Standardization of Smoke Generation for Certification Testing

International Systems Fire Protection Working Group
Atlantic City – Fall 2017

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Motivation

What smoke to use to certify the latest Smoke Detectors?

1/6/94 AC 25-9A

a. Acceptable Smoke Generators for Smoke Detection Tests.

(1) Generators. An appropriate generator should be selected, e.g.,:

(i) Paper Towel Burn Box (see Appendix II);
(ii) Rosco Theatrical smoke generator [see 10a.3)];
(iii) Helium-injected Rosco Theatrical smoke generator;
(iv) A pipe or cigar;
(v) A Woodsman Bee Smoker; or
(vi) Any other acceptable smoke generator.

(2) Fuel. Representative materials should be selected, e.g.,:

(i) Plastic;
(ii) Rags;
(iii) Tobacco;
(iv) Burlap;
(v) Paper; or
(vi) Any other acceptable fuel

Alarm threshold for single optical SD	
	Light Obscuration
Aviator UL smoke generator	2.03%
Rosco smoke generator	2.67%

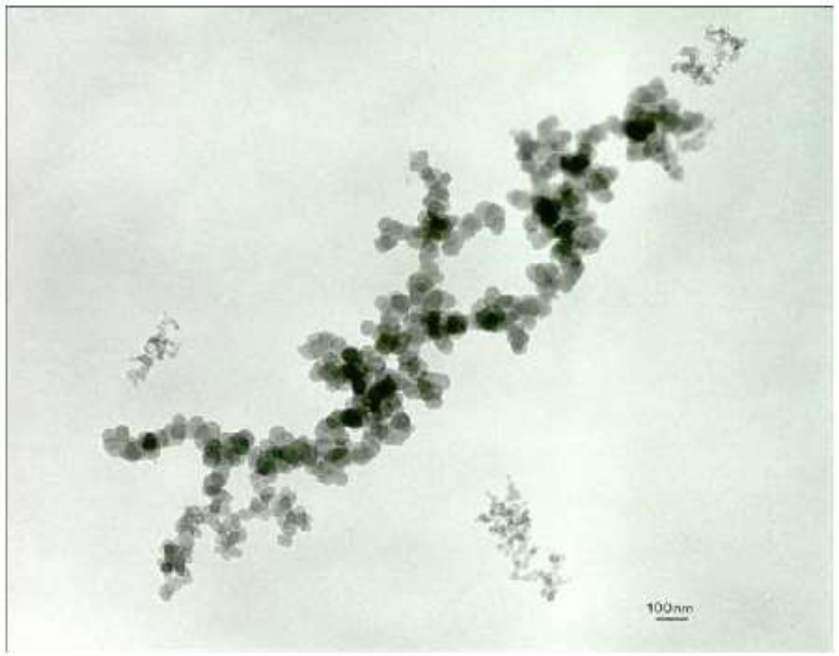
Alarm threshold for smart SD	
	Light Obscuration
Aviator UL smoke generator	3,27%
Rosco smoke generator	52,36%

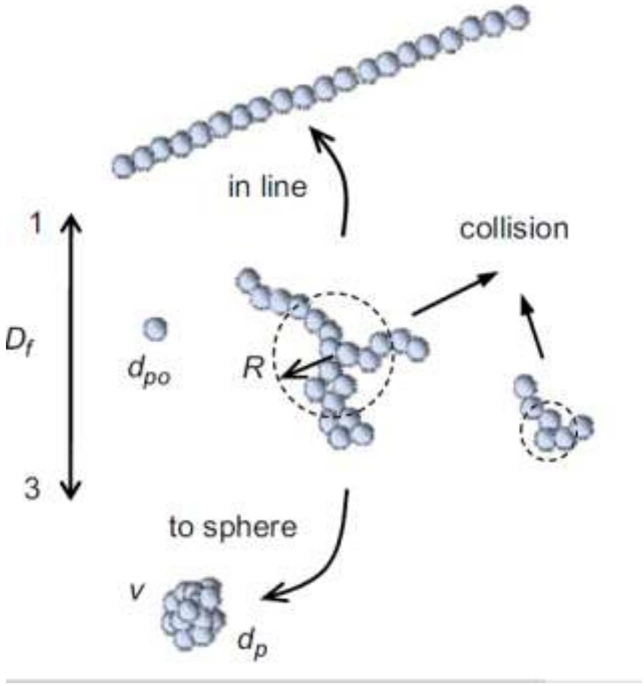
Today, it makes a difference which smoke generator we use

Particle Size Measurement Challenges

- Measurement principle: Number Distribution vs. Volume/Mass Distribution

- Aerosols are dynamic in time in terms of particle size distribution:
- Coagulation: Number of particles decreases while the total mass of the aerosol remains unchanged

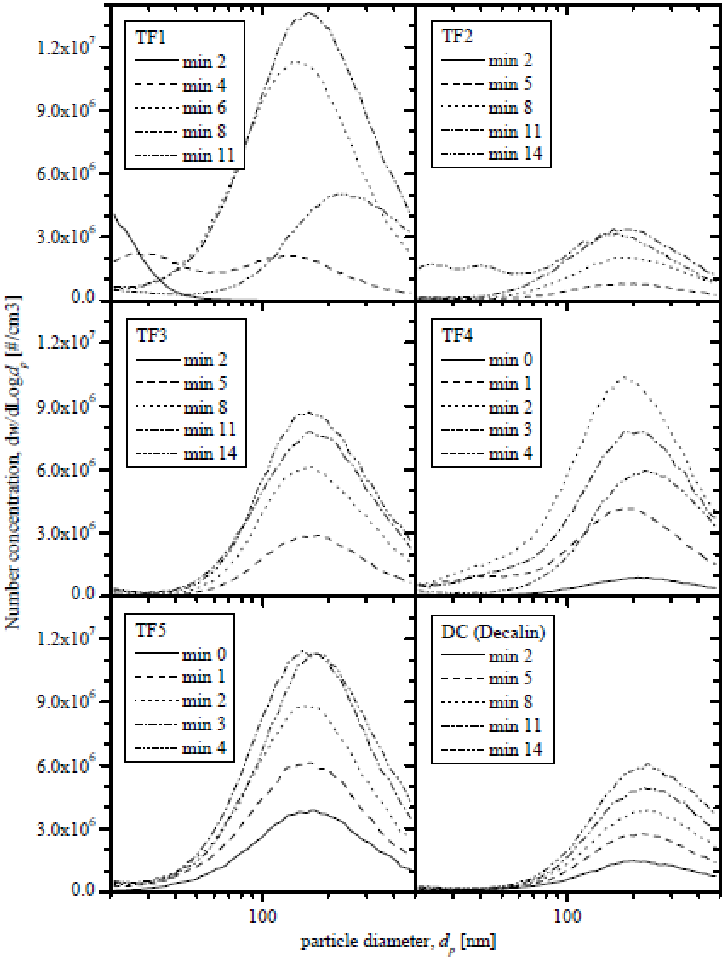




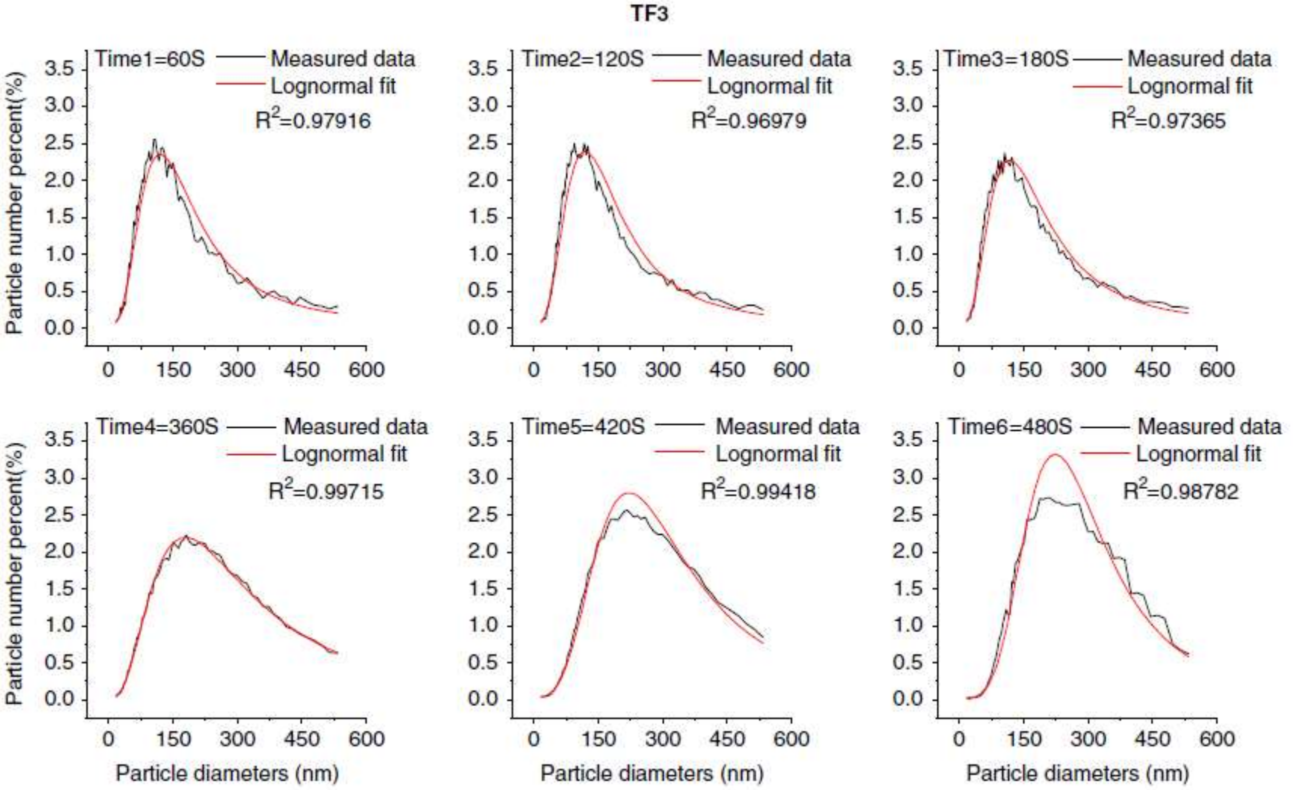
Df: Fractal Dimension

For Smoke Particles, Df is in the range of appr. 1.6

Particle Size Measurements



[2], Keller, Loepfe



[7], Qie et al

The Particle size distribution is dependent on the fire evolution over time: Fuel consumption and coagulation

TF1: Burning Wood, TF2: smouldering wood, TF3: smouldering cotton, TF4: PU foam, TF5: heptane-toluene, TF6: Alcohol

Particle Size Measurements in Literature

The mean diameters d_g nm and standard deviations σ_g nm of the lognormal fitting for each subfigure in Figs. 6–9

Time series	TF2		TF3		TF4		TF5	
	d_g	σ_g	d_g	σ_g	d_g	σ_g	d_g	σ_g
Time1	207.74	1.11	120.38	1.20	78.33	0.89	117.79	2.60
Time2	211.85	1.09	119.33	1.19	75.47	0.87	109.78	2.38
Time3	116.64	2.26	117.06	1.32	78.94	0.93	195.37	1.55
Time4	108.94	0.96	178.83	1.61	78.90	0.89	201.13	0.96
Time5	163.80	0.90	221.85	1.10	80.16	0.90	207.15	0.95
Time6	177.44	0.88	223.07	0.98			209.66	0.95

[7], Qie et al

Some Polymers produce bigger particles

Time dependancy!

TABLE 2-15.3 ***Particle Size of Smoke from Burning Wood and Plastics***

Type	d_{gm}, µm*	d_{32}, µm**	σ_g	Combustion Conditions	Ref. No.
Douglas fir	0.5–0.9	0.75–0.8	2.0	pyrolysis	1, 3
Douglas fir	0.43	0.47–0.52	2.4	flaming	1, 3
polyvinylchloride	0.9–1.4	0.8–1.1	1.8	pyrolysis	3
polyvinylchloride	0.4	0.3–0.6	2.2	flaming	3
polyurethane (flexible)	0.8–1.8	0.8–1.0	1.8	pyrolysis	3
polyurethane (flexible)		0.5–0.7		flaming	3
polyurethane (rigid)	0.3–1.2	1.0	2.3	pyrolysis	3
polyurethane (rigid)	0.5	0.6	1.9	flaming	3
polystyrene		1.4		pyrolysis	1
polystyrene		1.3		flaming	1
polypropylene		1.6	1.9	pyrolysis	1
polypropylene		1.2	1.9	flaming	1
polymethylmethacrylate		0.6		pyrolysis	1
polymethylmethacrylate		1.2		flaming	1
cellulosic insulation	2–3		2.4	smoldering	6

[10], Mullholland

Table 24.2 Aerodynamic mass mean diameter of smoke from flaming plastics[a]

Material	d_{ag}, µm	σ_g	Environment
Nylon	0.4	2.0	1.0 m^3 smoke box
Polycarbonate	3.0	3.4	1.0 m^3 smoke box
Polyethylene	1.0	2.5	1200 m^3 enclosure
Polymethylmethacrylate	2.3	4.4	1200 m^3 enclosure
	0.7–1.0	NR	0.37 m^2 duct [28]
Polypropylene	1.2	2.0	1200 m^3 enclosure
Polyurethane	2.0	1.8	0.18 m^2 duct [29]
Polyvinylchloride	1.1	1.8	1.0 m^3 smoke box
Polystyrene	2.0	2.6	1.0 m^3 smoke box
	2.4	2.1	1200 m^3 enclosure
	1.5–2.5	NR	0.37 m^2 duct [28]

[9], Newman et al.

TF1: Burning Wood, TF2: smouldering wood, TF3: smouldering cotton, TF4: PU foam, TF5: heptane-toluene, TF6: Alcohol

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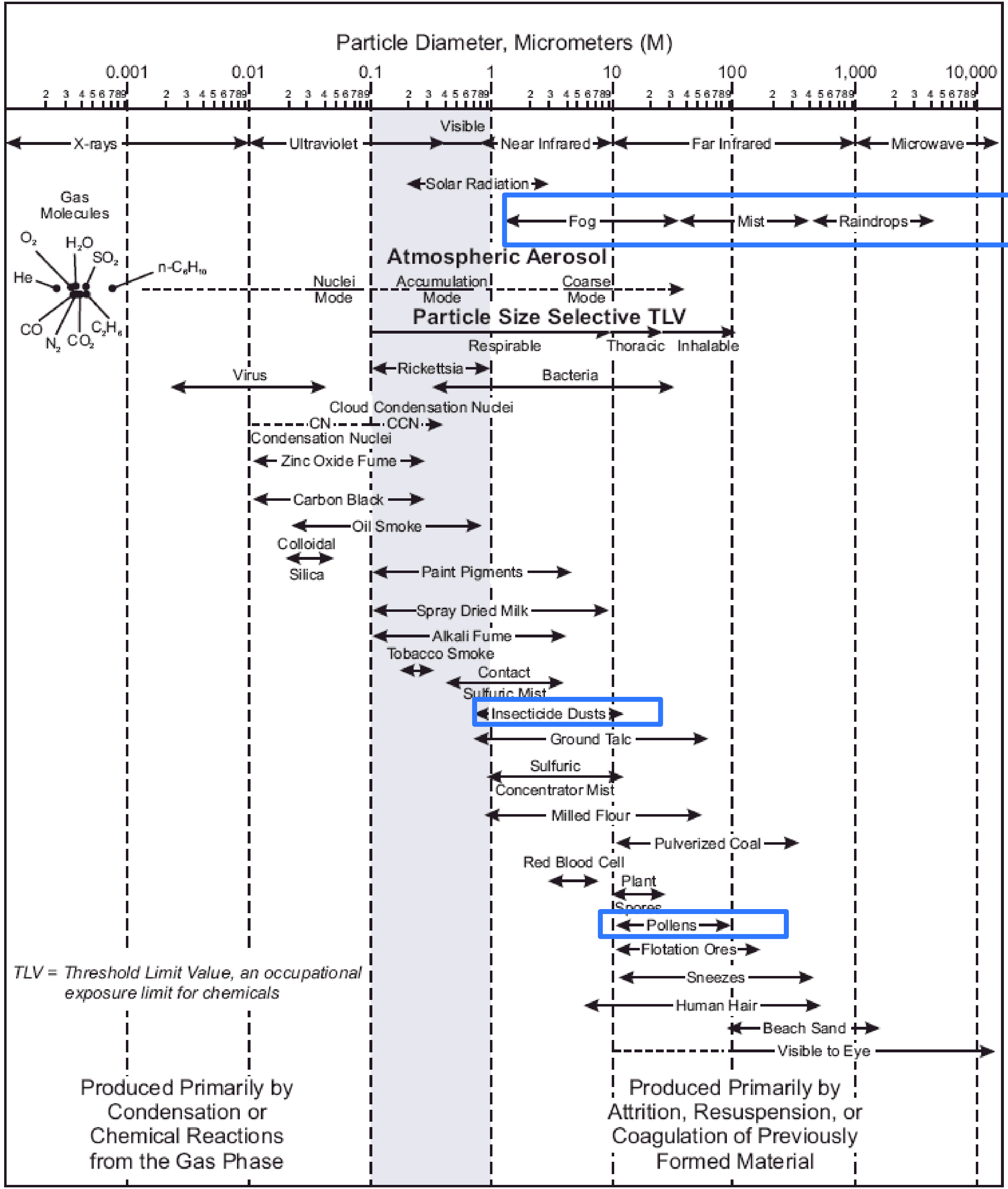
Particle Sizes in comparison



Source:
https://www.engineersedge.com/filtration/filtration_particle_size.htm
17 Oct 2017

Dust

- Dust particle properties

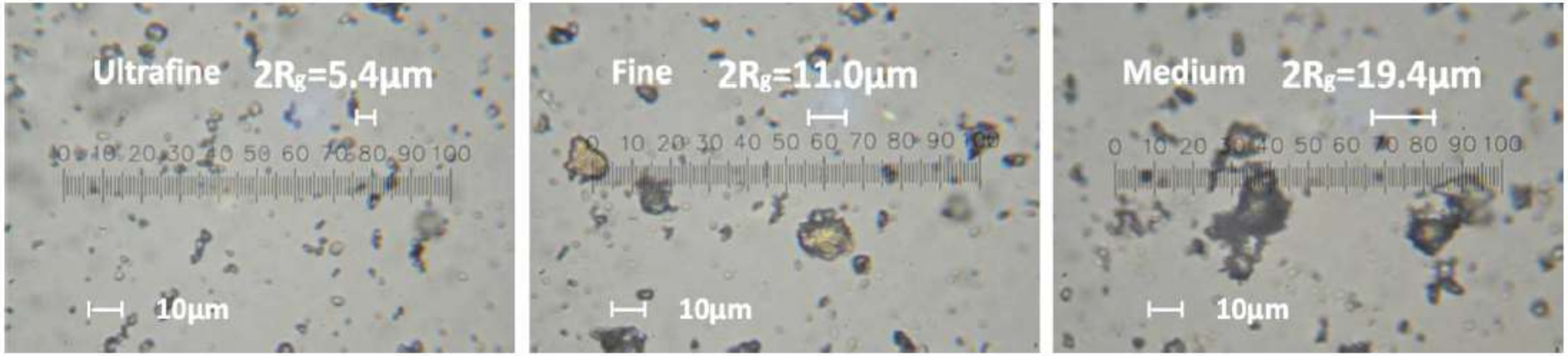


Fig. 12. The images for three AZRD samples under an optical compound microscope. Each figure has a 10 µm scale bar in the lower left and a scale bar equal to the light scattering determined $2R_g$ in the upper right for comparison to the images. Note that light scattering is strongly affected by the largest particles in an ensemble.

Compared to smoke particles:

The shape of dust particles is different (Fractal dimension > 2)

The size of dust particles is bigger

Comparison of Actual and Simulated Smoke for the Certification of Smoke Detectors in Aircraft Cargo Compartments [1] FAA report 2003

FIGURE 1. FUEL SOURCES—RESIN CAKE, JET A, AND A SUITCASE

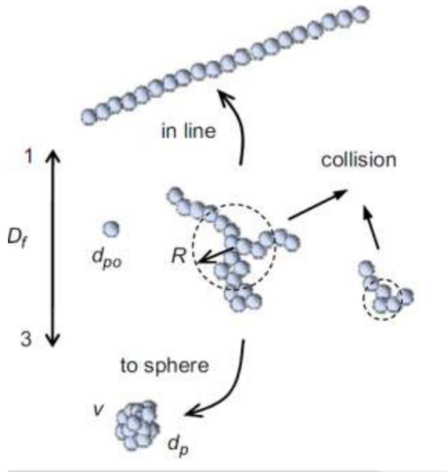


TABLE 2. SOOT MORPHOLOGY RESULTS

	D_p	k_f	D_f	R_g
Resin B-707	86.4 nm	7.34	1.71	297 nm
Suitcase B-707	81.0 nm	7.15	1.58	253 nm
Jet A B-707	75.9 nm	7.59	1.56	349 nm

Report conclusion: Standardization of the in-flight certification process through characterization of simulated smoke generators (specification of machine, operating setting, etc.) is the only way to ensure all cargo compartment detection systems are being certified under similar conditions.

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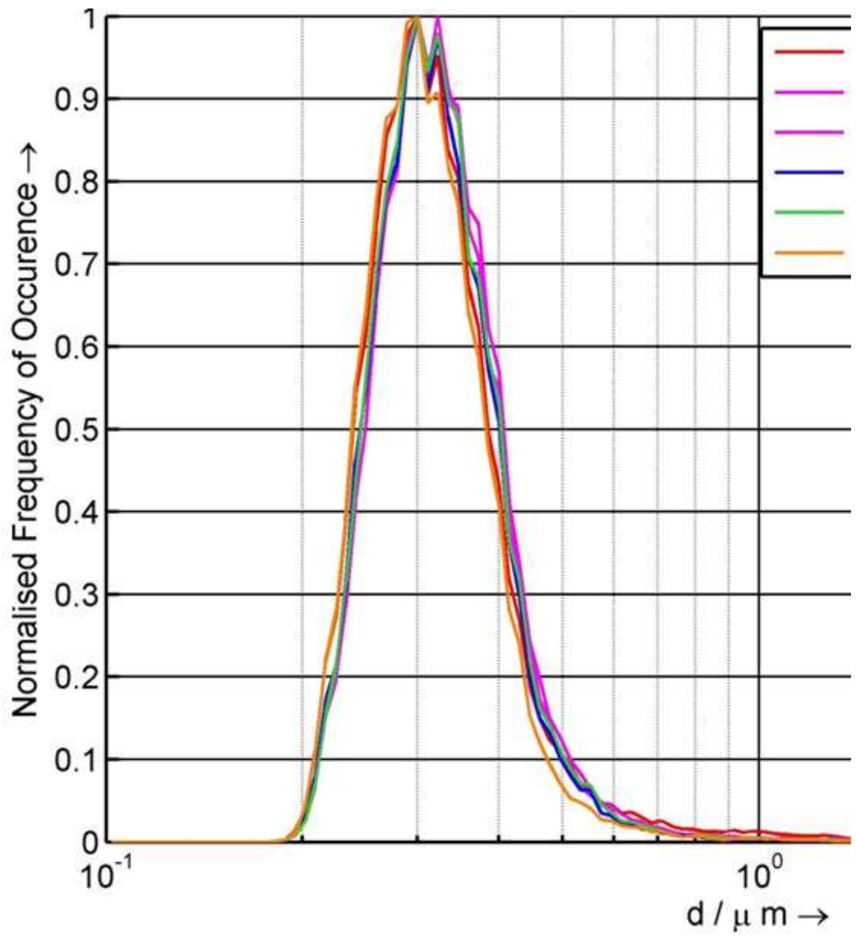
Today’s standards

used by Airbus

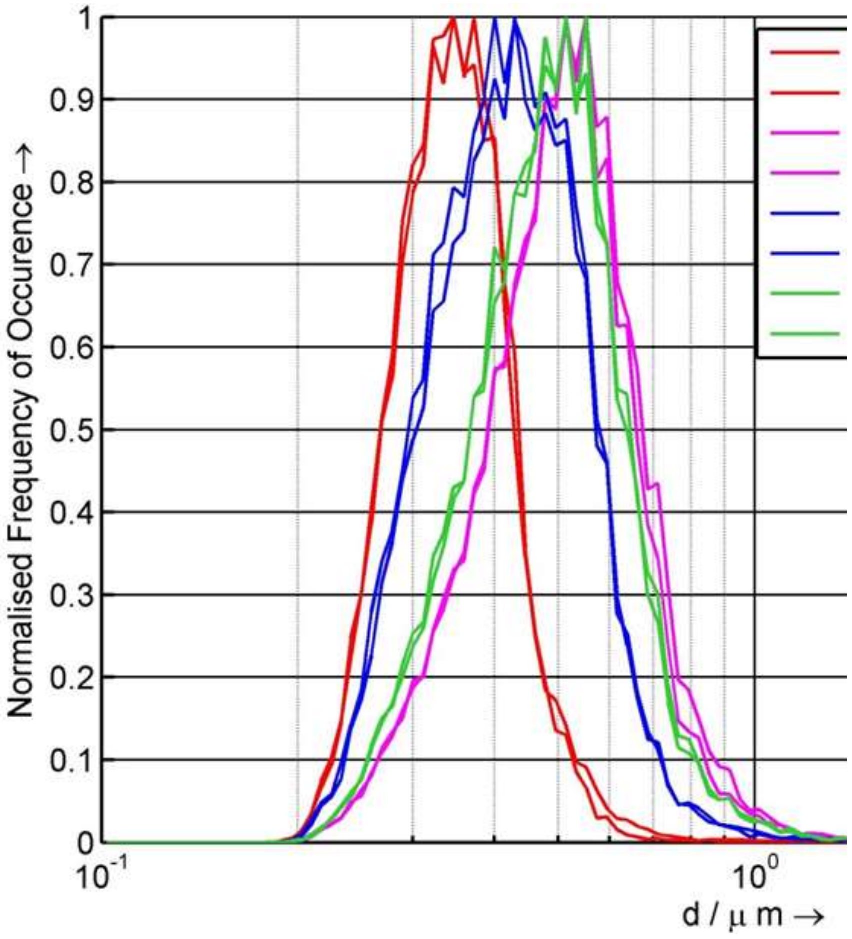
used by other OEM?

Standardisation?!

Smoke Generator Characteristics



Small nozzle



Generator 1

Generator 2

Generator 3

Generator 4

Large nozzle

Need for Standardisation - Conclusion

Items to be worked on / Next steps / Questions to be answered

- What should the standard cover, what not?
- Academic approach on requirements for smoke generator
  - Are there more parameters than only particle size which are relevant to characterize the detection performance, eg. Smoke dynamics etc.?
- How to reflect in a standard the dependency of smoke detection performance on particle size?
- Agreement on particle size measurement principle
- Define certification test validity criteria, e.g. amount of smoke generator fuel consumed
- What standard should it be? SAE? FAA AC update?

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Literature

[1] Comparison of Actual and Simulated Smoke for the Certification of Smoke Detectors in Aircraft Cargo Compartments, Jill Suo-Anttila, Walt Gill, and Louis Gritzo, Report No. DOT/FAA/AR-03/34, November 2003

[2] Online determination of the refractive index of test fires, A. Keller, M Loepfe et al. Proceedings of the AUBE2004, Conference on Automatic Fire Detection

[3] A light-scattering study of the scattering matrix elements of Arizona Road Dust, Yuli Wang, Amitabha Chakrabarti, Christopher M. Sorensen, Journal of Quantitative Spectroscopy & Radiative Transfer 163 (2015) 72–79

[4] Development of the size distribution of smoke particles in a compartment fire, Jaehark Goo , Fire Safety Journal 47 (2012) 46–53

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[8] Aerosol particle concentration and size distribution measurements of test-fires as a background for smoke detector modelling, E. Tamm et al. Proceedings of the AUBE’99, Universität Duisburg-Essen, Germany, 1999.

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[10] Smoke production and properties, George W. Mulholland, IN: DiNenno, P.J., et al., Editors, SFPE Handbook of Fire Protection Engineering, 2nd Edition, 1995, Chapter 15, Section 2, 2/217-2/227

[11] Light Scattering Characteristics and Size Distribution of Smoke and Nuisance Aerosols, DARRYL W. WEINERT, THOMAS G. CLEARY et al. FIRE SAFETY SCIENCE--PROCEEDINGS OF THE SEVENTH INTERNATIONAL SYMPOSIUM, pp. 209-220

Thank you