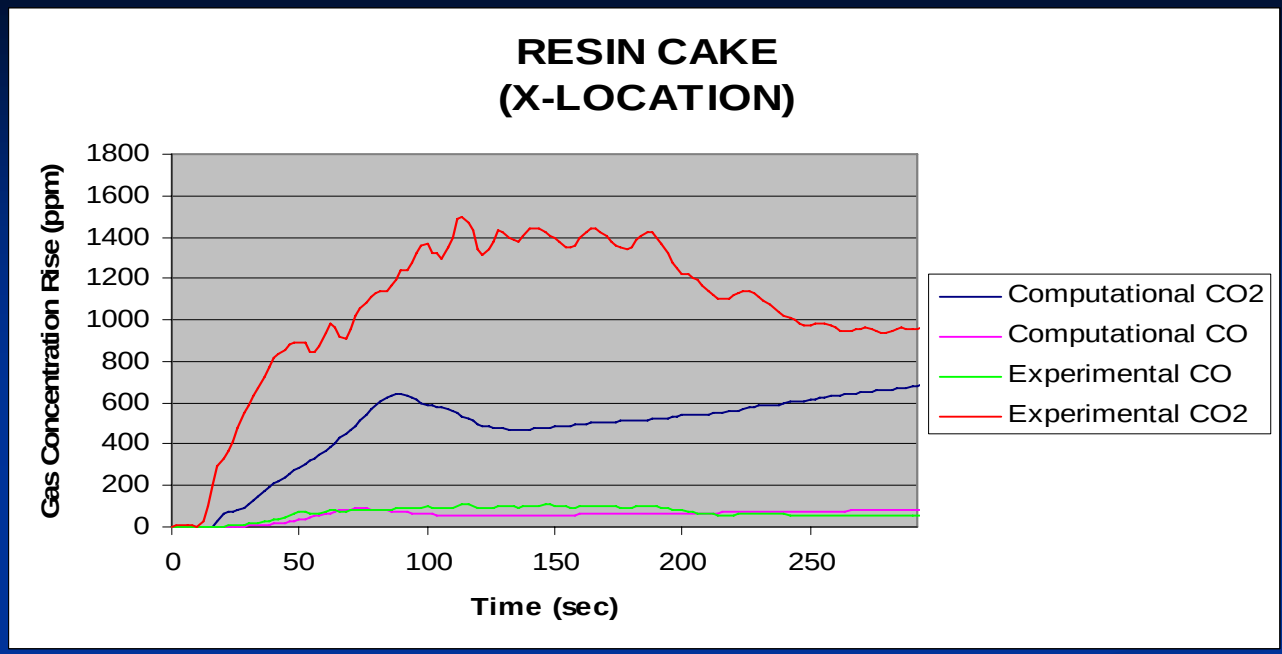
- FAA Smoke Transport Model
  - Sandia National Laboratories
  - Source Terms
    - Volumetric Mass
    - Energy-Heat
  - FORTRAN 77 Mathematical Analyzer
  - Post Processor
    - Light Transmission Data
    - Temperature Data
    - Gas Concentration Data
- Experimental vs. Computational Results
- Resin Cake Common Fire Source
  - Volumetric Mass source term
  - Energy source term (Heat)
- CFD Validation
  - CFD - Eliminate experimental testing
  - CFD - Multi-Sensor Detector range
  - CFD Virtual Detector
- 1 Hour Computational Run-Time for 1 Min Experimental Real-Time

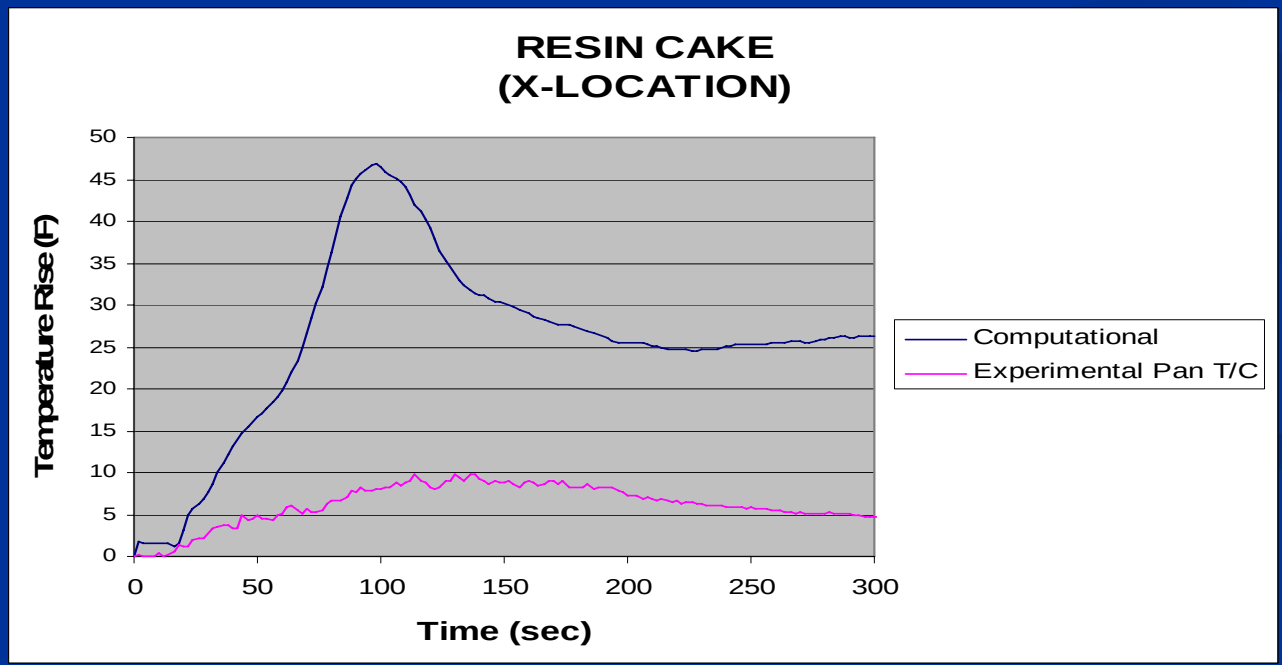
Computational vs. Experimental Results





Computational vs. Experimental Results





Experimental vs. Computational Alarm Time Comparison

TABLE 5.7
ALARM TIMES
(SECONDS)

FIRE SOURCES	ALGORITHM					PHOTOELECTRIC	IONIZATION
	1	2	3	4	5		
EXPERIMENTAL							
Resin Cake (X-Location)	20	18	18	24	14	20	20
PERIMETER TESTING							
Resin Cake (FWD)	70	48	48	50	48	54	84
Resin Cake (AFT)	50	50	50	54	50	50	42
Resin Cake (SIDEWALL)	38	26	26	38	26	36	42
COMPUTATIONAL							
Resin Cake (X-Location)	20	18	18	20	18	18	18
PERIMETER TESTING							
Resin Cake (FWD)	70	52	52	52	50	52	82
Resin Cake (AFT)	50	50	50	50	46	48	48
Resin Cake (SIDEWALL)	28	26	26	28	26	30	34
ALARM TIME COMPARISON							
(Computational vs. Experimental)							
Resin Cake (X-Location)	0	0	0	4	4	2	2
Resin Cake (FWD)	0	4	4	2	2	2	2
Resin Cake (AFT)	0	0	0	4	4	2	6
Resin Cake (SIDEWALL)	10	0	0	10	0	6	8

Alarm Time Comparison and Spatial Distribution Results

- Average alarm time uncertainty between computational and experimental
  - 2.57 seconds
  - 10 second maximum difference
- CFD Validation
  - Smoke Meter, MIC, CO, and alarm time agreement
  - Virtual detector for similar volume cargo compartments
- Multi-Sensor Detector range
  - At least 913 cubic feet (707 FWD Cargo Compartment)
  - Subject to change relative to size of other compartments

Conclusions

- The Multi-Sensor Detector:
  - Complied with Code of Federal Regulations 14 CFR 25.858
    - Alarm within 60 seconds
  - Demonstrated faster response times than current detectors
  - Provided 100% nuisance immunity
  - Yielded a 100% success rate when subjected to 30 different tests
    - 5 Fire Sources
    - 5 Nuisance Sources
  - Provided a range of successful operation of at least 913 ft^3
    - Relative to compartments of similar or lesser volume to 707
- Algorithm 5 most successful
  - Based on CO_2 gas, Temperature, %LT/ft, and MIC
  - Included the Rate of Rise parameter
- Computational Fluid Dynamic Model
  - Successfully simulate fires in compartments of similar volume to 707
  - Accurate virtual detector within Federal Regulation time (60 sec)
    - Average Alarm Time Uncertainty of 2.57 seconds

Recommendations

- Multi-Sensor Detector
  - Experimentation with a wider distribution of fire and nuisance sources
    - Larger matrix for improved algorithm development
  - Detector Manufacturing
    - Packaging
    - Dimensions
    - Total Cost (all 4 sensors)
  - More Gas Sensors
    - Total Hydrocarbons
    - Water Vapor
- Computational Fluid Dynamic Model
  - Improve Temperature data
  - Improve CO2 gas concentration data
  - Improve computational run-time to experimental real-time ratio

Acknowledgements

- Rutgers Mechanical and Aerospace Engineering Dept.
  - Dr. Tobias Rossmann (Advisor)
  - Dr. Constantine Polymeropolous (Co-Advisor)
- FAA Fire Safety Branch
  - Richard G. Hill (Director)
  - Gus Sarkos (Director)
  - Dave Blake (Engineering Mentor)
  - Rick Whedbee (Chief Technician)
  - Frank Gibbons (Technician)
  - Mark Materio (Technician)
- Family and Friends

QUESTIONS ?

APPENDIX

TABLE 5.1
EXTREME DETECTOR LEVELS

	MIC	Rate-Rise	Smoke Meter	Rate-Rise	CO	Rate of	CO2	Rate of	Temp.	Temp.
	(Volts)	(Volts/sec)	(%LT/Ft)	%LT/ft/sec	(ppm)	Rise CO	(ppm)	Rise CO2	Change (°F)	Rate of Rise
REFERENCE SOURCE										
Resin Cake (X-Location)	0.589	-0.522	48.743	-3.036	108.889	4.580	1497.116	49.026	9.831	0.815
PERIMETER TESTING										
Resin Cake (FWD)	0.583	-0.246	59.959	-1.522	86.243	3.571	1076.050	34.180	3.831	0.312
Resin Cake (AFT)	0.447	-0.340	55.755	-0.010	88.763	2.369	997.473	58.431	6.782	0.302
Resin Cake (SIDEWALL)	0.691	-0.391	53.372	-2.722	94.696	2.777	1245.117	24.185	5.352	0.332
NUISANCE SOURCE										
(X-LOCATION)										
Arizona Test Dust (Container)	2.801	-0.694	91.276	-1.798	0.088	0.047	0.135	0.078	0.037	0.018
Vaporizer (Fog Formation)	4.822	-0.029	41.823	-4.653	0.107	0.076	5.231	0.619	2.159	0.289
Exhaust Fumes (Forklift Loading)	4.845	-0.046	94.126	-0.149	493.172	45.242	712.394	55.237	0.294	0.137
Heat Gun (Heated Container)	1.854	-0.262	49.049	-3.982	0.274	0.106	0.539	0.144	22.967	0.889
Occupied Compartment (Human)	4.850	-0.023	98.966	-0.029	0.095	0.024	307.159	23.041	0.087	0.026
PERIMETER TESTING										
Arizona Test Dust (Under Pan)	2.705	-0.713	70.513	-10.582	0.045	0.028	0.103	0.087	0.046	0.031
Arizona Test Dust (2 Feet)	3.110	-0.665	60.638	-19.684	0.045	0.028	0.103	0.087	0.046	0.031
Arizona Test Dust (4 Feet)	4.990	-0.038	97.366	-1.308	0.045	0.028	0.103	0.087	0.046	0.031

TABLE 5.2

EXTREME DETECTOR LEVELS

FIRE SOURCES	MIC (Volts)	Rate-Rise (Volts/sec)	Smoke Meter (%LT/Ft)	Rate-Rise %LT/ft/sec	CO (ppm)	Rate of Rise CO	CO2 (ppm)	Rate of Rise CO2	Temp. Change (°F)	Temp. Rate of Rise
(X-LOCATION)										
FLAMING Sources										
Denatured Alcohol (40mL)	4.552	-0.038	86.089	-1.239	1.624	0.119	1831.611	99.377	13.154	0.529
Alcohol Soaked Rags	1.430	-0.322	83.655	-1.184	14.191	1.428	1880.348	110.544	14.674	1.016
Polyurethane Foam	1.390	-0.736	91.385	-0.702	15.128	2.211	2098.261	321.620	23.051	2.844
SMOLDERING Sources										
Shredded Newspaper	1.491	-0.497	51.799	-2.808	171.324	24.803	1994.328	276.974	33.145	2.398
Suitcase	1.965	-0.103	64.367	-1.744	372.643	10.697	346.922	9.406	1.423	0.095
PERIMETER TESTING										
Alcohol Soaked Rags (Average)	1.341	-0.257	95.627	-0.195	21.074	1.508	1885.504	83.748	4.619	0.117
Polyurethane Foam (Average)	1.216	-0.247	94.604	-0.373	6.703	0.779	2070.223	192.934	5.699	0.200
Shredded Newspaper (Average)	0.785	-0.695	72.410	-2.449	157.376	19.125	1912.648	214.622	13.945	0.391
Alcohol Soaked Rags (FWD)	1.370	-0.271	96.955	-0.279	2426.186	112.548	1678.543	50.625	3.659	0.166
Polyurethane Foam (FWD)	1.278	-0.501	92.476	-0.754	1011.260	157.490	2044.346	385.902	5.910	0.276
Shredded Newspaper (FWD)	0.497	-0.990	74.829	-1.475	1194.612	140.035	1764.622	369.124	12.777	0.670
Alcohol Soaked Rags (AFT)	1.198	-0.287	90.787	-0.512	1385.884	172.563	2032.288	46.734	5.055	0.139
Polyurethane Foam (AFT)	1.074	-0.431	94.169	-0.375	838.361	43.948	2096.167	124.795	6.656	0.225
Shredded Newspaper (AFT)	0.942	-0.745	69.521	-3.422	1952.917	367.176	2060.719	429.367	15.327	0.651

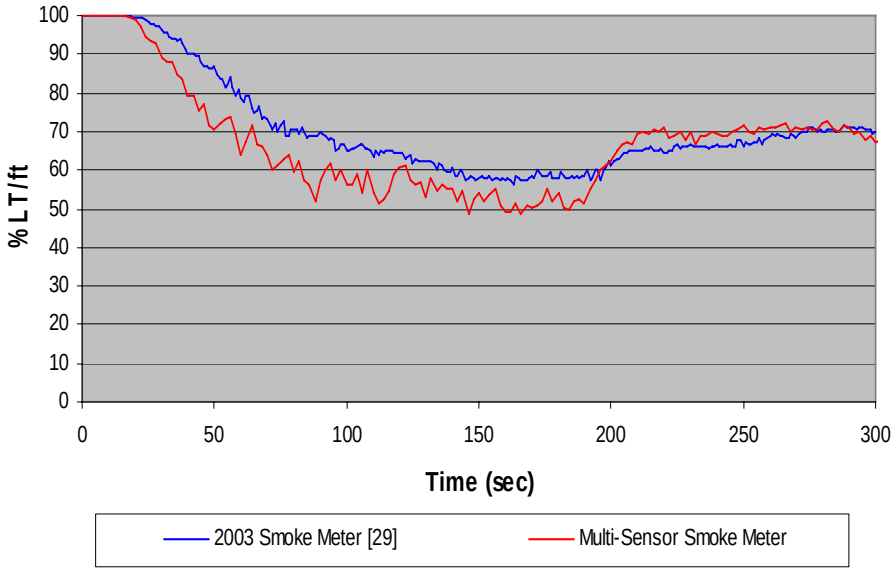
TABLE 5.3
ALARM TIMES
(SECONDS)

	ALGORITHM					PHOTOELECTRIC	IONIZATION
	1	2	3	4	5		
REFERENCE SOURCE							
Resin Cake (X-Location)	20	18	18	24	14	20	20
PERIMETER TESTING							
Resin Cake (FWD)	70	48	48	50	48	54	84
Resin Cake (AFT)	50	50	50	54	50	50	42
Resin Cake (SIDEWALL)	38	26	26	38	26	36	42
NUISANCE SOURCE (X-LOCATION)							
Arizona Test Dust (Container)	X	X	X	X	X	6	8
Vaporizer (Fog Formation)	X	X	X	X	X	8	X
Exhaust Fumes (Forklift Loading)	X	X	X	X	X	70	X
Heat Gun (Heated Container)	X	X	X	X	X	30	18
Occupied Compartment (Human)	X	X	X	X	X	X	X
PERIMETER TESTING							
Arizona Test Dust (Under Pan)	X	X	X	X	X	6	8
Arizona Test Dust (2 Feet)	X	X	X	X	X	6	8
Arizona Test Dust (4 Feet)	X	X	X	X	X	X	X

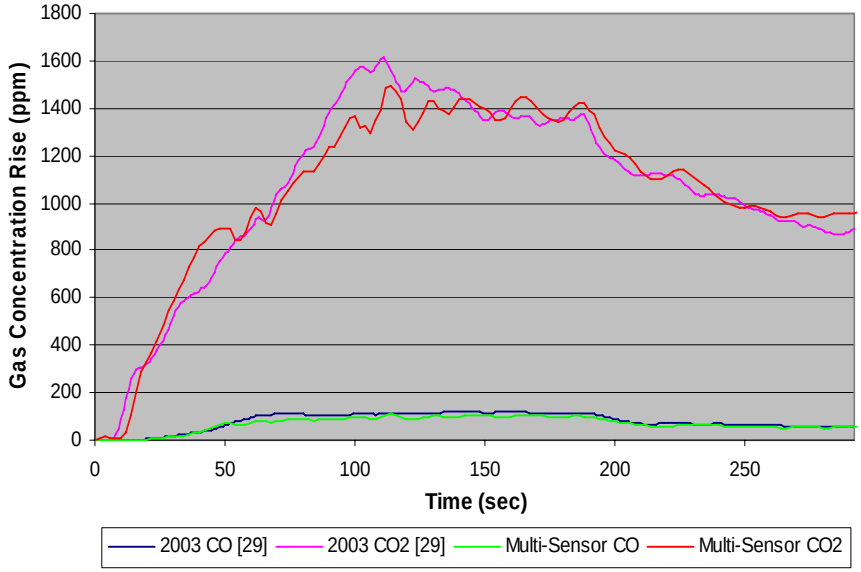
TABLE 5.4
ALARM TIMES
(SECONDS)

FIRE SOURCES	ALGORITHM					PHOTOELECTRIC	IONIZATION
	1	2	3	4	5		
(X-LOCATION)							
FLAMING Sources							
Denatured Alcohol (40mL)	114	20	80	X	14	118	X
Alcohol Soaked Rags	22	14	14	18	14	32	14
Polyurethane Foam	12	12	12	14	10	38	10
SMOLDERING Sources							
Shredded Newspaper	20	16	16	18	16	20	18
Suitcase	60	44	44	46	44	62	126
PERIMETER TESTING							
Alcohol Soaked Rags (Average)	28	32	32	36	30	214	34
Polyurethane Foam (Average)	34	24	24	28	18	38	22
Shredded Newspaper (Average)	32	28	28	32	28	34	22
Alcohol Soaked Rags (FWD)	202	30	30	34	30	X	34
Polyurethane Foam (FWD)	24	24	24	28	22	22	20
Shredded Newspaper (FWD)	38	38	38	40	38	34	36
Alcohol Soaked Rags (AFT)	48	36	34	36	32	50	46
Polyurethane Foam (AFT)	46	40	40	46	34	52	36
Shredded Newspaper (AFT)	46	28	28	30	28	48	22

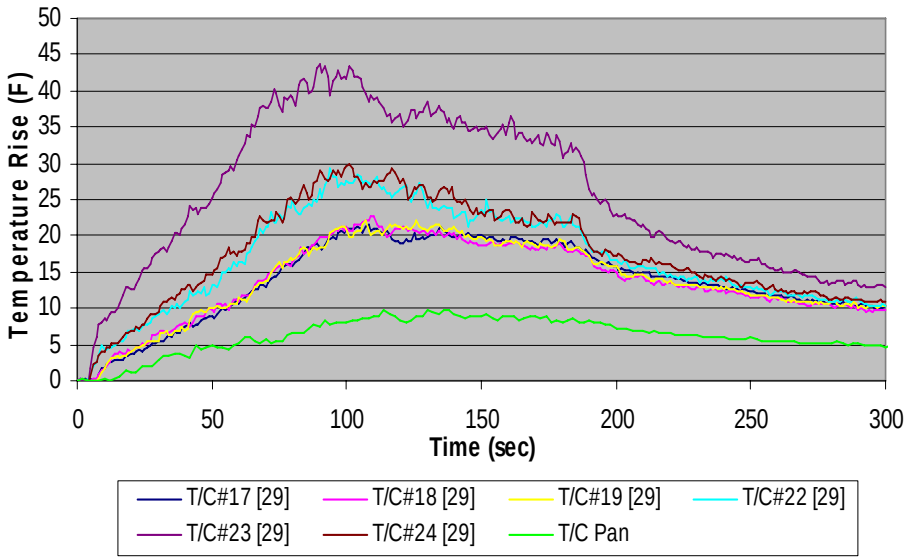
RESIN CAKE
(X-LOCATION)



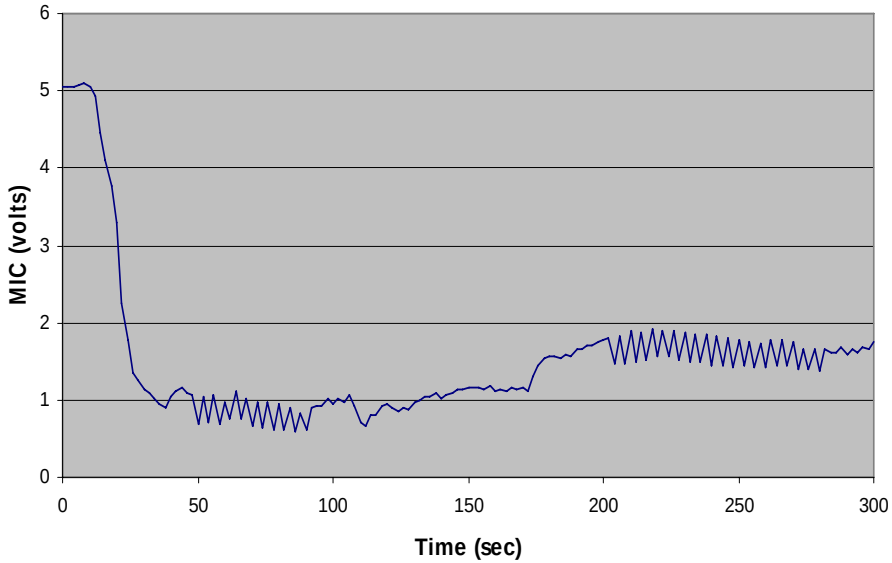
RESIN CAKE
(X-LOCATION)



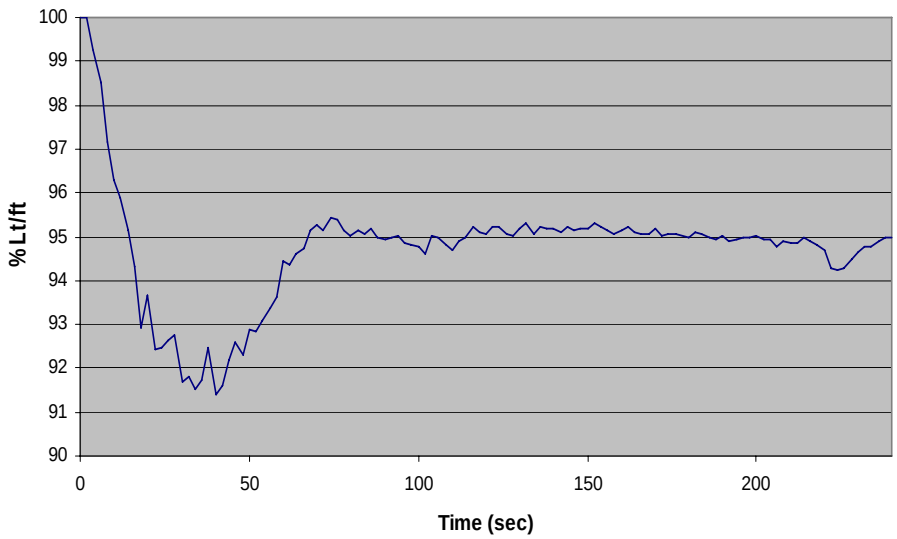
RESIN CAKE
(X-LOCATION)



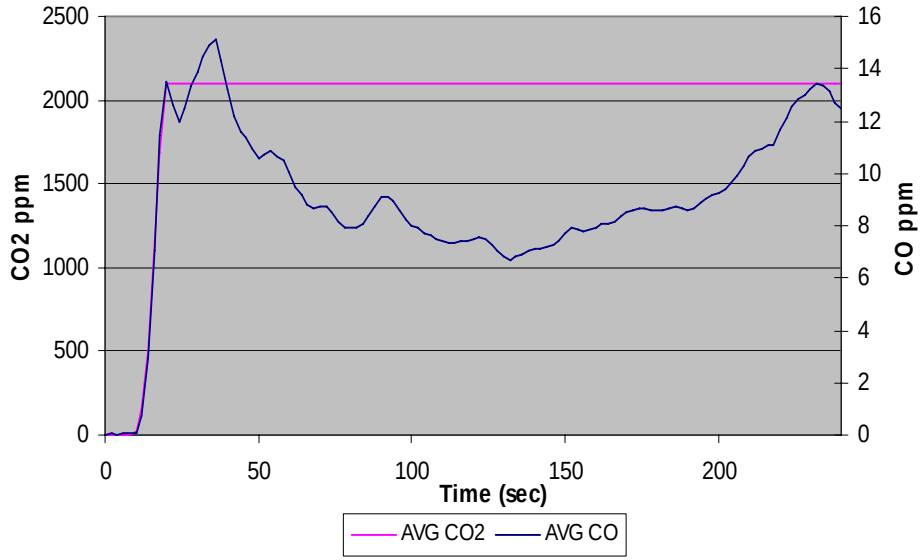
RESIN CAKE
(X-LOCATION)



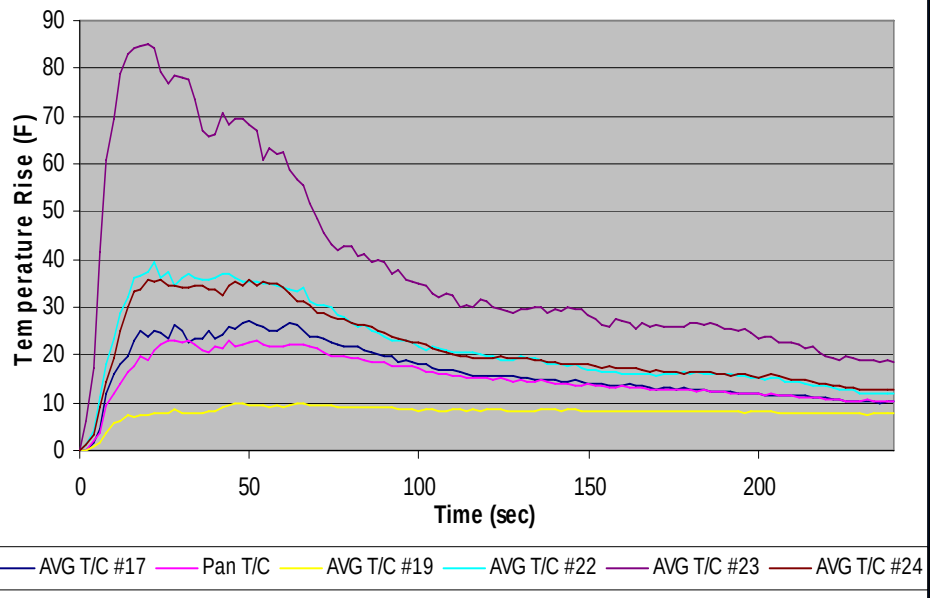
POLYURETHANE FOAM (X-LOCATION)



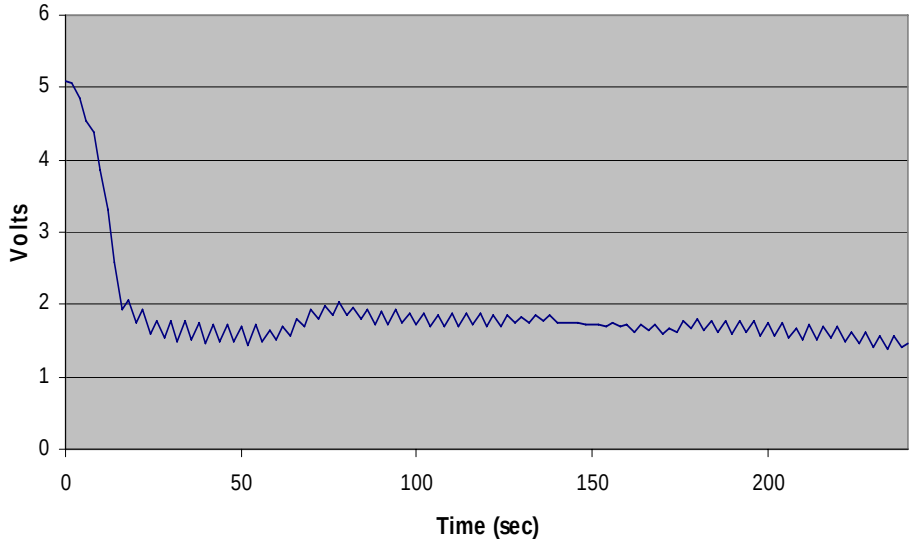
POLYURETHANE FOAM (X-LOCATION)

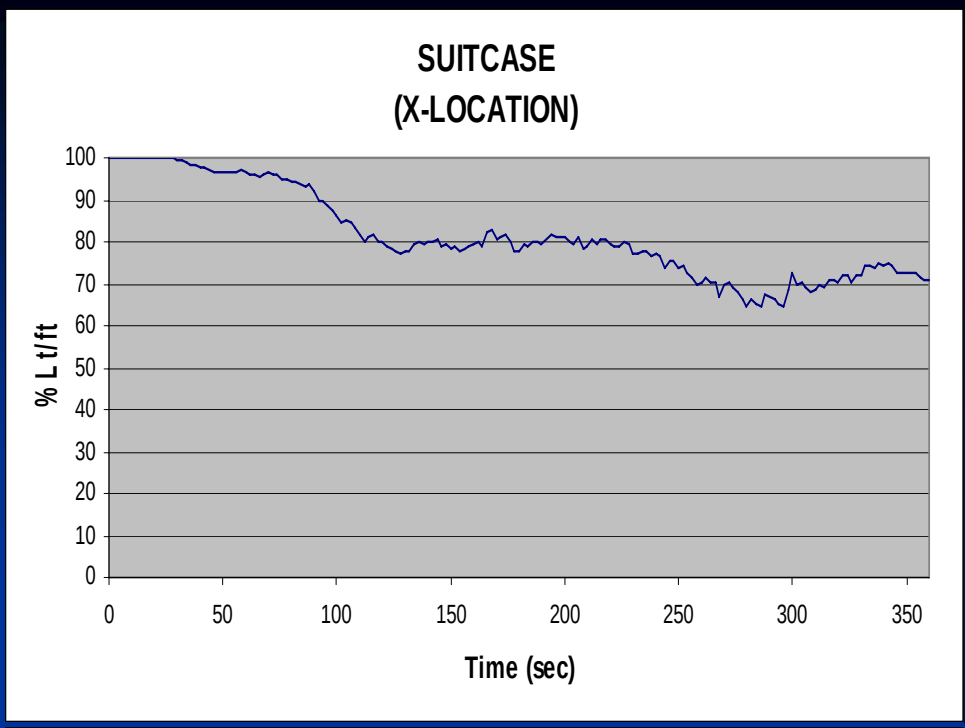


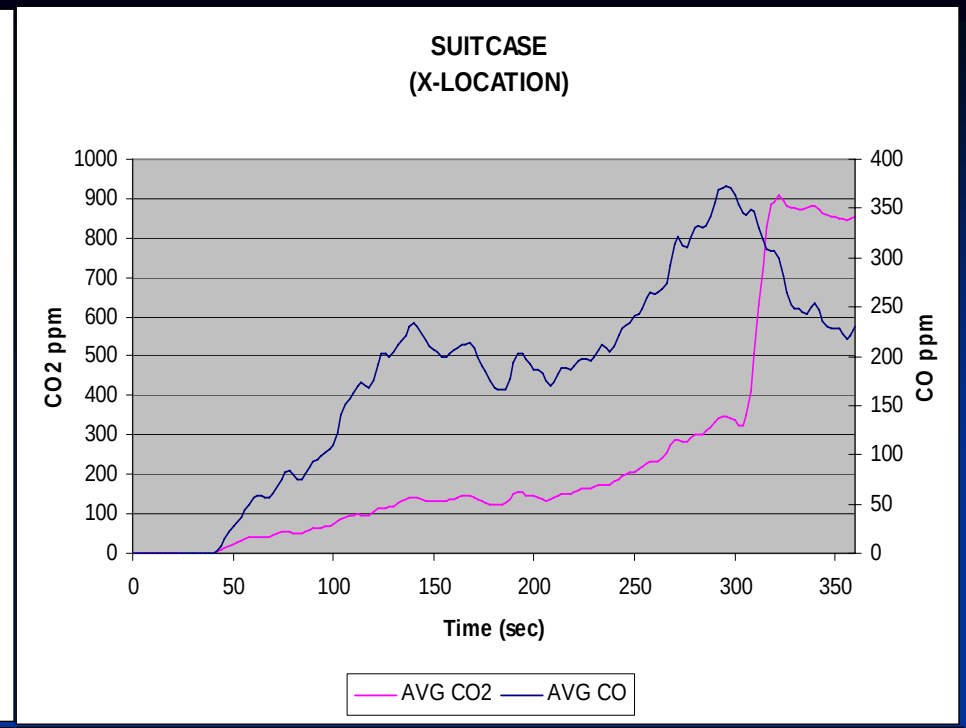
POLYURETHANE FOAM (X-LOCATION)

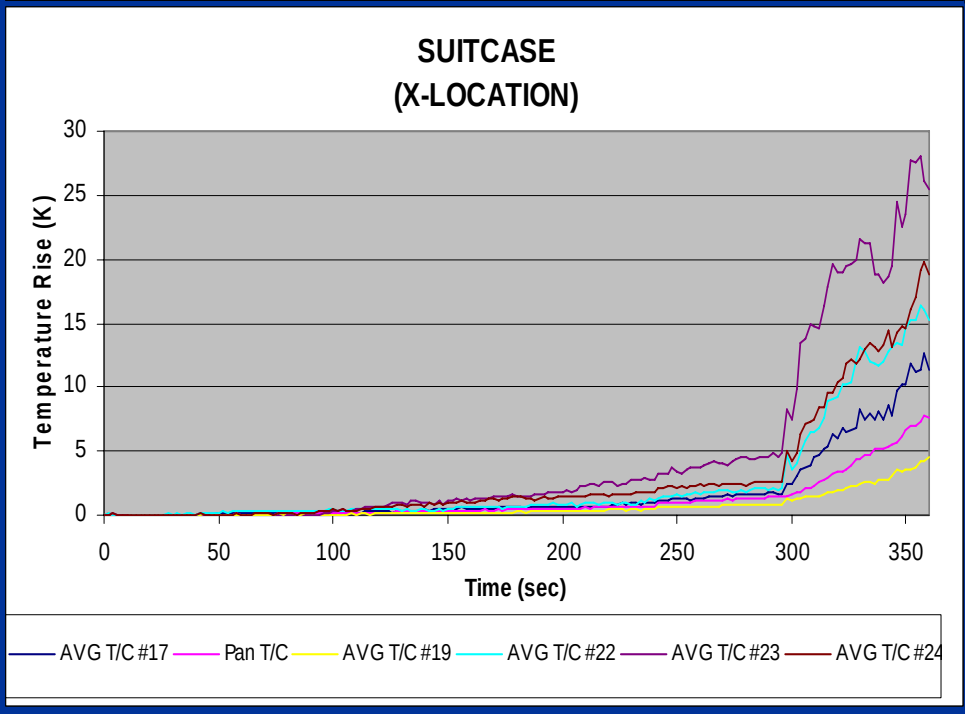


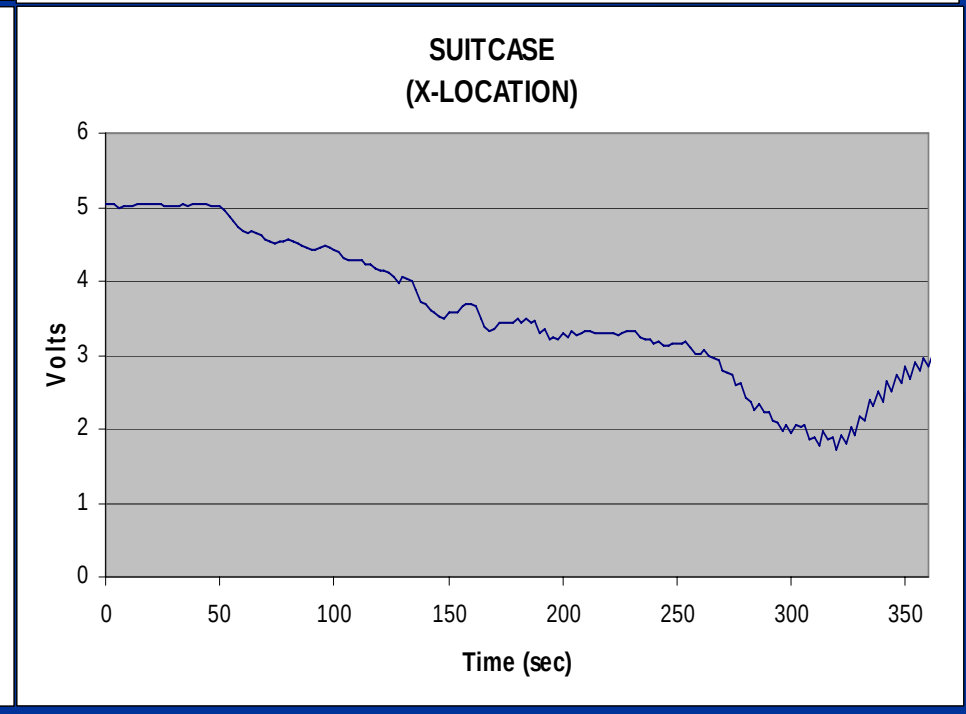
POLYURETHANE FOAM (X-LOCATION)



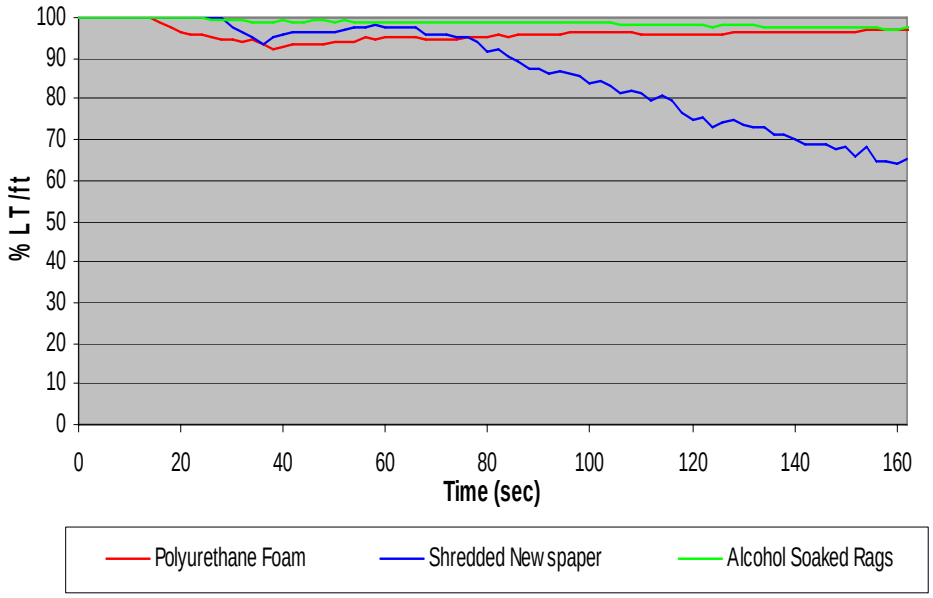

SUITCASE
(X-LOCATION)
% L t/ft
Time (sec)


SUITCASE
(X-LOCATION)
CO2 ppm
CO ppm
Time (sec)
AVG CO2
AVG CO

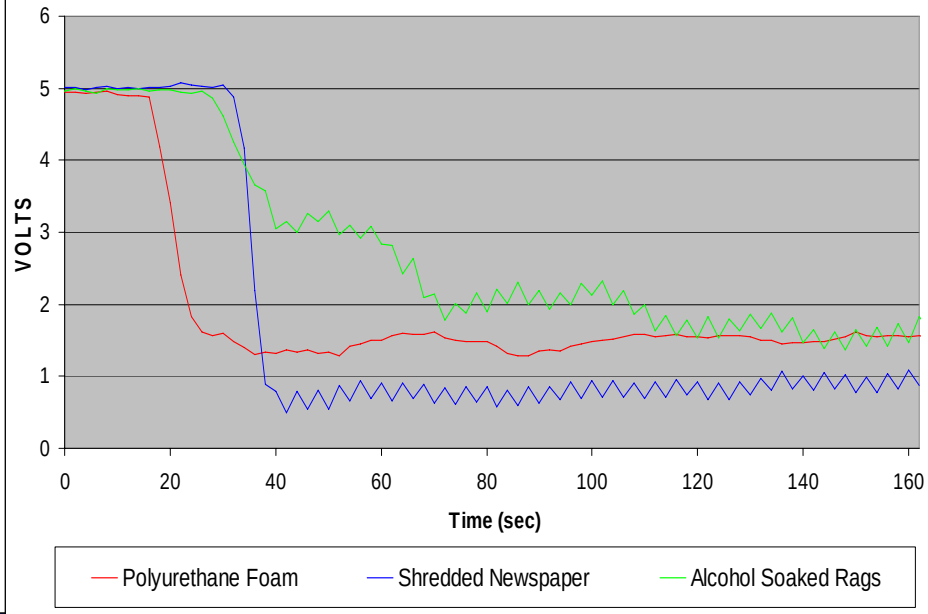

SUITCASE
(X-LOCATION)
Temperature Rise (K)
Time (sec)
AVG T/C #17
Pan T/C
AVG T/C #19
AVG T/C #22
AVG T/C #23
AVG T/C #24


SUITCASE
(X-LOCATION)
Volts
Time (sec)

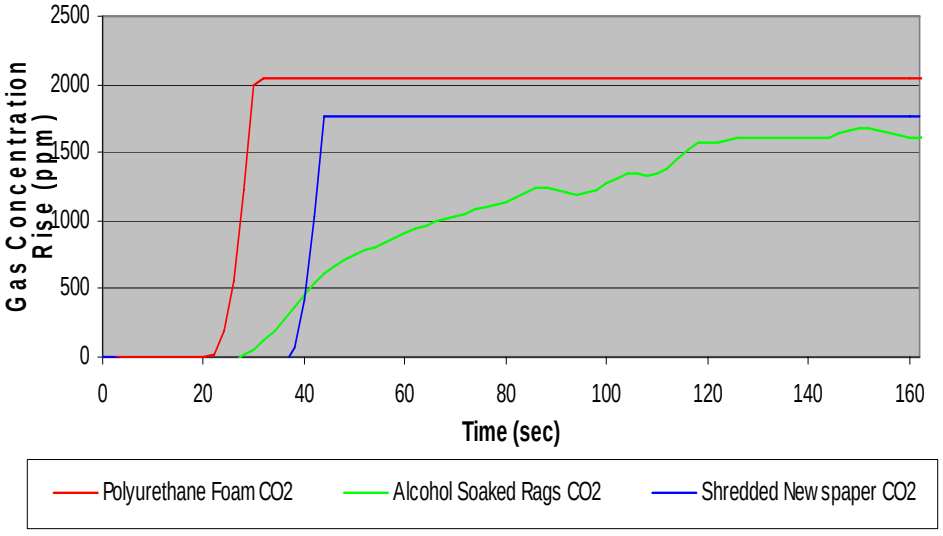
SMOKE METER
Forward Starboard Corner



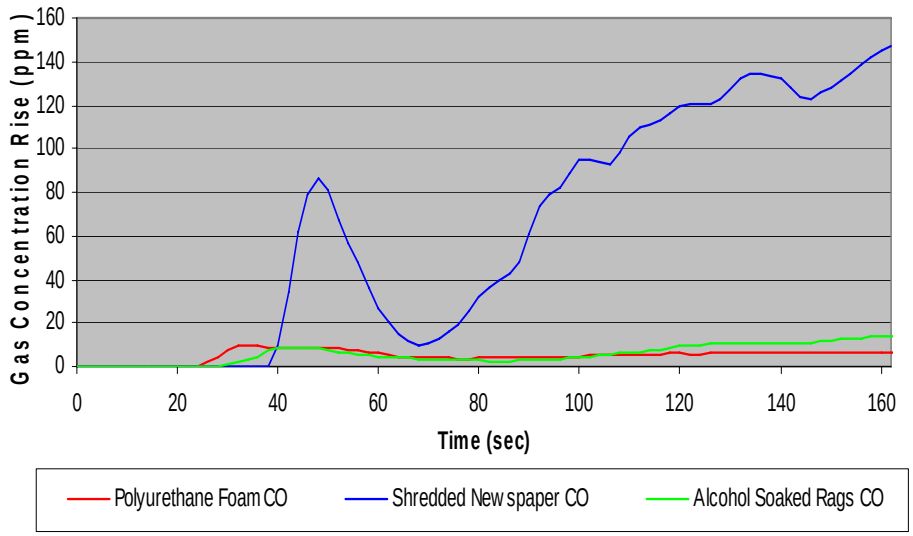
MEASURING IONIZATION CHAMBER
Forward Starboard Corner



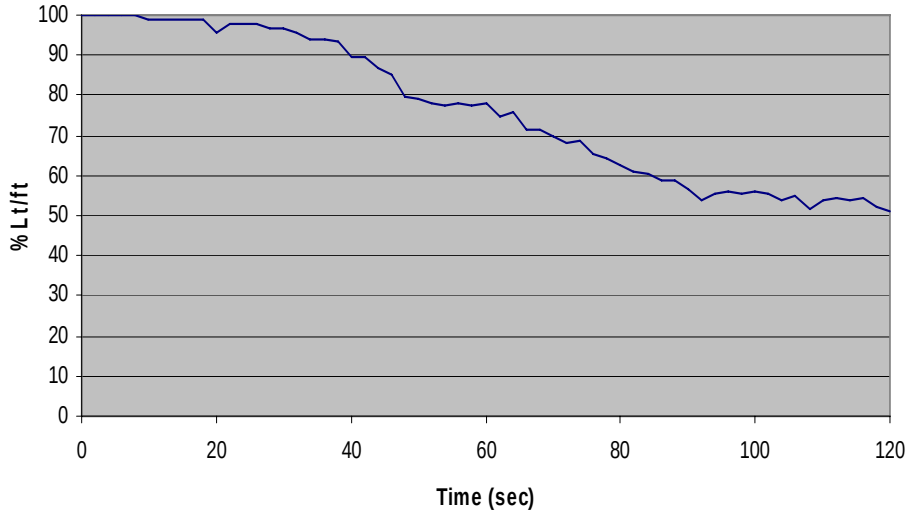
CO_2 GAS PROBE
Forward Starboard Corner



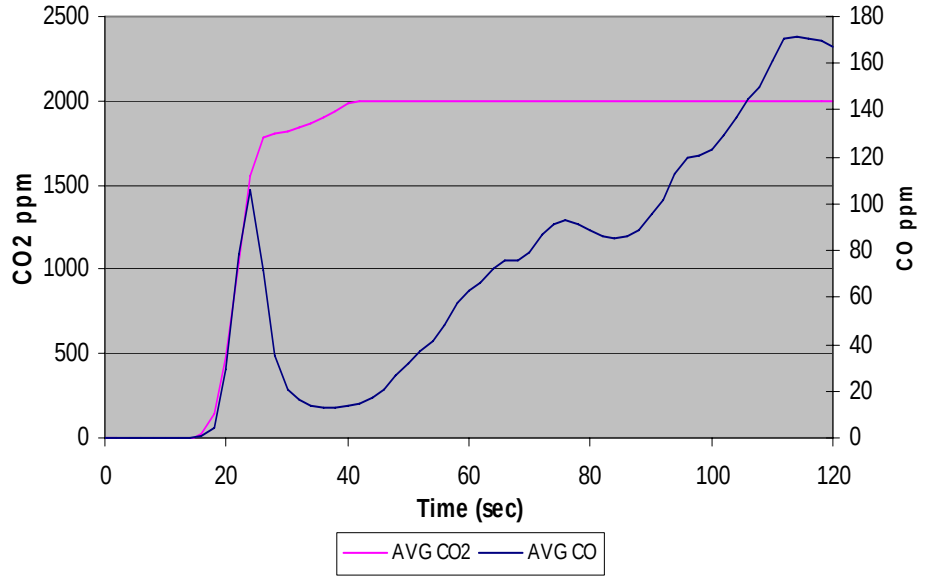
CO GAS PROBE
Forward Starboard Corner



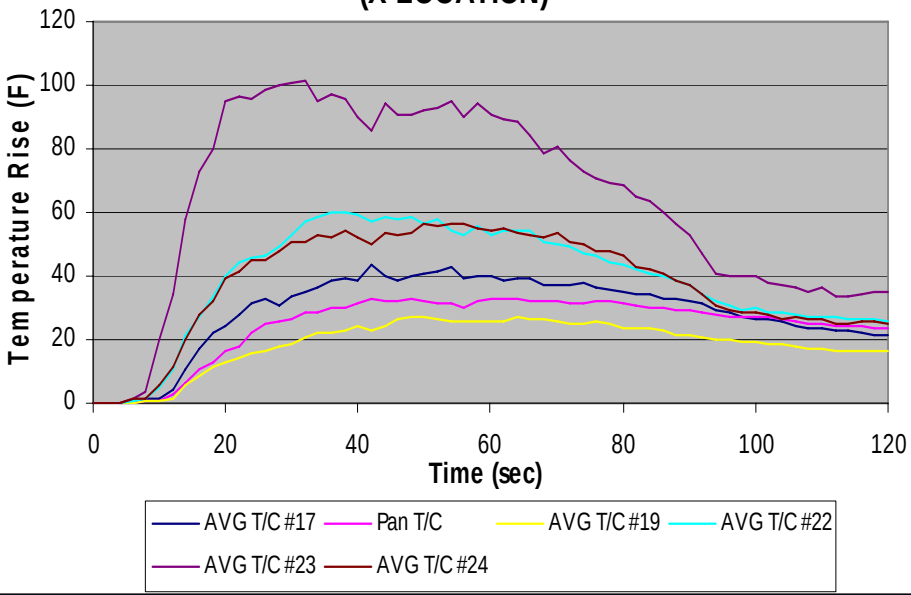
SHREDDED NEWSPAPER (X-LOCATION)



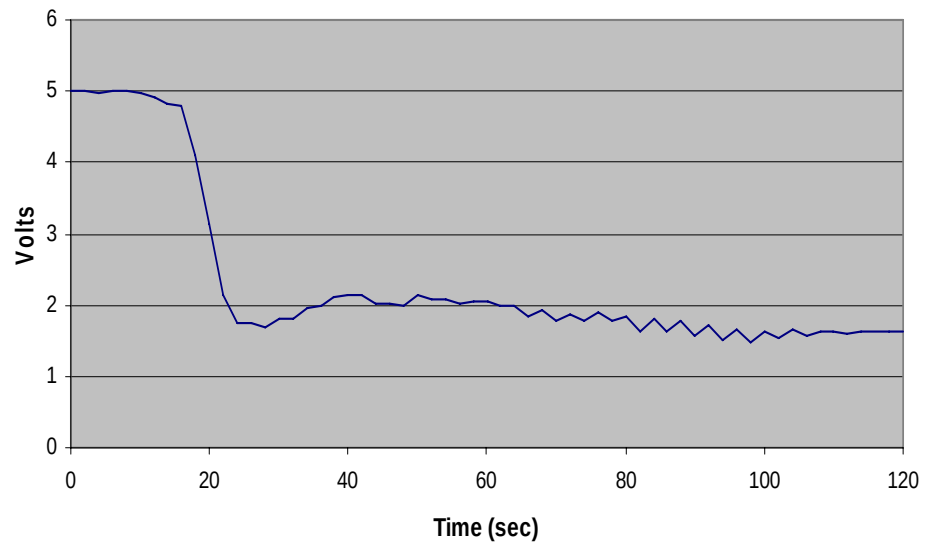
SHREDDED NEWSPAPER (X-LOCATION)

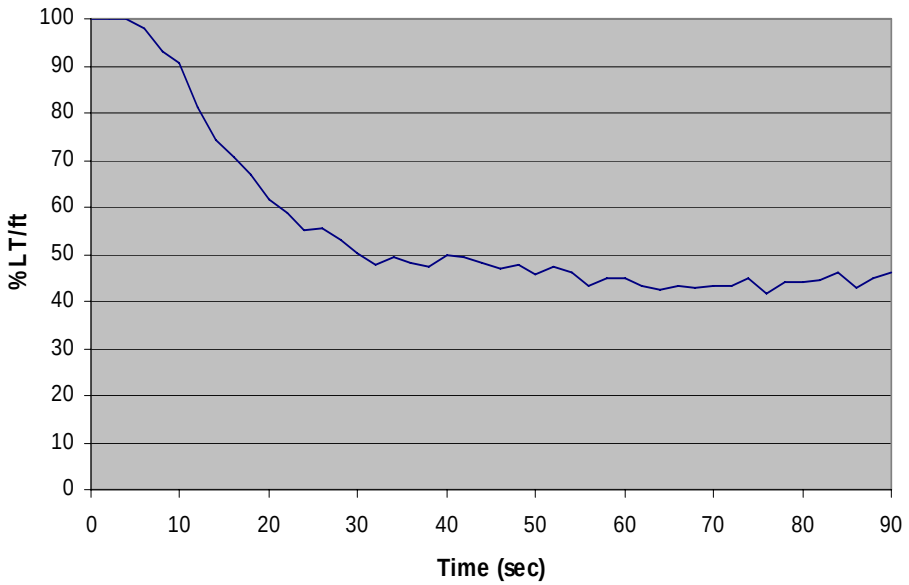


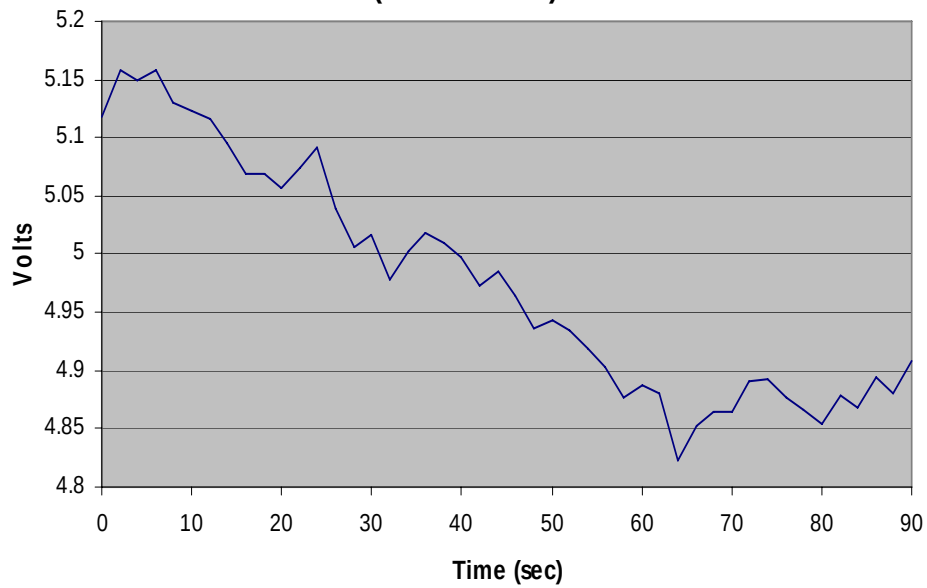
SHREDDED NEWSPAPER (X-LOCATION)

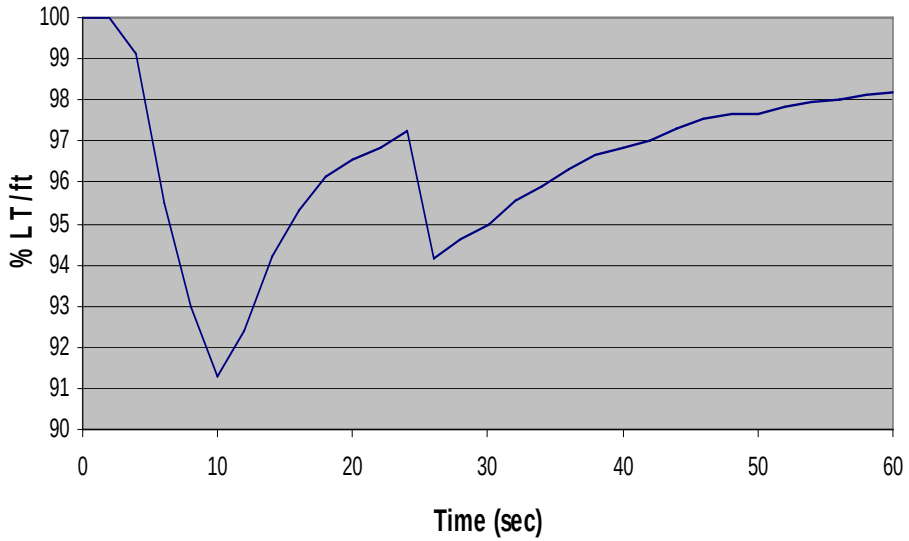


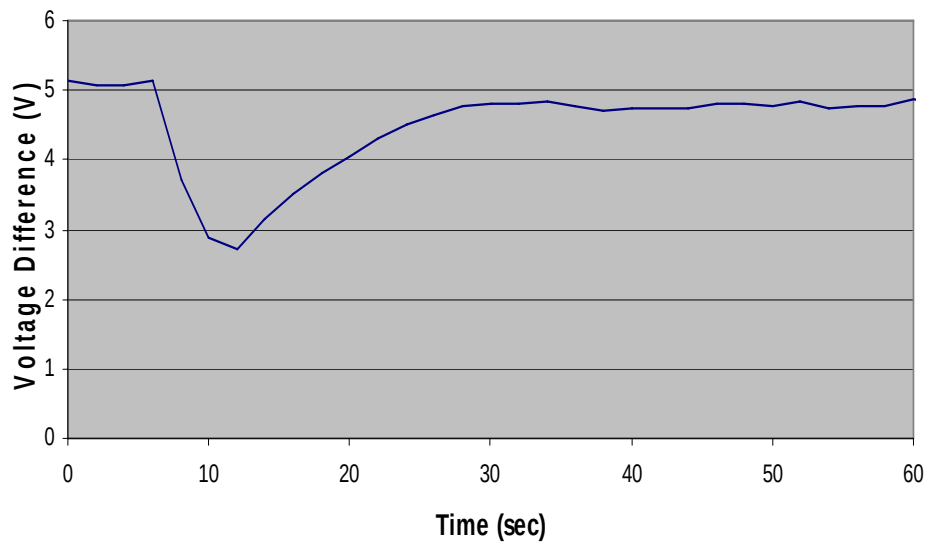
SHREDDED NEWSPAPER (X-LOCATION)



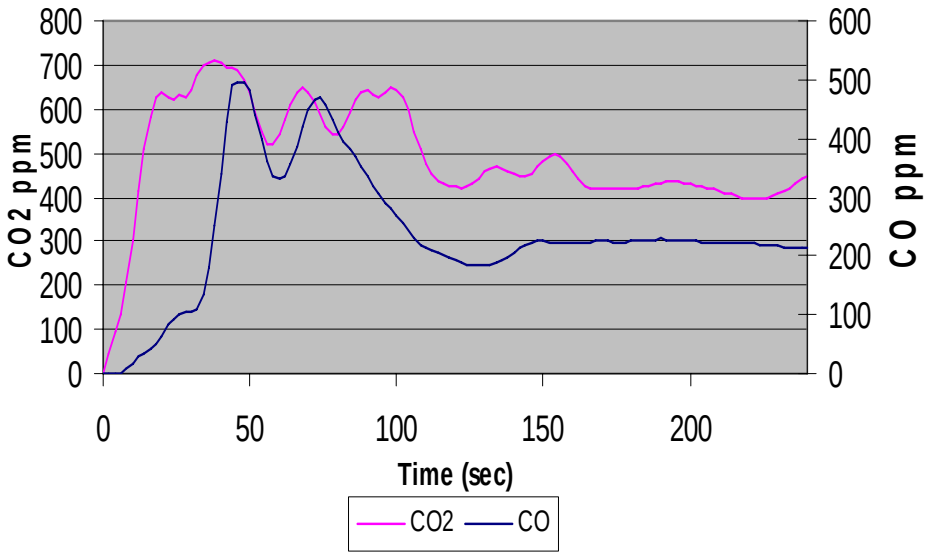

VAPORIZER
(X-LOCATION)
% L T/ft
100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
Time (sec)


VAPORIZER
(X-LOCATION)
Volts
5.2
5.15
5.1
5.05
5
4.95
4.9
4.85
4.8
0
10
20
30
40
50
60
70
80
90
Time (sec)

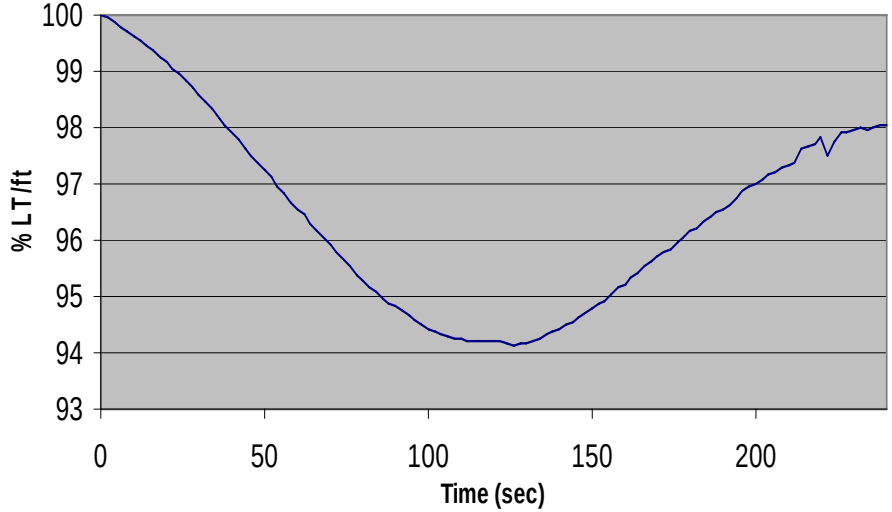

ARIZONA TEST DUST
(X-LOCATION)
% L T/ft
100
99
98
97
96
95
94
93
92
91
90
0
10
20
30
40
50
60
Time (sec)


ARIZONA TEST DUST
(X-LOCATION)
Voltage Difference (V)
6
5
4
3
2
1
0
0
10
20
30
40
50
60
Time (sec)

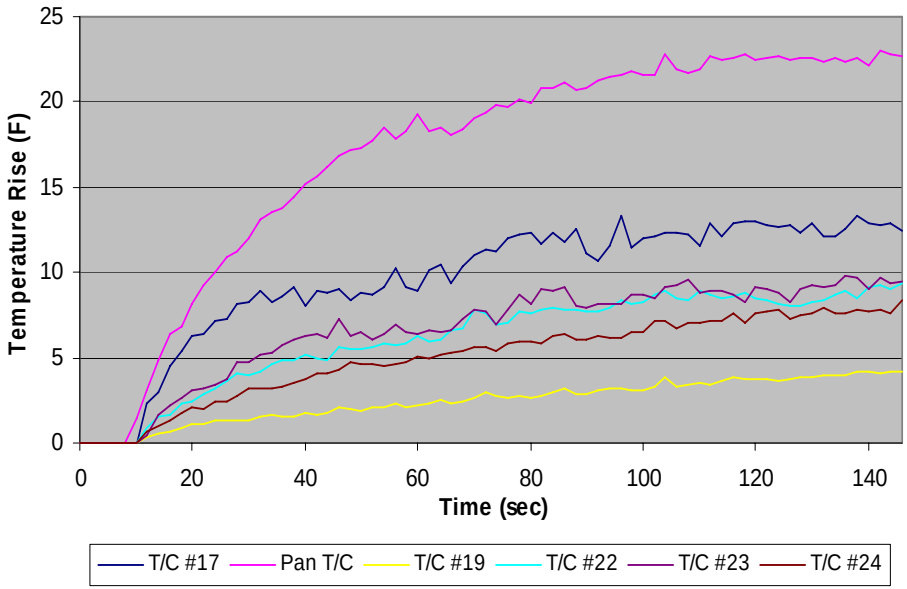
EXHAUST FUMES (X-LOCATION)



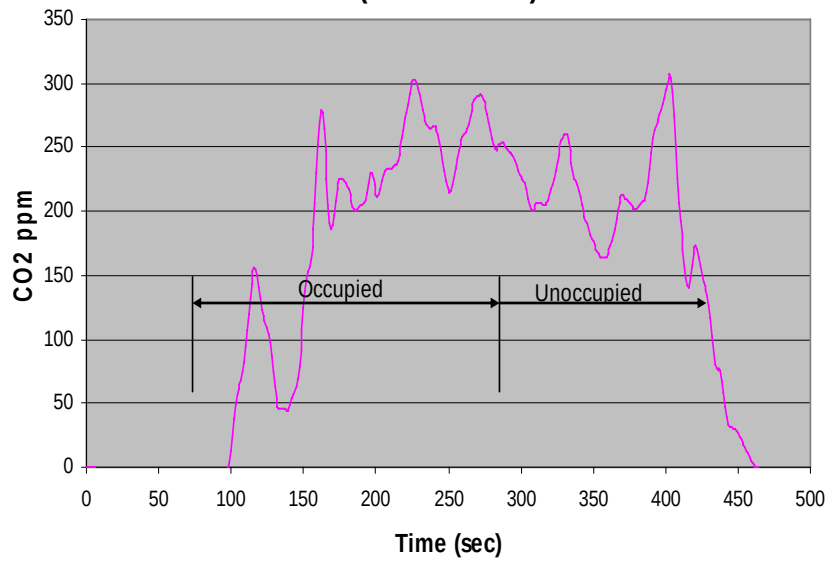
EXHAUST FUMES (X-LOCATION)



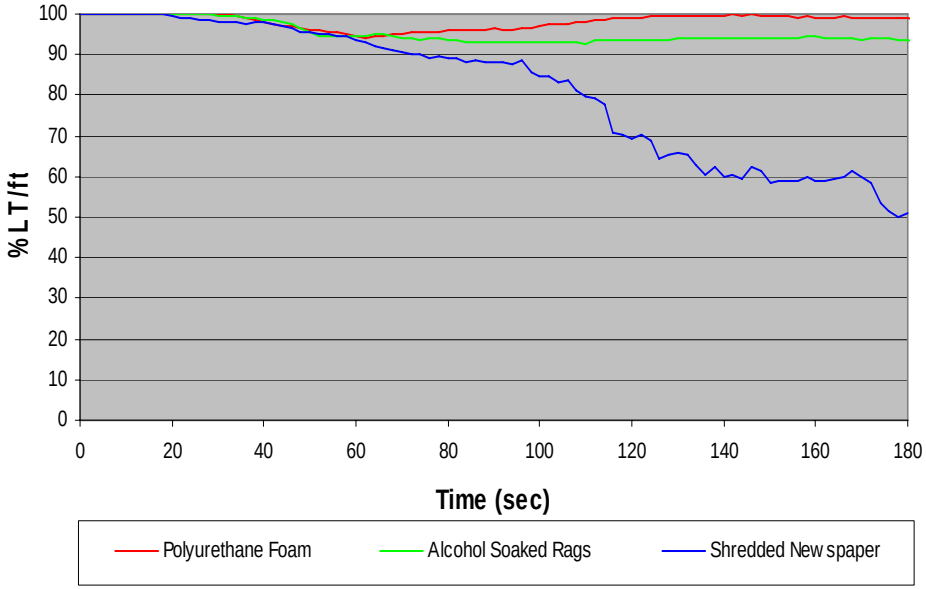
HEAT GUN (X-LOCATION)



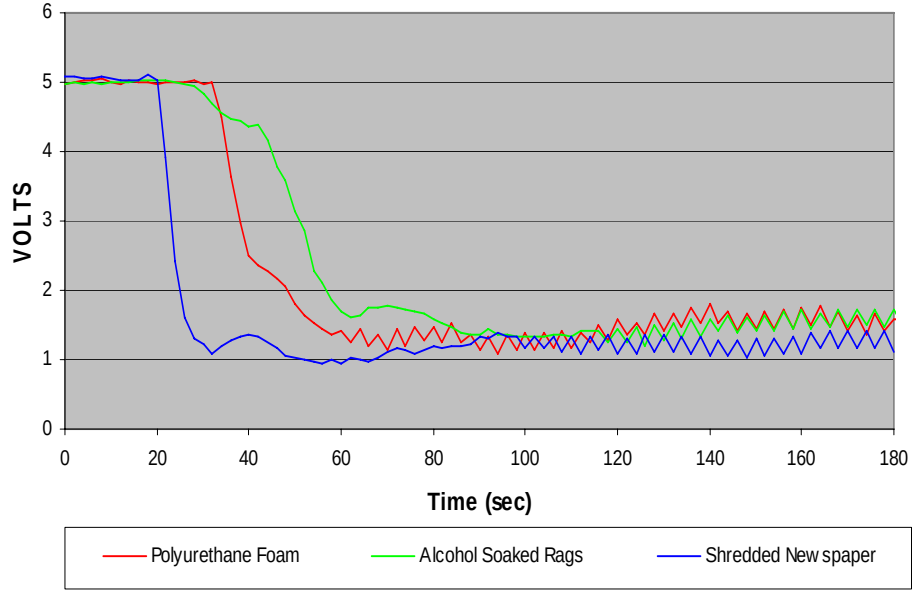
HUMAN CO2 PRODUCTION (X-LOCATION)



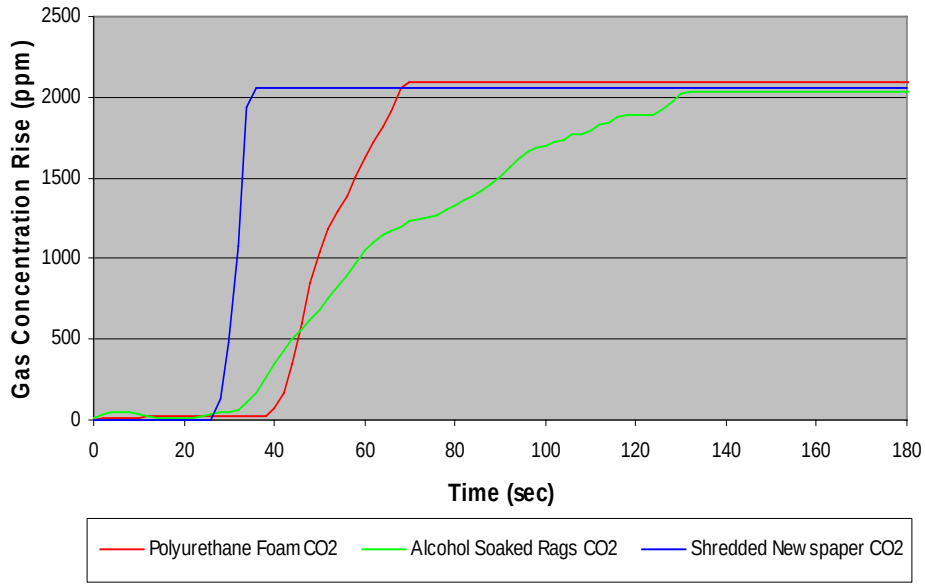
SMOKE METER
AFT Starboard Corner



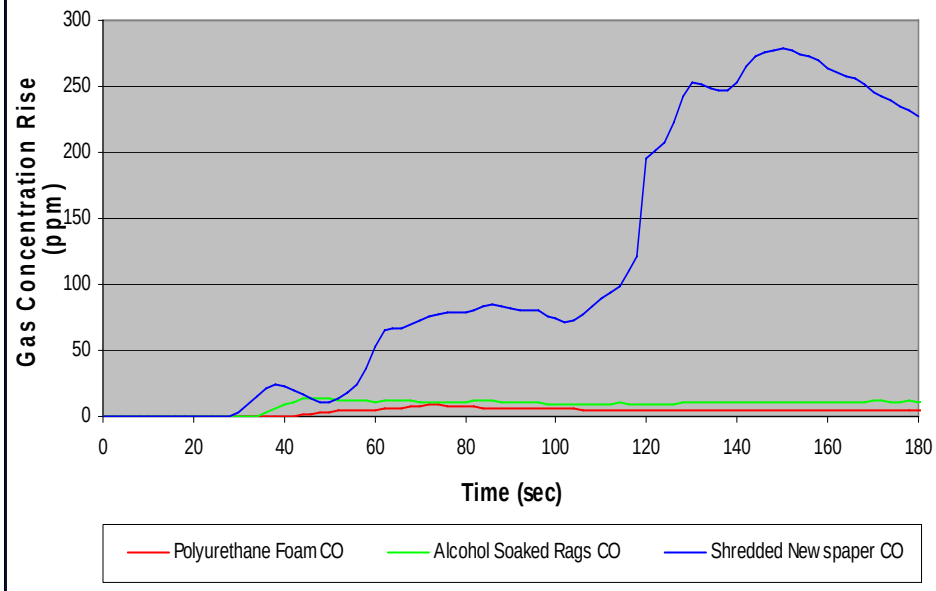
MEASURING IONIZATION CHAMBER
AFT Starboard Corner

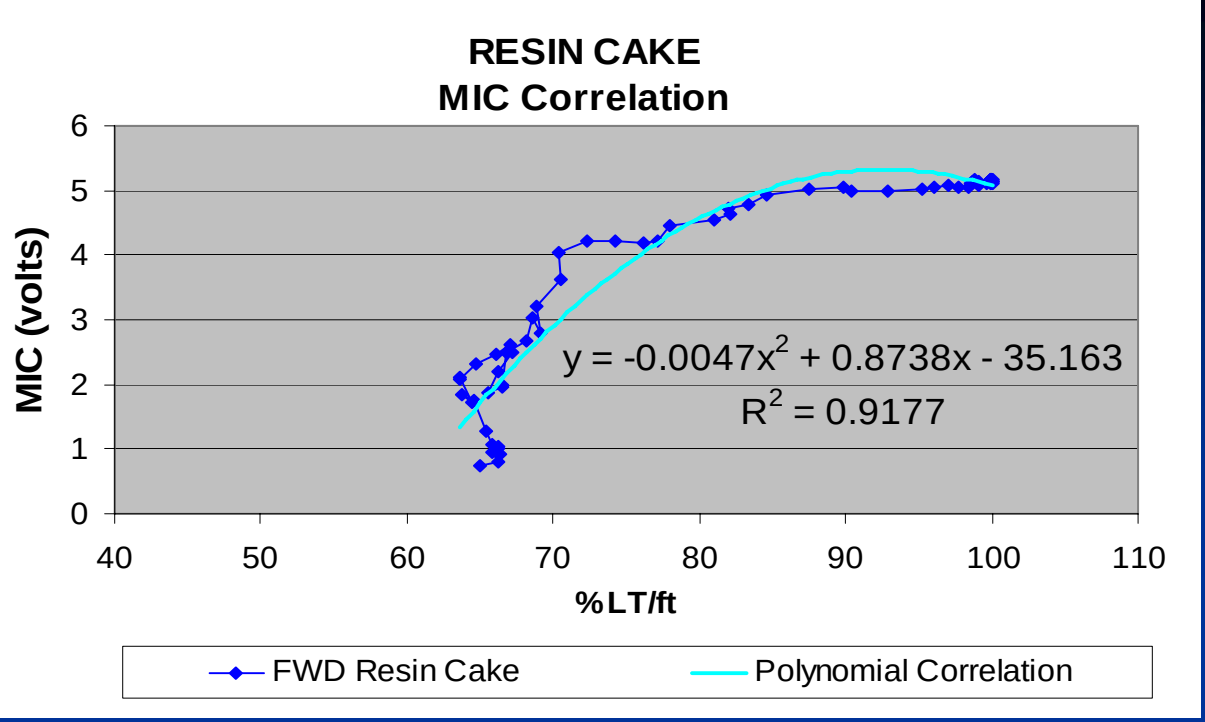


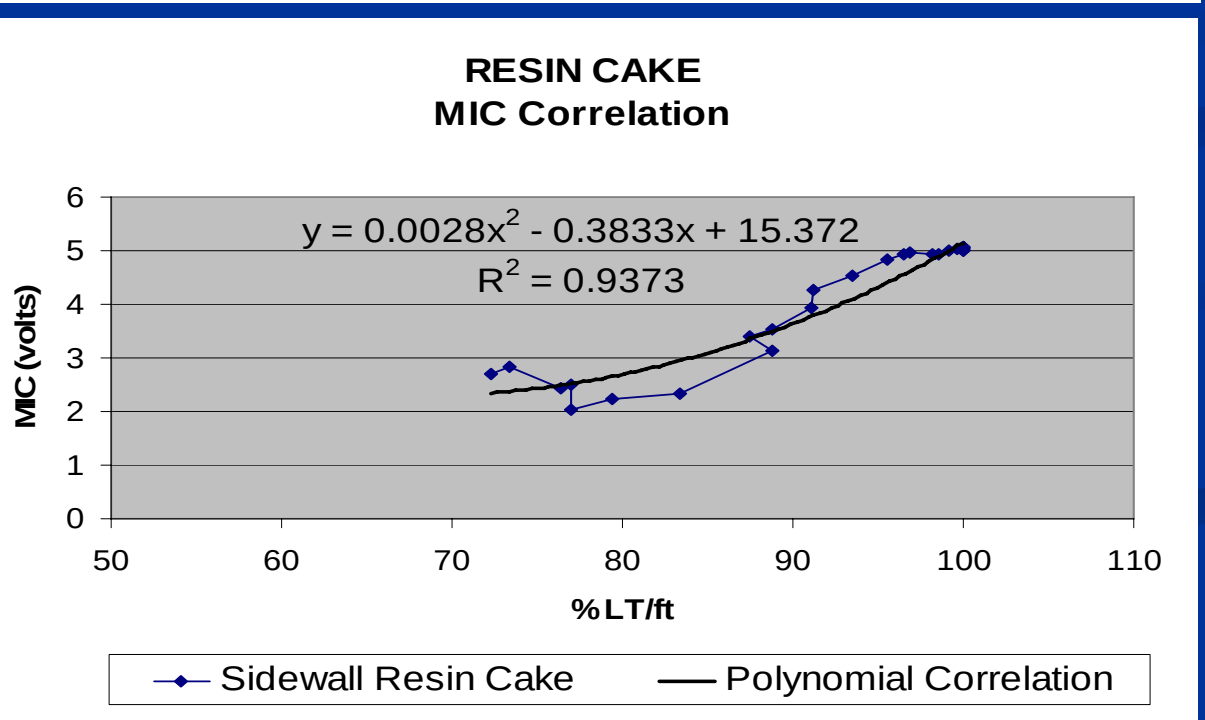
CO_2 GAS PROBE
AFT Starboard Corner



CO GAS PROBE
AFT Starboard Corner



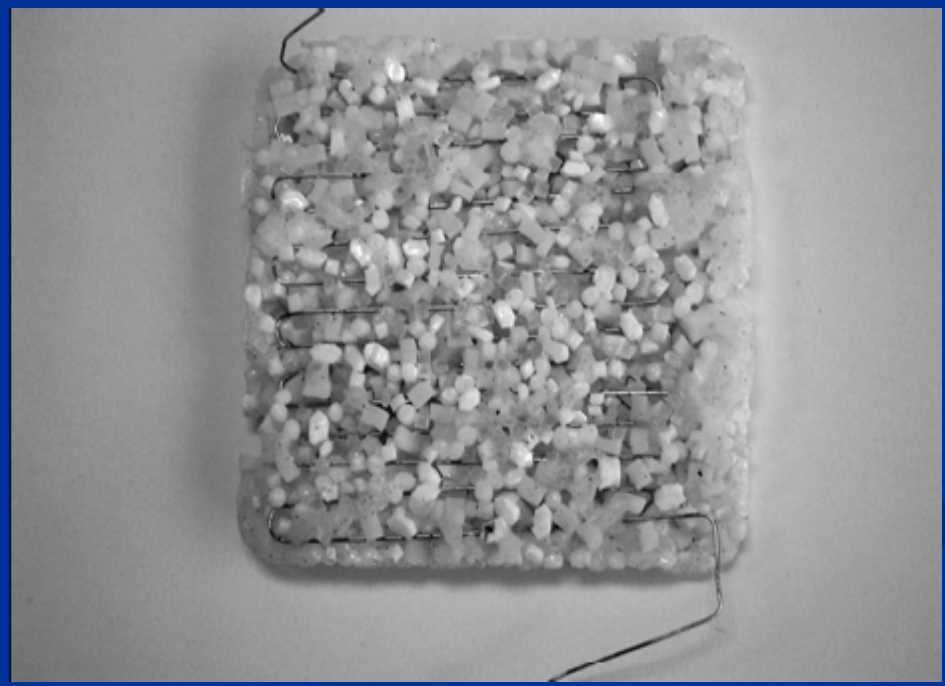

RESIN CAKE
MIC Correlation
MIC (volts)
0
1
2
3
4
5
6
40
50
60
70
80
90
100
110
%LT/ft
y = -0.0047x2 + 0.8738x - 35.163
R2 = 0.9177
FWD Resin Cake
Polynomial Correlation


RESIN CAKE
MIC Correlation
MC (volts)
0
1
2
3
4
5
6
50
60
70
80
90
100
110
%LT/ft
y = 0.0028x2 - 0.3833x + 15.372
R2 = 0.9373
Sidewall Resin Cake
Polynomial Correlation

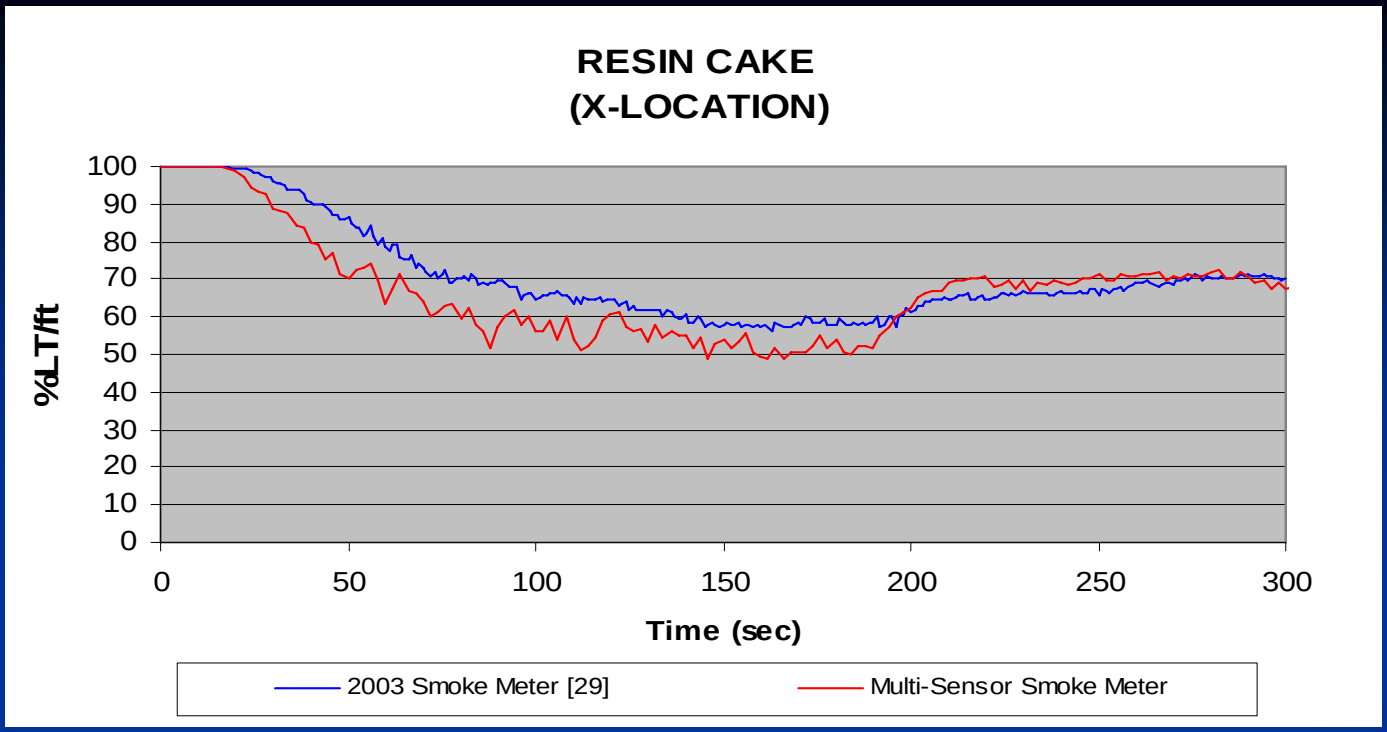
Resin Cake Reference Testing

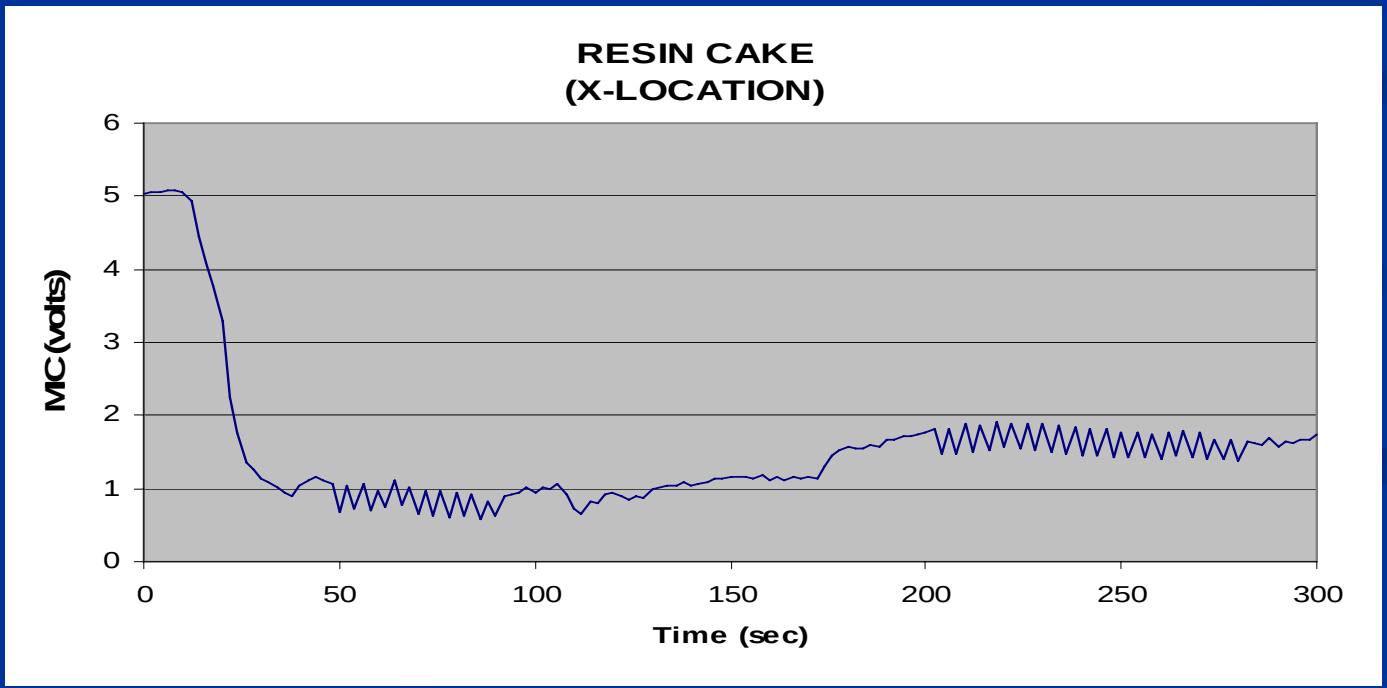
- Resin Cake is:
  - FAA Repeatable Fire Source
  - Flaming fire source
  - 4” length, 4” width, 3/8” thick
- Resin Cake Composition
  - Nylon
  - Polyethylene
  - Polyvinyl Chloride
  - Polystyrene
  - Polybutylene Terephthalate
  - Polyurethane
- Nichrome wire heat source
  - 40 Volts AC
  - 2 mL heptane

- Purpose
  - Assess functionality; 4 sensors
  - Response Time
  - Accuracy
- Comparison to past data

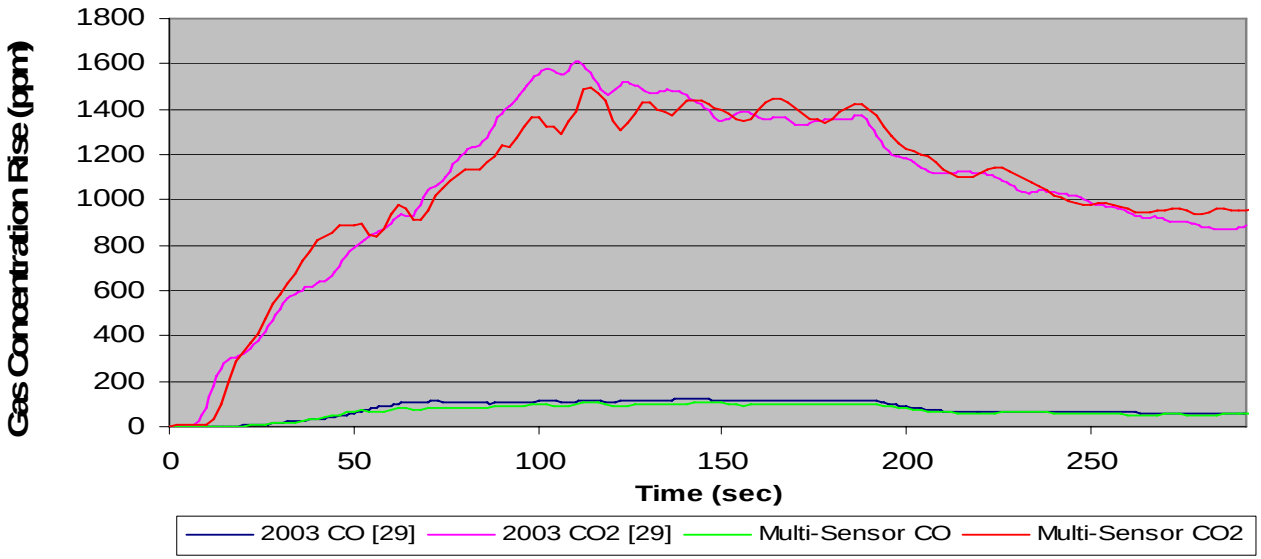


RESIN CAKE

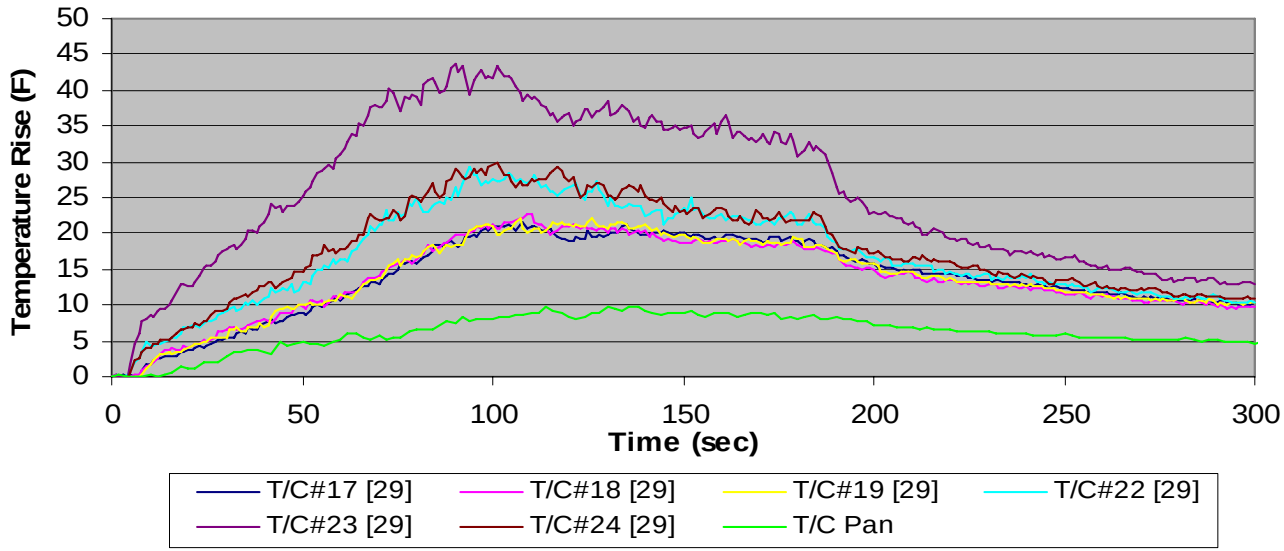

RESIN CAKE
(X-LOCATION)
%LT/ft
100
90
80
70
60
50
40
30
20
10
0
0
50
100
150
200
250
300
Time (sec)
2003 Smoke Meter [29]
Multi-Sensor Smoke Meter


RESIN CAKE
(X-LOCATION)
MC (volts)
6
5
4
3
2
1
0
0
50
100
150
200
250
300
Time (sec)

RESIN CAKE
(X-LOCATION)



RESIN CAKE
(X-LOCATION)



CFD Conversions

- Smoke Meter (%Lt/ft)
  - Beer's Law
  - σ = Specific extinction coefficient (7400 m^2/kg)
  - ϱ_{cell} = Gas density/output cell
  - C_{soot} = Soot concentration

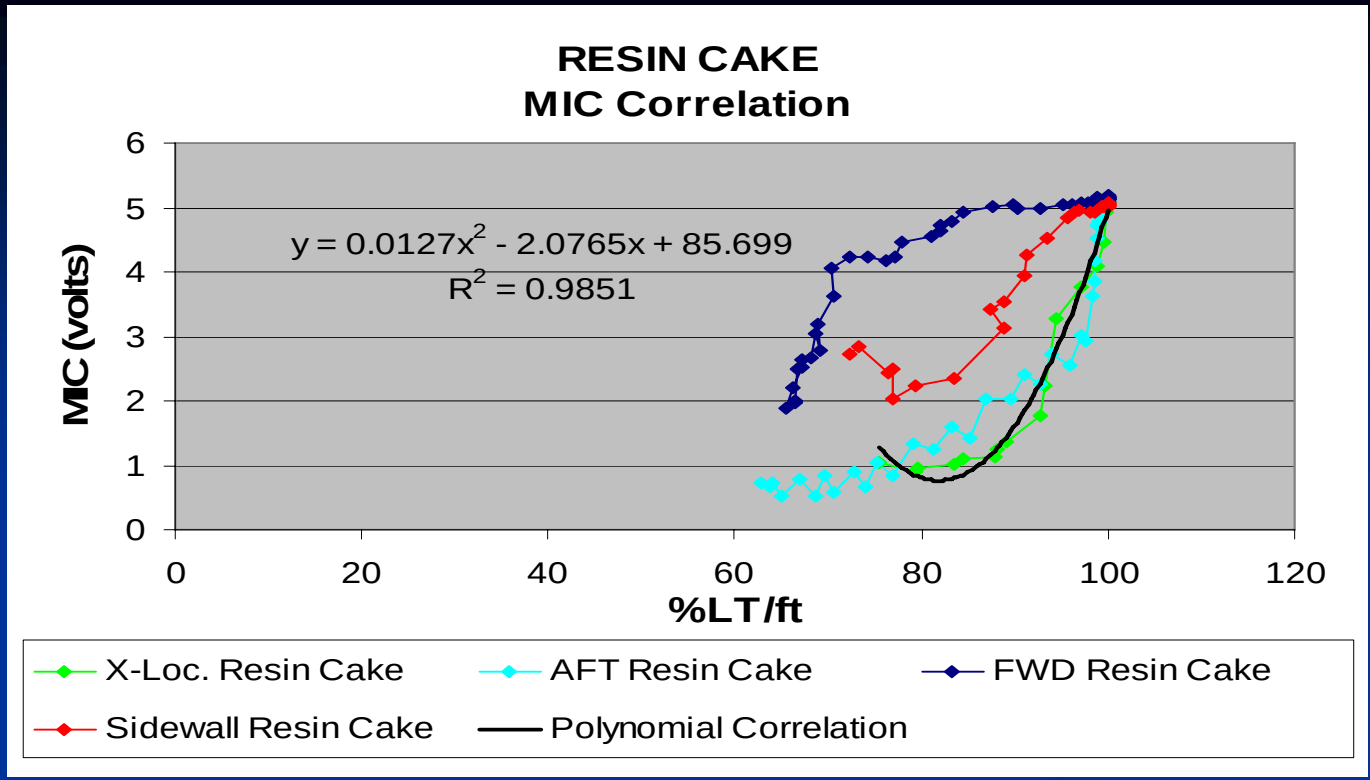
- Gas Data (parts per million)
  - C_{gas} = CO/CO_2 mass fraction
  - ϱ_{cell} = Gas density/output cell
  - ϱ_{gas} = CO/CO_2 gas density
    - CO = 1.145 kg/m^3
    - CO_2 = 1.833 kg/m^3

$$\frac{I}{I_0} = e^{-\int_0^L k(x)dx} \quad where \quad k(x) = C_{soot}(x) * \rho_{cell}(x) * \sigma_s$$

$$C_{gas}(ppm) = C_{gas}(in\frac{kg}{kg}) \times (\frac{\rho_{cell}}{\rho_{gas}}) \times 10^6$$

- Thermocouple (ºF)

$$T(°F) = \left[\left(T(°K) - 273.15 \right) \times 1.8 \right] + 32$$



- X and AFT Locations

$$Volts = 0.0127*(x^2) - 2.0765*(x) + 85.699$$

- Forward Location

$$Volts = 0.0028*(x^2) - 0.3833*(x) + 15.372$$

- Sidewall Location

$$Volts = 0.0047*(x^2) + 0.8738*(x) - 35.163$$