Local Soot Loading Distribution in Cordierite Diesel Particulate Filters by Dynamic Neutron Radiography

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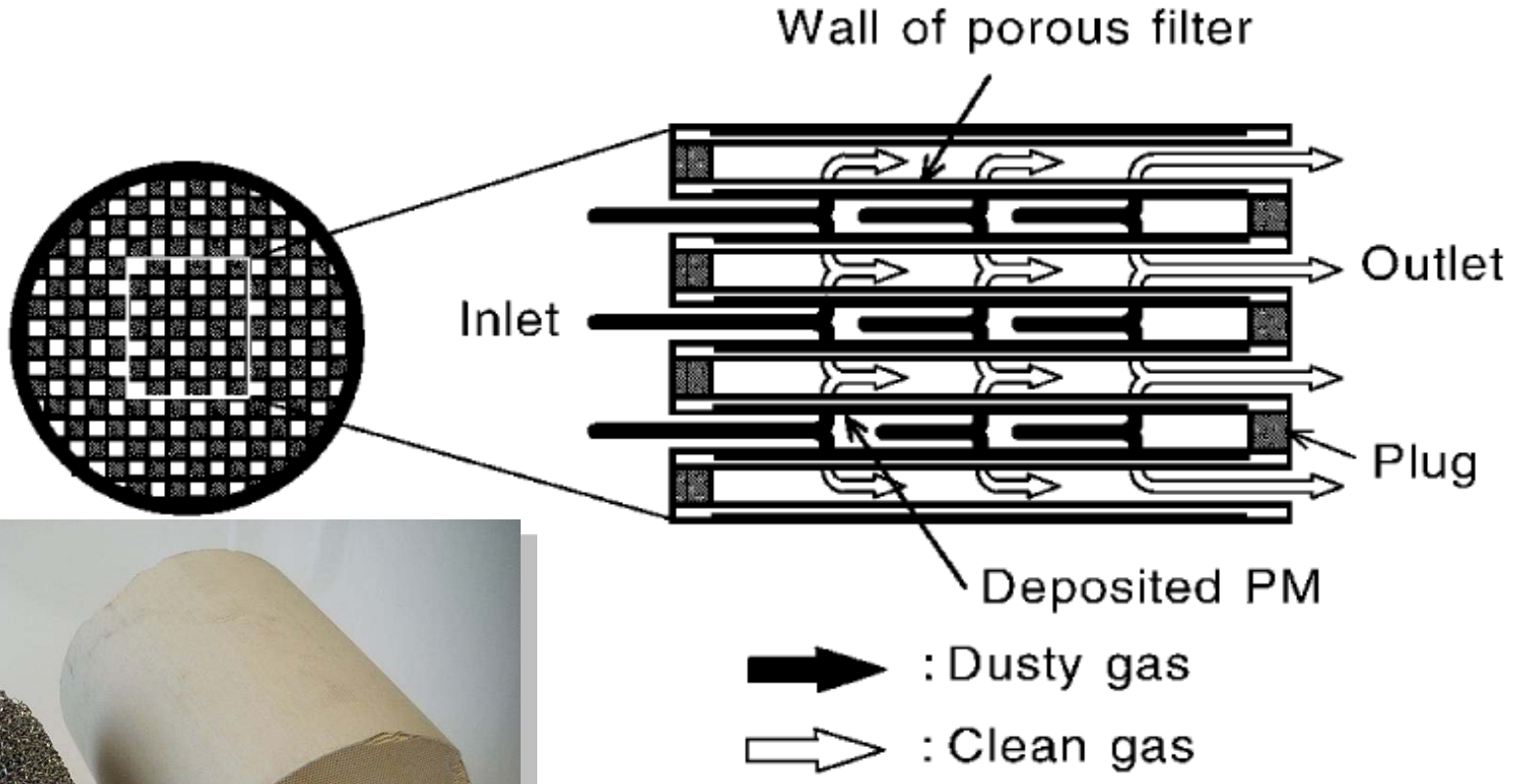
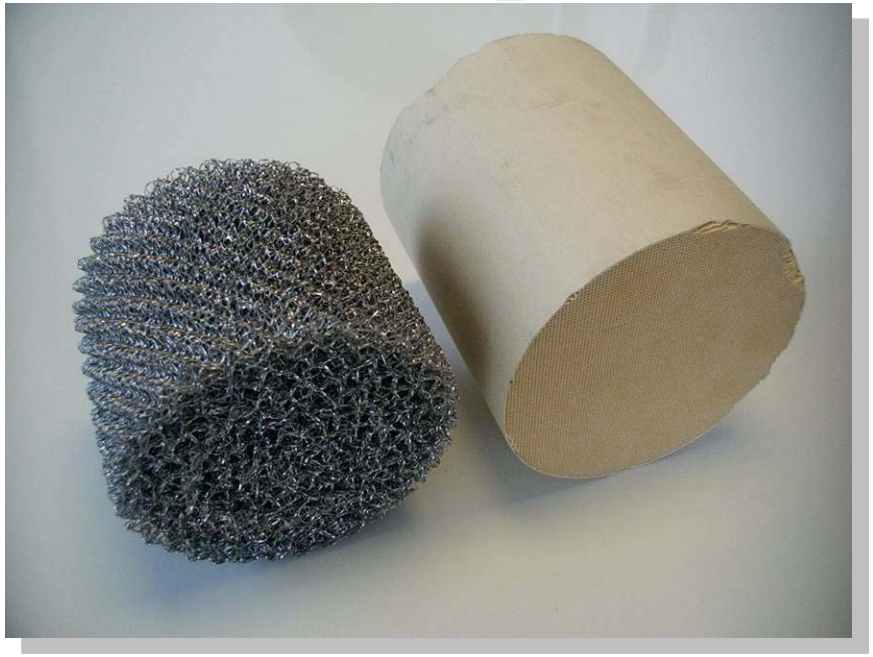
Outline of Presentation

- Brief Discussion on Diesel Particulate Filters
- Description of Dynamic Neutron Radiography
- Soot Characterization – Attenuation Coefficients
- Cordierite DPF Imaging Results
- SiC DPF Imaging Results

Typical Ceramic Diesel Particulate Filters (DPFs)



Modified from Okubo, et. al. 2004.

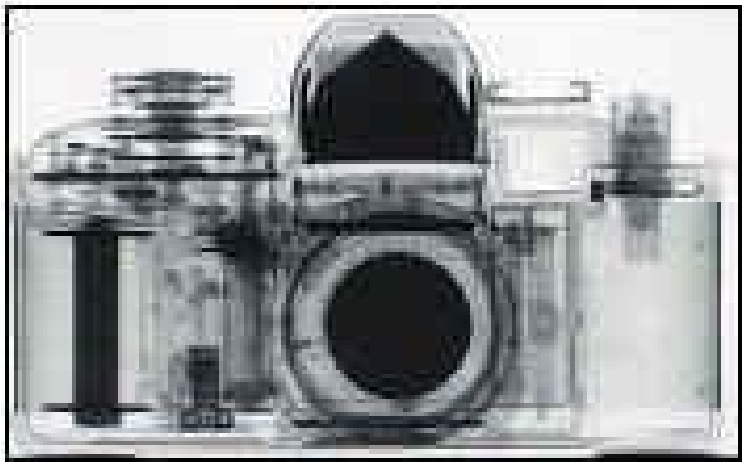


Problem for pressure build-up after soot deposition

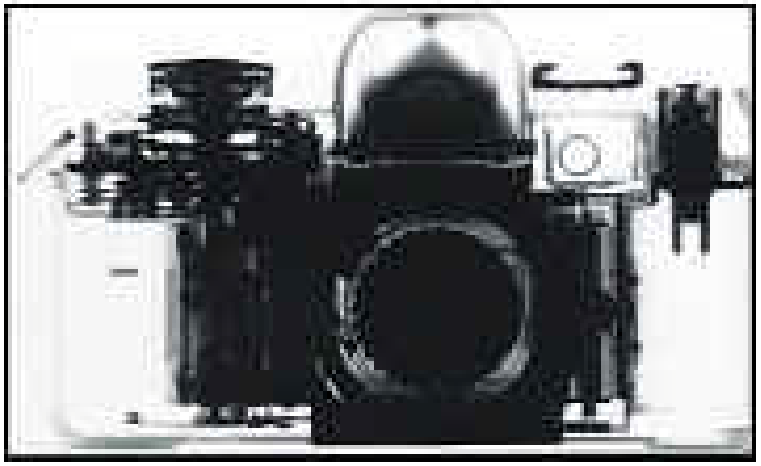
Characteristics of Diesel Particulate Filters used in this work

	Units	59%DPF	52% DPF	SiC DPF
DPF Diameter	cm	16	16	14.4
DPF Length	cm	14.9	14.8	15.2
DPF CS Area	cm2	201.0619	201.0619	162.8602
DPF Volume	cm3	2995.823	2975.717	2475.474
Density	g/cm3	1.68	1.68	2.05
Porosity	%	0.59	0.515	0.59
Total Mass	g	1421.995	1529.034	1686.282

Neutron vs X-ray Image



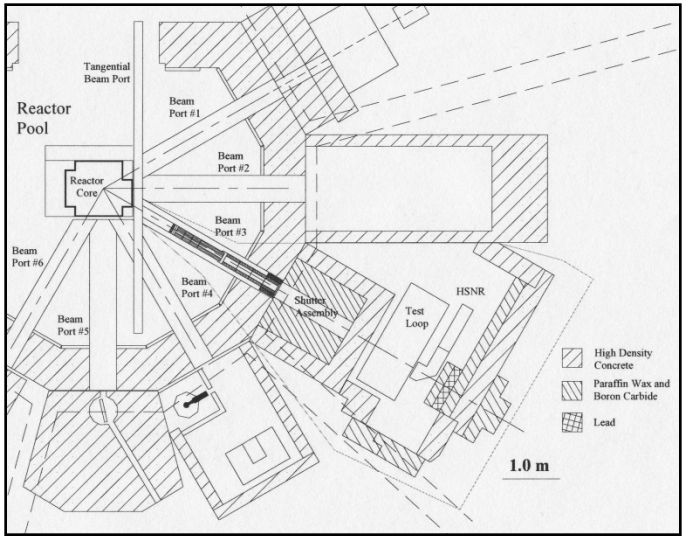
Neutron Image



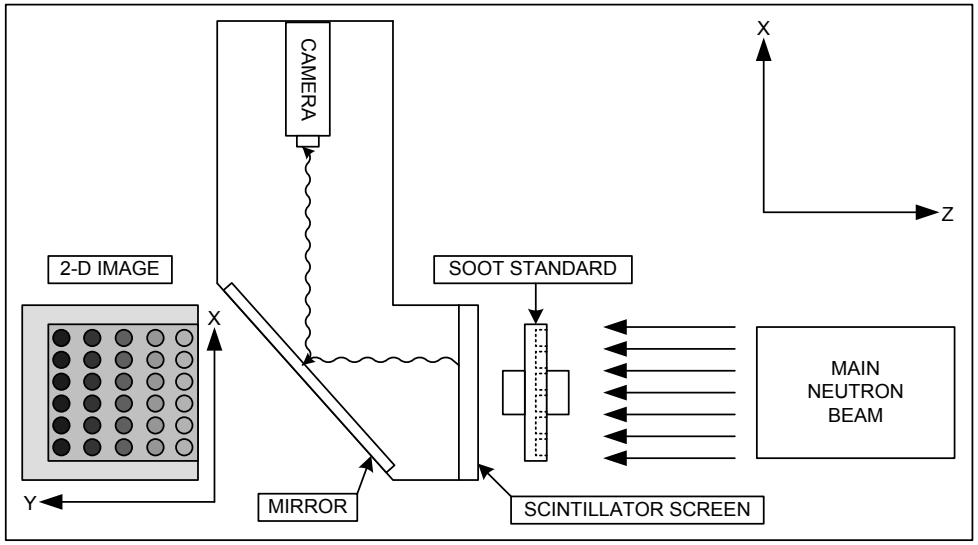
X-ray Image

Dynamic Neutron Radiography

- Dynamic Neutron Radiography (DNR) Process;
  - Uniform neutron beam irradiates target object through beam port
  - Neutrons are attenuated by target object (i.e. Soot Standard)
  - Attenuation formula: $I(x) = I_0 Bu(x) e^{-\mu x}$
  - Neutrons pass through LiF scintillator screen producing light emission
  - Mirror redirects light emission to real time video camera



Facility at McMaster Nuclear Reactor



DNR System used for Radiography

Neutron Attenuation Coefficients

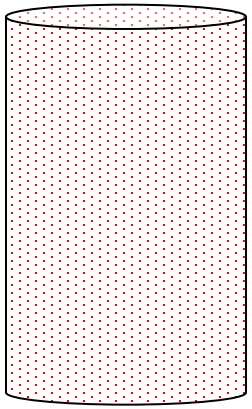
w = elemental wt%, Na = Avogadro's, A = atomic mass

$$\frac{I}{I_0} = e^{-\Sigma x}$$

$$\Sigma = \sigma N$$

$$N = \frac{\omega * N_a * \rho}{100 * A}$$

Packing Density



Depends on Soot Composition- Soot, Ashes, Hydro Carbone, Water etc.

UOIT
CHALLENGE INNOVATE CONNECT

Dry Diesel Soot Composition

- Soot composition will affect RTNR image

Diesel Soot (*Clague, A.D.H. et al / Carbon V 37 #10 (1999) 1553-1565*)

Elemental Composition of Diesel Exhaust Soot by wt%													
C	**H**	**O**	**N**	**S**	**Ca**	**Zn**	**P**	**Fe**	**Mg**	**Al**	**Cu**	**Pb**	**Si**
51.4	**0.7**	**26.7**	**0.3**	**5.0**	**2.0**	**0.9**	**1.2**	**7.8**	**0.3**	**0.2**	**0.2**	**1.0**	**0.2**

Carbon Black (*Clague, A.D.H. et al / Carbon V 37 #10 (1999) 1553-1565*)

Elemental Composition of Carbon Black by wt%													
C	**H**	**O**	**N**	**S**	**Ca**	**Zn**	**P**	**Fe**	**Mg**	**Al**	**Cu**	**Pb**	**Si**
95.5	**0.6**	**2.2**	**0.3**	**2.1**	**2.0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

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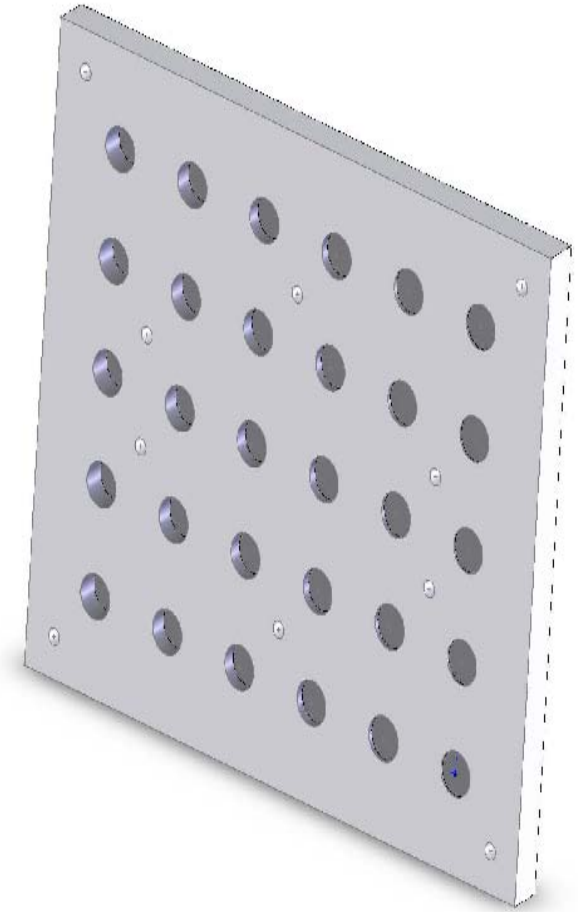
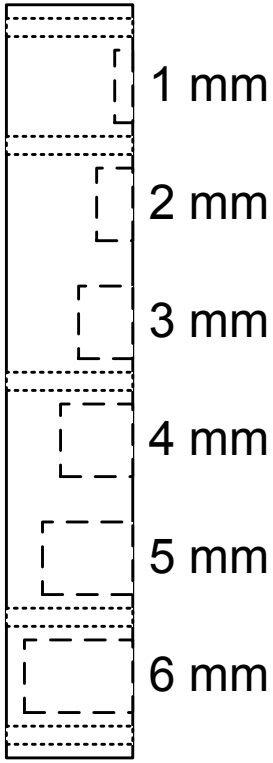
CHALLENGE INNOVATE CONNECT

Soot Standard Test for Neutron Attenuation Coefficient Measurement





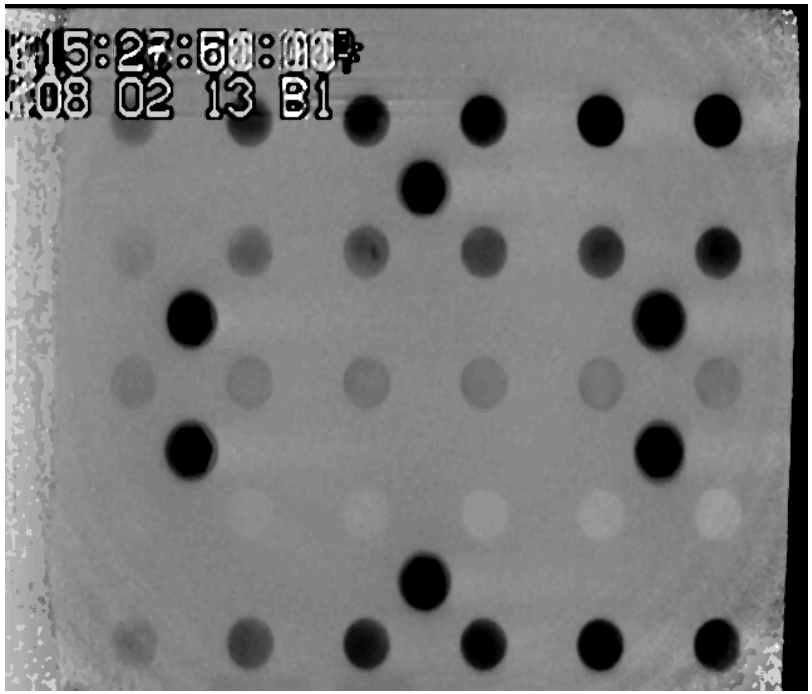
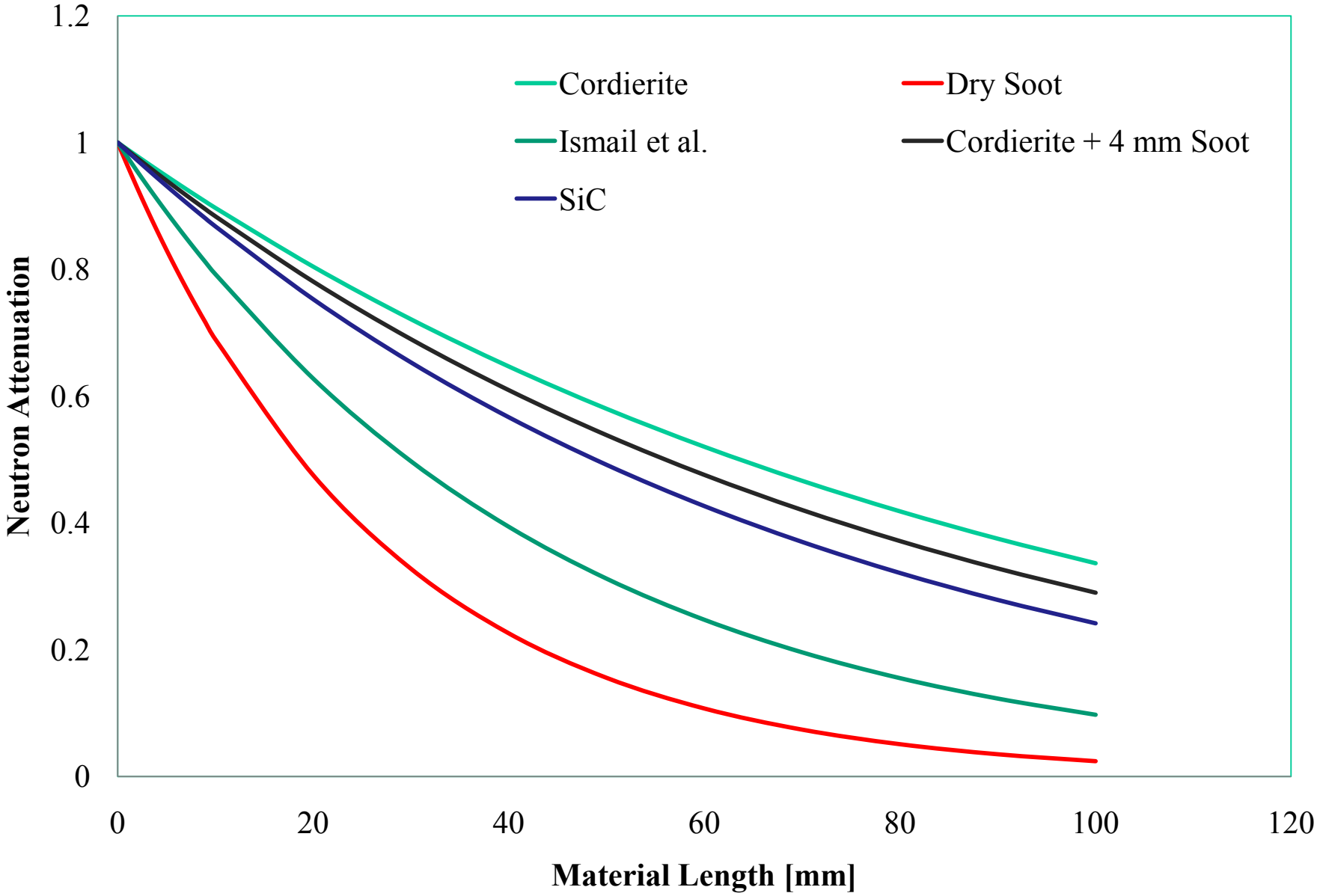


Table 2 – Linear Attenuation Coefficients for Different Materials

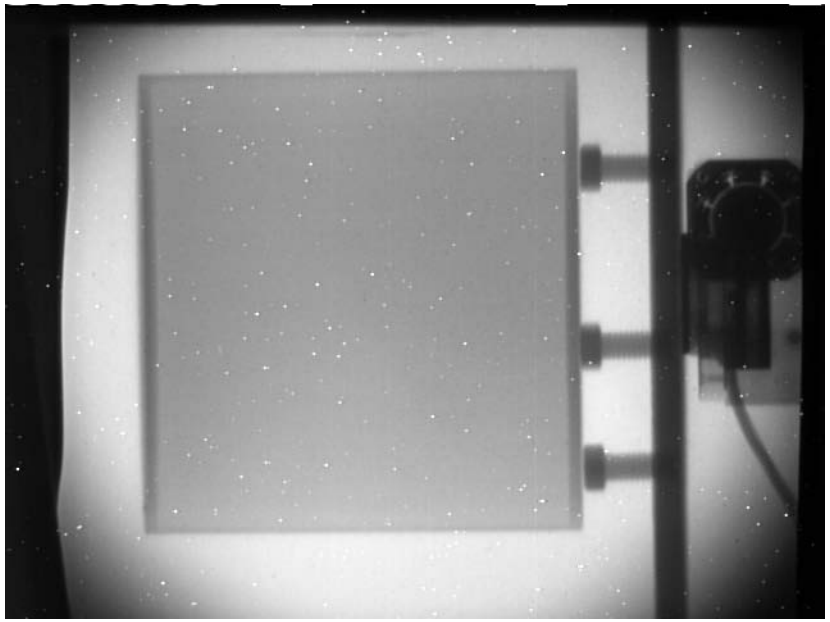
DPF Material Neutron Attenuation Coefficient

Diesel Soot	
Soot – Ismail et al. [5]	0.0233 mm^{-1}
Soot – Present Soot from Measurement	0.0372 mm^{-1}
Soot + Hydrocarbons- Theory	0.0850 mm^{-1}
DPF Material	
Cordierite – Theory	0.0109 mm^{-1}
SiC – Theory	0.0142 mm^{-1}

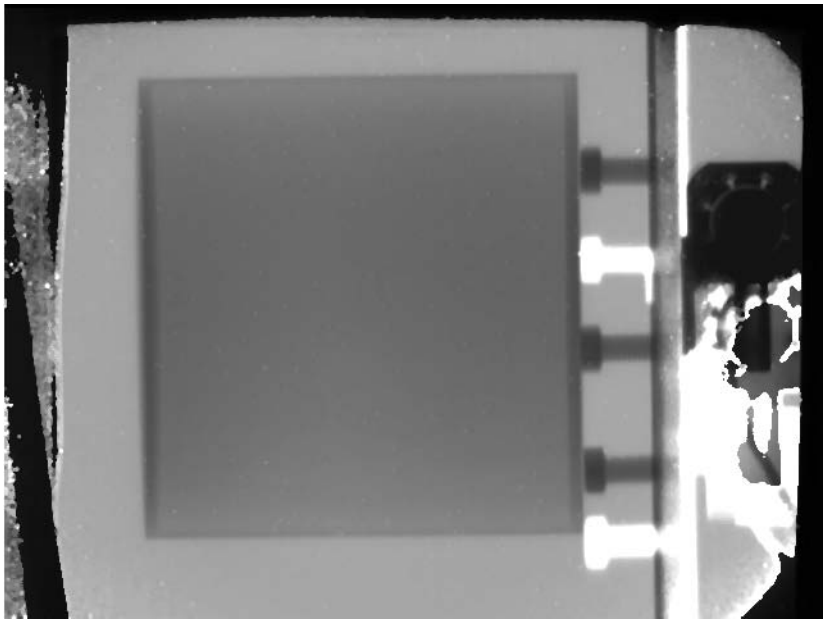

Cordierite
Dry Soot
Ismail et al.
Cordierite + 4 mm Soot
SiC
Neutron Attenuation
1.2
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
120
Material Length [mm]

5 g/l DPF: (a) clean, (b) soot, (c)Corrected, (d) Processed

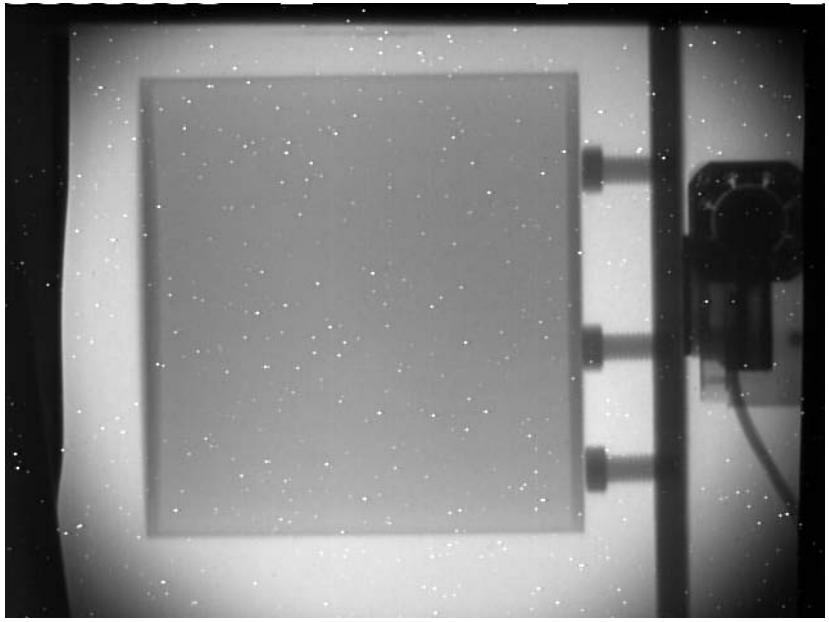
(a)



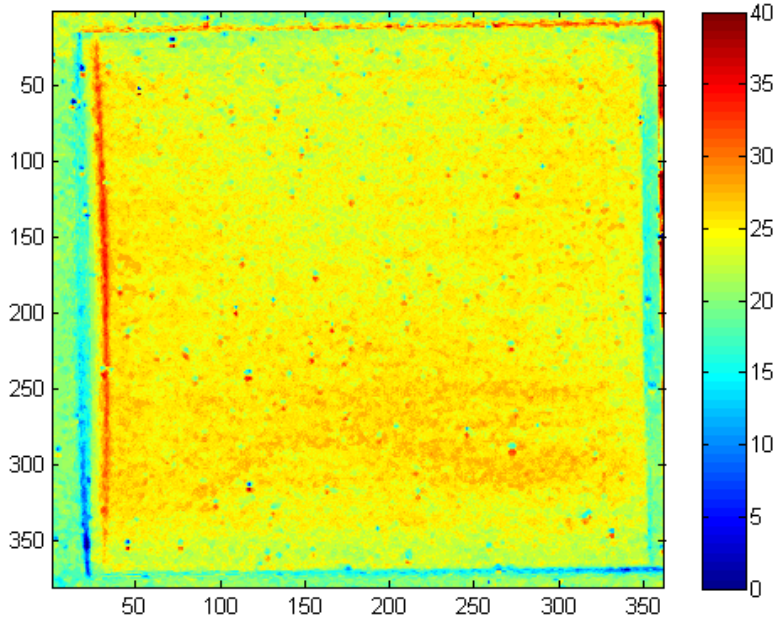
(c)



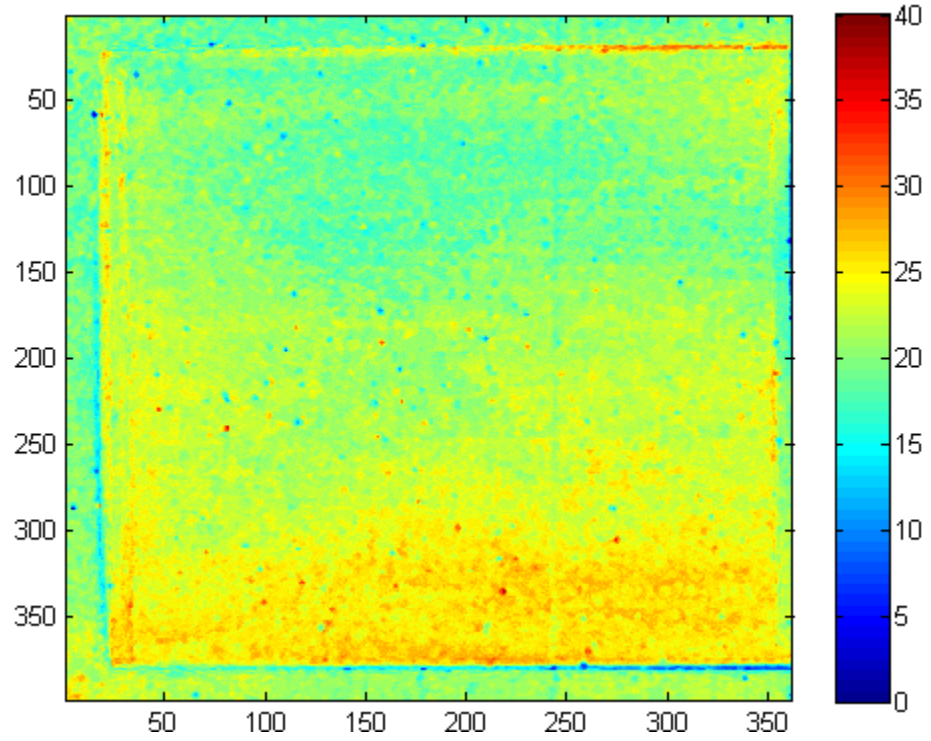
(b)



(d)

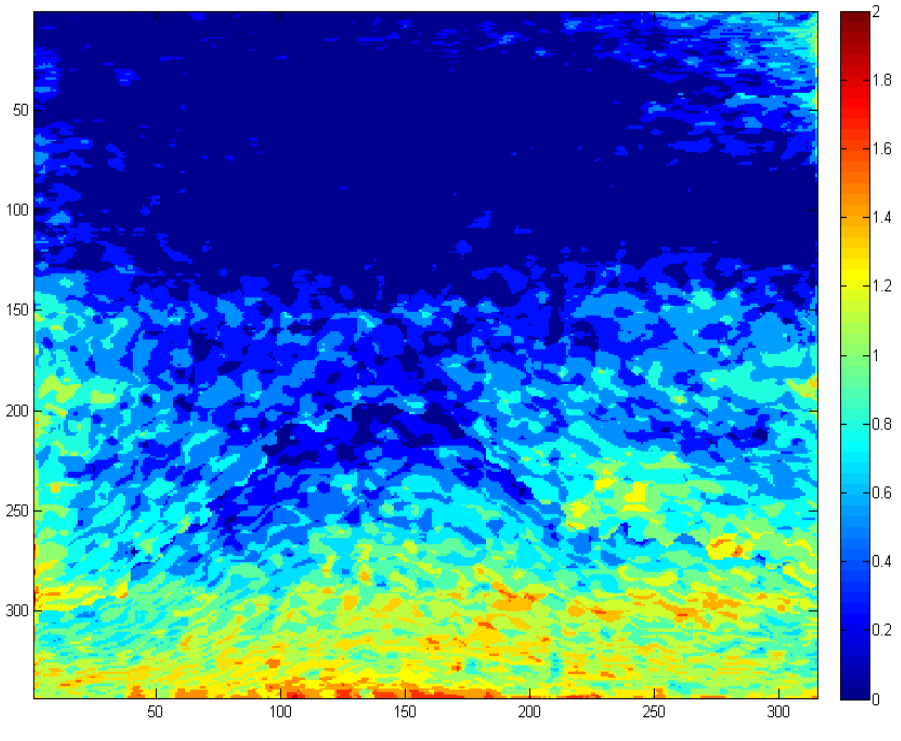


Qualitative Image



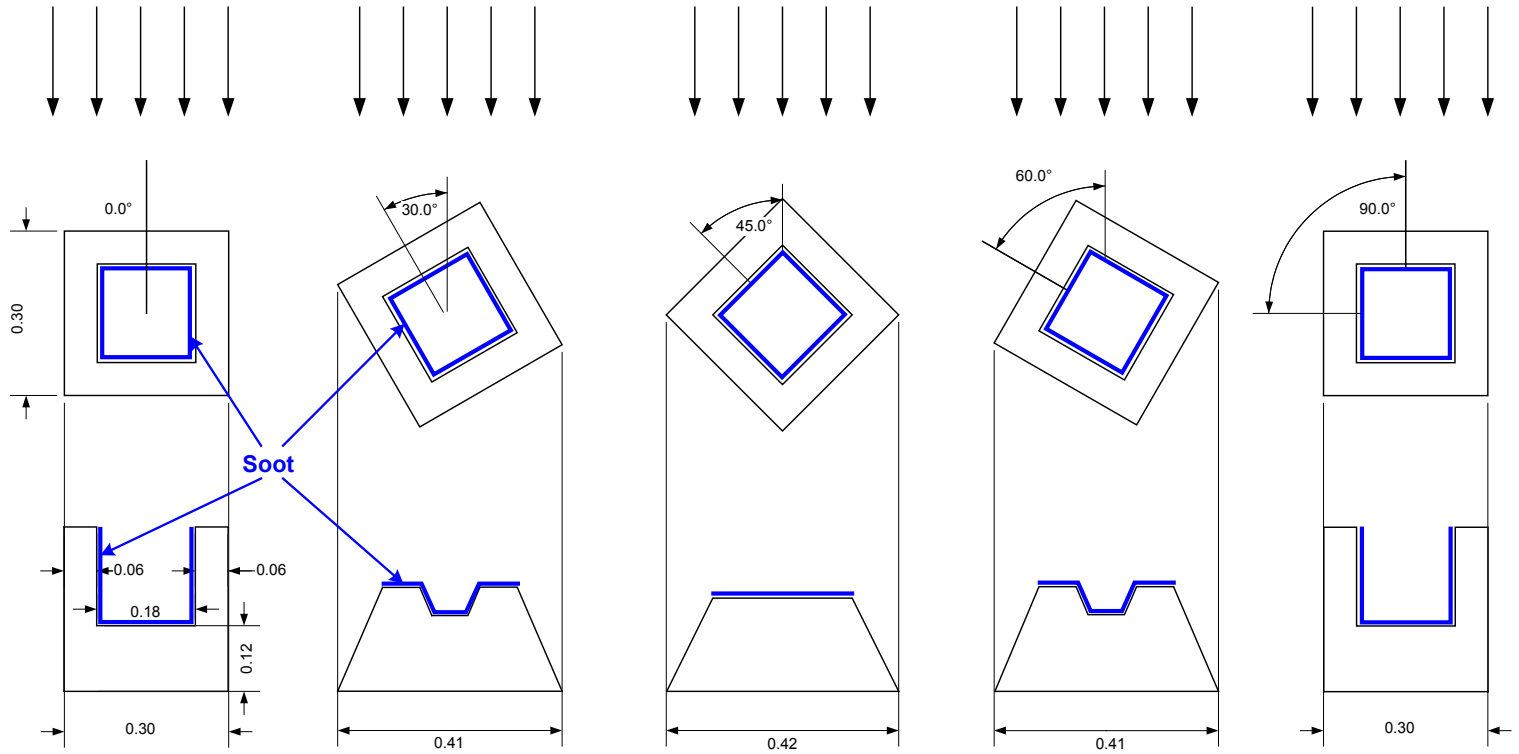
(a)

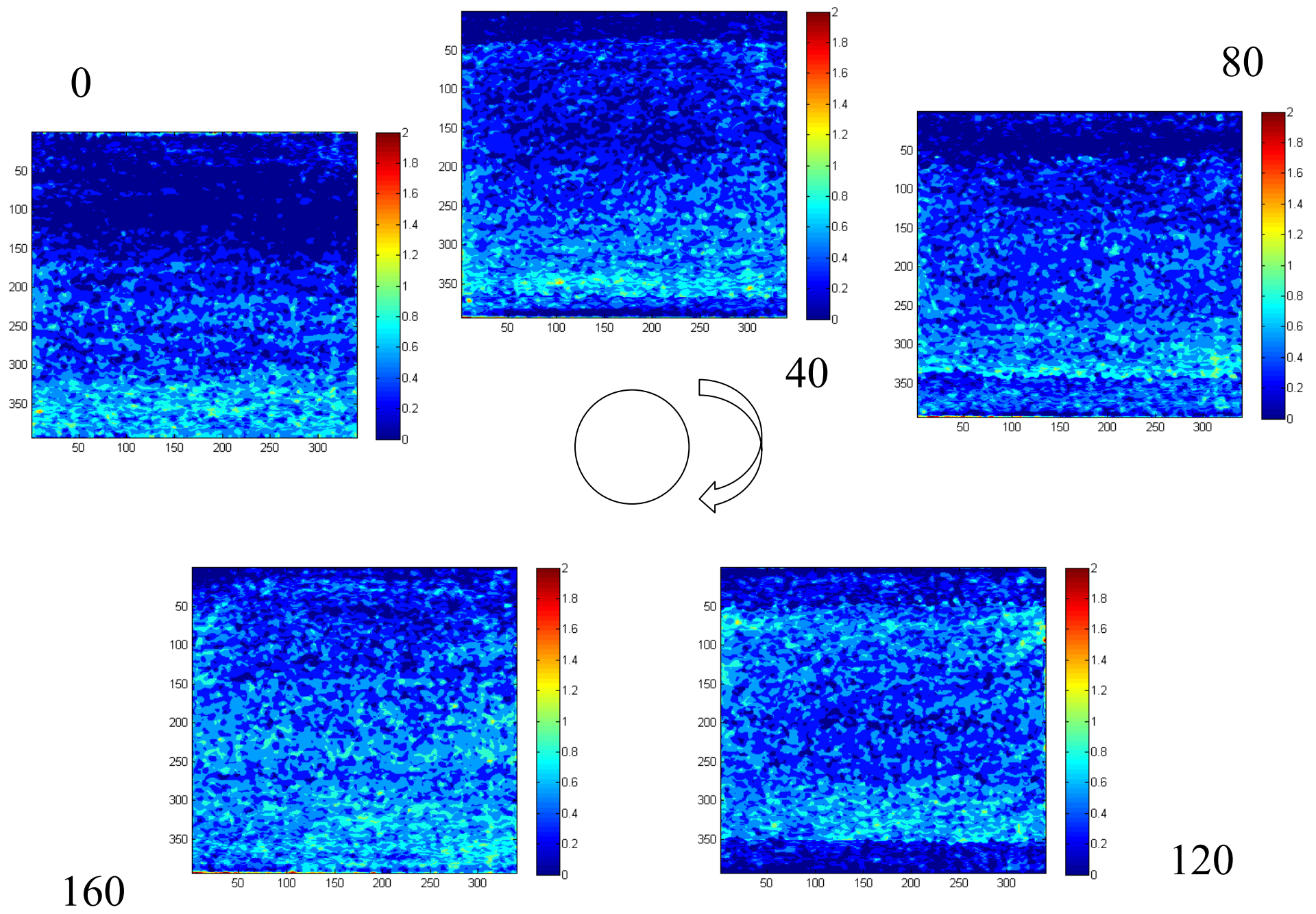
Quantitative Image

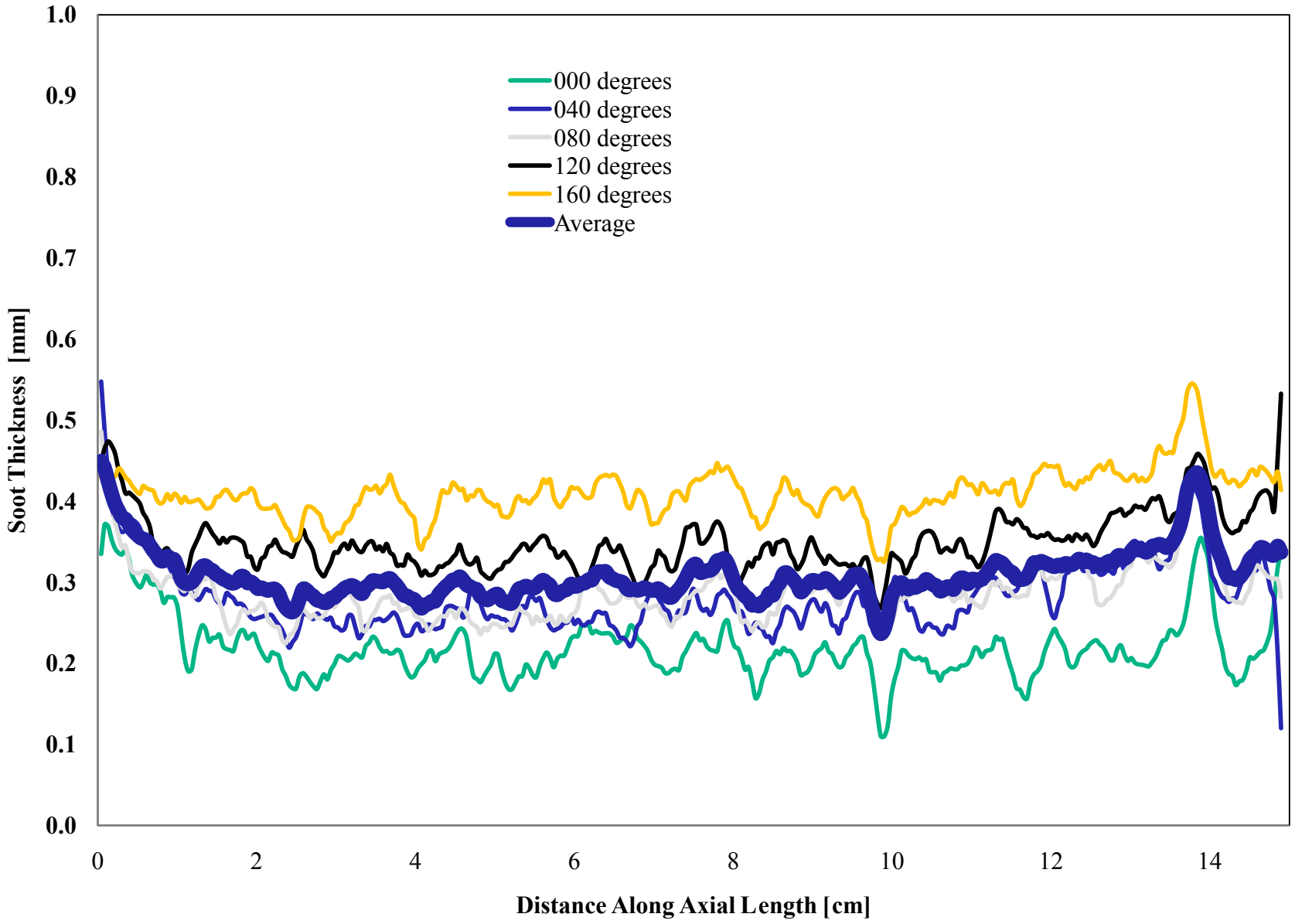


(b)

Effect of DPF Rotation on Neutron Path Length

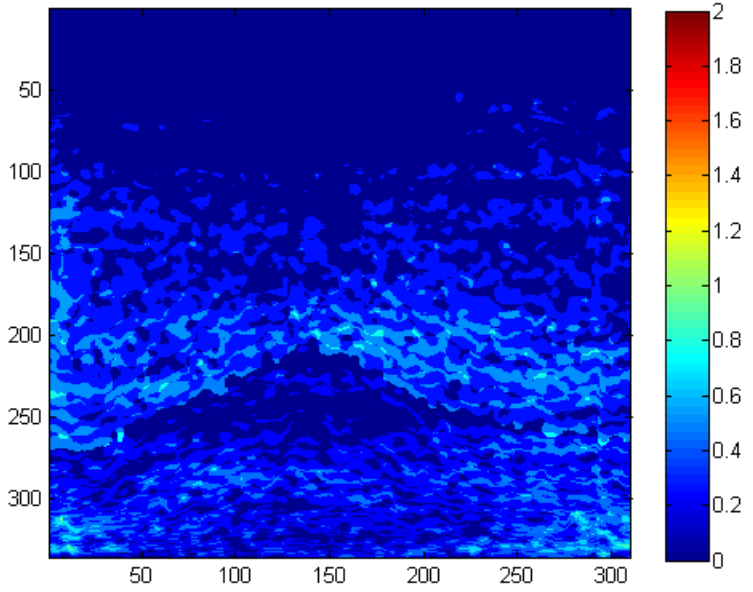



0
40
80
120
160
3g/l Soot Loading in Cordierite DPF

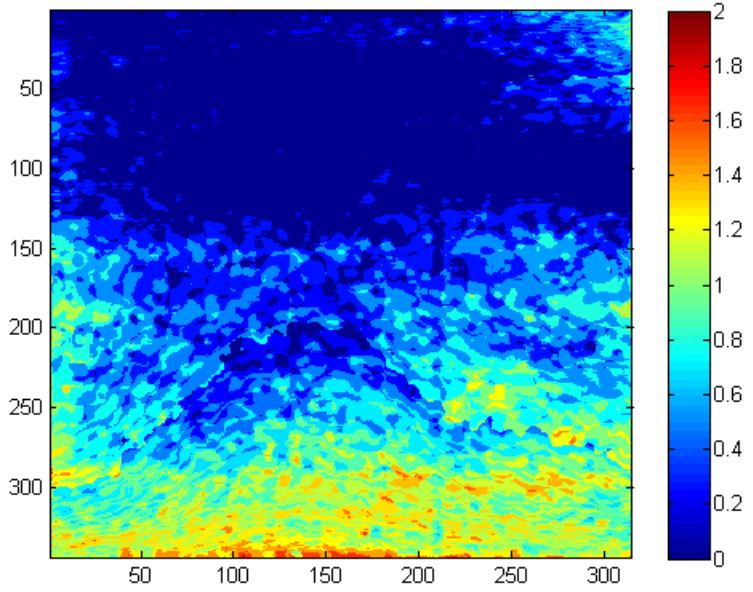

Cross-sectional Averaged Deposited Soot Thickness
000 degrees
040 degrees
080 degrees
120 degrees
160 degrees
Average
Soot Thickness [mm]
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
2
4
6
8
10
12
14
Distance Along Axial Length [cm]

Effect of Soot Loading/Deposition Time on DPF Image: (a) 1 g/l, (b) 3 g/l, (c) 5 g/l

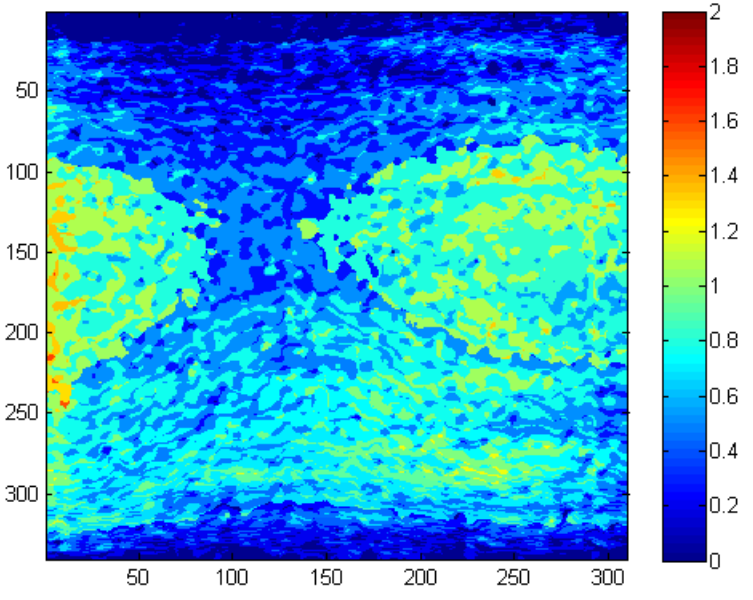
(a)

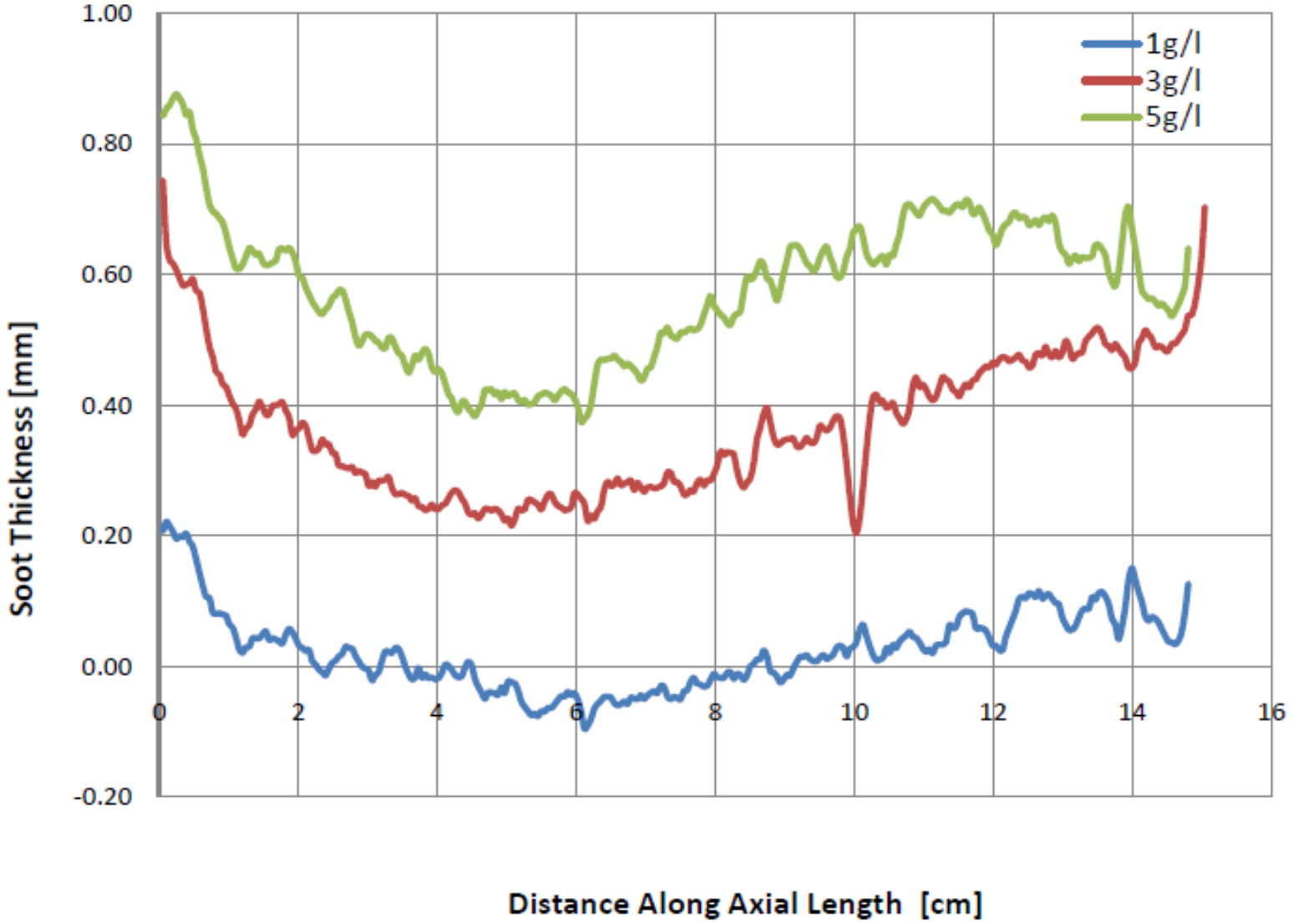


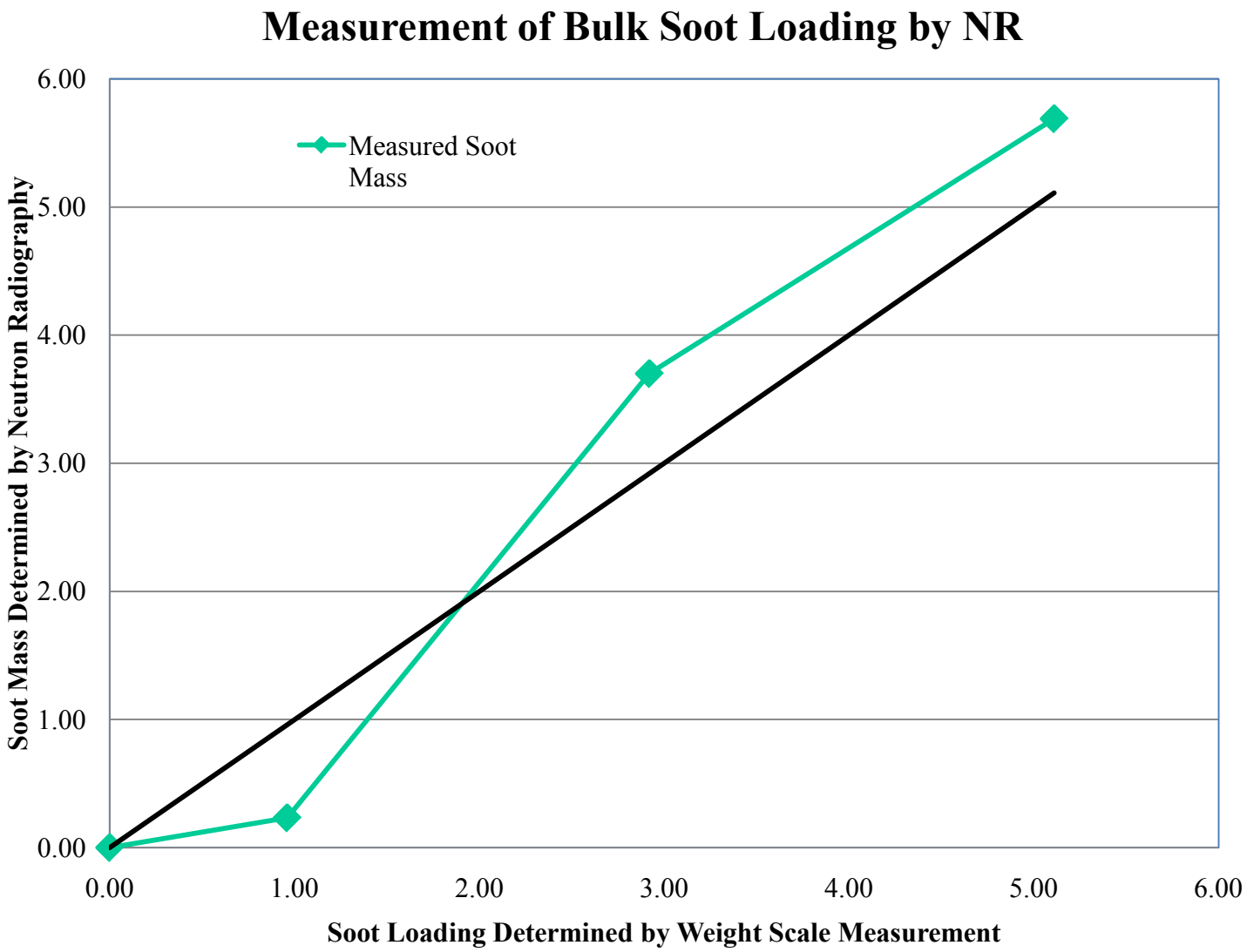
(b)



(c)



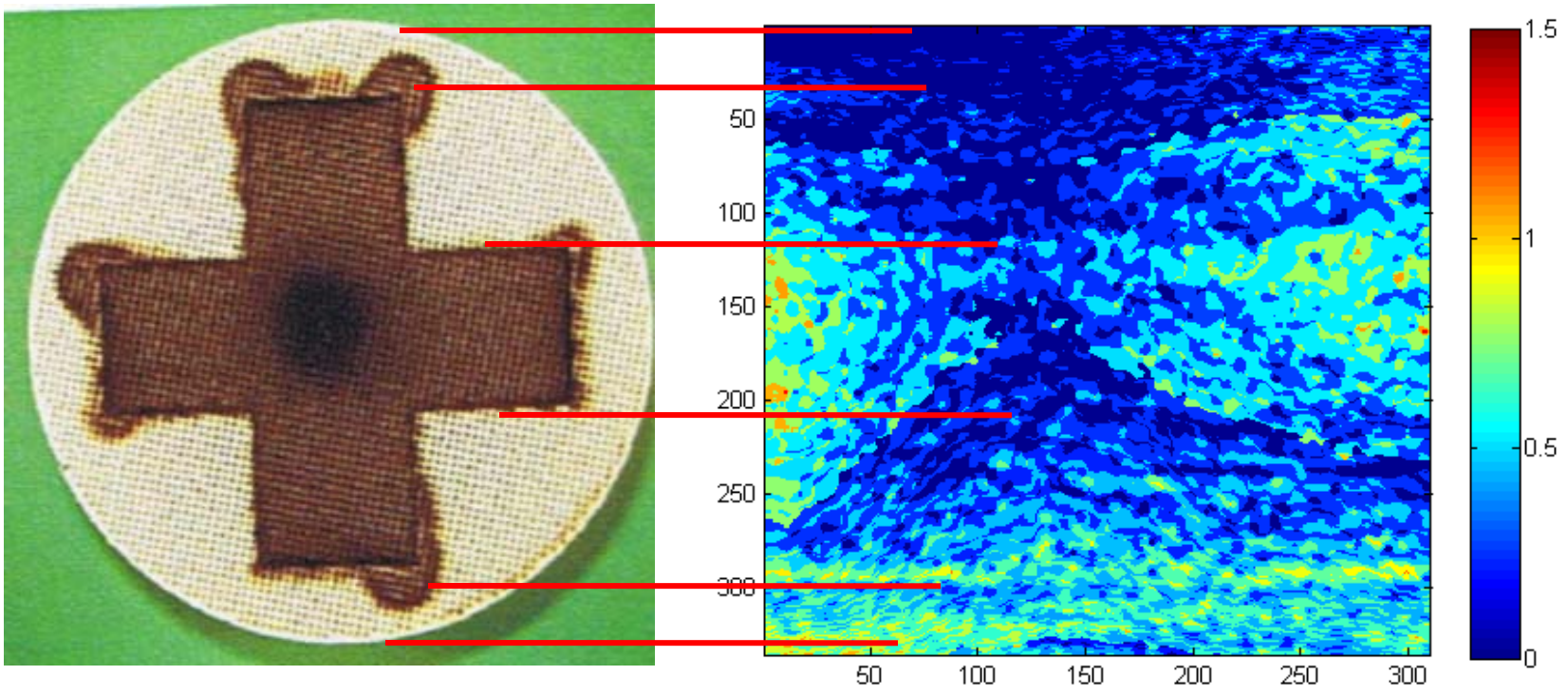

1.00
0.80
0.60
0.40
0.20
0.00
-0.20
0
2
4
6
8
10
12
14
16
1g/l
3g/l
5g/l
Soot Thickness [mm]
Distance Along Axial Length [cm]



Average Discrepancy 0.21 g/L

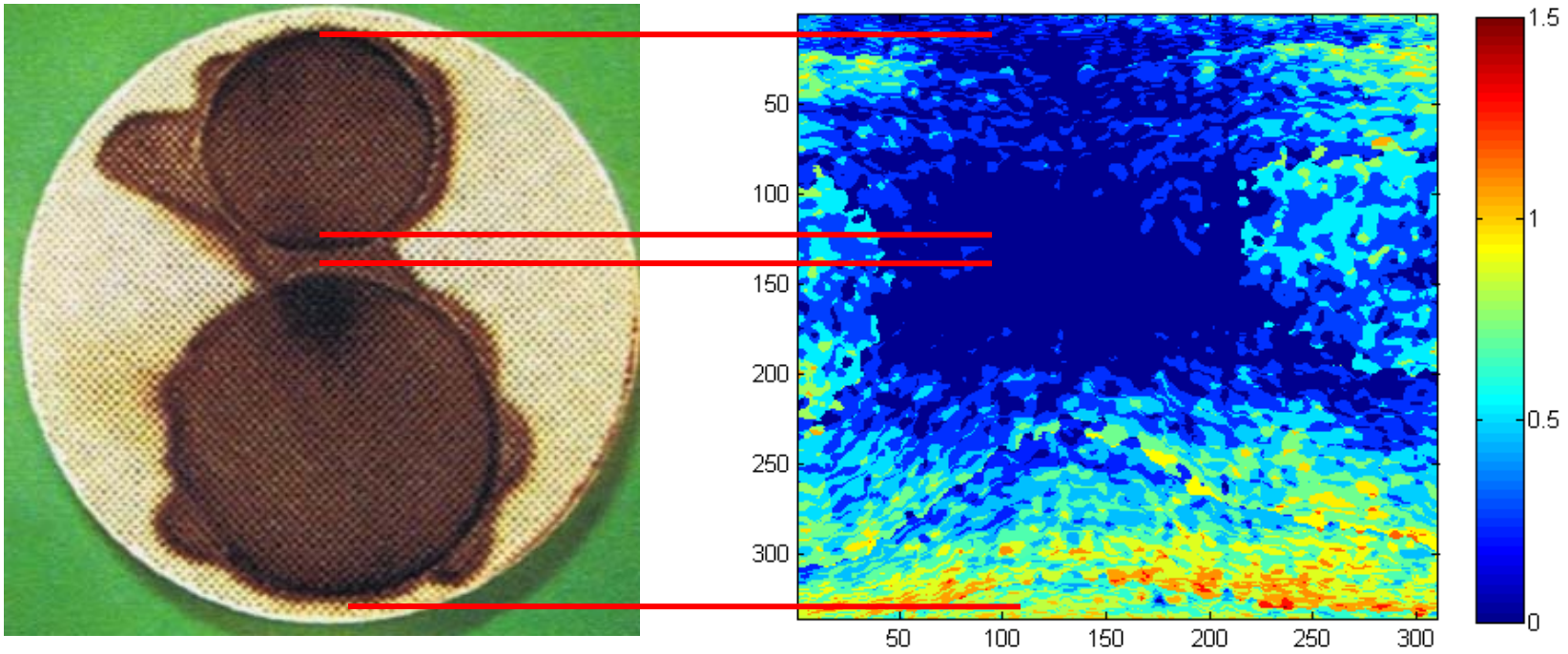
Neutron Radiography measurements agree relatively well both qualitatively and quantitatively .

Effect of Flow Channel Blockage : Sample Cross



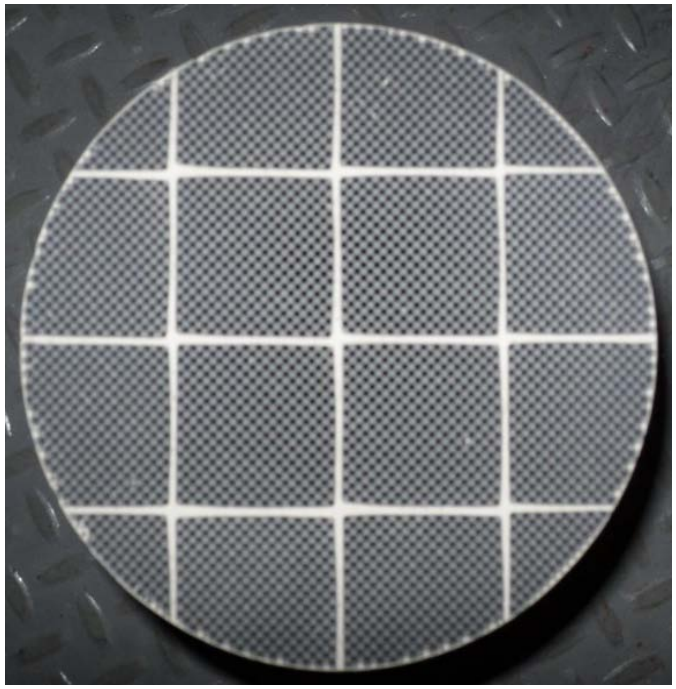
(a) (b)

Effect of Flow Channel Blockage : Sample Double Circle

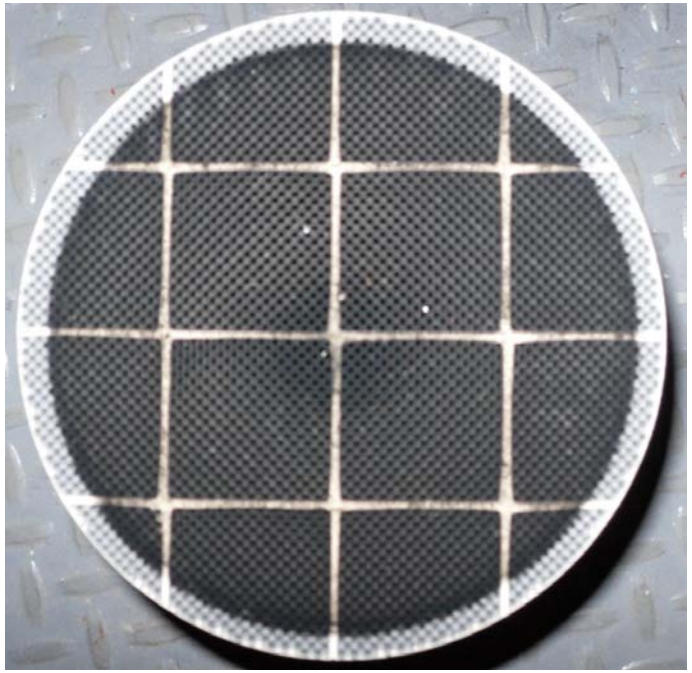


(a) (b)

SiC DPF

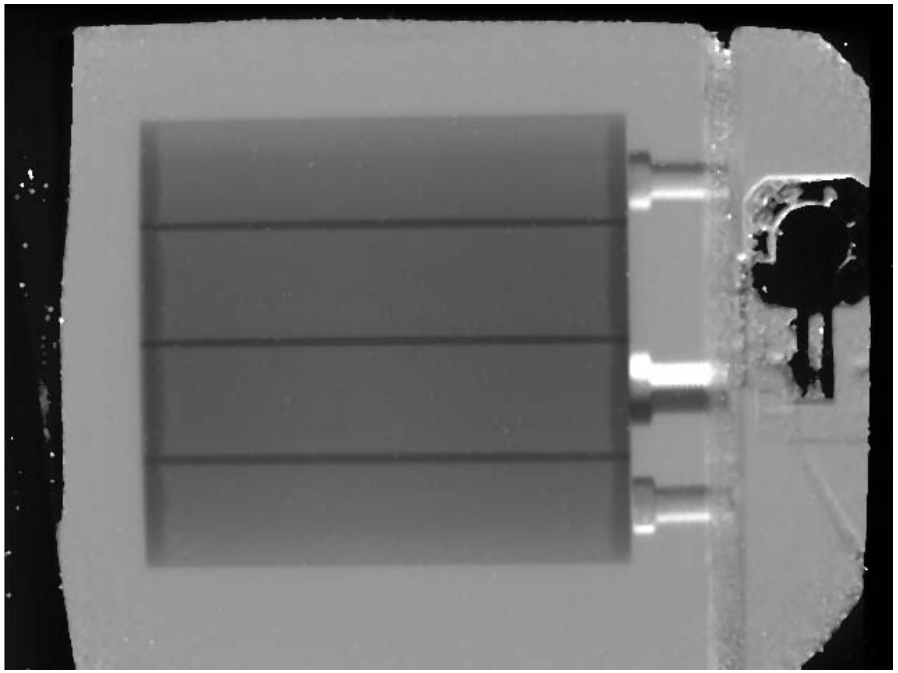


(a) Clean

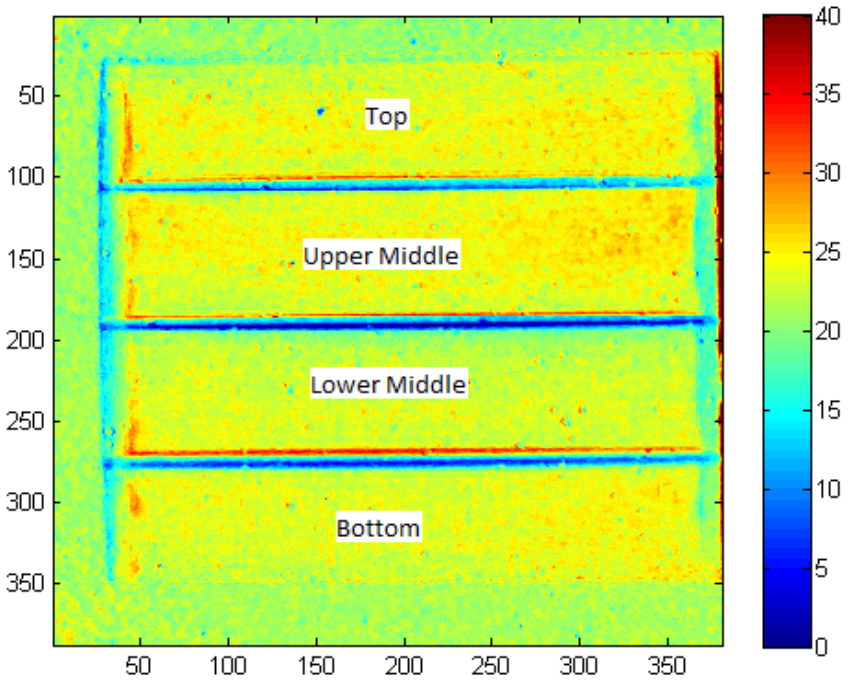


(b) 3g/l soot loaded

Soot Distribution in a SiC type DPF



(a)

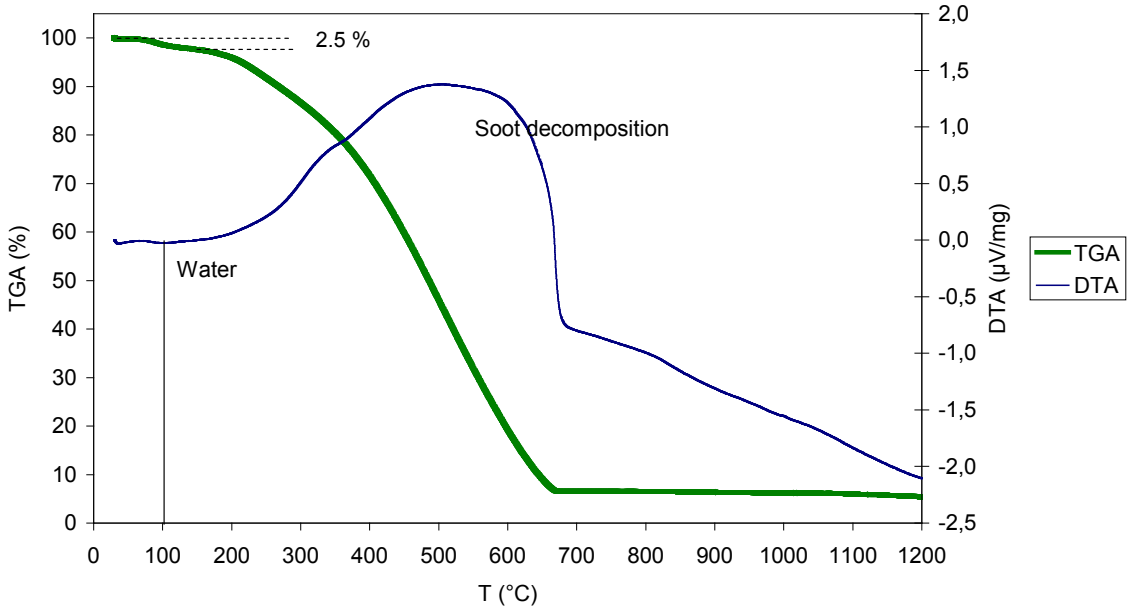


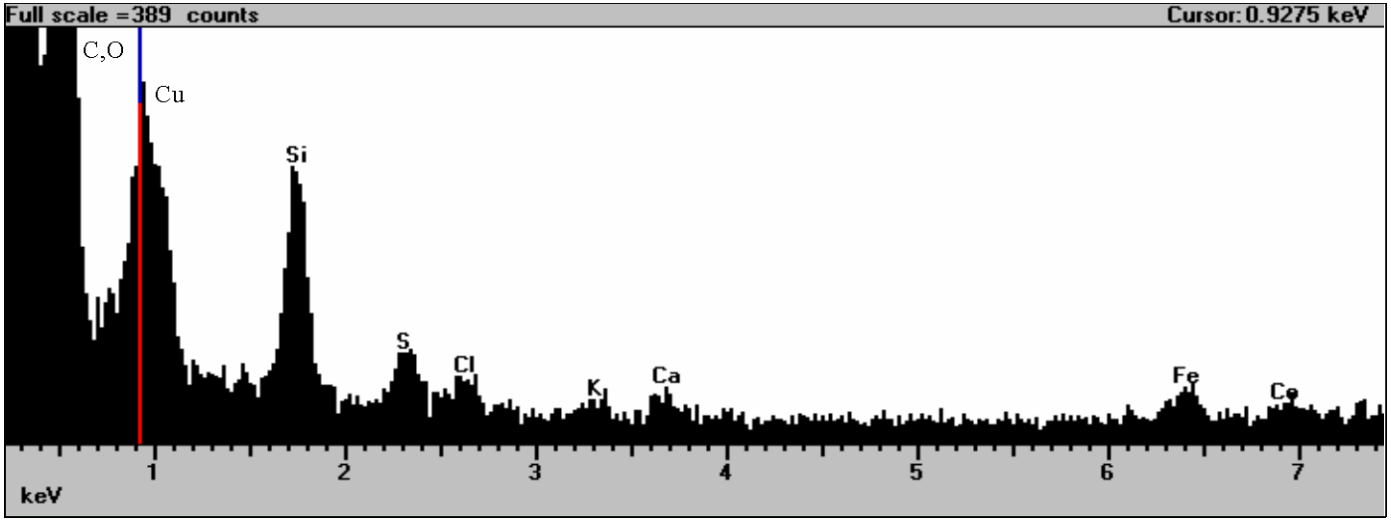
(b)

General Conclusions

- Neutron Visualization of Deposited Soot Distribution is achieved for
  - Cordierite DPF, 1g/l, 3g/l, 5g/l
  - SiC DPF, 3g/l
- Axial and Azimuthal distributions observed
- Quantitative analysis for total soot loading measurement indicates good agreement between weight measurements and neutron radiography measurements

Dry Soot Particle Characterization (Ayrault et al 2010)





DTA – Change in the difference between the oven and sample temperatures

TGA – Sample weight

XRD-X-ray Diffraction Spectrum-surface elements