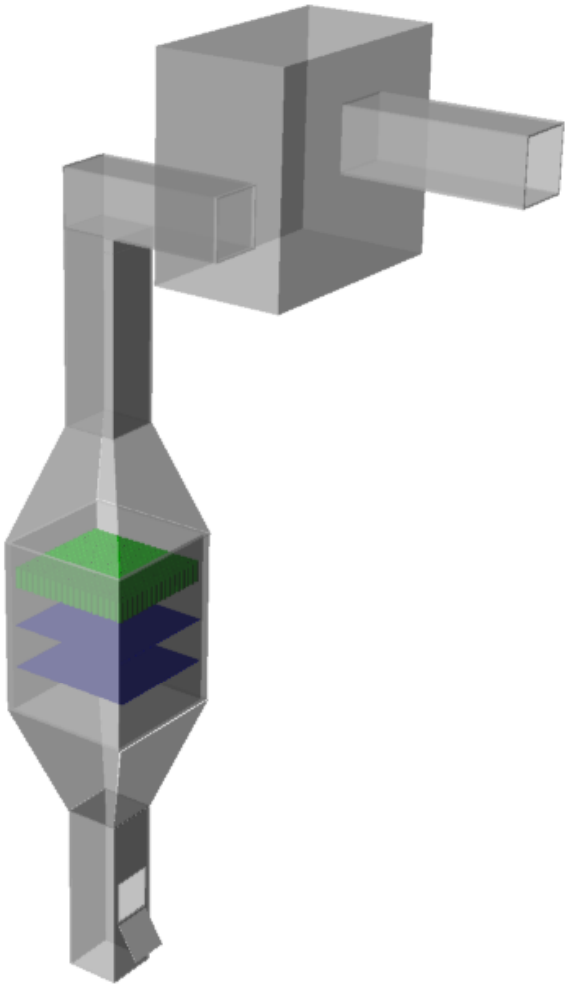

Heat Detector RTI – New Developments

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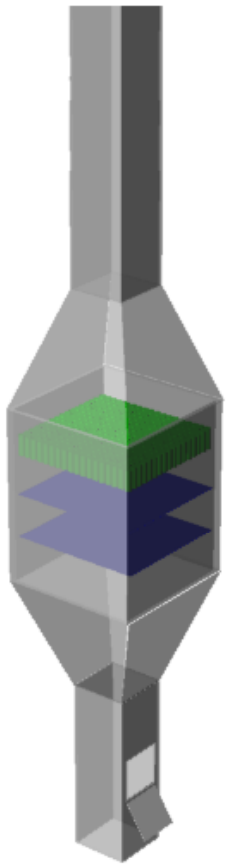
HUGHES ASSOCIATES, INC.
30 YEARS OF FIRE ENGINEERING LEADERSHIP

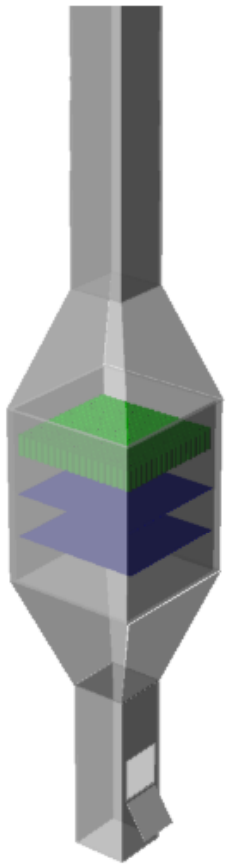
SUPDET
March 23,2011

Outline



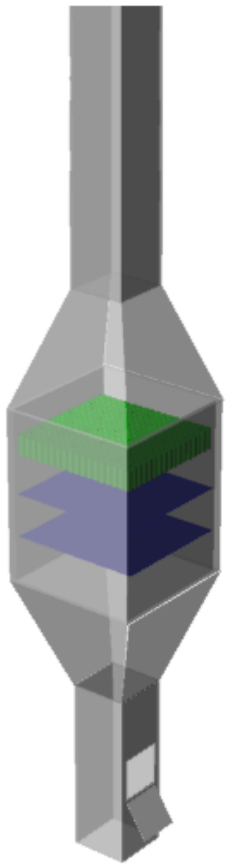
- Introduction to RTI
- RTI and operating conditions for heat detectors
- Modified plunge test apparatus
  - Design
  - Characterization
- Test results
- Conclusions

Response Time Index (RTI)



- Sprinkler RTI developed by Heskestad and Smith
- Measure of thermal lag in response
- Plunge test
  - Heated wind tunnel (original = flow-through design)
  - Gas temperature and velocity known and constant
  - Rapidly plunge device into air stream

Response Time Index (RTI)



- RTI derived from energy balance on the heat sensing element.

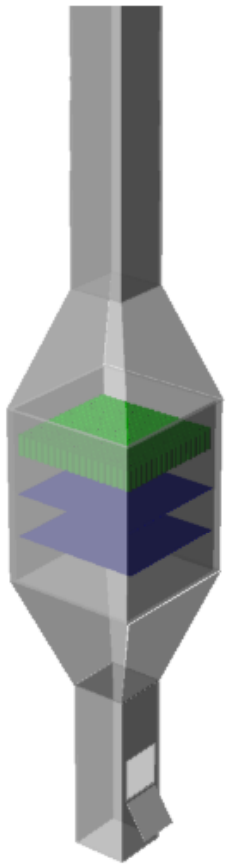
$$m\,C_p\frac{dT_e}{dt} = h_c A\left(T_g - T_e\right) \qquad \tau = mC_p/h_cA$$

where

A = surface area of the sensing element
m = mass of the sensing element
hc = convective heat transfer coefficient
Cp = specific heat of sensing element
Te = temperature of sensing element
Tg = gas temperature
τ = time constant defined as (mC_p/h_cA)

- Assumptions in this model:
  1. Convection is the dominant form of heat transfer,
  2. Conduction heat losses are negligible,
  3. The element heats isothermally, and
  4. There is no activation heat needed.

RTI



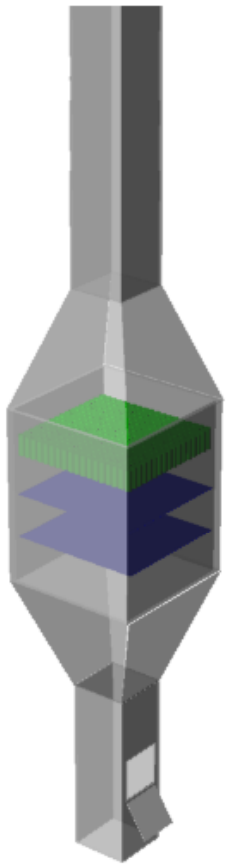
$$\tau = mC_p / h_c A = \text{time constant}$$

$$h_c \text{ proportional to } u^{1/2} \quad \text{(in some cases)}$$

$$\tau = \text{constant} / u^{1/2}$$

$$\tau \cdot u^{1/2} = \text{constant} = RTI$$

Measuring RTI

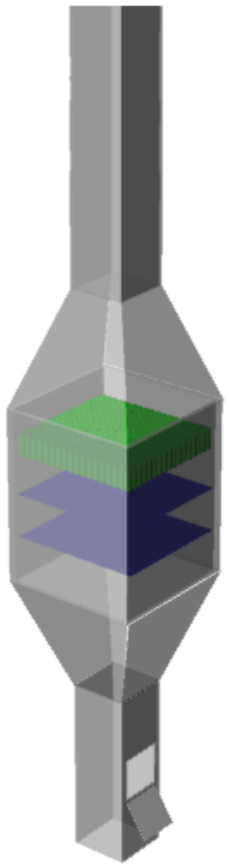


$$RTI = \frac{t_a u^{1/2}}{\ln\left(1 - \frac{\Delta T_a}{\Delta T_g}\right)}$$

where

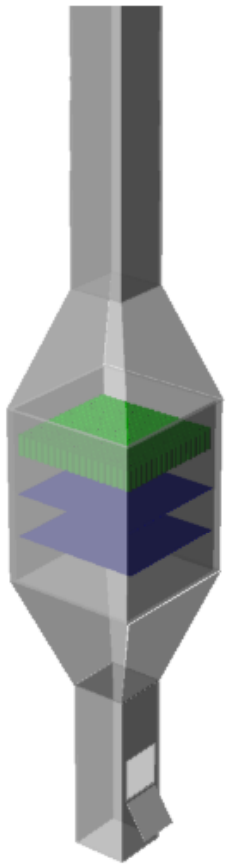
- t_a = activation time
- u = gas velocity inside the plunge test tunnel
- ΔT_a = difference between activation temperature and ambient temperature
- ΔT_g = difference between gas temperature and ambient temperature

RTI and Heat Detectors

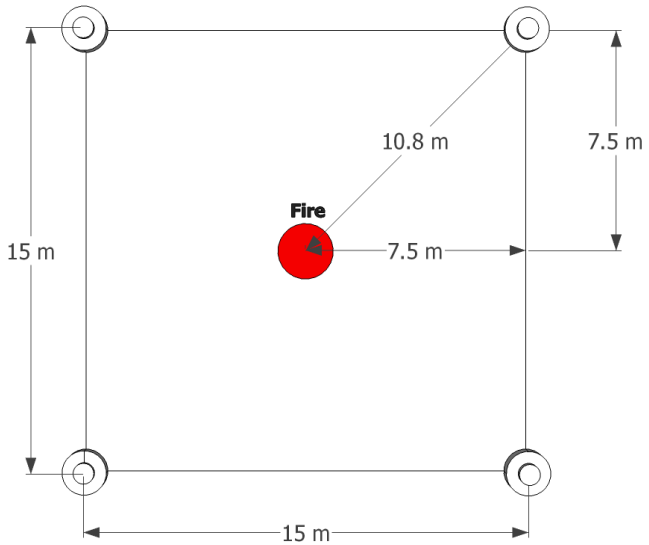


- Bissel (1988): RTI highly dependent on test conditions
- NFPA 72: heat detectors shall be marked with their RTI
- Nam (2004): basis for current RTI testing
- FM 3209 (test conditions vary with detector class)
  - 135°C, 197°C, 230°C and 371°C (275, 387, 446, 700°F)
  - 1.6 m/s

Determining Realistic Conditions

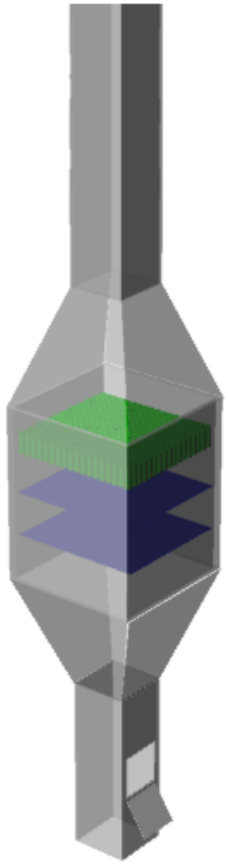


- Alpert's equations used for ceiling jet temperatures and velocities.
- Maximum radial distance to the fire
  - Based on 4.6 m (15 ft) and 15.2 m (50 ft) spacing
  - 6.5 m (21 ft) and 10.7 m (35 ft)
- Ceiling heights: 3 to 6.1 m (10 – 20 ft).
- Fire sizes: 100 kW to 1 MW.



Operating Conditions

Detector spacing of 15 m x 15 m (50 ft x 50 ft)



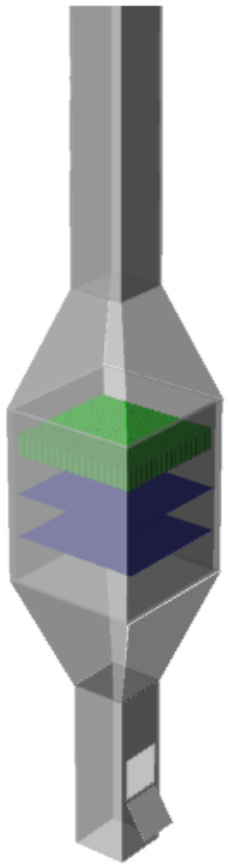
Fire Size (kW)	Ceiling Heights (m (ft))			
	3.0 m (10 ft)	**3.7 m (12 ft)**	**4.6 m (15 ft)**	**6.1 m (20 ft)**
5000 kW	0.8 m/s 125°C	0.88 m/s 108°C	0.98 m/s 90°C	**1.13 m/s** **73°C**
4000 kW	0.74 m/s 111°C	0.81 m/s 96°C	0.91 m/s 81°C	NA
3000 kW	0.67 m/s 95°C	0.74 m/s 83°C	**0.83 m/s** **70°C**	NA
2500 kW	0.64 m/s 86°C	**0.7 m/s** **75°C**	NA	NA
2000 kW	**0.59 m/s** **77°C**	NA	NA	NA
1500 kW	NA	NA	NA	NA

Velocity:
0.6 to 1.1 m/s

Temperature:
70°C to 77°C

Operating Conditions

Detector spacing of 4.6 m x 4.6 m (15 ft x 15 ft)

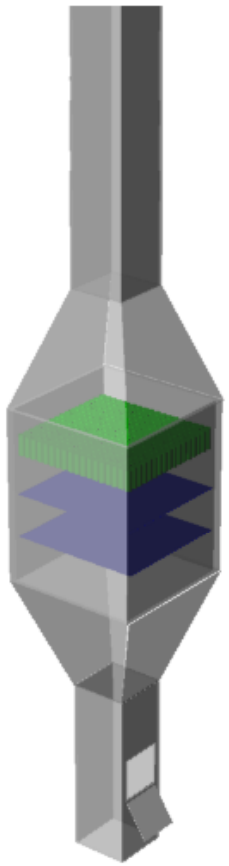


Fire Size (kW)	Ceiling Heights (m)			
	3.0 m (10 ft)	**3.7 m (12 ft)**	**4.6 m (15 ft)**	**6.1 m (20 ft)**
5000 kW	2.21 m/s 258°C	2.42 m/s 218°C	2.7 m/s 178°C	3.12 m/s 139°C
4000 kW	2.05 m/s 225 °C	2.25 m/s 191°C	2.51 m/s 156°C	2.9 m/s 122°C
3000 kW	1.86 m/s 189°C	2.04 m/s 161°C	2.28 m/s 133°C	2.63 m/s 104°C
2000 kW	1.63 m/s 149°C	1.78 m/s 127°C	1.99 m/s 106°C	**2.3 m/s** **84°C**
1000 kW	1.29 m/s 101°C	**1.41 m/s** **88°C**	**1.58 m/s** **74°C**	NA
500 kW	**1.2 m/s** **71°C**	NA	NA	NA
100 kW	NA	NA	NA	NA

Velocity:
1.2 to 2.3 m/s

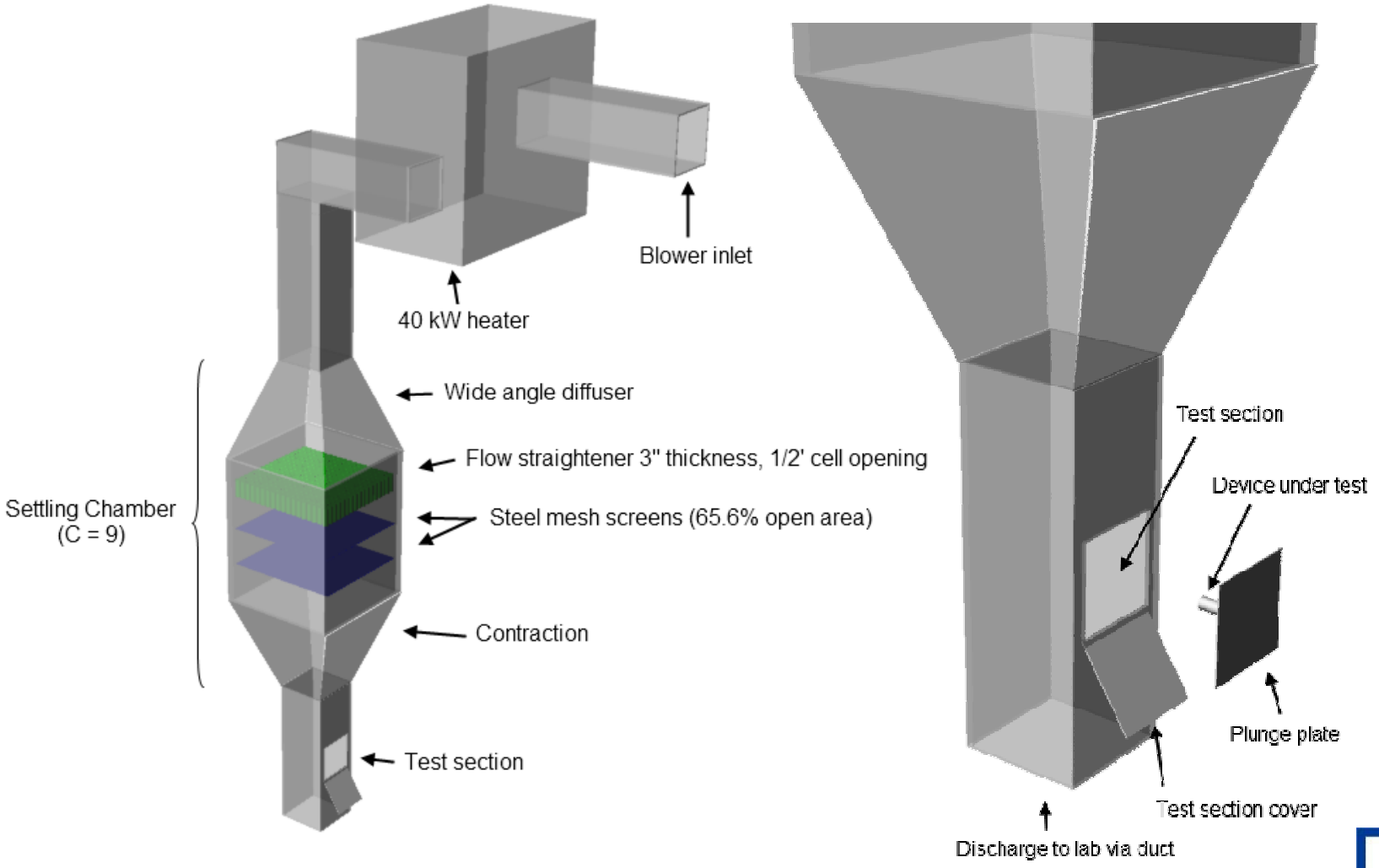
Temperature:
71°C to 88°C

Modified Plunge Test Apparatus



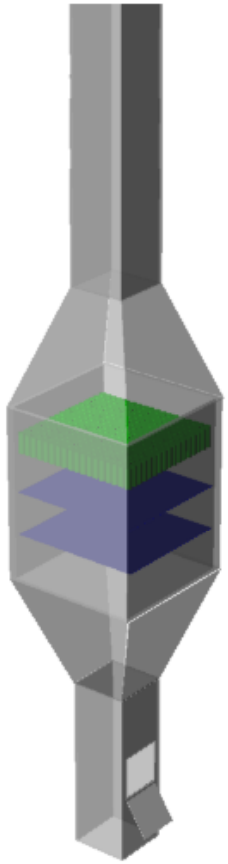
- Vertical, downward flow test section
- Flow-through tunnel design
- 40 kW heater
- Insulated test section
- Velocity: 0.2 m/s to 4 m/s
- Temperature: ~250°C max

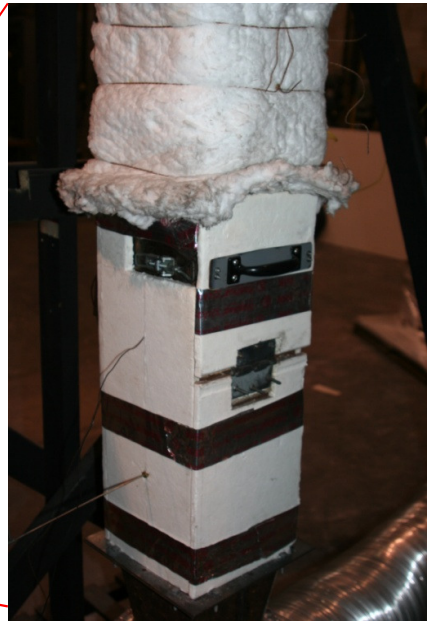
HAI Plunge Test Apparatus

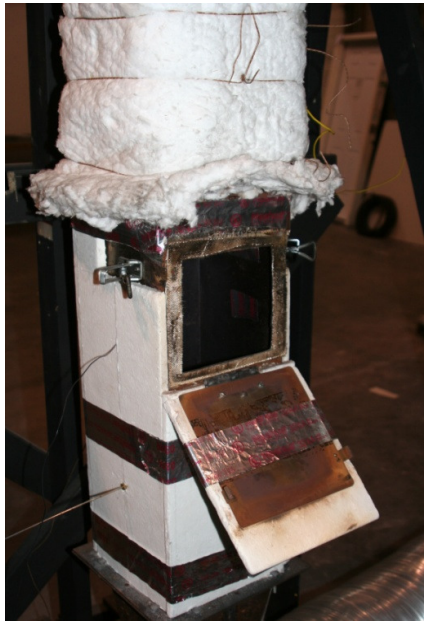


The settling chamber was designed to specifications for wind tunnels per Mehta and Bradshaw (1979).

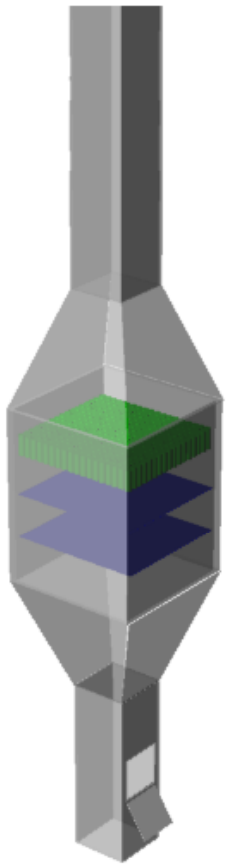
HAI Plunge Test Apparatus



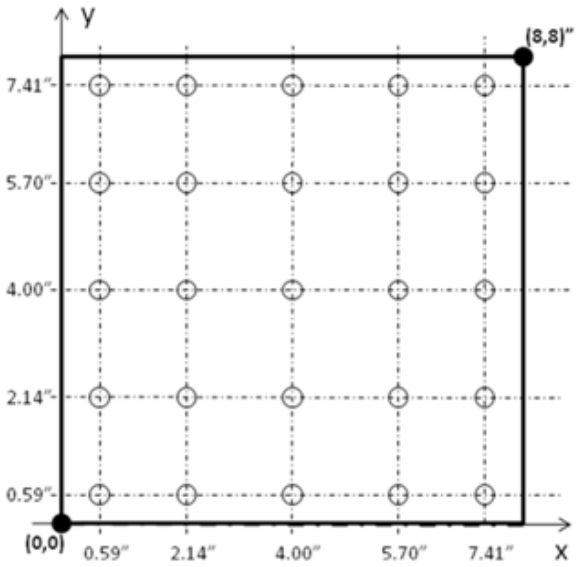


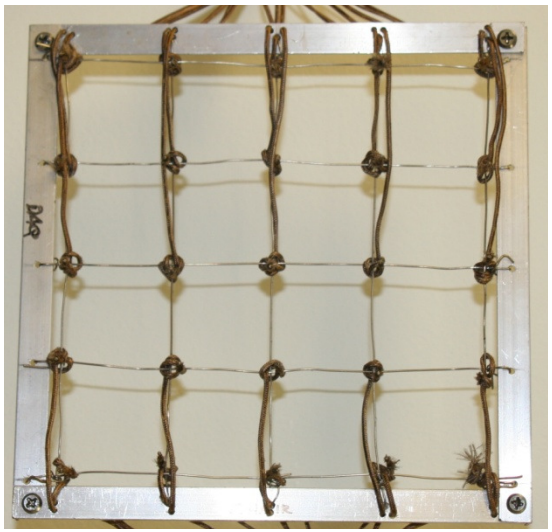


Temperature Uniformity

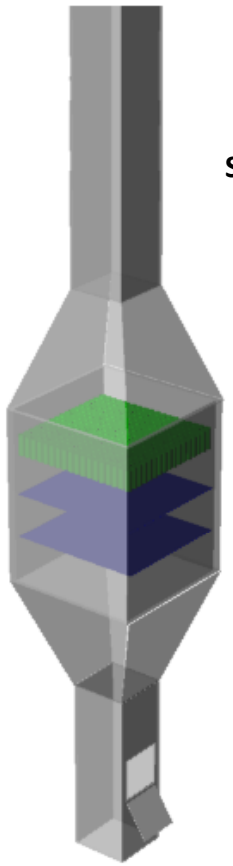


- Twenty-five (25) thermocouples per the Log-Chebyshev method of duct traversing
- Uniformity in working section
  - < 1°C std dev for 75°C condition
  - < 3°C std dev for 200°C condition

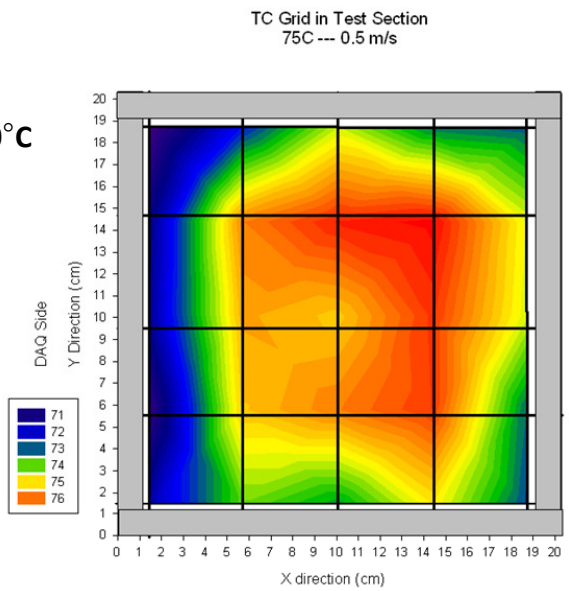


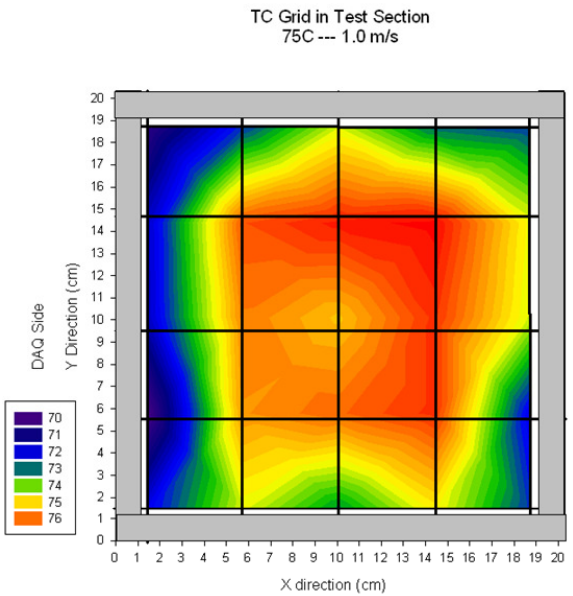


75°C Temperature Profile



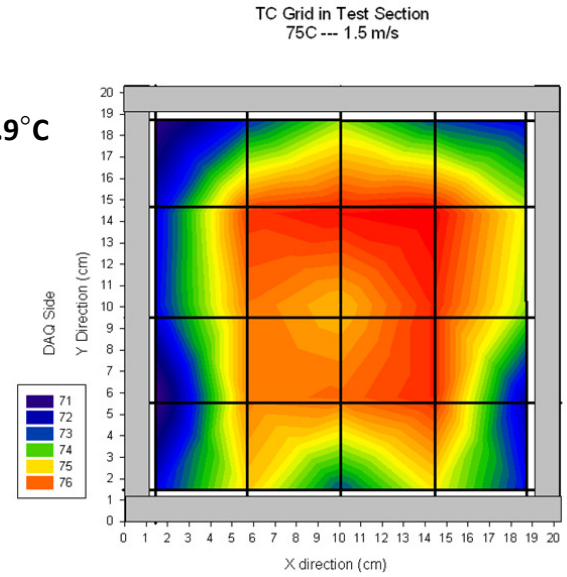
StDev = 2.0°C

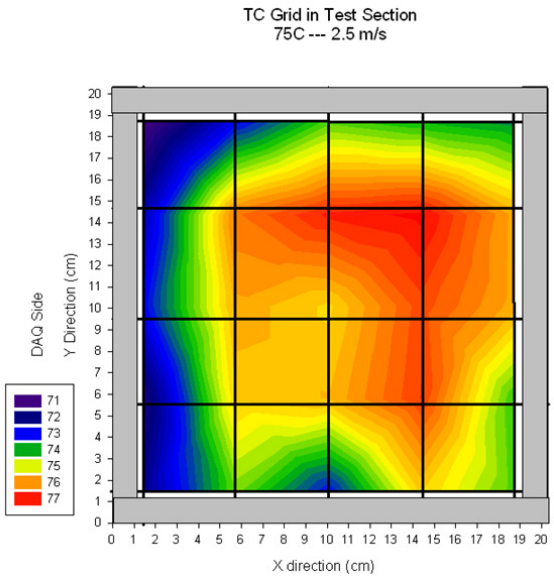




StDev = 2.1°C

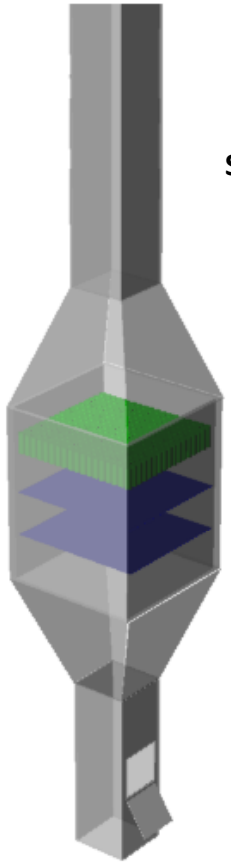
StDev = 1.9°C



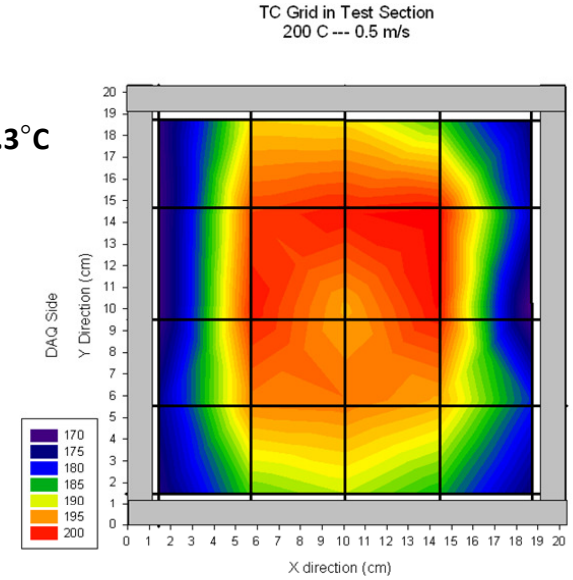


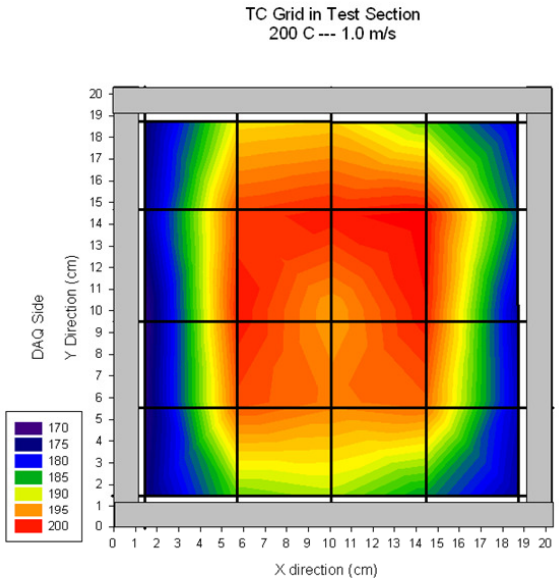
StDev = 1.7°C

200°C Temperature Profile



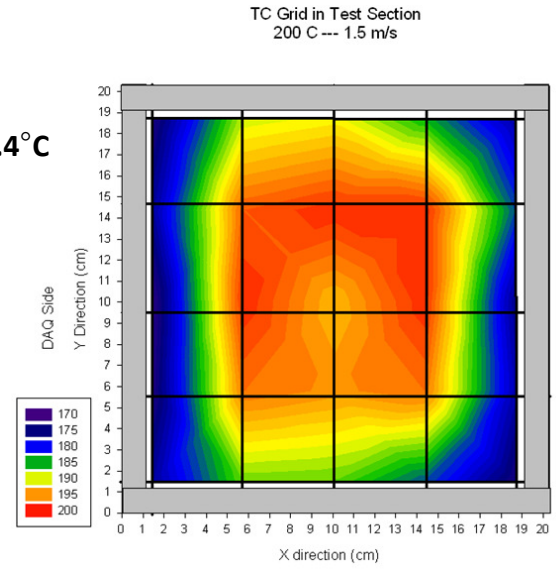
StDev = 11.3°C

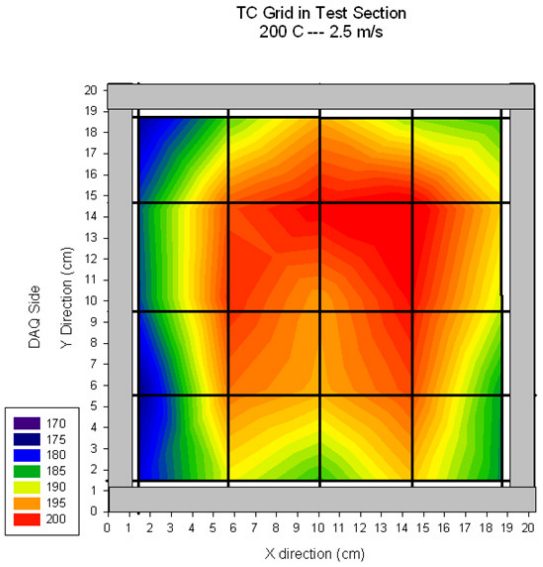




StDev = 10.4°C

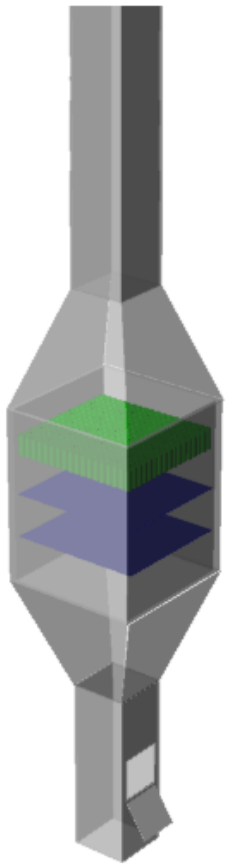
StDev = 10.4°C





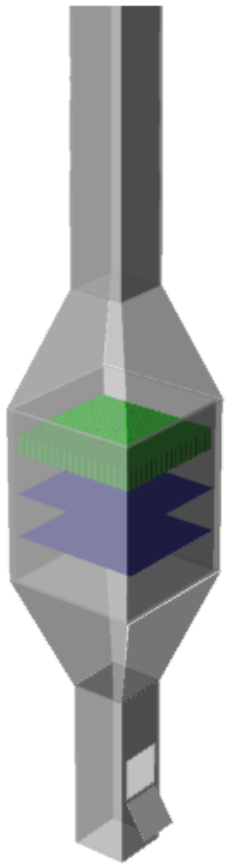
StDev = 7.9°C

Velocity Uniformity



- Twenty-five (25) pitot probe points per the Log-Chebyshev method of duct traversing
- Uniformity
  - In working section ~ 0.1 m/s for 1 and 2.5 m/s conditions
  - Total test section ~ 0.2 m/s and 0.3 m/s for 1 and 2.5 m/s conditions

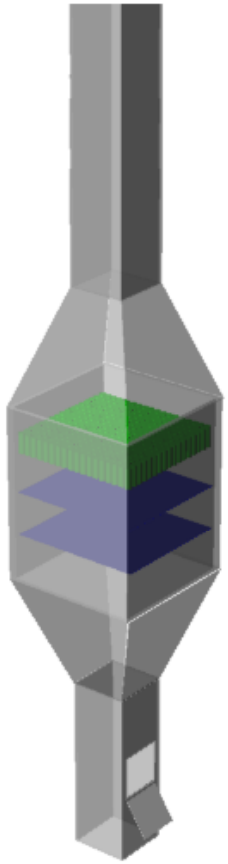
Testing



- Velocities of 0.5, 1.0, 1.5, and 2.5 m/s and temperatures of 75°C and 200°C.
- Only fixed temperature heat detectors were tested.

Test Condition	Nominal Air Temperature (°C)	Air Velocity (m/s)
1	75	0.5
2	75	1
3	75	1.5
4	75	2.5
5	200	0.5
6	200	1
7	200	1.5
8	200	2.5

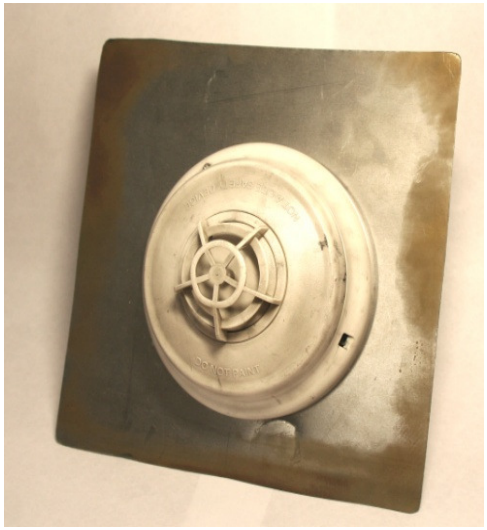
Detectors



Det A

Rate Compensated

60°C (140°F)
71°C (160°F)



Det B

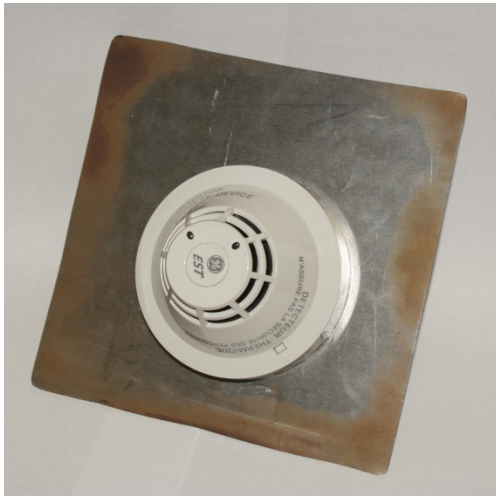
Thermistor

47°C (117°F)
57°C (135°F)

Det C

Thermal Link

57°C (135°F)

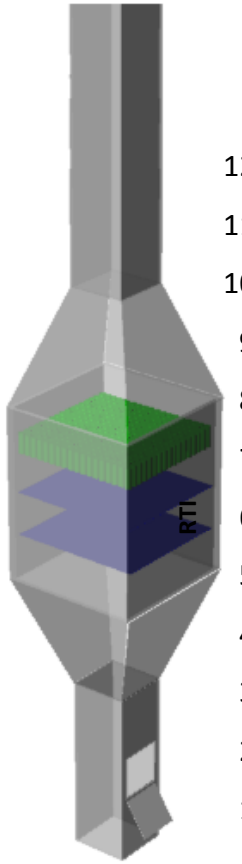


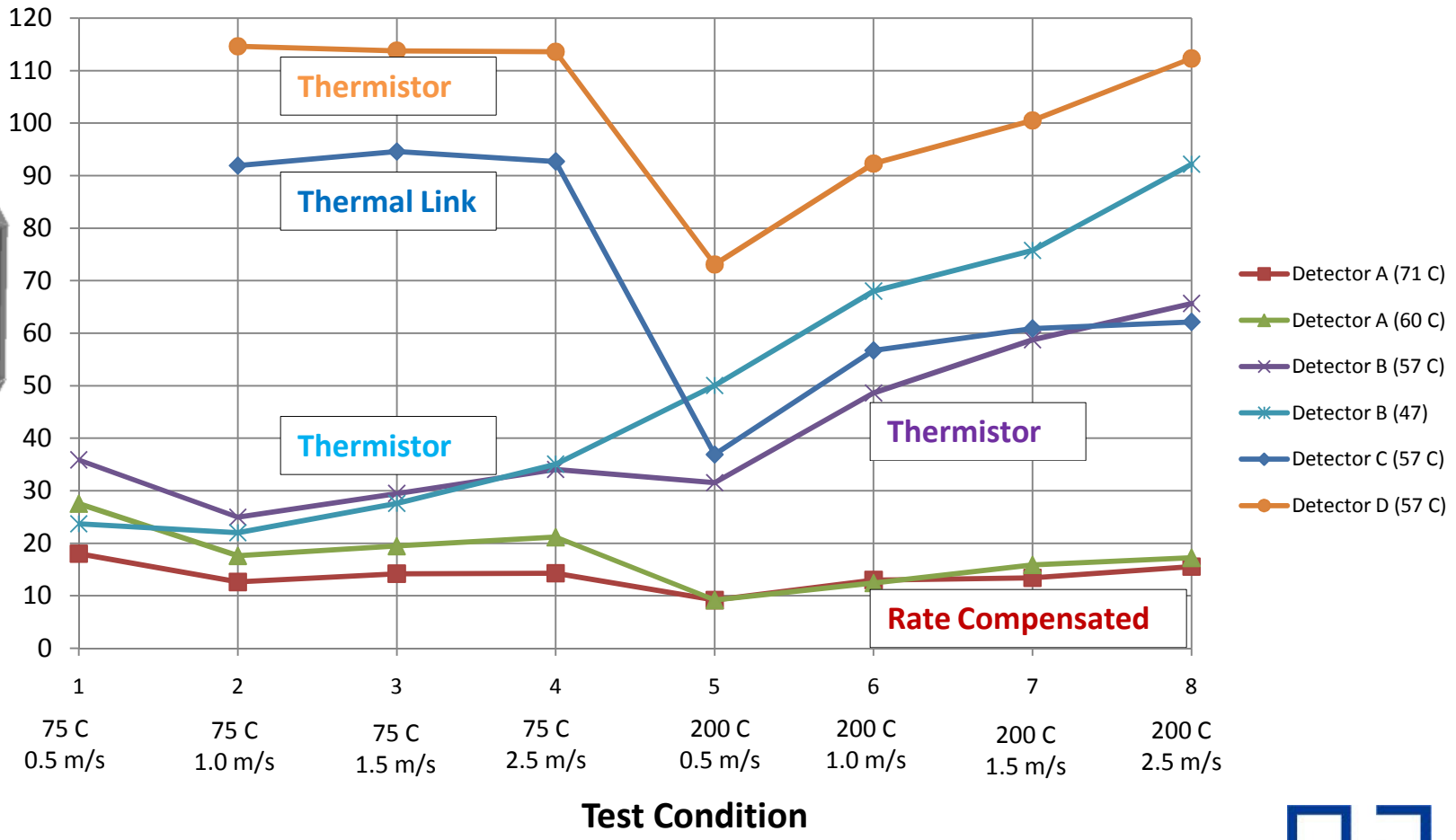
Det D

Thermistor

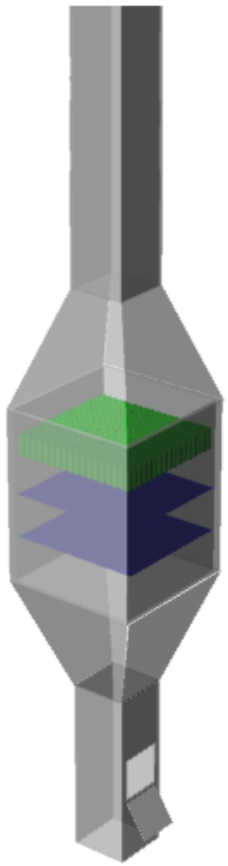
57°C (135°F)

Graph of Average RTI



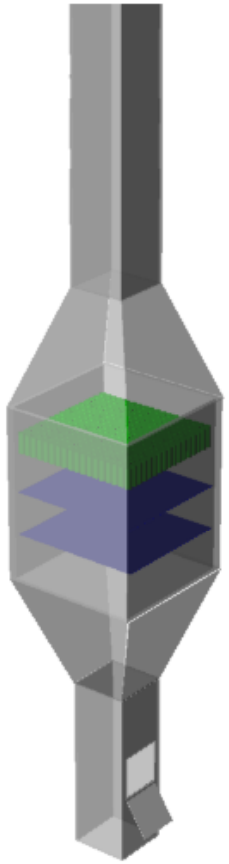


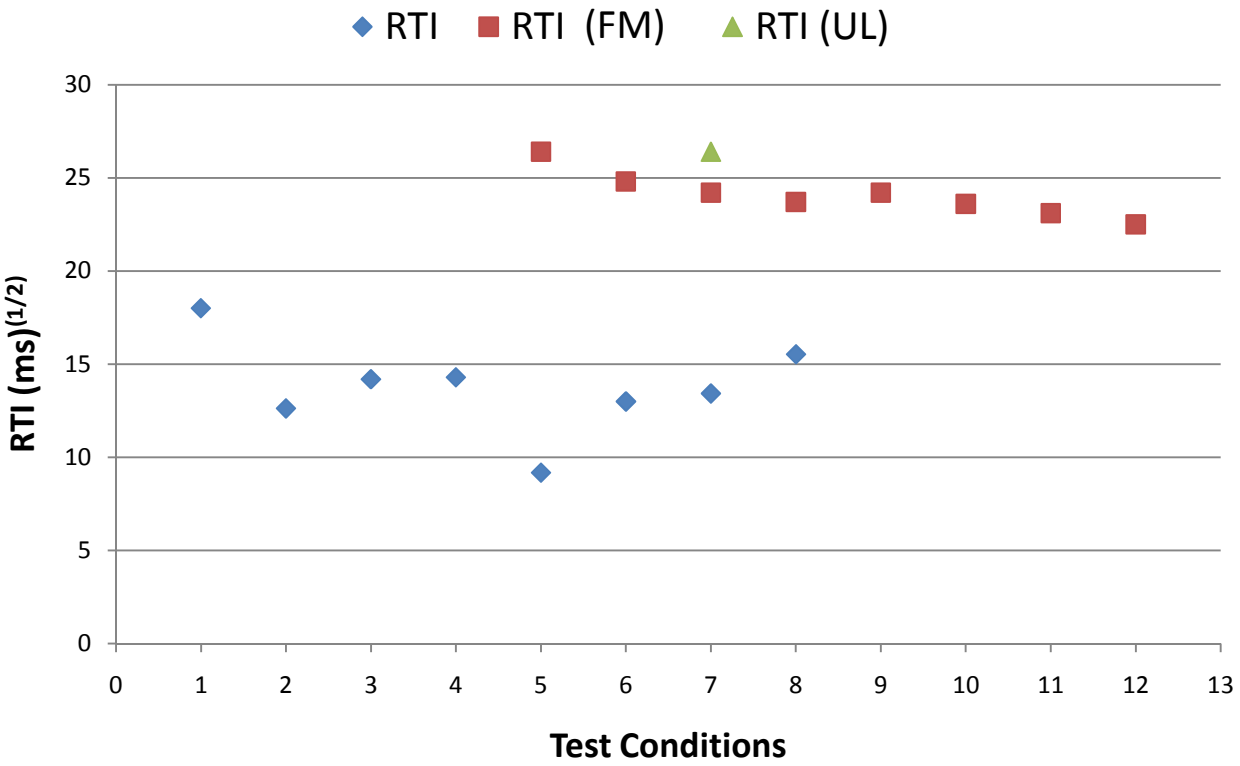
Observations



- Trends not consistent among all models.
- RTI not independent of temperature and velocity for all conditions.

Lab Comparison

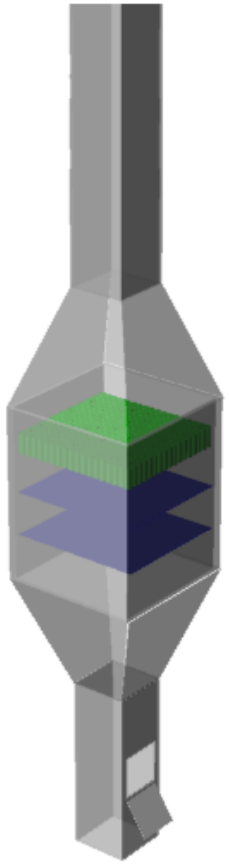


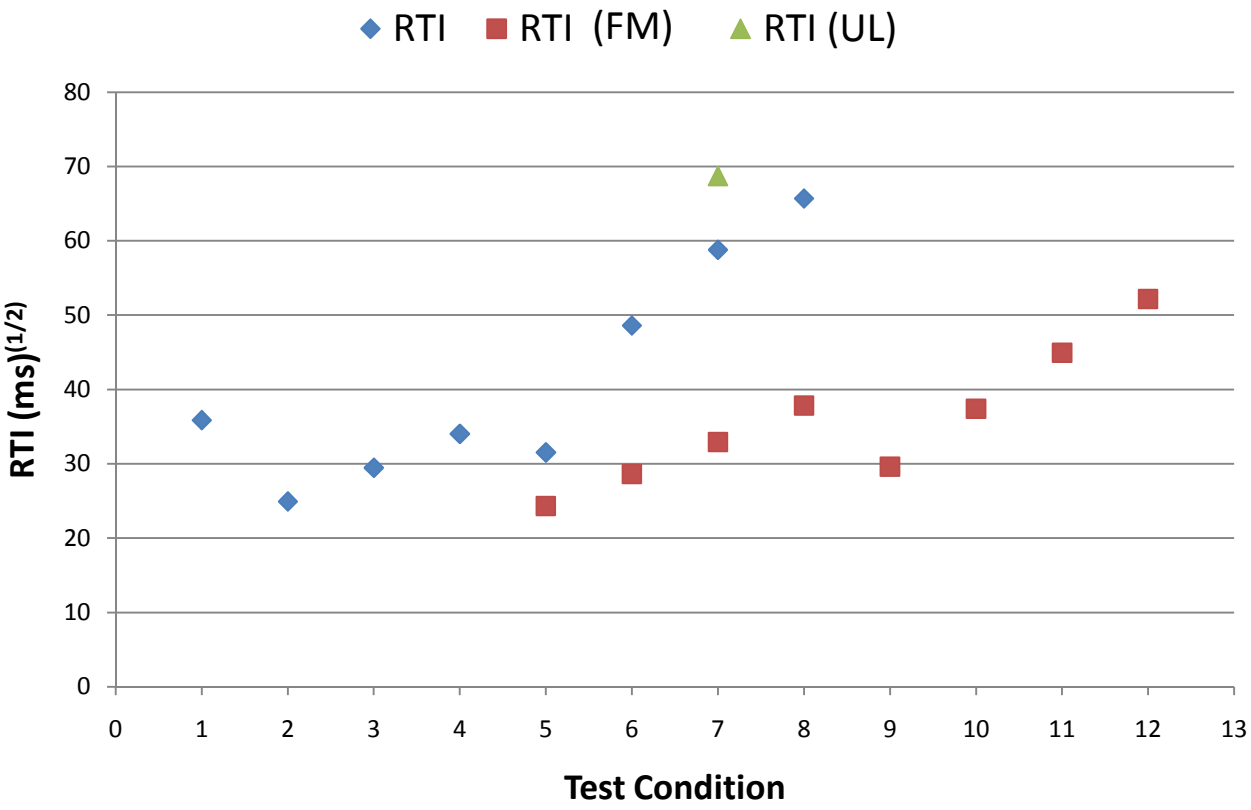


Test #	T (C)	V m/s
1	75	0.5
2	75	1.0
3	75	1.5
4	75	2.5
5	200	0.5
6	200	1.0
7	200	1.5
8	200	2.5
9	291	0.5
10	291	1.0
11	291	1.5
12	291	2.5

Rate Compensated Detector A (71°C (160°F))

Lab Comparison

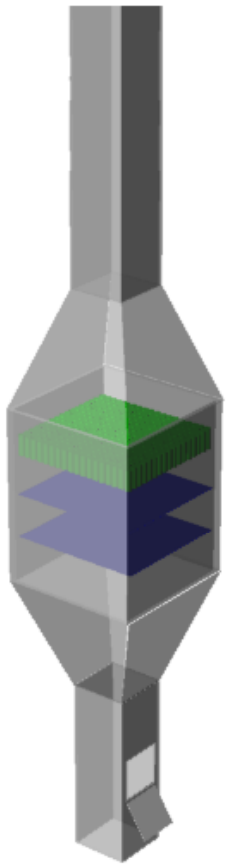




Test #	T (C)	V m/s
1	75	0.5
2	75	1.0
3	75	1.5
4	75	2.5
5	200	0.5
6	200	1.0
7	200	1.5
8	200	2.5
9	291	0.5
10	291	1.0
11	291	1.5
12	291	2.5

Thermistor detector B (57°C (135°F))

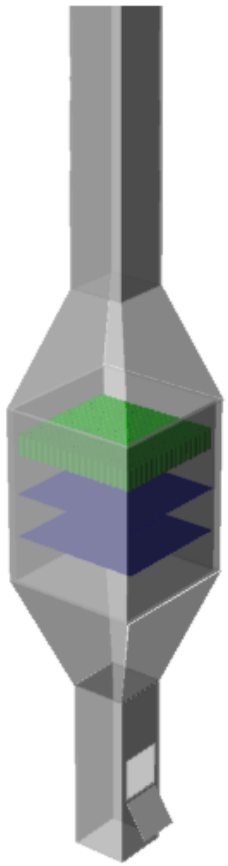
Conclusions



- $RTI = \tau \cdot u^{1/2}$
  - not constant as it should be
  - not independent of temperature and velocity for all devices
- Exp. of ½ not optimal for all conditions

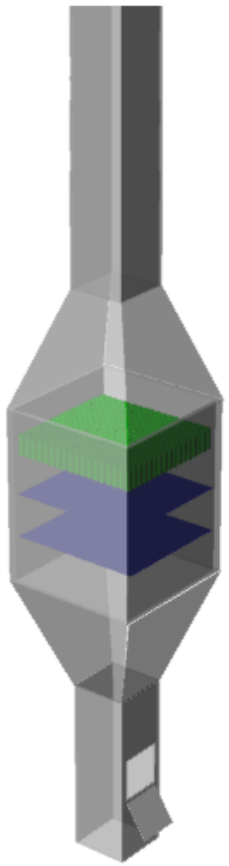
- Variations in lab-to-lab results require detailed test standards
  - Performance requirements vs geometrical design
  - Well characterized test section
  - Thermal stratification considered for low Temp

Conclusions



- RTI Utility for Response Predictions
  - NEEDS MORE WORK for general applicability
  - RTI varied by 2x to 4x over different V and T
  - Single RTI for all conditions not appropriate (Bissell had same conclusion)
  - RTI values should be evaluated at realistic conditions (Vel < 1 m/s, Temps closer to activation T)
- RTI fine for a relative measure if conditions are specified

Acknowledgements



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