Optical Properties of Multi-component Mixtures of Carbonaceous Dusts and Aerosols

Charles D. Litton
Pittsburgh Research Laboratory
National Institute for Occupational Safety and Health
Pittsburgh, PA 15213

Particle Types of Interest

- Dusts
  - Primarily Coal Dusts
  - Mixtures of Coal Dusts and Limestone Dust
- Combustion Generated Aerosols (CGA)
  - From Different Combustion Sources
  - From Different Combustion Modes
- Mixtures of Dusts and CGA
  - Mixtures of Coal Dust and Diesel Exhaust Particles
- Mixtures of Different CGA's
  - Mixtures of Smoldering and Flaming CGA's

Theories Used in Analysis

- Dusts
  - Mie Theory for Absorption/Scattering by a Sphere
  - Index of Refraction from Volatility Measurement
  - Size Distributions Measured with Coulter Counter
- Combustion Generated Aerosols (CGA)
  - Fractal-like Aggregates
  - Measured Mass Extinction Coefficients and Albedos
  - Index of Refraction Determined from Above Parameters
- Mixtures of Dusts and Aerosols
  - Mass-weighted by Component

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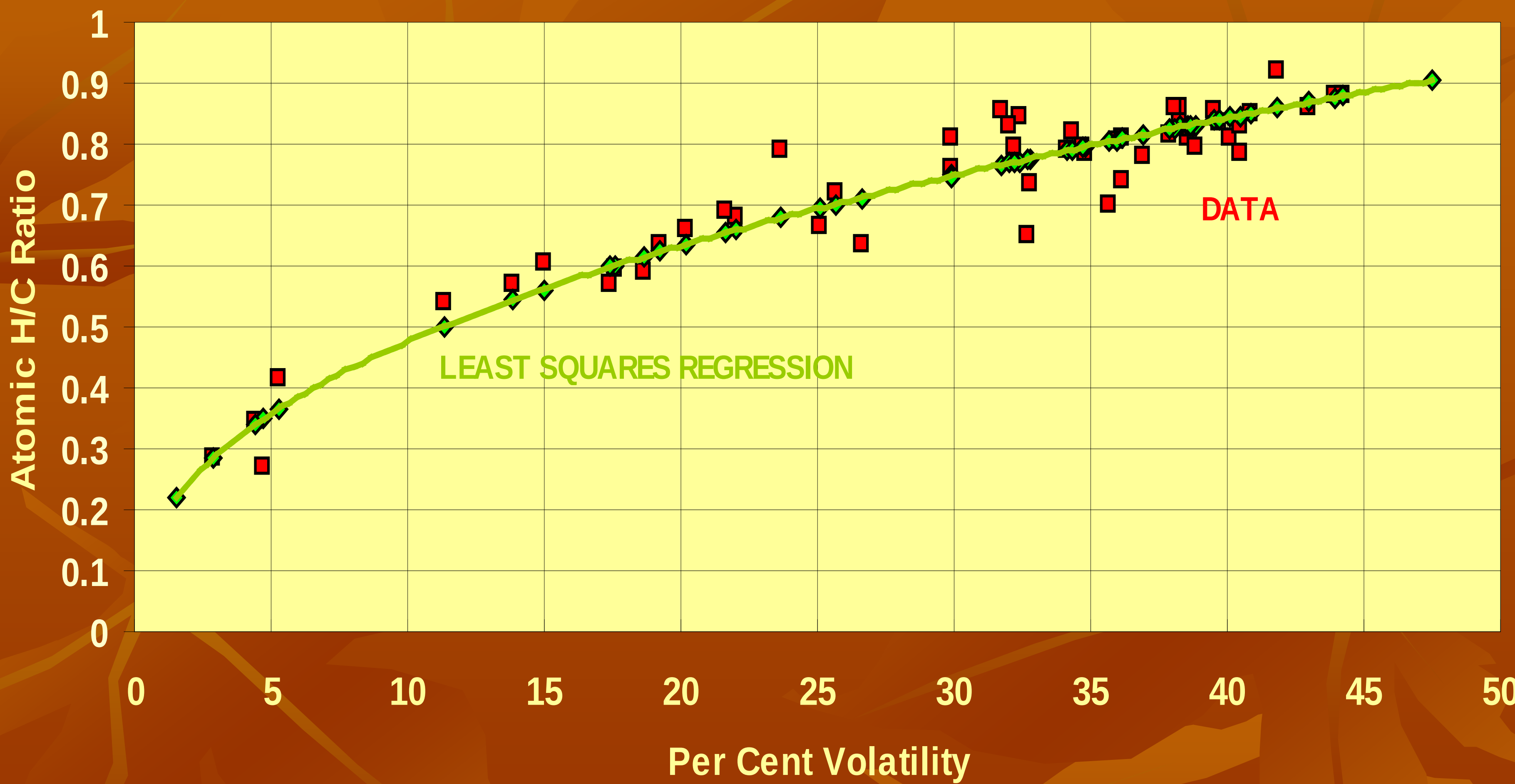
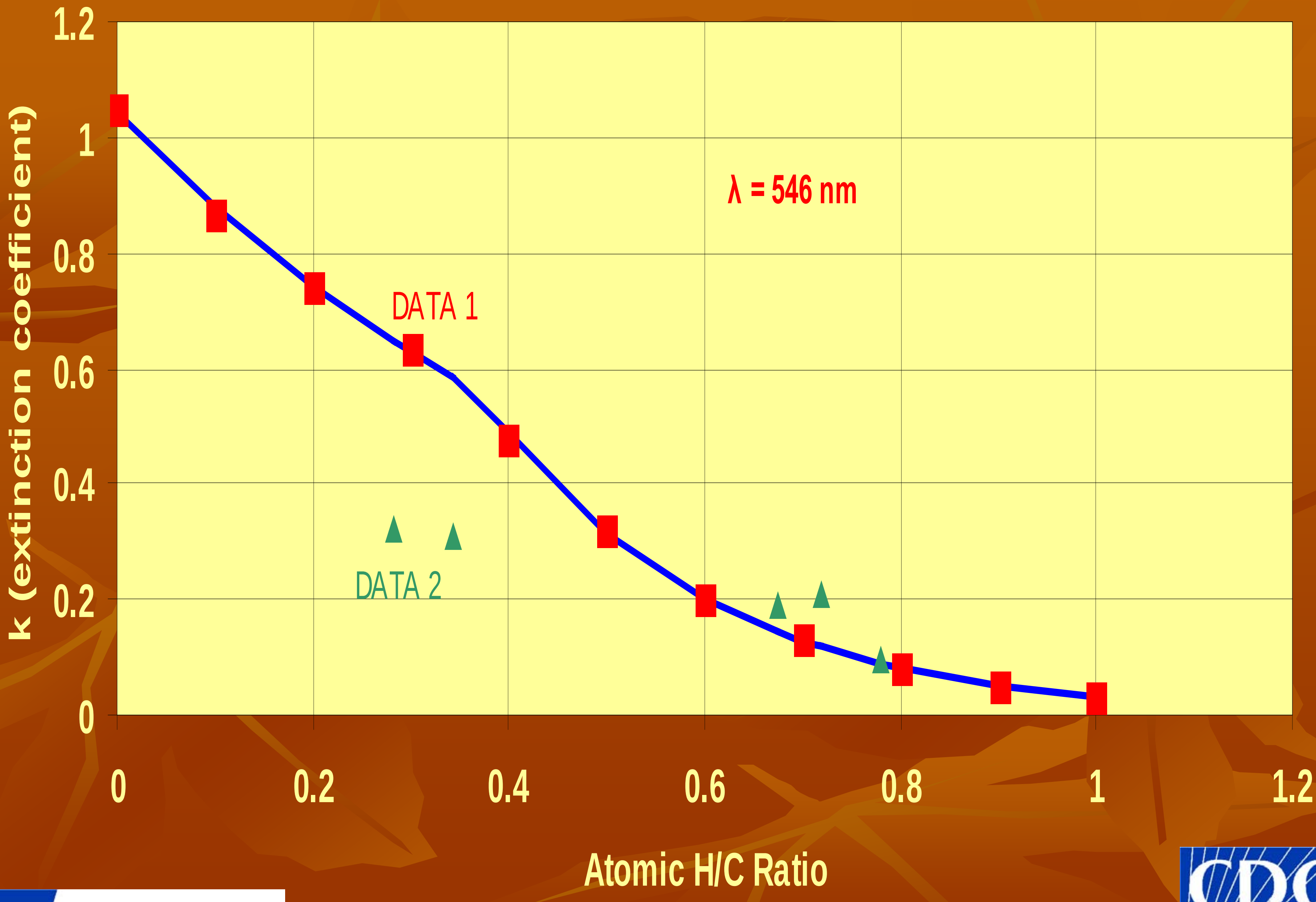
Coal Dusts

- Index of Refraction ($m = n - ik$) Varies with Volatility via Atomic H/C Ratio and with Wavelength of Incident Radiation, λ



Atomic H/C Ratio
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15
20
25
30
35
40
45
50
Per Cent Volatility
DATA
LEAST SQUARES REGRESSION


k (extinction coefficient)
1.2
1
0.8
0.6
0.4
0.2
0
λ = 546 nm
DATA 1
DATA 2
0
0.2
0.4
0.6
0.8
1
1.2
Atomic H/C Ratio

Larger Coal Dust Particles

- Dust Explosibility is Primary Concern
- Absorption of Flame Radiation/Particle Devolatilization Dominant Mechanism for Flame Propogation
- Rock (Limestone) Dust Used to Inert Coal Dust/Air Mixtures
- Mass Fractions of Coal Dust/Rock Dust Determined Optically via Reflectance
- Same Measurement Determines Coal Dust Mass Absorption Coefficient


ON / OFF
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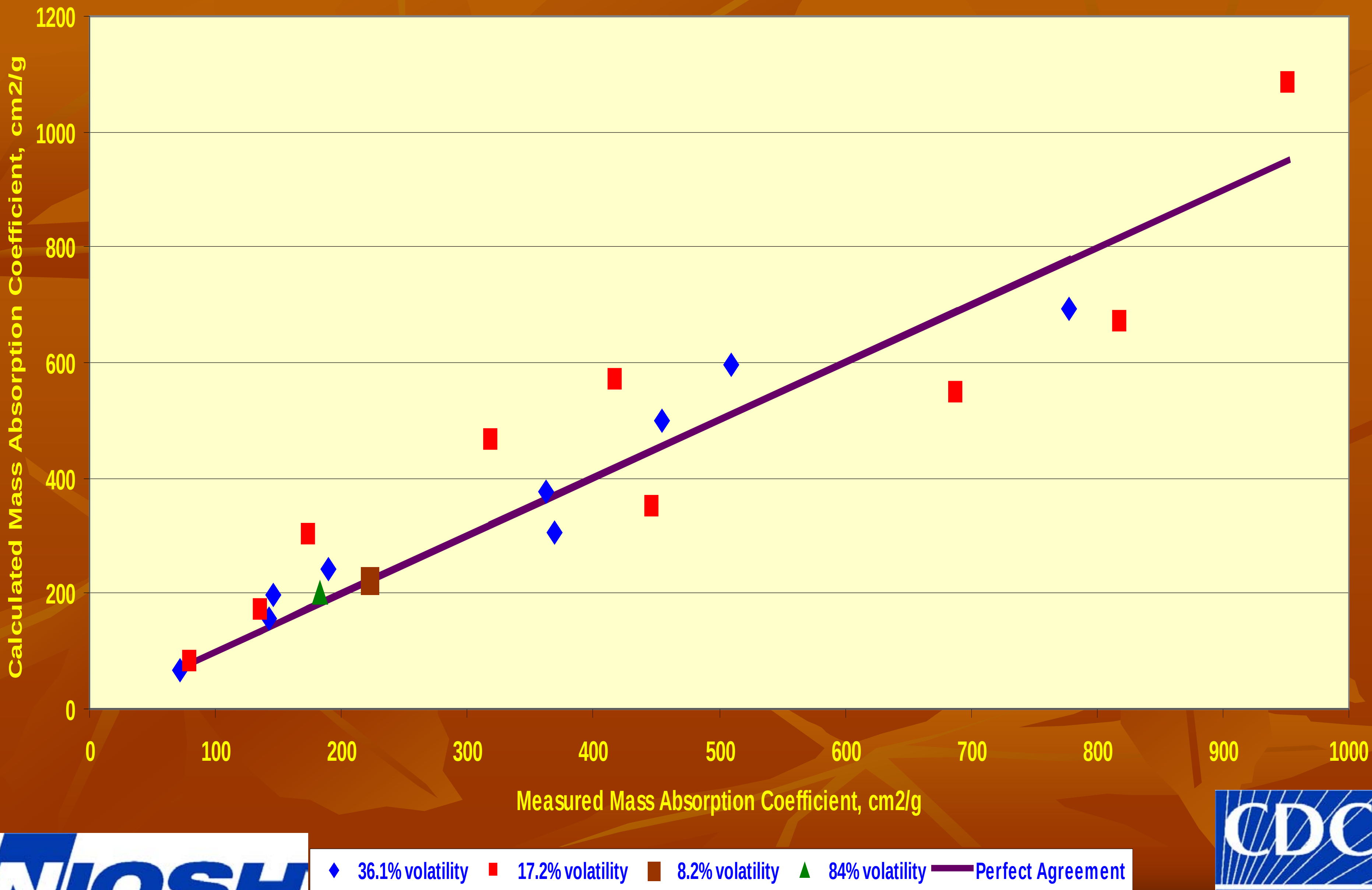
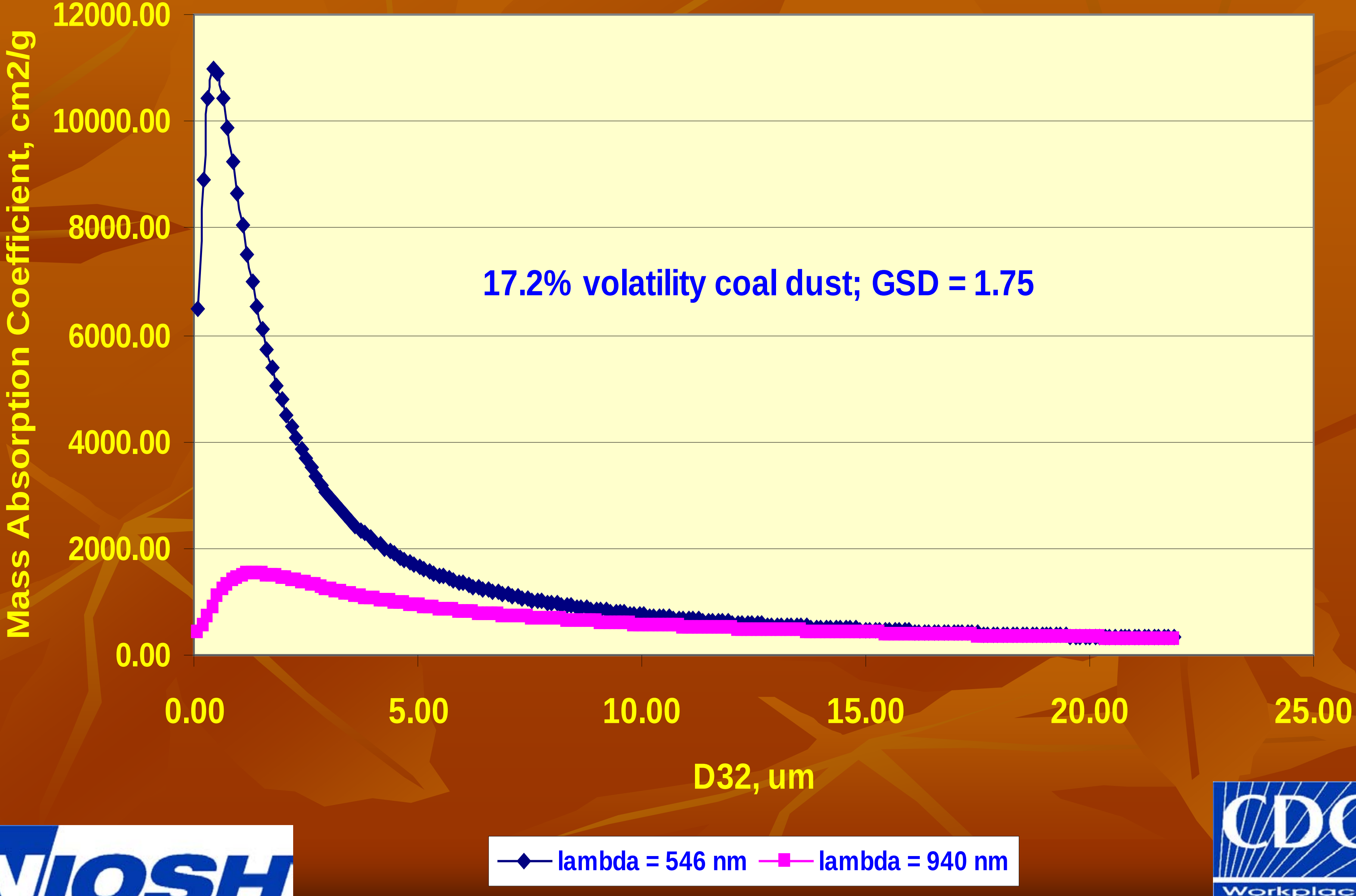
Coal
Dust
Explosibility
Meter
ENTER

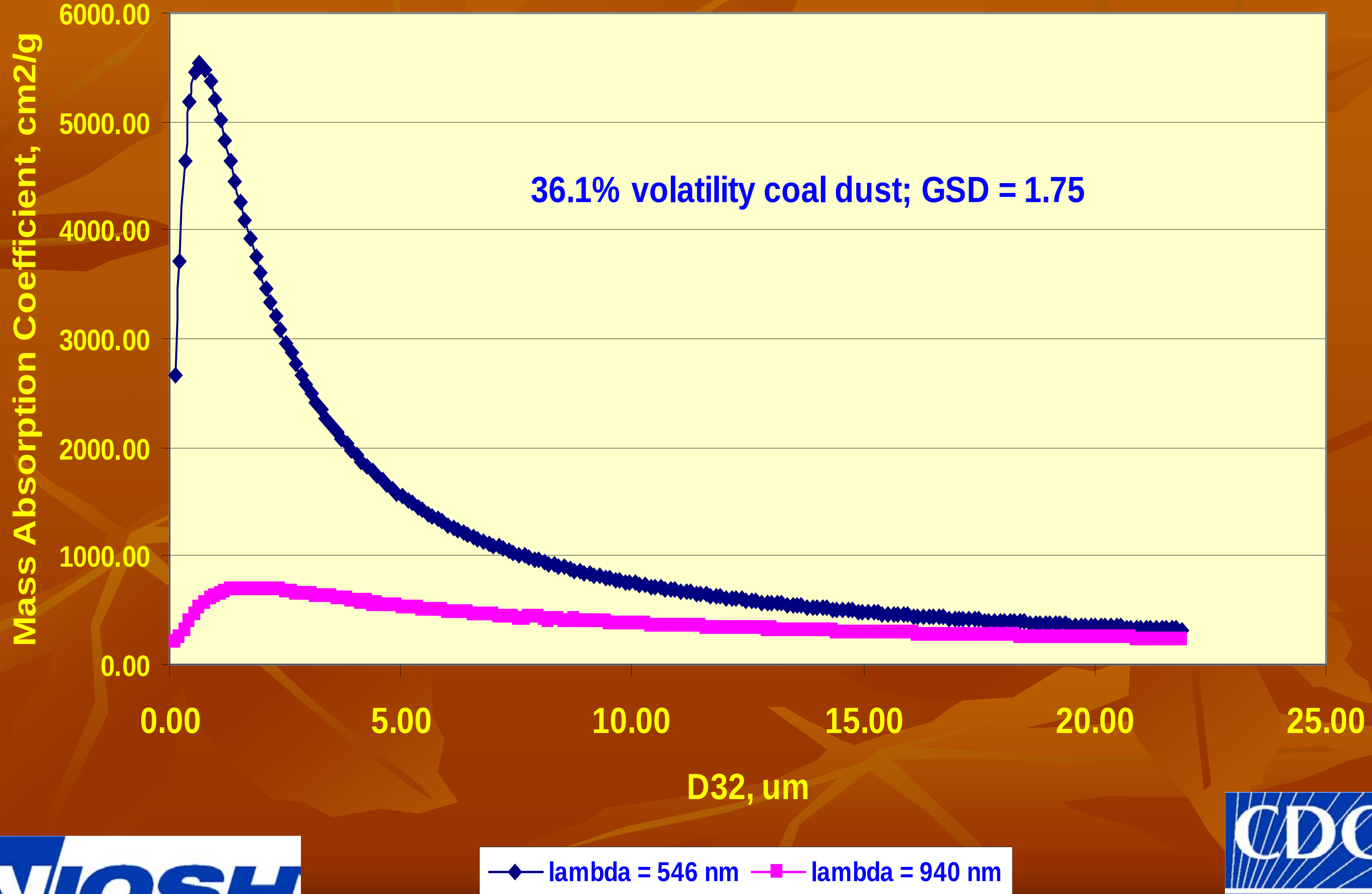
Calculated vs Measured Mass Absorption Coefficients



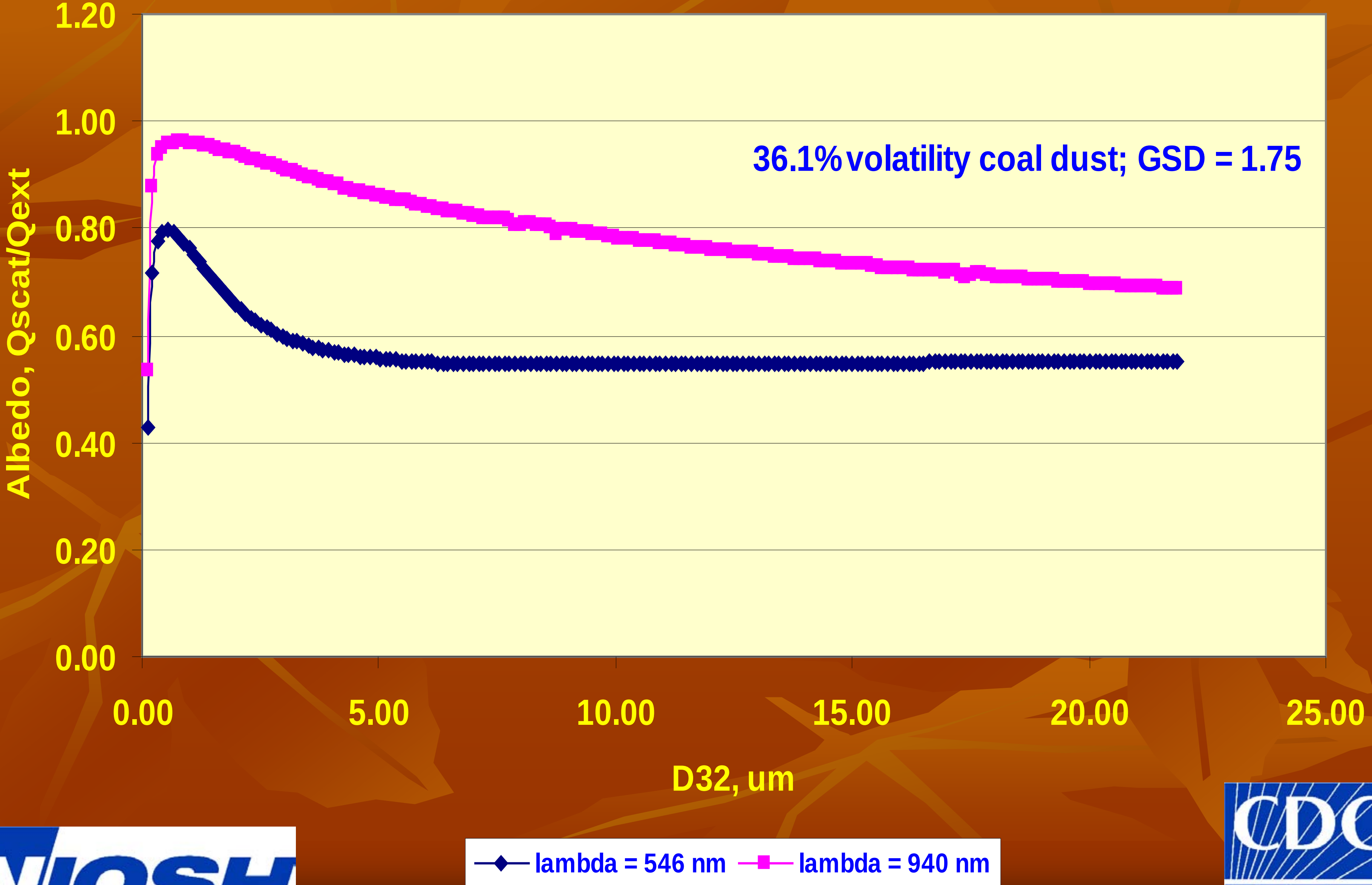
Mass Absorption Coefficient vs D32



Mass Absorption Coefficient vs D32

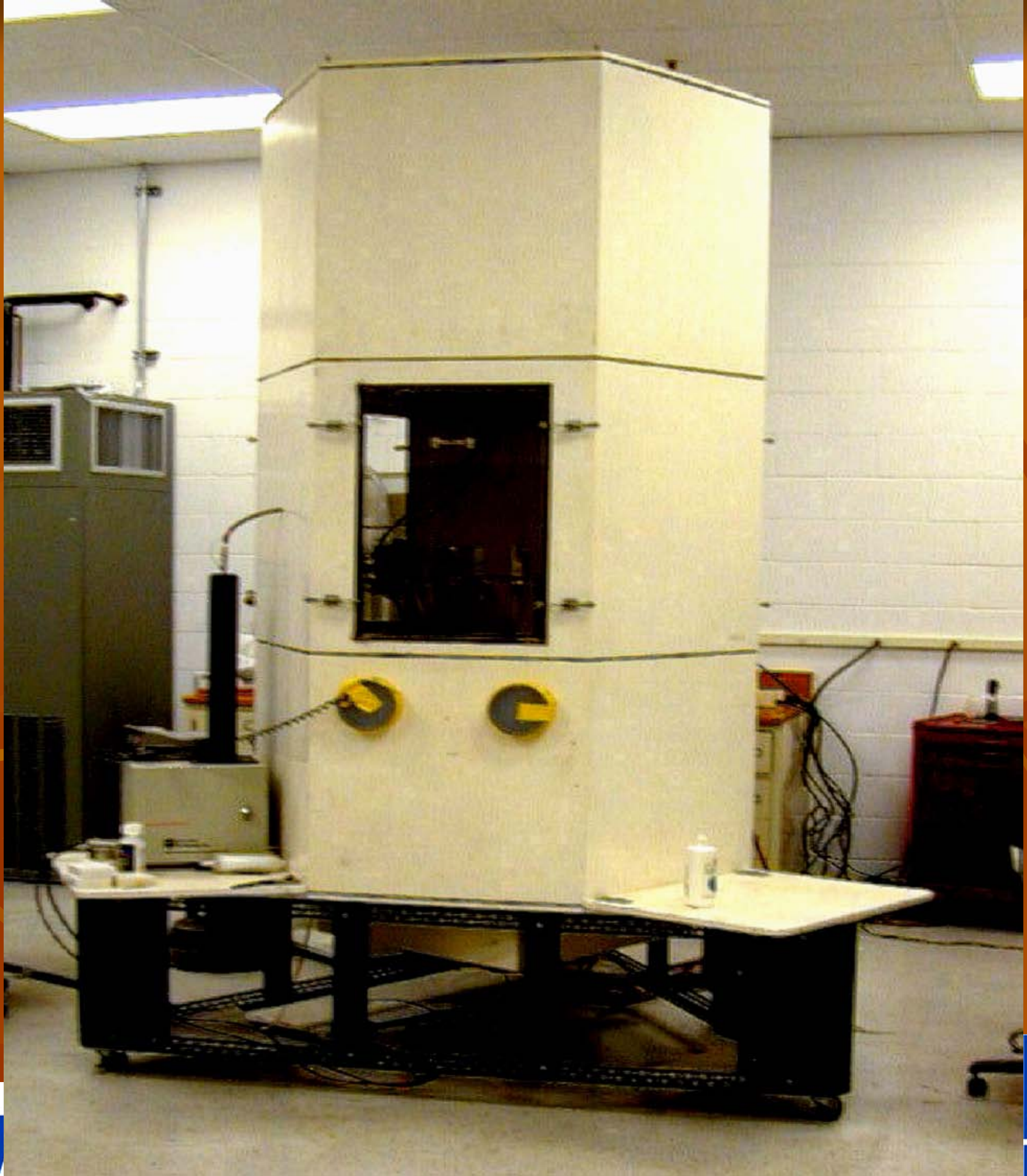


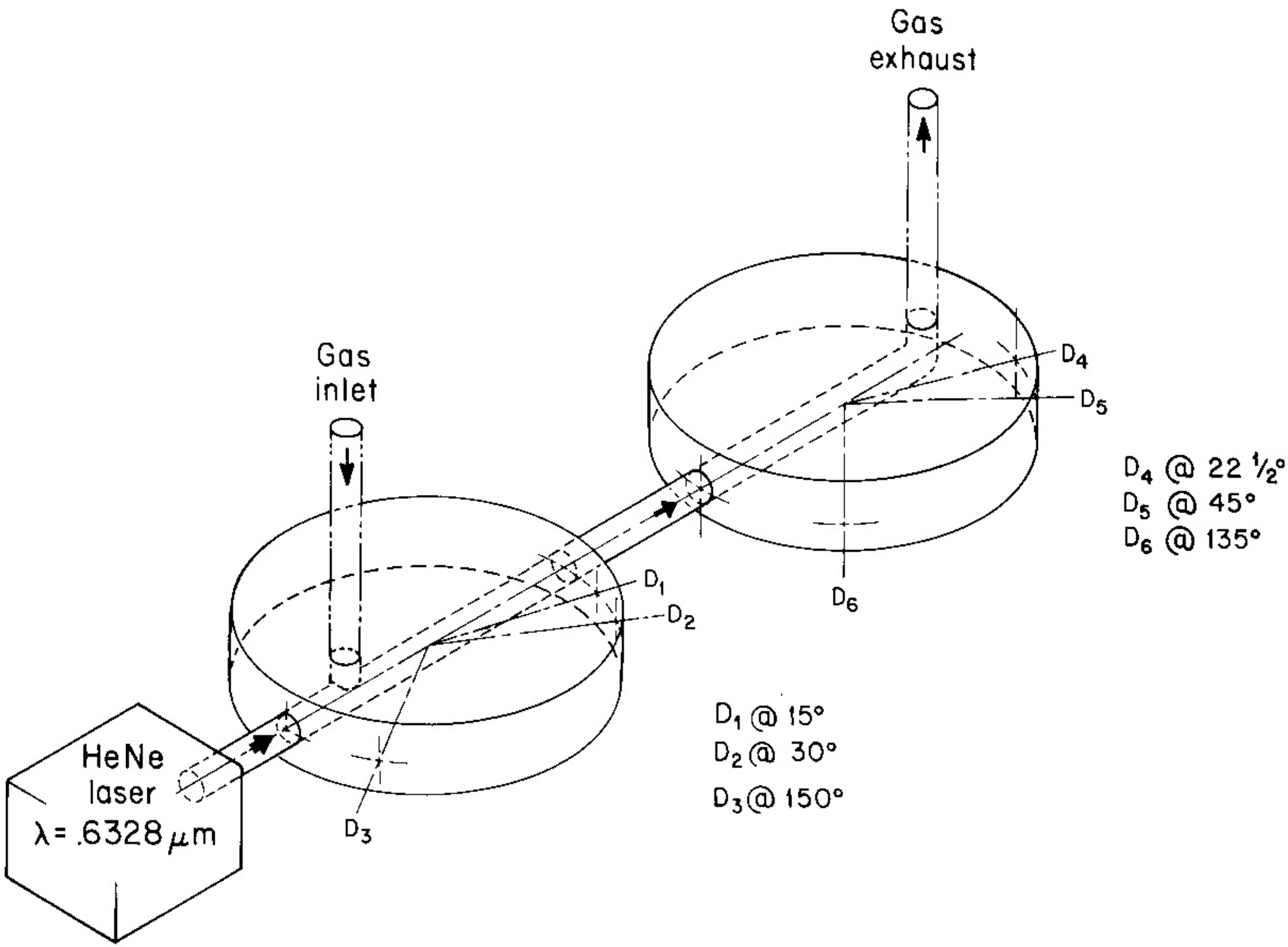
Albedo vs D32



Smaller Coal Dust Particles

- Primary Interest is Respirable Coal Dust
- Measurement of Respirable Coal Dust Difficult if Atmosphere is Contaminated by Diesel Particulate Matter (DPM)
- Scattering at Discrete Forward Angles May be Used to:
  - Discriminate Dust from DPM
  - Quantify Dust and DPM Mass Concentrations





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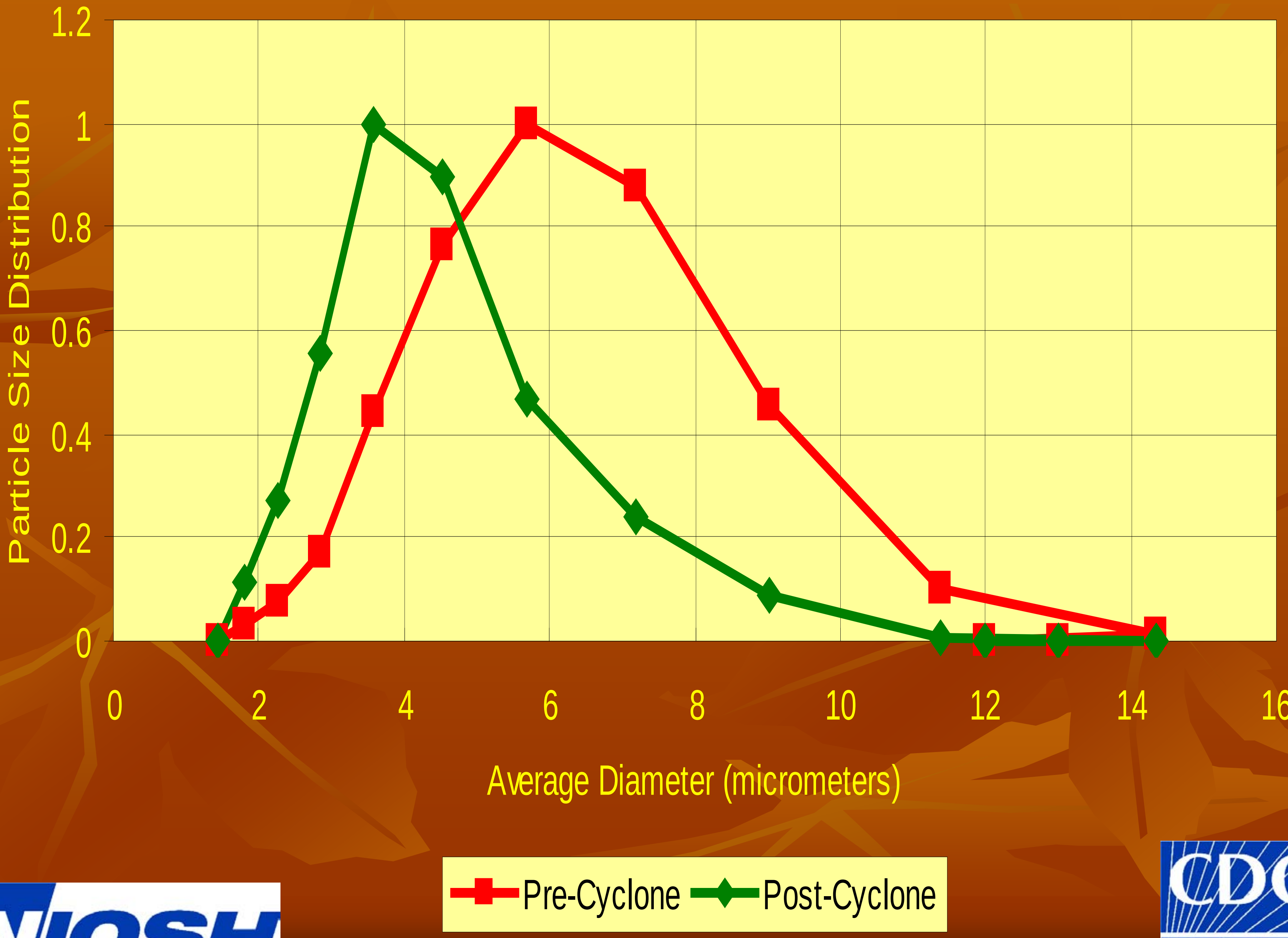
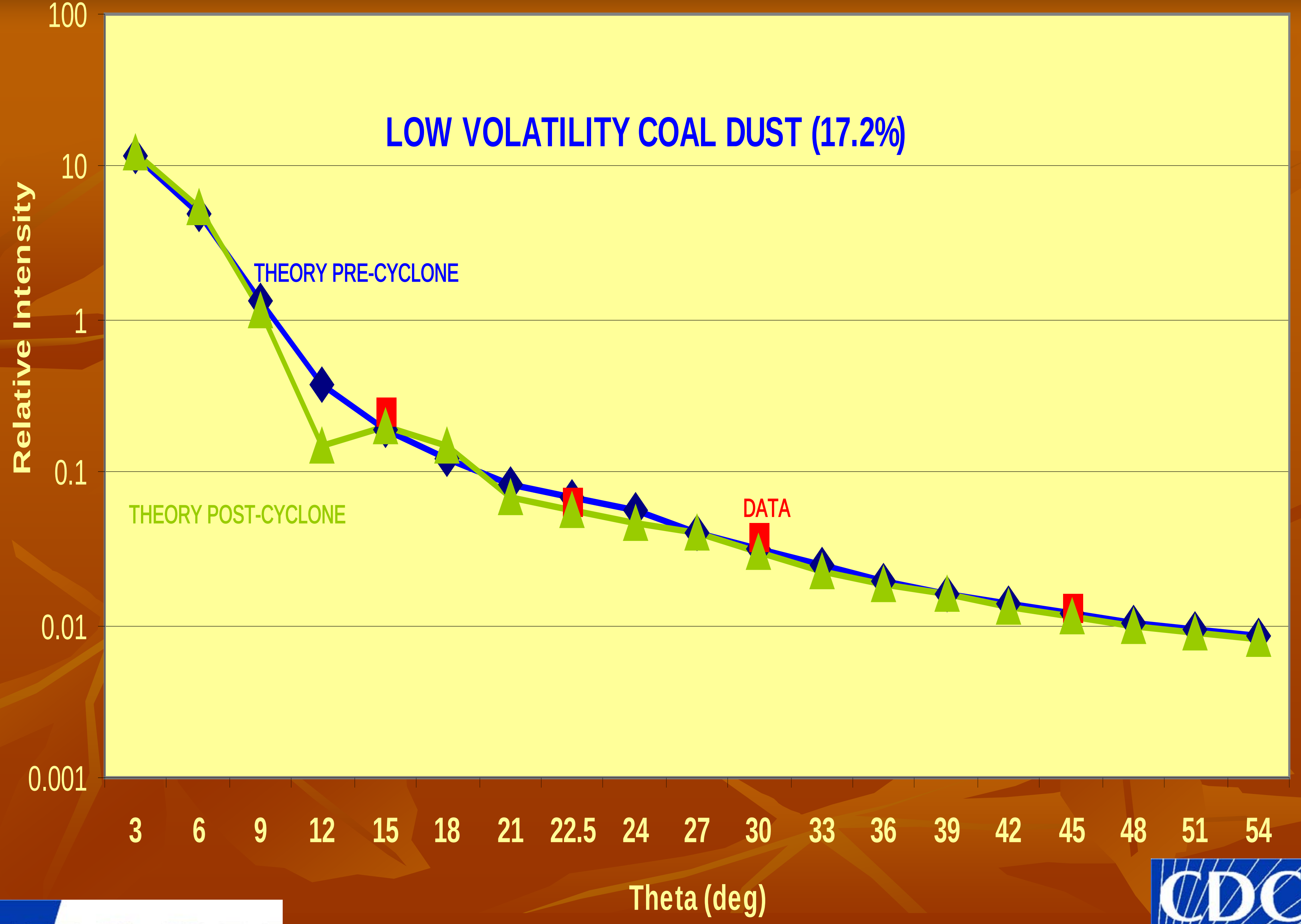
Experiments

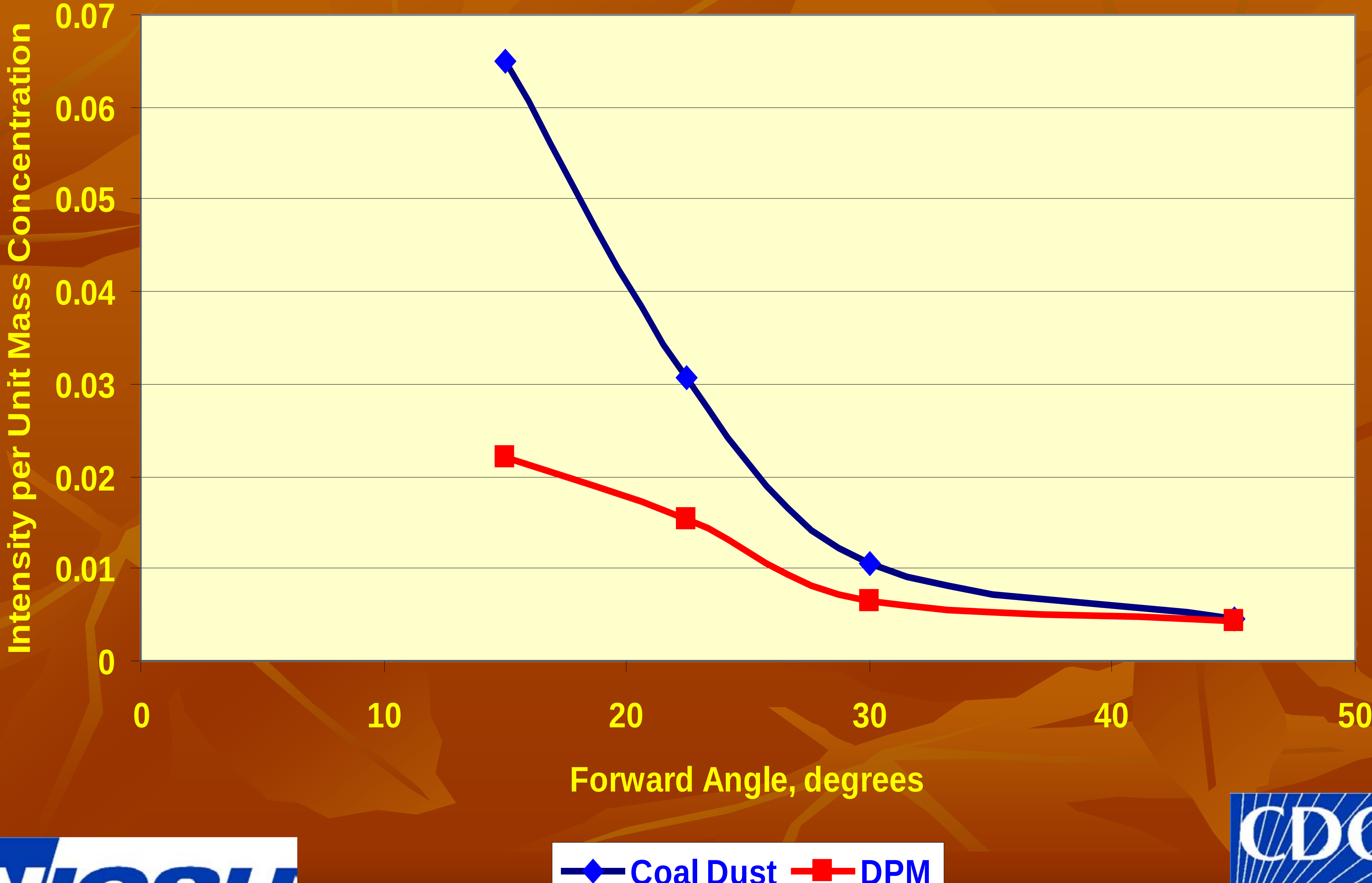
- Measured Angular Scattering Intensities per Unit Mass Concentration for Coal Dusts and DPM
- Added DPM to Existing Coal Dust or
- Added Coal Dust to Existing DPM
- Measured the Angular Scattering Intensities for the Mixtures



Particle Size Distribution
1.2
1
0.8
0.6
0.4
0.2
0
0
2
4
6
8
10
12
14
16
Average Diameter (micrometers)
Pre-Cyclone
Post-Cyclone


LOW VOLATILITY COAL DUST (17.2%)
Relative Intensity
100
10
1
0.1
0.01
0.001
THEORY PRE-CYCLONE
THEORY POST-CYCLONE
DATA
3
6
9
12
15
18
21
22.5
24
27
30
33
36
39
42
45
48
51
54
Theta (deg)

Scattering Intensities per Unit Mass Concentration



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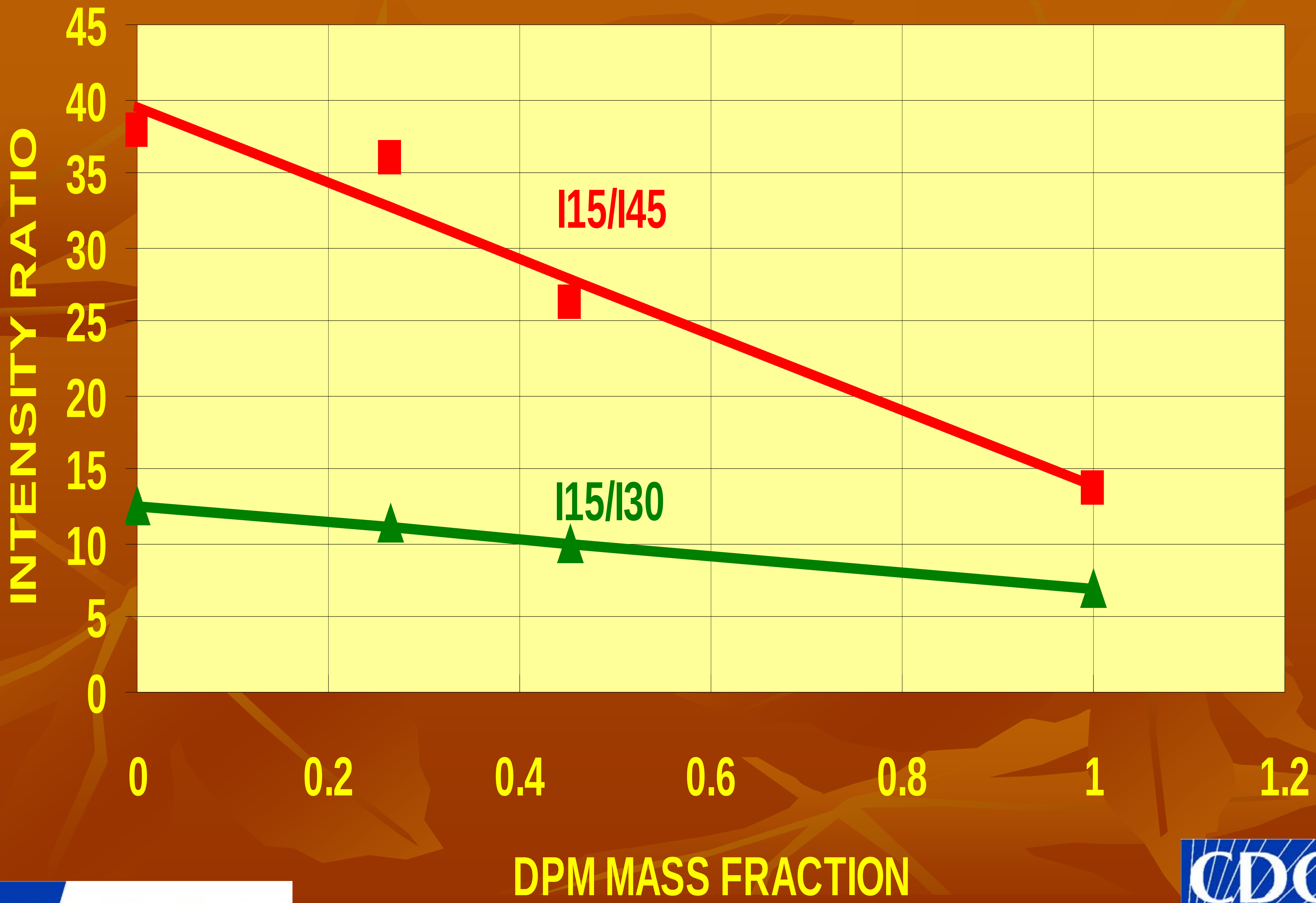

INTENSITY RATIO
45
40
35
30
25
20
15
10
5
0
I15/I45
I15/I30
0
0.2
0.4
0.6
0.8
1
1.2
DPM MASS FRACTION

Conclusions from Coal Dust/Rock Dust and Coal Dust/DPM Experiments

- Coal Dust/Rock Dust Experiments
  - Extinction Coefficient Relatively Small for Most Coal Dusts Resulting in Small Mass Absorption Coefficients and Large Albedos
  - Mass Absorption from Binary Dust Mixtures Can be Calculated Using Mass-Weighted Averages
- Coal Dust/DPM Experiments
  - Angular Intensity Distributions Significantly Different
  - For Mixtures, Mass-Weighted Intensities Reliably Predict Measured Intensity Values

Combustion Generated Aerosols

- Combustion Aerosols (D_P < 0.80 µm) Produce Angular Intensity Distributions Much Different from Dusts
- Mie Theory Generally Inadequate for Predicting Angular Intensities from Combustion Aerosols
- Treatment of Combustion Aerosols as Fractal-Like Aggregates Yields Better Results
- Different Combustion Modes Produce Different Angular Intensity Distributions
- Different Combustion Aerosols also Produce Different Angular Intensity Distributions

  -Diesel Particulate Matter (DPM)

  -Flaming Combustion Aerosols (FCA)

  -Smoldering Combustion Aerosols (SCA)

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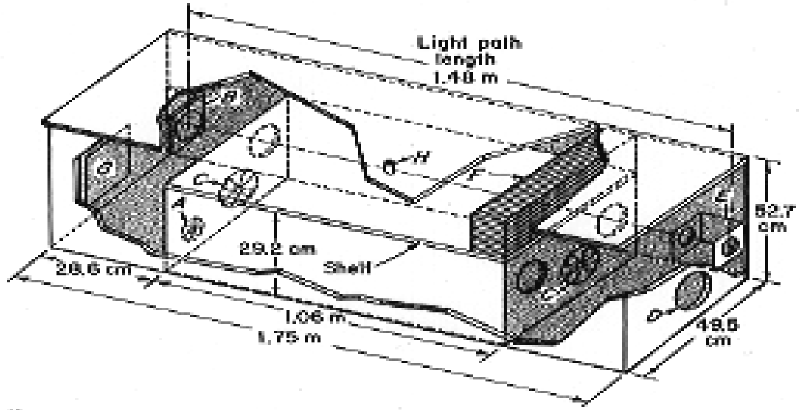
Rationale for Research

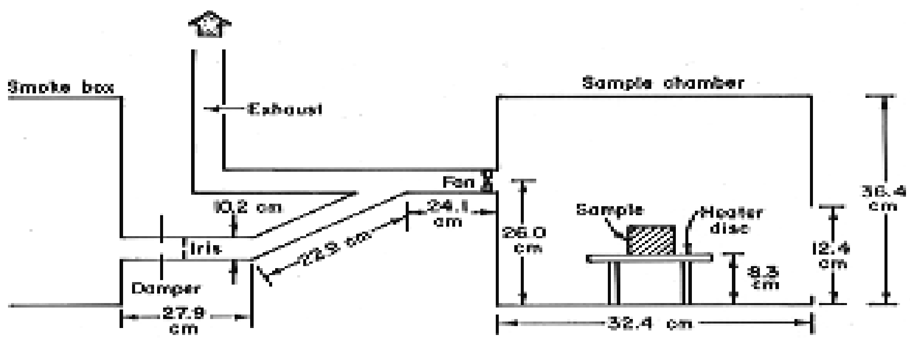
Experimental Configuration

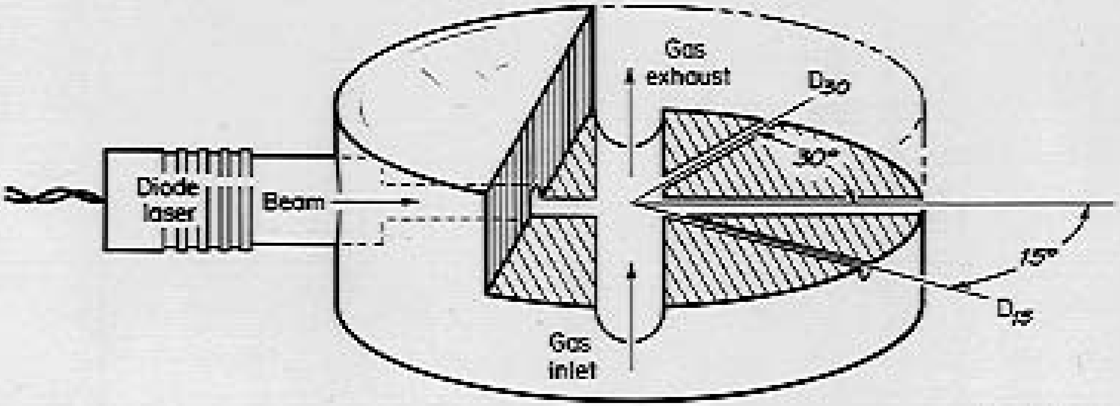
- UL 268 Smoke Box
  - Light Source/Detector To Mimic Response of Human Eye (Peak Response at λ = 546 nm)
  - Internal Shelf to Hold Aerosol Monitors
  - Extraction Port
- Separate Combustion Chamber Connected to Smoke Box Using a Variable Orifice



Key

A	12-V dc circulating fan	*E*	Photocell
B	6-V automotive lamp	*F*	Honeycomb (air straightener)
C	120-V ac circulating fan	*G*	Access door from sample chamber
D	Exhaust port with damper	*H*	Sample port




Gas
exhaust
Diode
laser
Beam
30°
15°
Gas
inlet

Normalized Angular Intensities per Unit Mass Concentration

Angle	Flame Wood	Smolder Wood	Flame Coal	Smolder Coal	Flame SBR	Smolder SBR
0	0.1613	0.5548	0.2889	0.2997	0.4580	0.3753
15	0.1425	0.4603	0.2145	0.2498	0.3652	0.2785
22.5	0.1193	0.3437	0.1226	0.1882	0.2506	0.1590
30	0.0833	0.2083	0.0678	0.1249	0.1508	0.0794
45	0.0508	0.1009	0.0287	0.0704	0.0760	0.0324
135	0.0105	0.0157	0.0058	0.0116		

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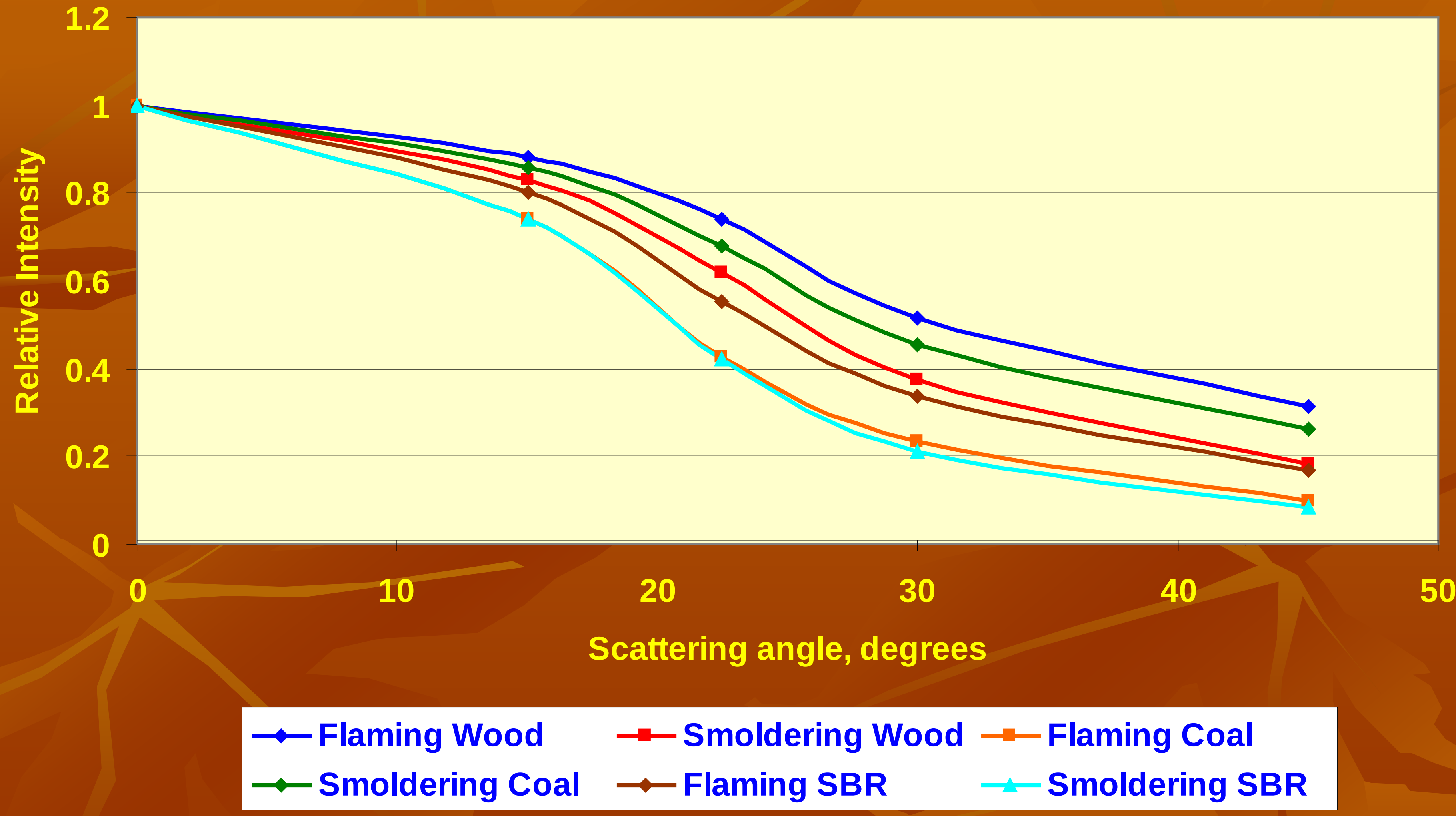
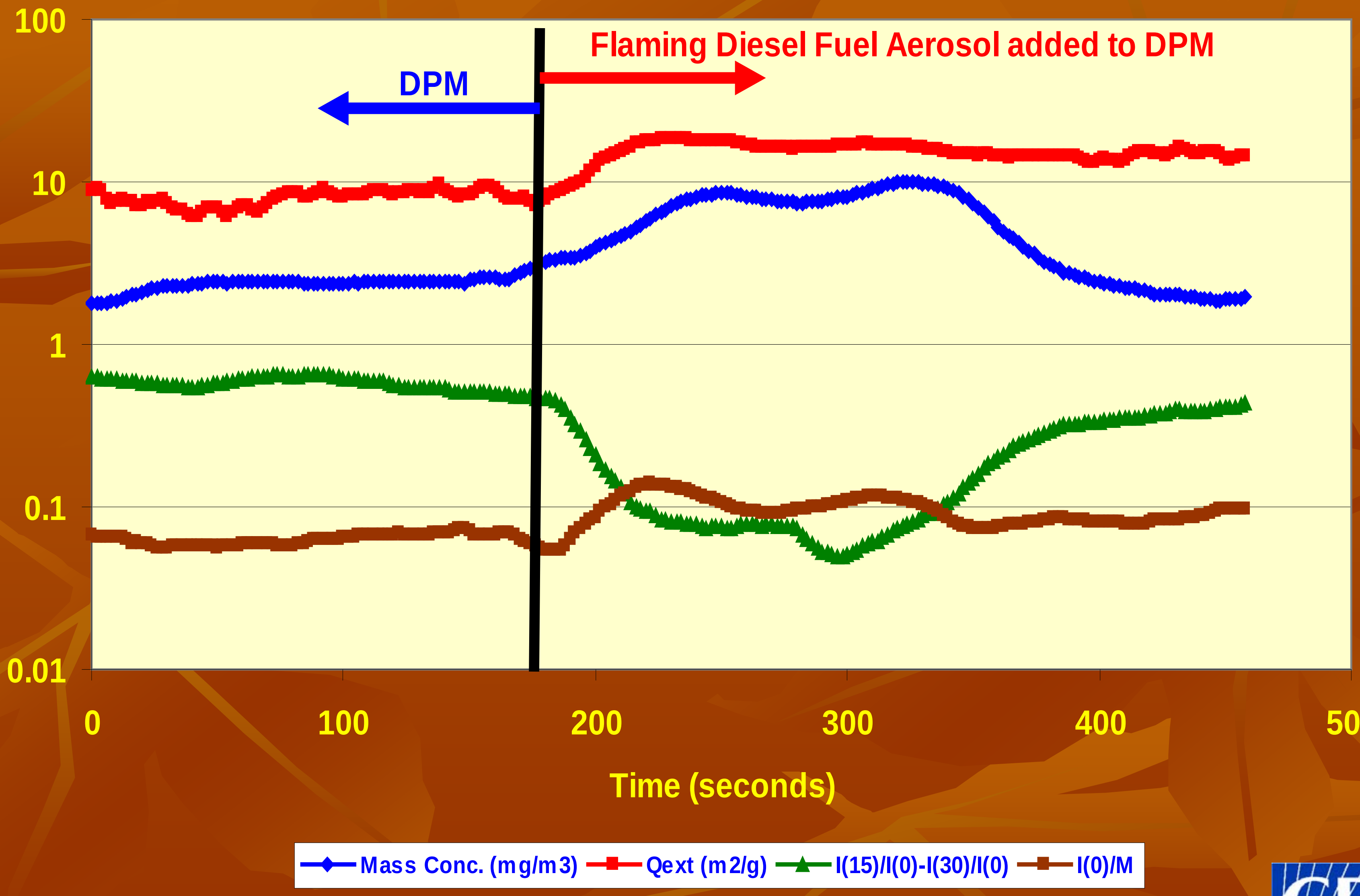
Angular Intensities

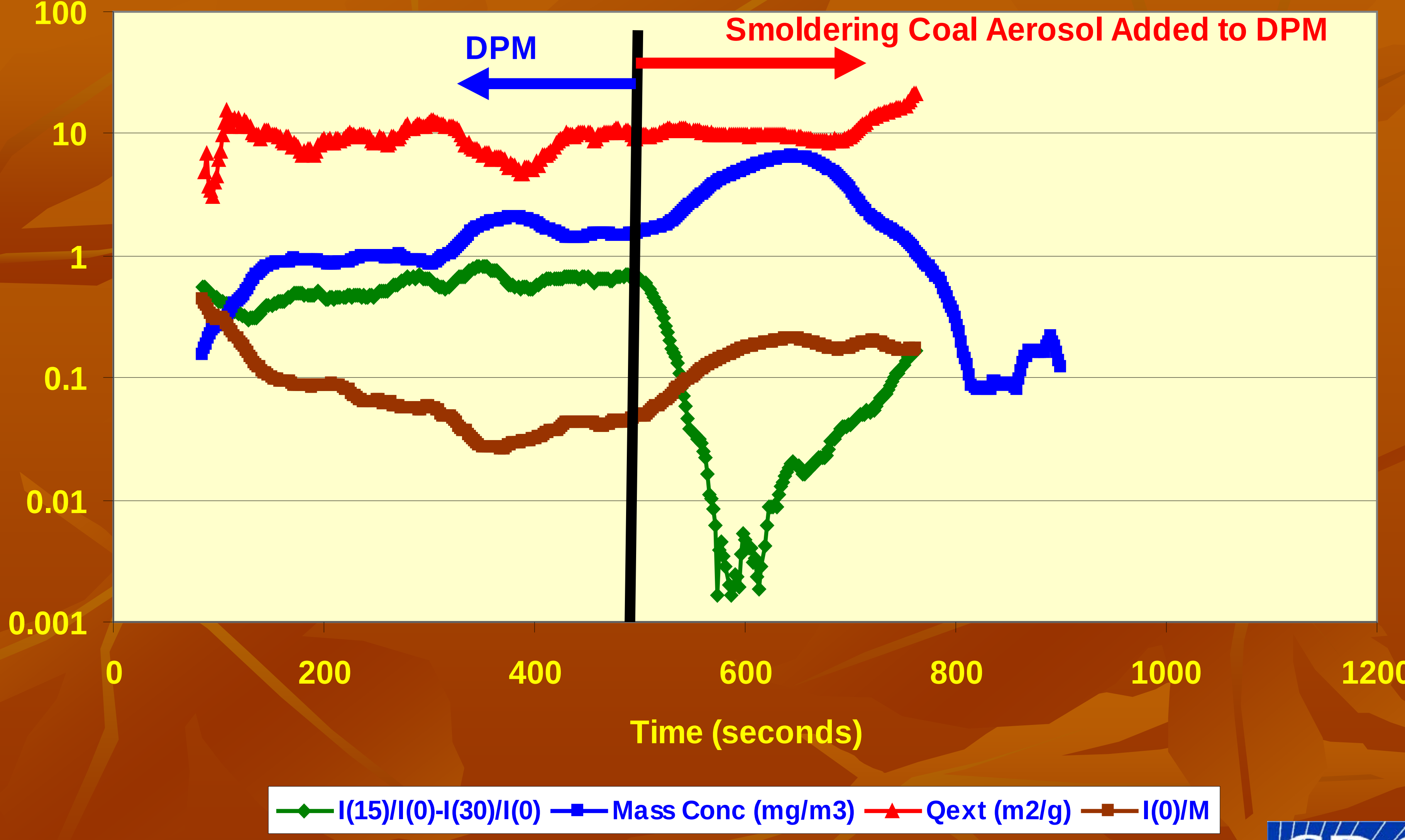


Combustion Source	Q_{EXT} (m^2/g)	Albedo, ω	Q_{ABS} (m^2/g)
Diesel Exhaust	9.5	0.18	7.8
Diesel Fuel Fire	10.5	0.23	8.1
Flaming Coal	10.4	0.19	8.4
Flaming SBR	9.1	0.21	7.2
Flaming Douglas Fir	8.6	0.25	6.5
Smoldering Coal	7.4	0.42	4.3
Smoldering Douglas Fir	6.4	0.39	3.8
Smoldering SBR	7.6	0.40	4.6

Mixing of Two Combustion Aerosols



Mixing of Two Combustion Aerosols



Discussion

- FCA’s typically have
  - Albedos in the range of 0.20
  - Mass Extinction Cofficients around 9.7 m^2/g
  - Mass Absorption Coefficients around 7.6 m^2/g
- SCA’s have
  - Albedos in the range of 0.40
  - Mass Extinction Coefficients around 7.1 m^2/g
  - Mass Absorption Coefficients around 4.2 m^2/g
- Mixing different combustion aerosols results in significant changes in the net optical properties

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Looking to the Future

- Add Some Additional Analysis Capabilities
- Expand Experiments to Include Analysis at Wavelengths extending to Near IR
- Perform More Extensive Aerosol Mixing Experiments
- Study the Effects of Humidity and Temperature on the Aerosol Optical Properties
- Study the Aging Process

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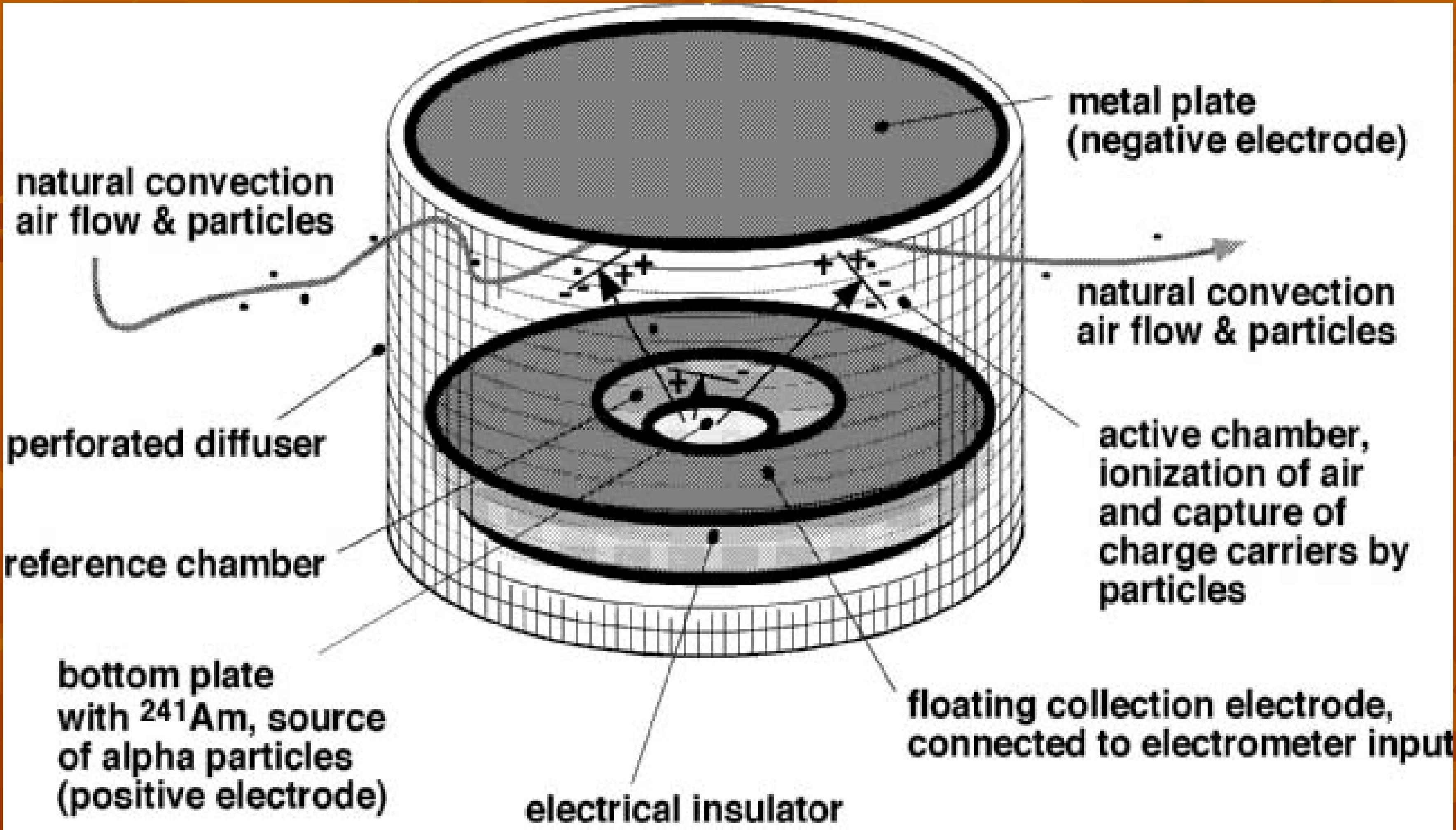
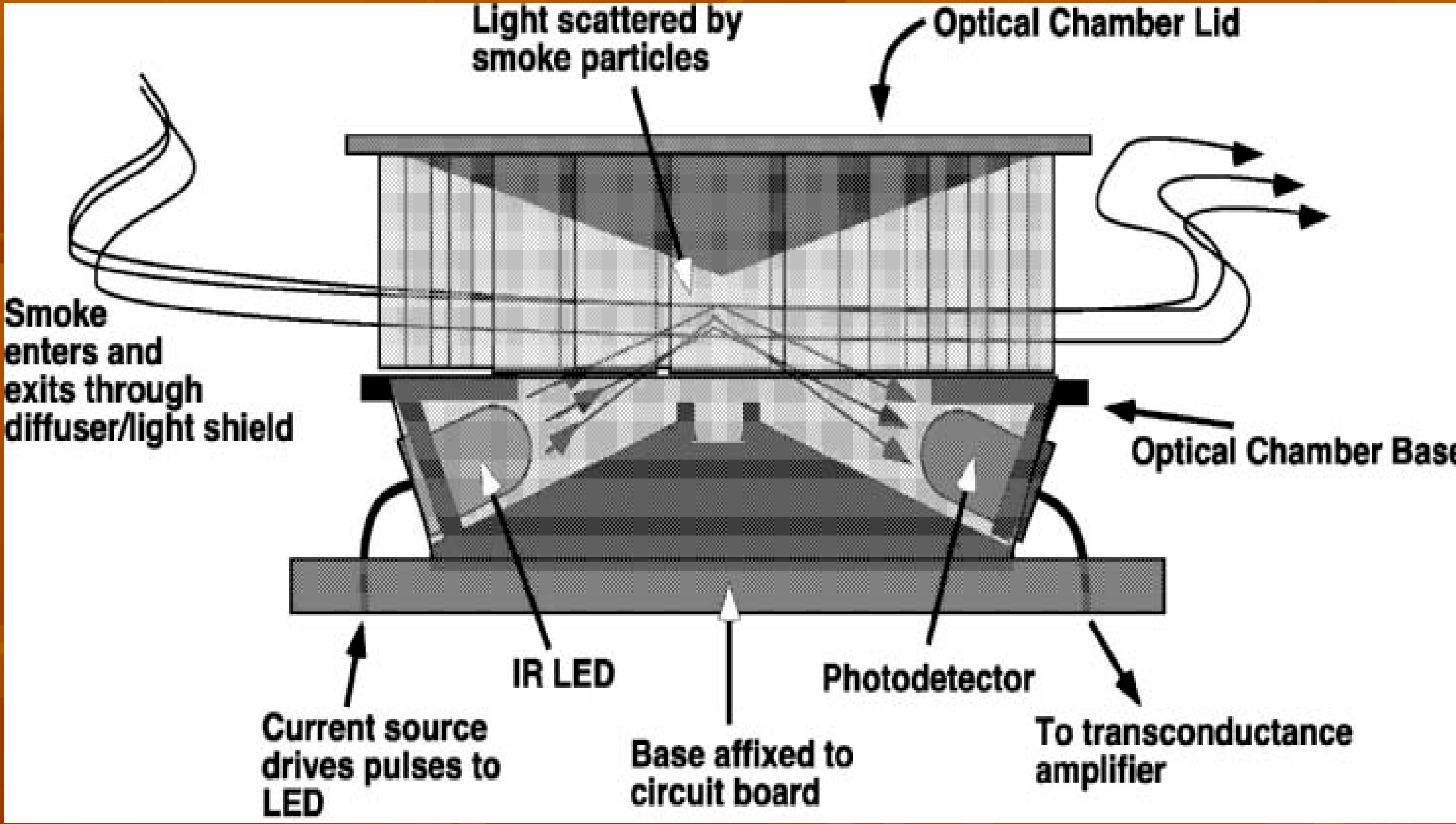
UCB Particle Sensor Update

- Combines Ionization Chamber Sensor with Forward Scattering Sensor at 45° and λ = 880 nm
- Uses the Ratio of the Two Sensor Outputs to Determine the Aerosol Mass Concentration, Surface Area, Number Concentration, and Average particle Diameter

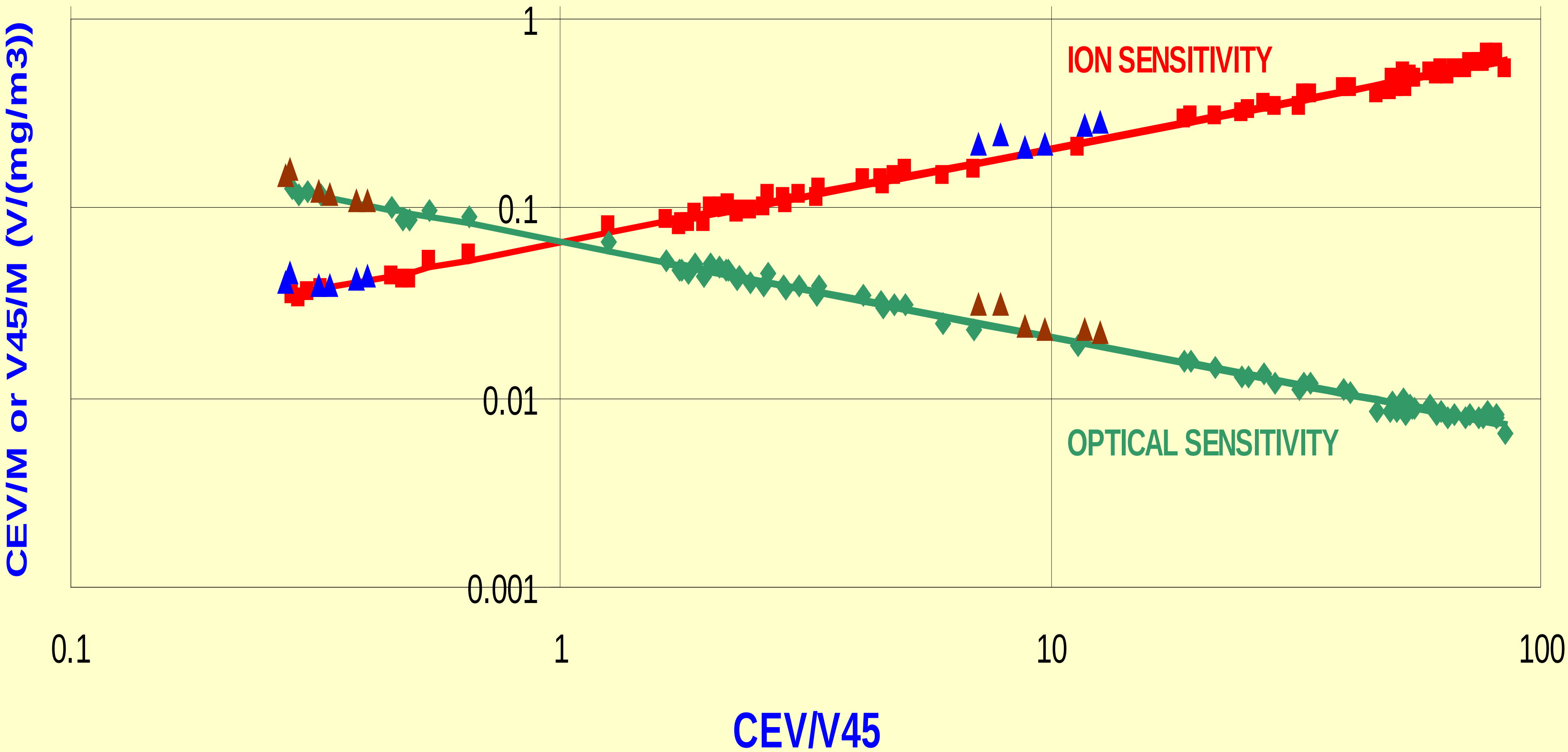
Ionization Chamber



Angular Scattering Chamber



ION & OPTICAL SENSITIVITIES



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OPTION Sensor

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