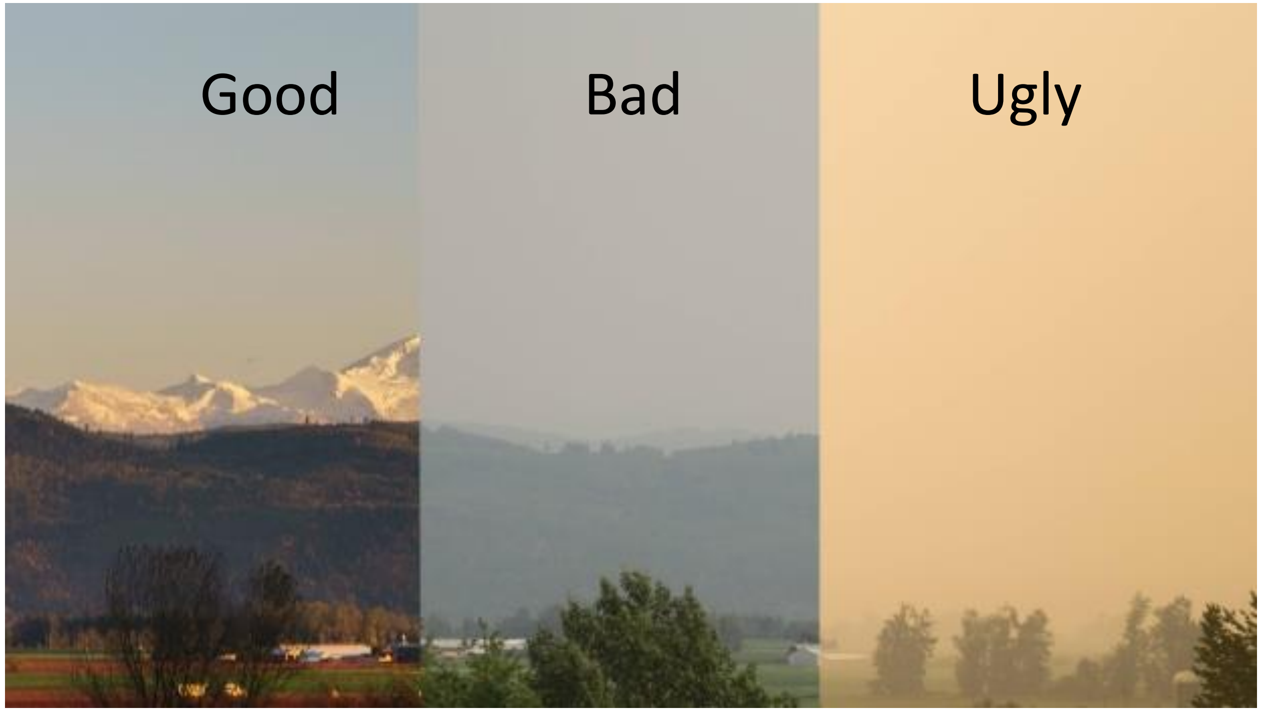
Atmospheric Aerosols



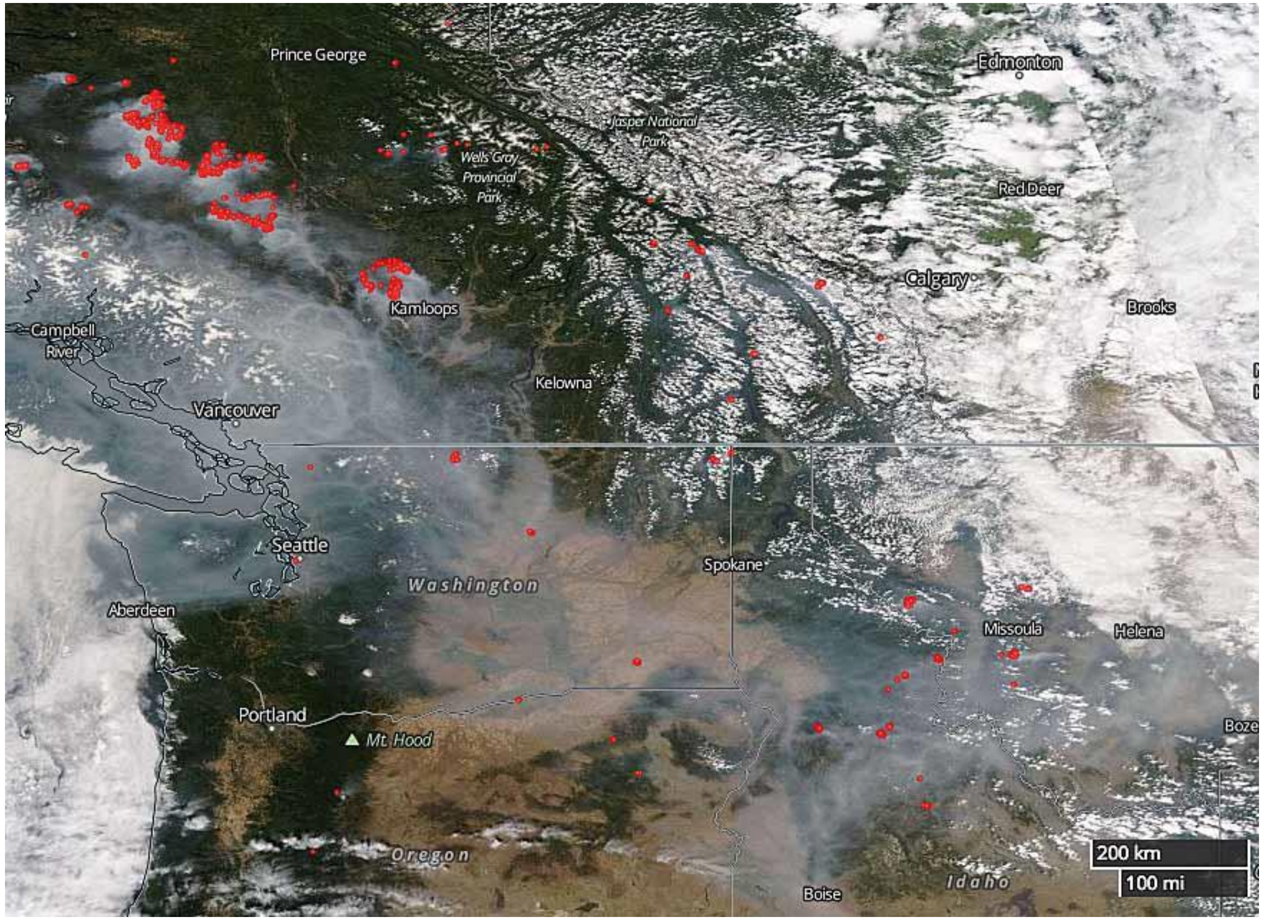
1. Introduction
2. Sources and Measurement
3. Concentrations and Residence times
4. Emission controls and abatement technology

Bejing, Jan., 2013

$PM_{2.5}$ = 122 ug/m^3

Tiananmen Square, Jan. 23rd, 2013

BC Forest Fires: July – August 2017



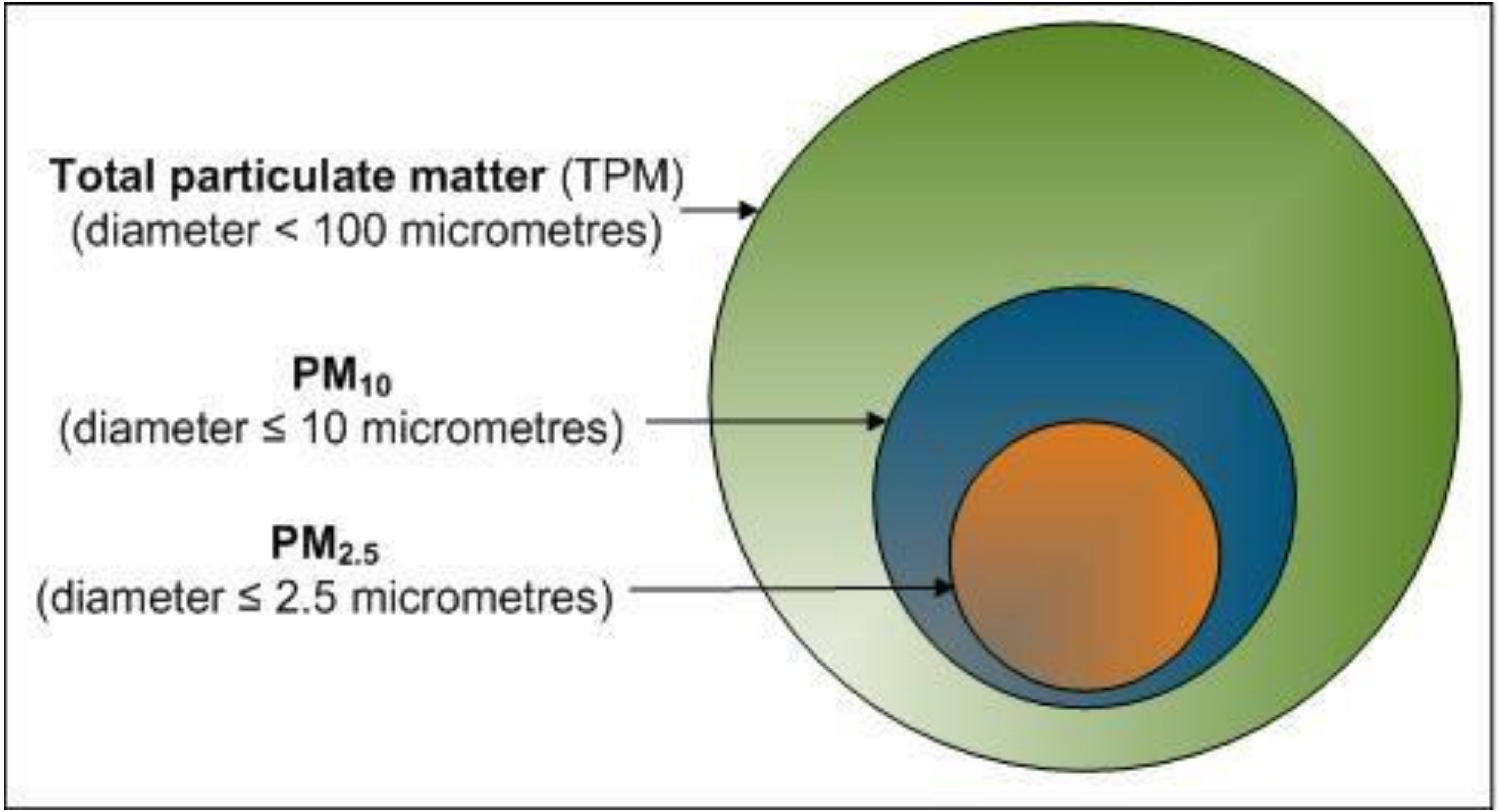
Smoke relief in the forecast comes too late for marathon runners

Vancouver, August 11, 2017

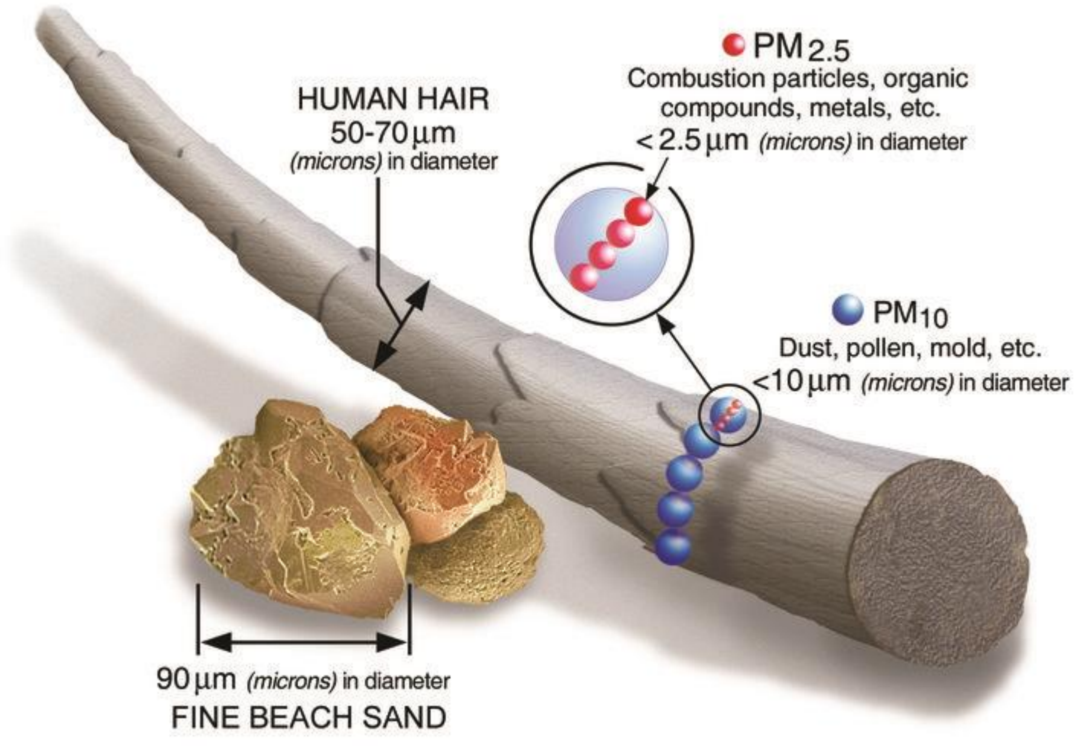
B.C. wildfire smoke triggers air quality statement for southwestern Manitoba

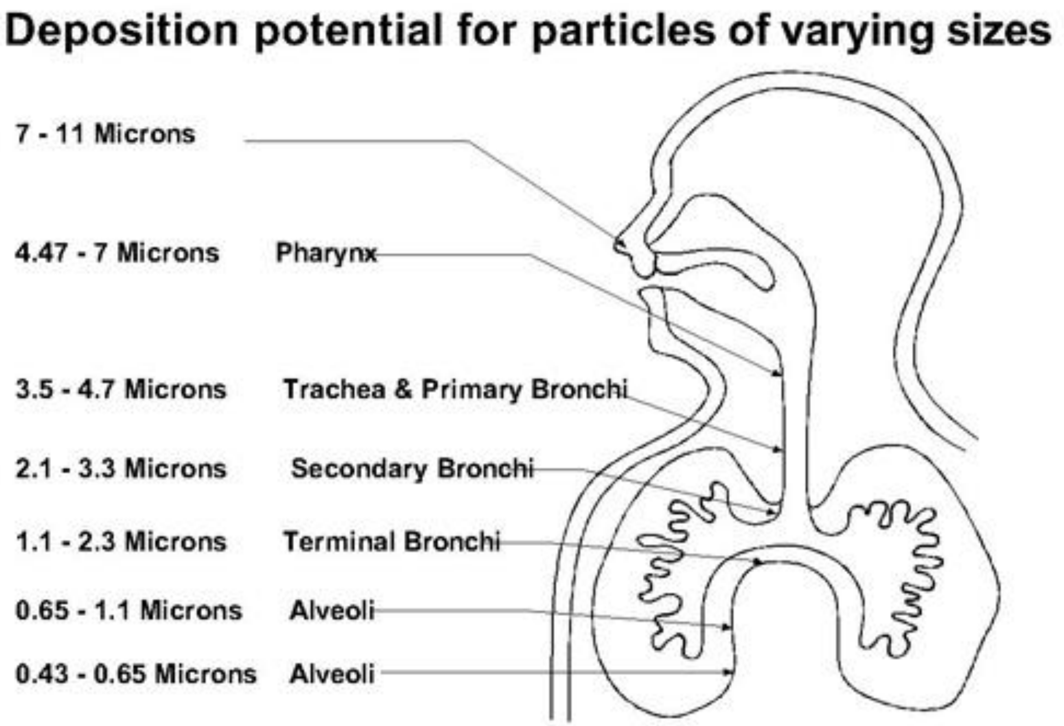
Smoke could cause issue for people living with asthma, irritate eyes

Downtown Calgary, July, 2017


Total particulate matter (TPM)
(diameter < 100 micrometres)
PM$_{10}$
(diameter ≤ 10 micrometres)
PM$_{2.5}$
(diameter ≤ 2.5 micrometres)

Size matters





Classification and properties of atmospheric particulates

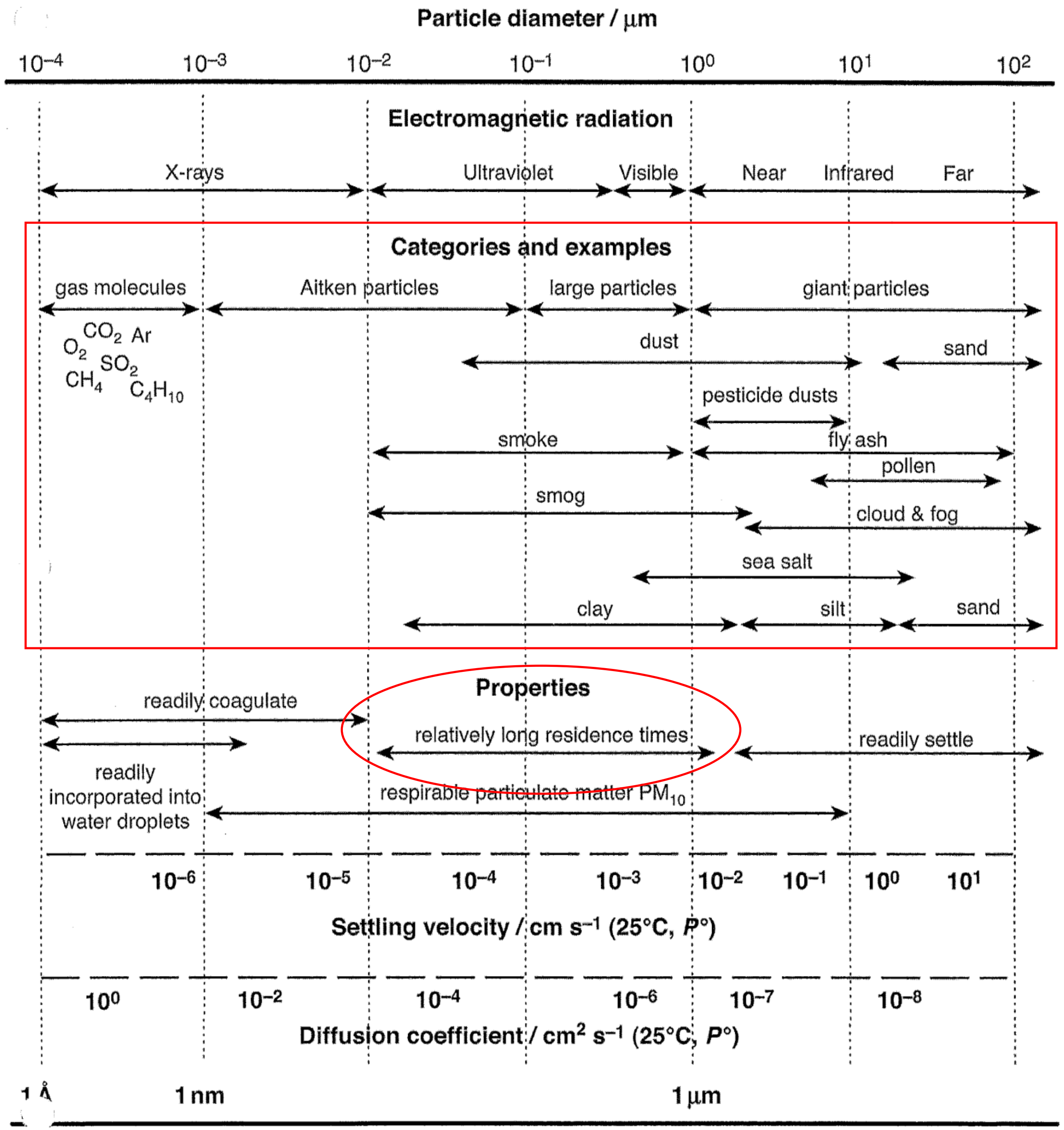
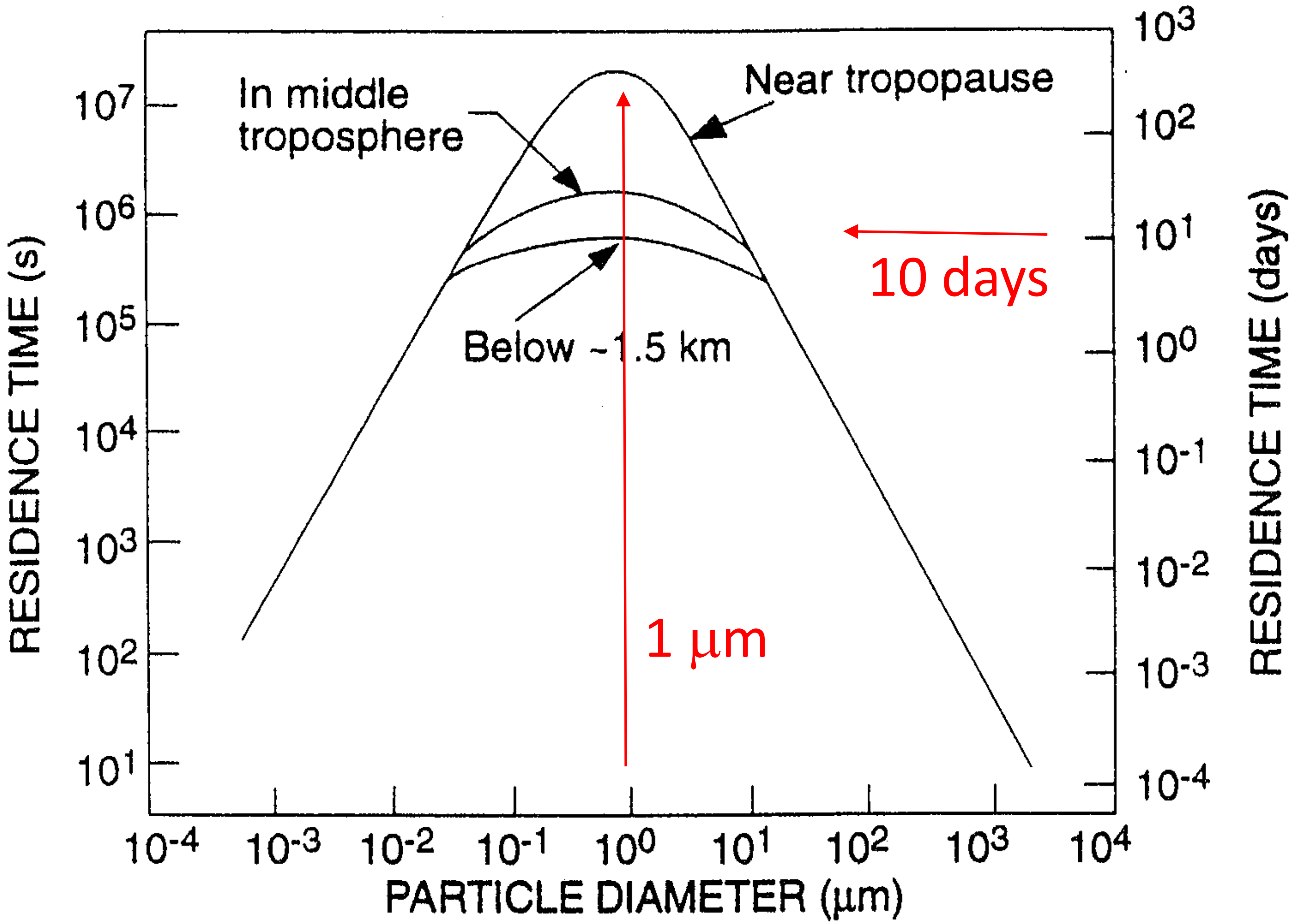


Fig. 6.1 Van Loon

Residence time of atmospheric aerosols



(a)

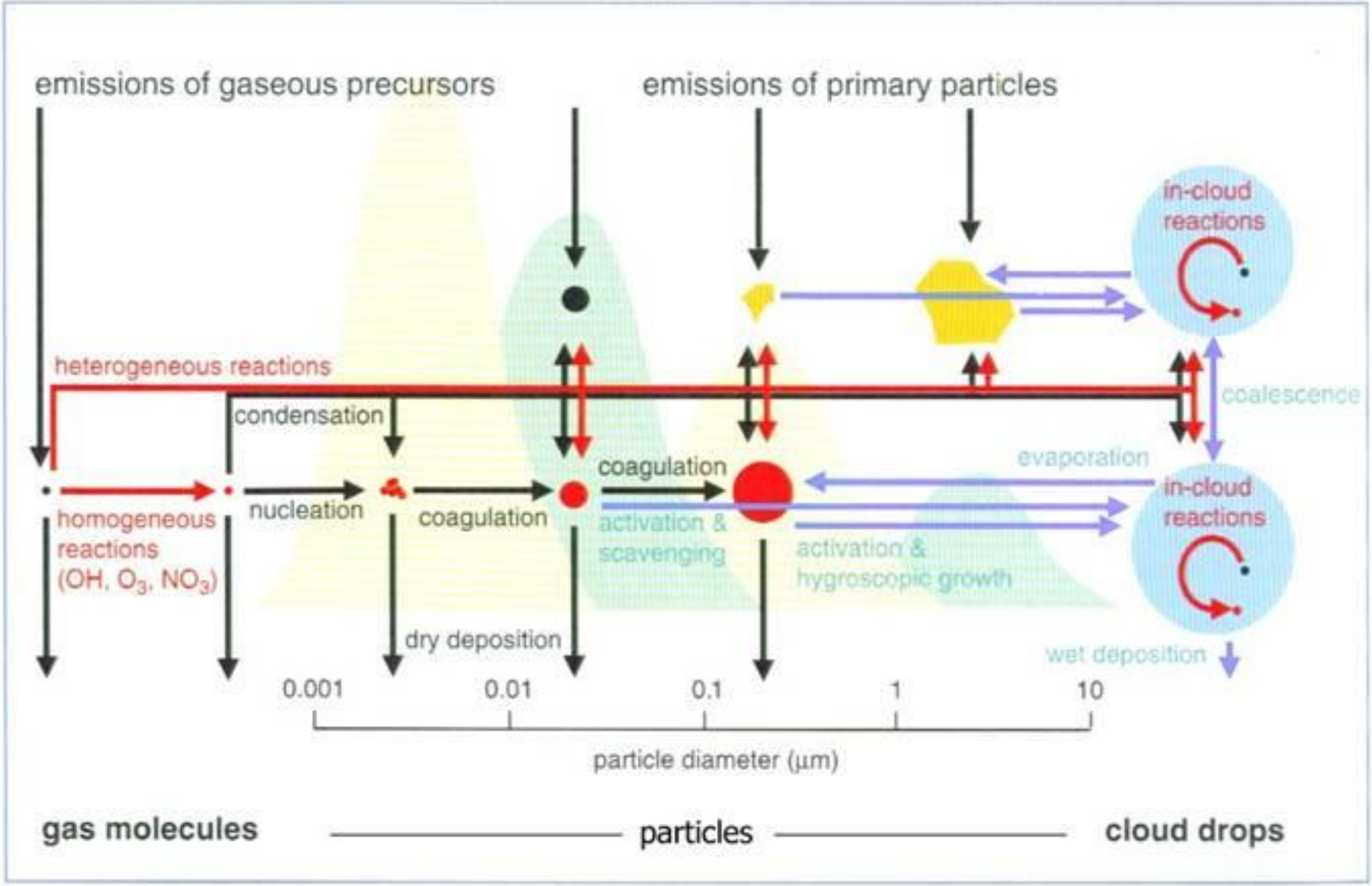
Canadian Ambient Air Quality Standards: Current and Proposed

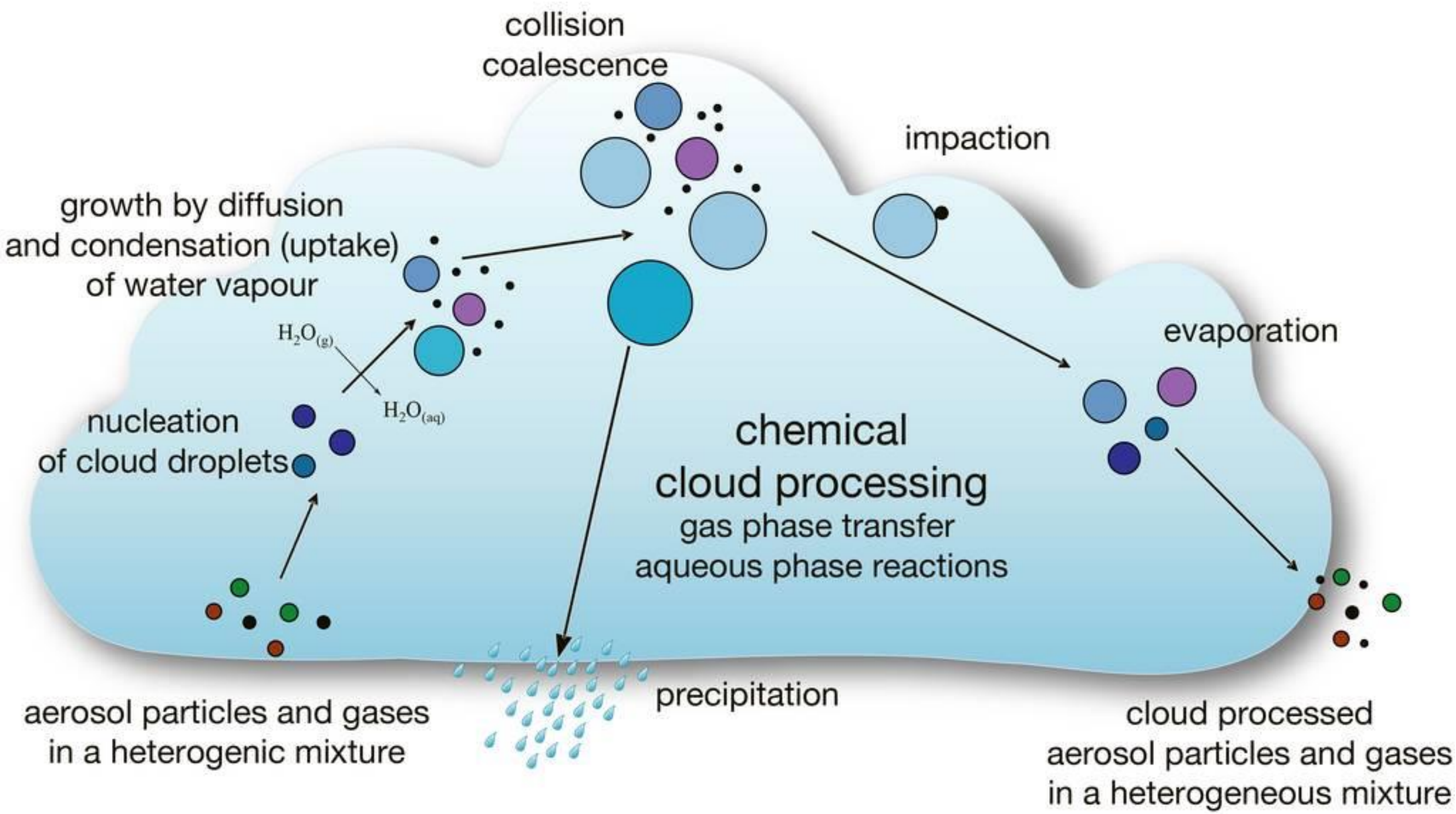
Management Level	Management Actions	Proposed Air Management Threshold Values					
		Ozone (ppb)		$PM_{2.5}$ Annual ($\mu g/m^3$)		$PM_{2.5}$ 24h ($\mu g/m^3$)	
		2015	2020	2015	2020	2015	2020
RED	Actions for Achieving Air Zone CAAQS						
Threshold		63 ppb	62 ppb	10.0 μg/m3	8.8 μg/m3	28 μg/m3	27 μg/m3
ORANGE	Actions for Preventing CAAQS Exceedance						
Threshold		56 ppb		6.4 μg/m3		19 μg/m3	
YELLOW	Actions for Preventing AQ Deterioration						
Threshold		50 ppb		4.0 μg/m3		10 μg/m3	
GREEN	Actions for Keeping Clean Areas Clean						

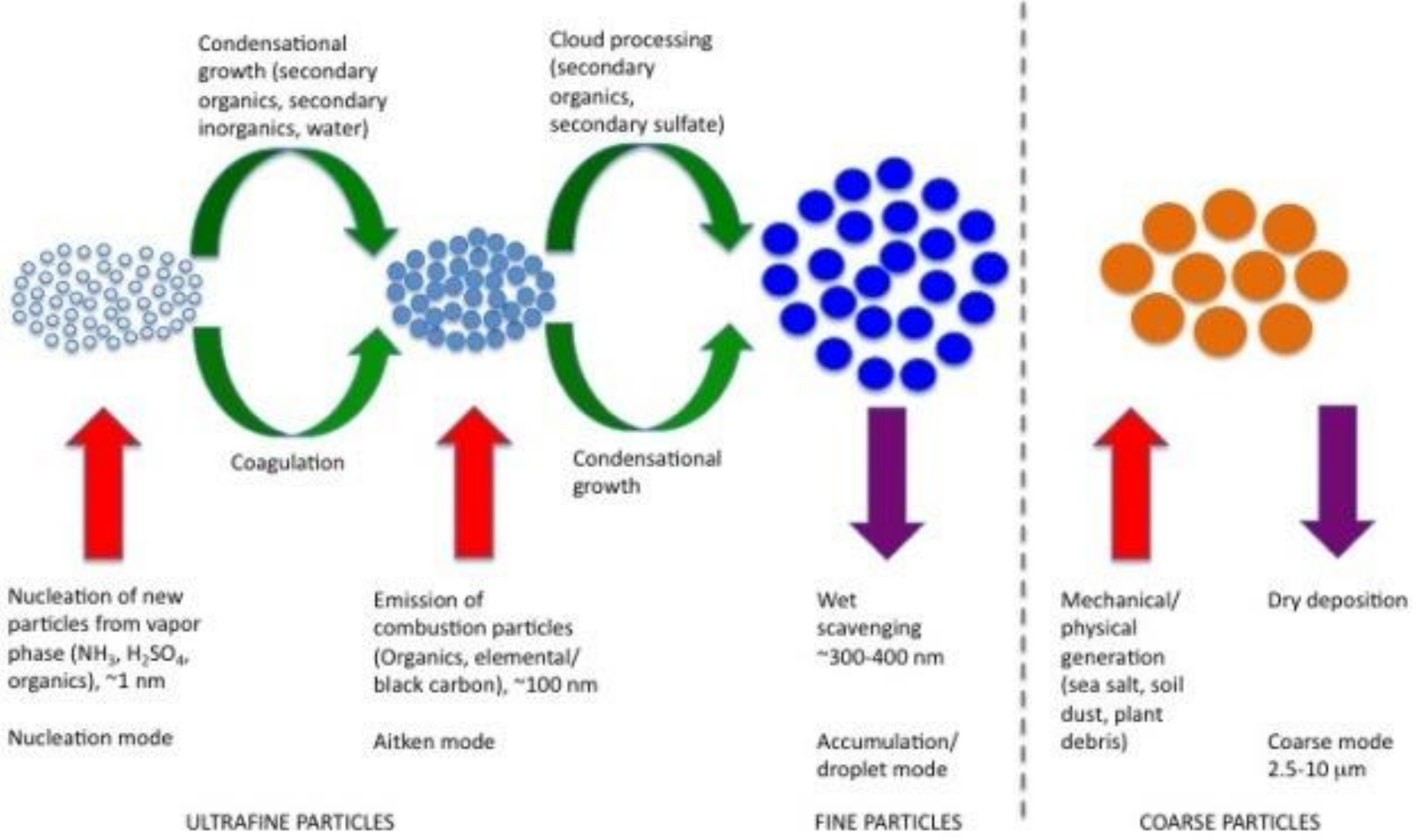
Aerosol Processes

- Diffusion
- Coagulation
- Condensation
- Chemical reactions
- Sedimentation

Physical and chemical processes influencing size distribution of aerosols




collision
coalescence
impaction
growth by diffusion
and condensation (uptake)
of water vapour
$H_2O_{(g)}$
$H_2O_{(aq)}$
nucleation
of cloud droplets
chemical
cloud processing
gas phase transfer
aqueous phase reactions
evaporation
precipitation
aerosol particles and gases
in a heterogenic mixture
cloud processed
aerosol particles and gases
in a heterogeneous mixture


Condensational growth (secondary organics, secondary inorganics, water)
Cloud processing (secondary organics, secondary sulfate)
Coagulation
Condensational growth
Nucleation of new particles from vapor phase (NH_3, H_2SO_4, organics), ~1 nm
Nucleation mode
Emission of combustion particles (Organics, elemental/ black carbon), ~100 nm
Aitken mode
Wet scavenging ~300-400 nm
Accumulation/ droplet mode
Mechanical/ physical generation (sea salt, soil dust, plant debris)
Dry deposition
Coarse mode 2.5-10 μm
ULTRAFINE PARTICLES
FINE PARTICLES
COARSE PARTICLES

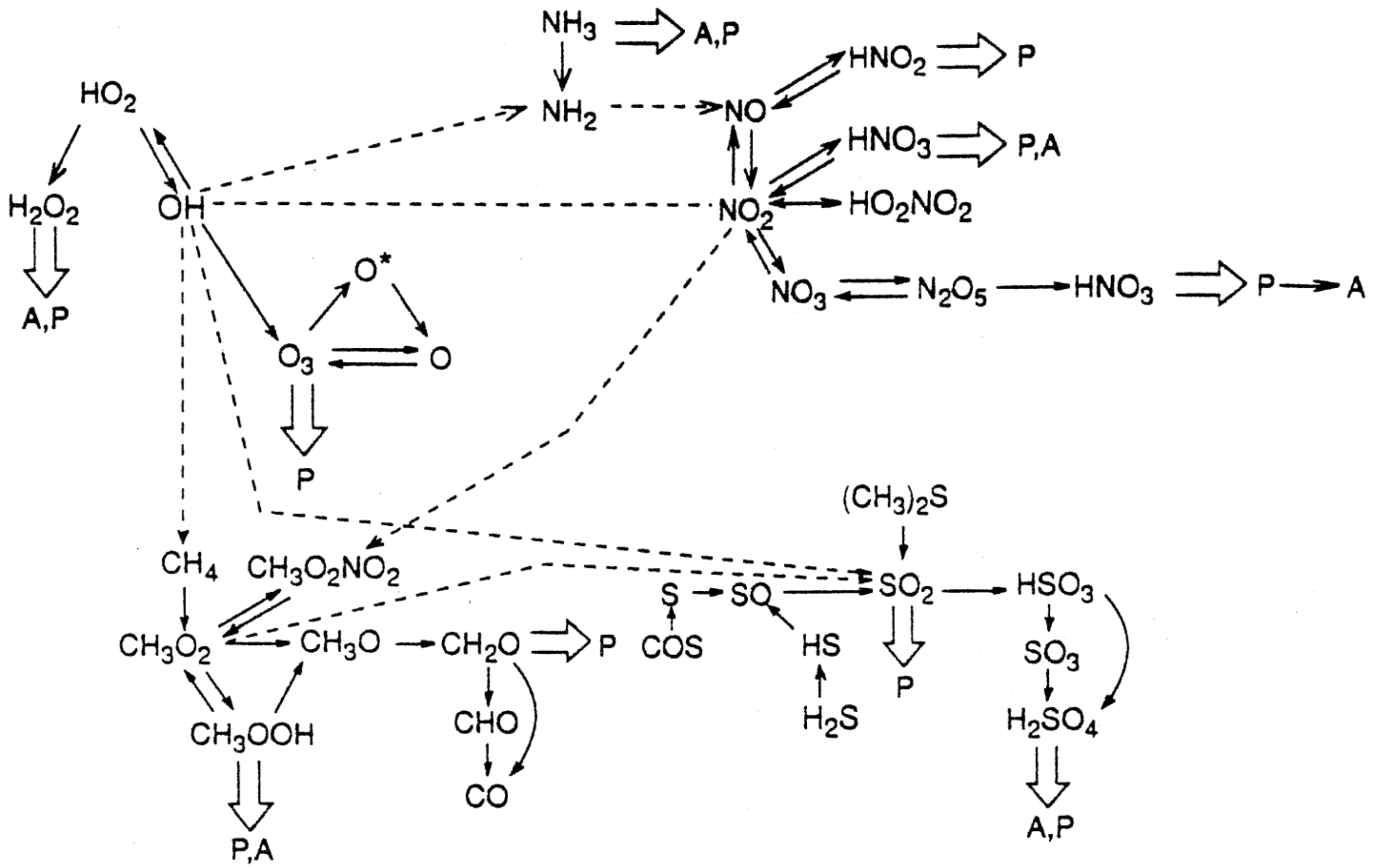


Figure 6.8. Schematic diagram of some of the primary pathways for trace gases to be converted to aerosols (A) in the troposphere. The major reactions involving gas-phase constituents are indicated by the solid lines. Interactions between chemical families are indicated by the dashed lines. Pathways leading to incorporation into precipitation (P) are also shown. [Adapted from R. P. Turco et al. in *Heterogeneous Atmospheric Chemistry*, ed. D. R. Schryer, American Geophysical Union, p. 234 (1982). Copyright © 1982 by the American Geophysical Union.]

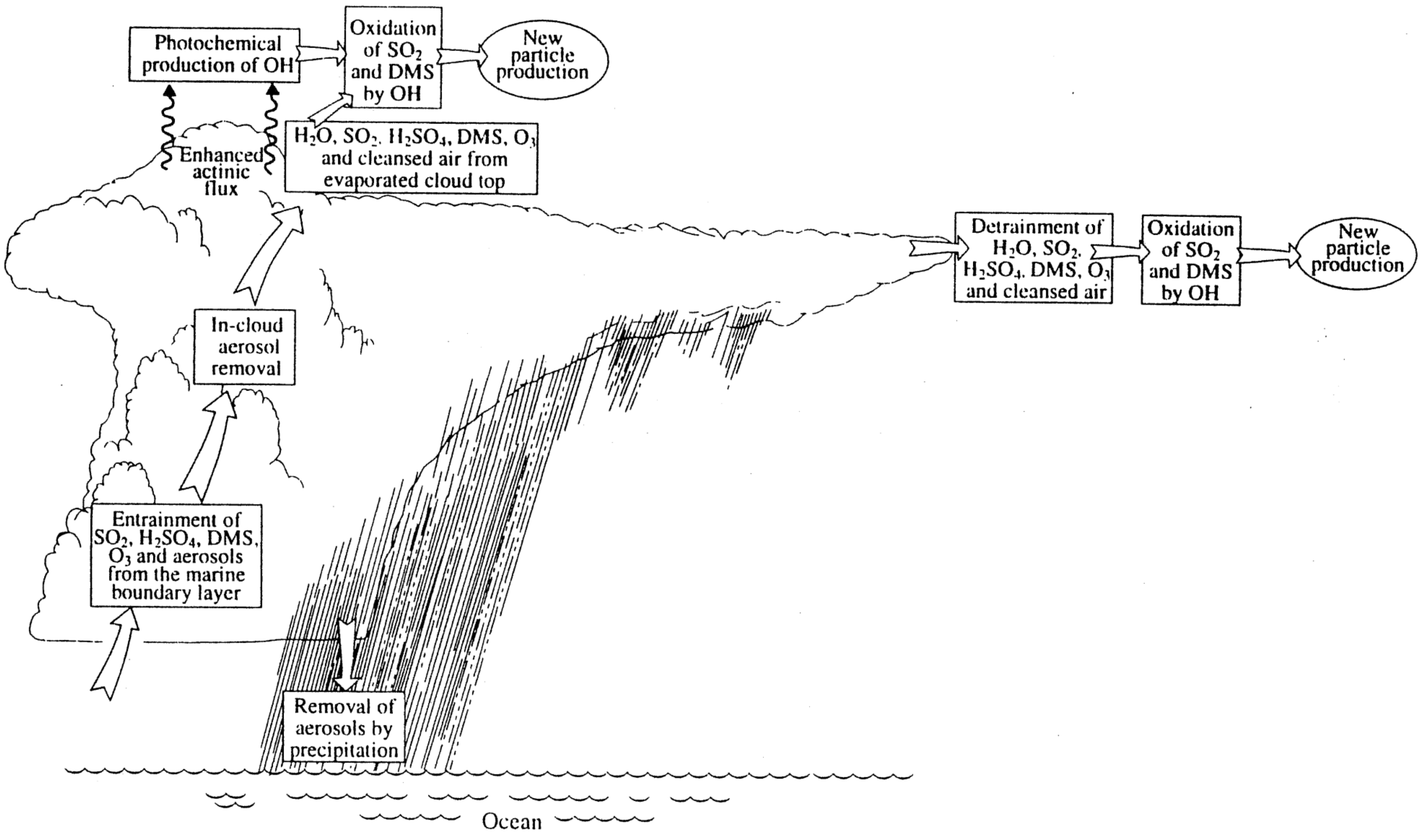


Figure 7.11. Schematic diagram illustrating a conceptual model for new particle production near marine convective clouds. [From K. Perry and P. V. Hobbs, *J. Geophys. Res.*, **99**, 22813 (1994). Copyright © by the American Geophysical Union.]

2. Sources and measurement

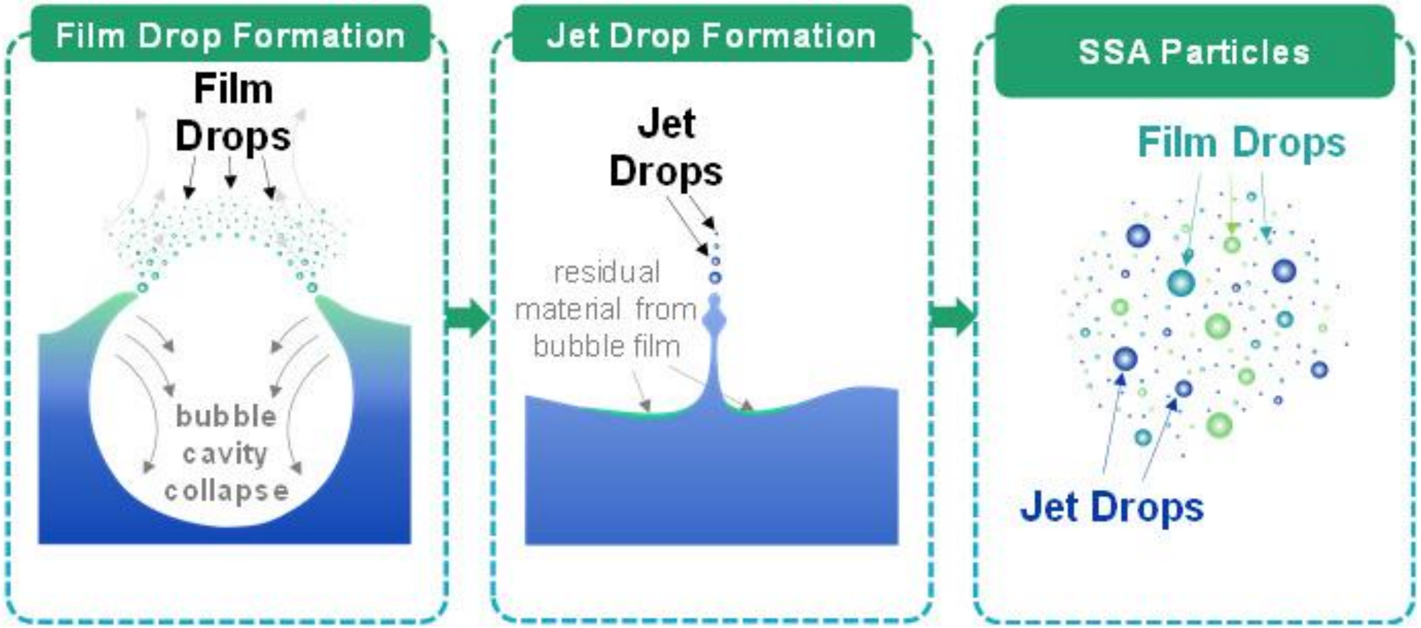
- Sea spray
- Dust
- Combustion
- Condensation –inorganic and organic
- Arctic haze
- Volcanoes

Sea spray

Chemical Concentration Factors (CCF)

$$CCF = \frac{(C_x / C_{Na})_{aerosol}}{(C_x / C_{Na})_{seawater}}$$

CCF > 100 for some heavy metals
(e.g., Hg, Cd, Pb)
&
organics



After water evaporation
fine salt aerosol remains
(i.e., 5 – 300 pg of NaCl(s))

Dust

Chemical composition reflects source

- Natural → soil and rock types
- Anthropogenic → brake lining, tire components, cement, construction materials

Combustion aerosols

- Forest fires
- Volcanoes
- Internal combustion engines
- Coal burning power plants
- Industry, roasting and smelting

Fly Ash & Bottom Ash

Inorganic minerals (Ca, Mg, SO4 etc)

Trace metals (Hg, Pb, Cd, Se, As)

Soot – elemental carbon

Trace organics (PAHs, PCBs etc)

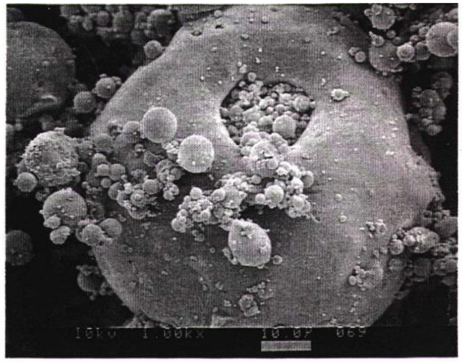
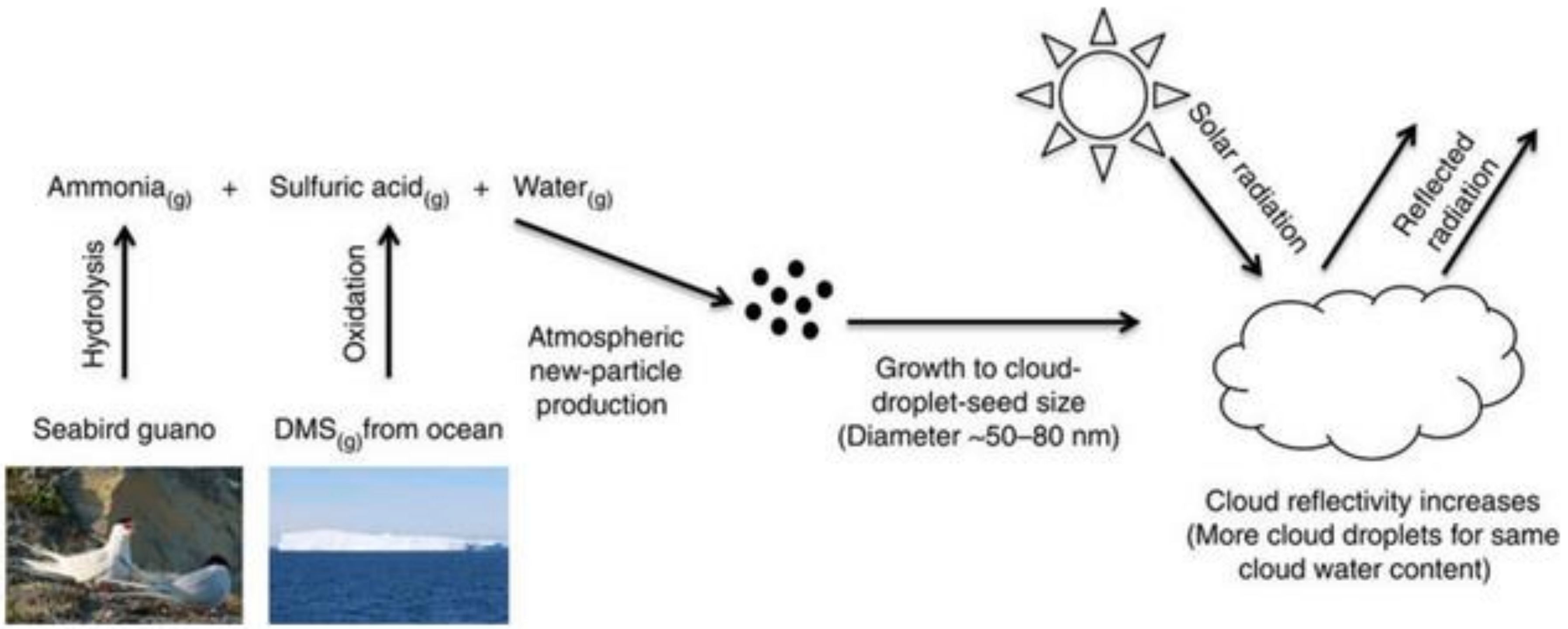


Figure 2.3.2. Fly ash showing large plerospheres containing smaller cenospheres (courtesy of Hills, 1995).

Condensation aerosols

Inorganics: Ammonium Sulfate and Ammonium Hydrogen Sulfate

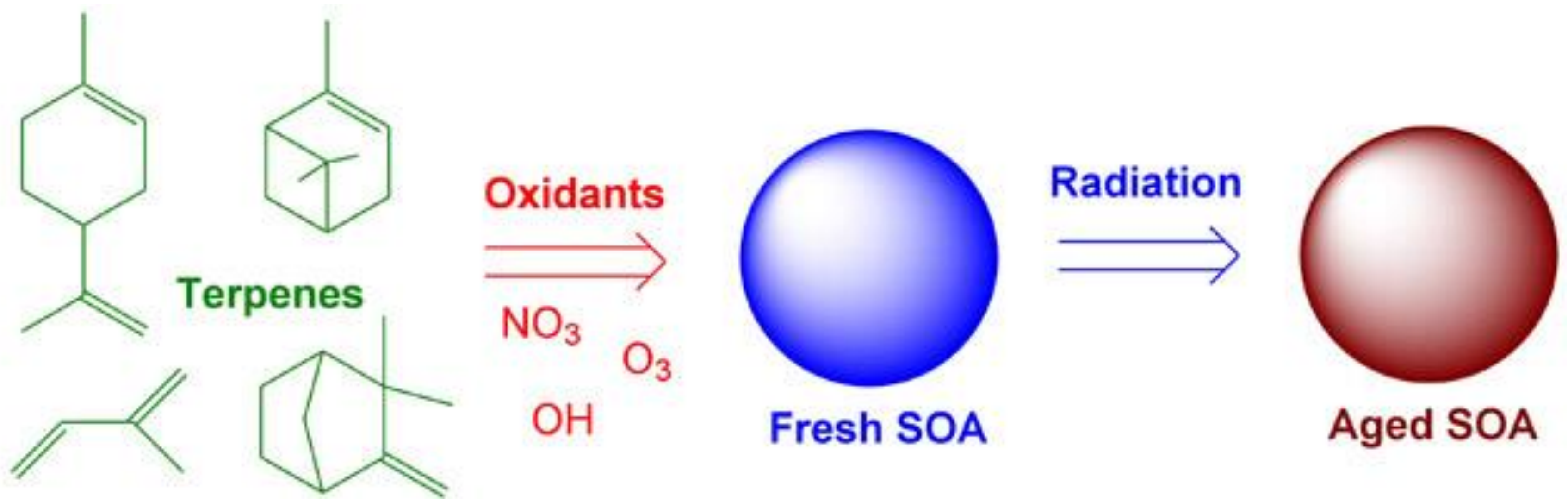
From: Contribution of Arctic seabird-colony ammonia to atmospheric particles and cloud-albedo radiative effect



Schematic summary of processes that couple Arctic seabird-colony ammonia emissions with climate.

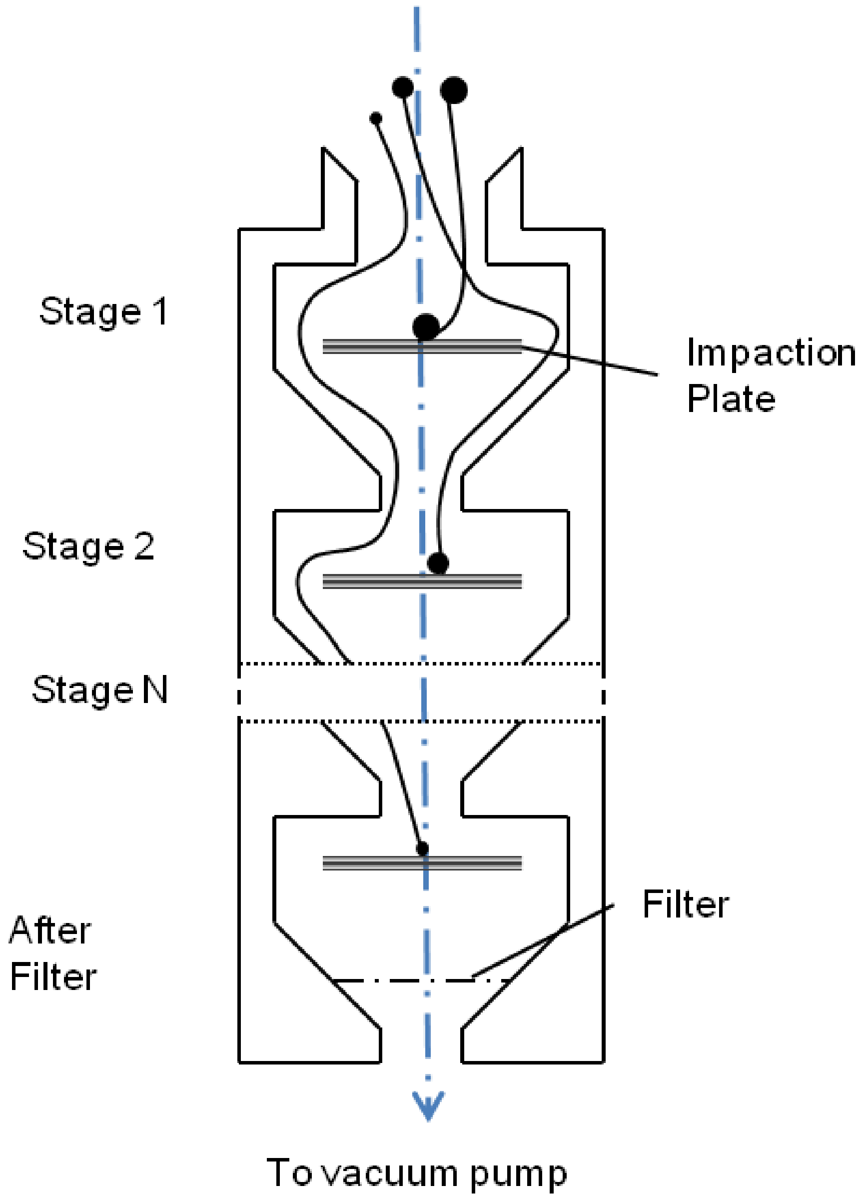
Condensation aerosols

Organics: secondary organic aerosols



Measurement
Particle Size Fractionation

aerodynamic impactors



Measurement
Optical Particle Sizer & Counter

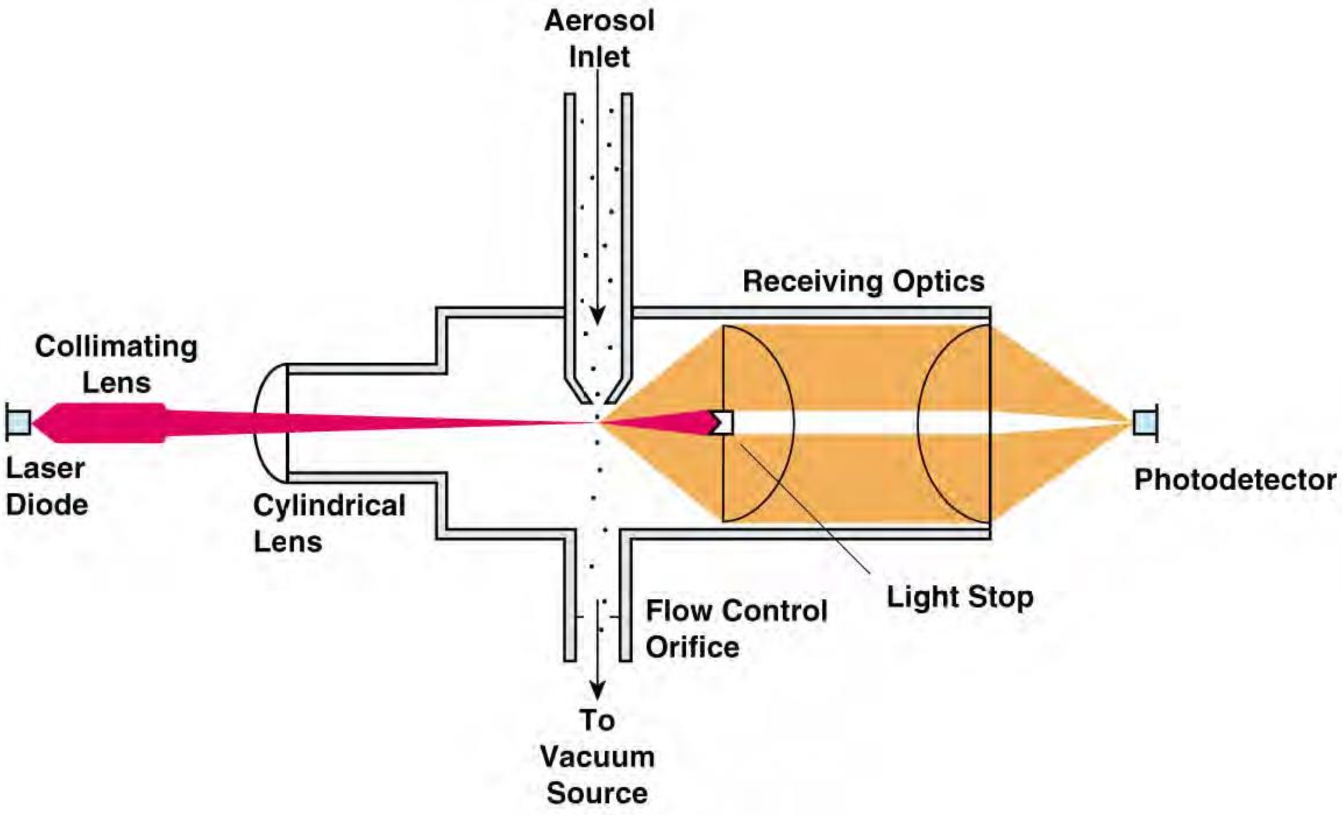
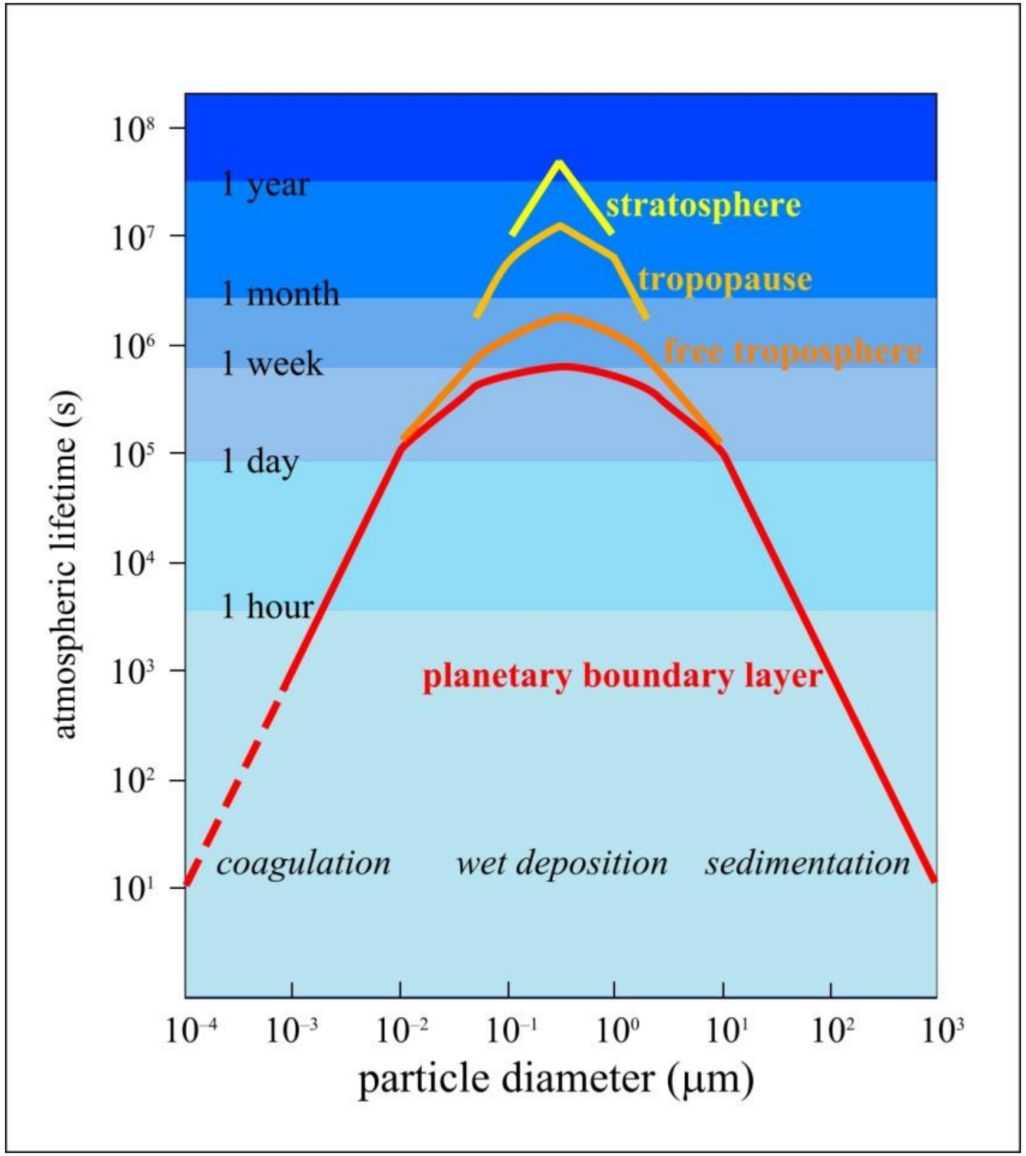


Figure 2
Flow Through an Optical Particle Counter

3. Concentrations and Residence times

Concentrations reported as either
Number density (# particles/m^3)
Mass density (μg/m^3)

Typical range:	10 – 500 μg/m^3
Rural forested	10 – 50 μg/m^3
Open ocean	10 – 150 μg/m^3
Urban	10 - 300+ μg/m^3



Settling velocity

$$v_t = \frac{(\rho_p - \rho_{air})\ C\ g\ d_p^2}{18\eta}$$

meters per second

ρ_p = density of particle (g m^{-3})

ρ_{air} = density of air (g m^{-3})

C = correction factor (see Table 6.4 Textbook)

g = 9.81 m s^{-2}

d_p = diameter of particle (m)

$\eta = 1.9 \times 10^{-2}$ g m^{-1} s^{-1} at T=298K, P= 1atm

Coagulation kinetics

$$\frac{-dN}{dt} = 4\pi DCd_p N^2$$

$$\frac{-dN}{dt} = k_2 N^2$$

where $k_2 = 4\ \pi\ D\ C\ d_p$

N =

D =

C =

d_p =

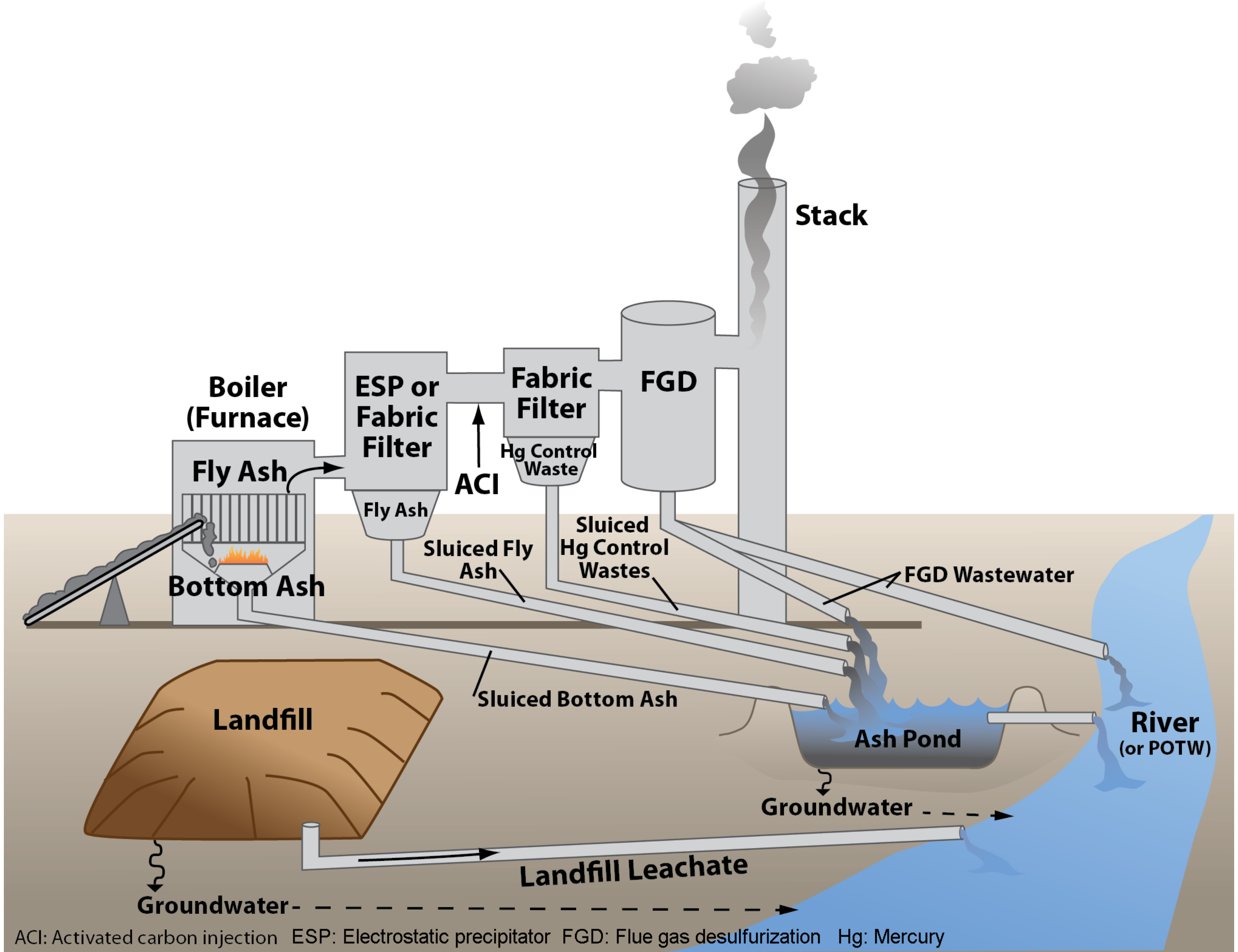
Table 6.4 Aerosol transport properties assuming spherical particles, density 2.0 g cm^{-3}, in air at P^o and 25 °C

d_p/μm	C	v_t/cm s^{-1}	D/m^2 s^{-1}	$t_{1/2}$
0.001	216		5.14×10^{-6}	1 min
0.005	43.6		2.07×10^{-7}	0.5 h
0.01	22.2		5.24×10^{-8}	2 h
0.05	4.95		2.35×10^{-9}	38 h
0.1	2.85	1.7×10^{-4}	6.75×10^{-10}	110 h
0.5	1.326	2.0×10^{-3}	6.32×10^{-11}	520 h
1.0	1.164	6.8×10^{-3}	2.77×10^{-11}	690 h
5.0	1.032	1.5×10^{-1}		
10.0	1.016	6.0×10^{-1}		
50.0	1.003	15		
100.0	1.0016	58		

For half-life calculations, particle number density in the atmosphere is taken as 10^9 m^{-3}.

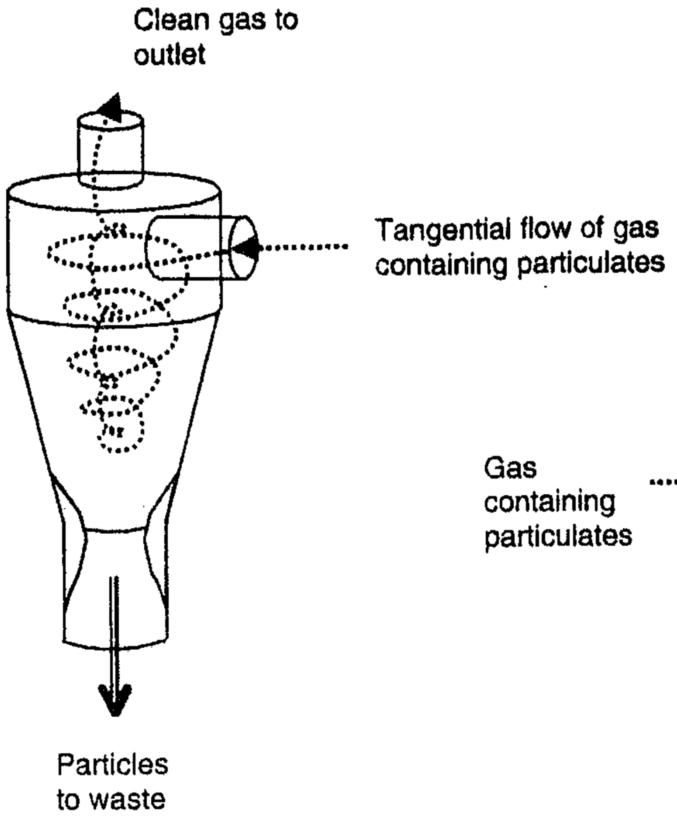
Van Loon
Pg 143

4. Emission controls and abatement technology

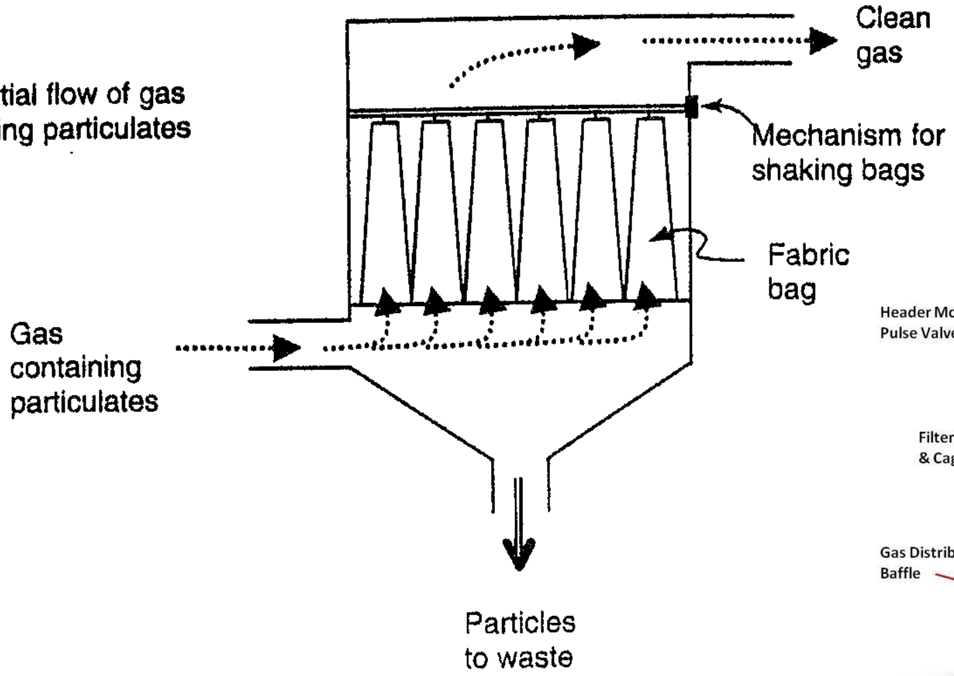


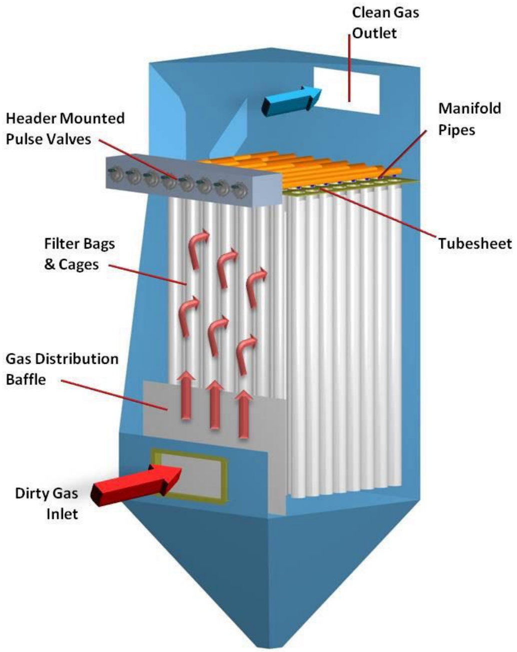
Aerosol control for larger particles

Cyclone precipitator



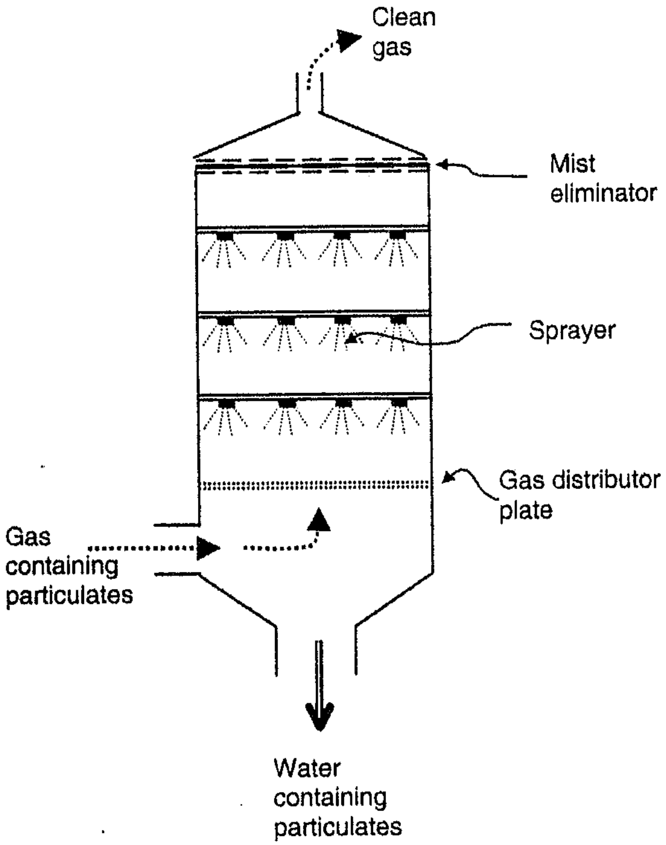
Fabric filtration



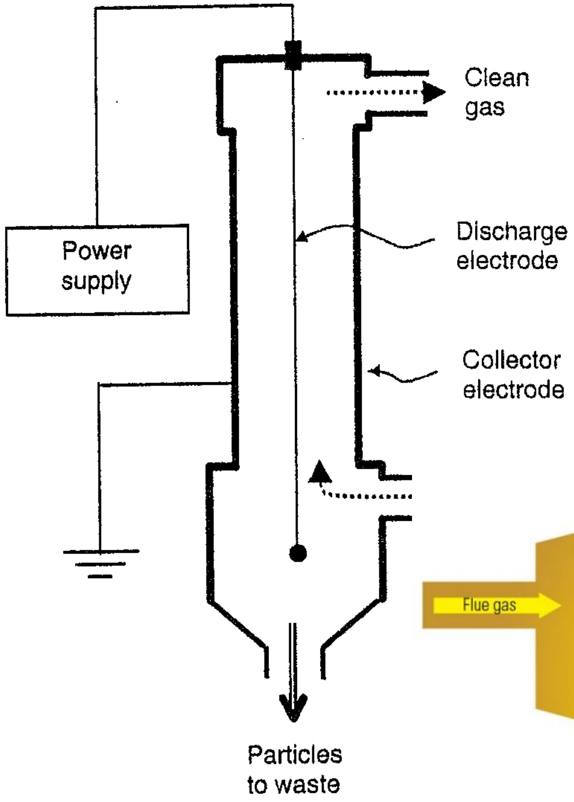


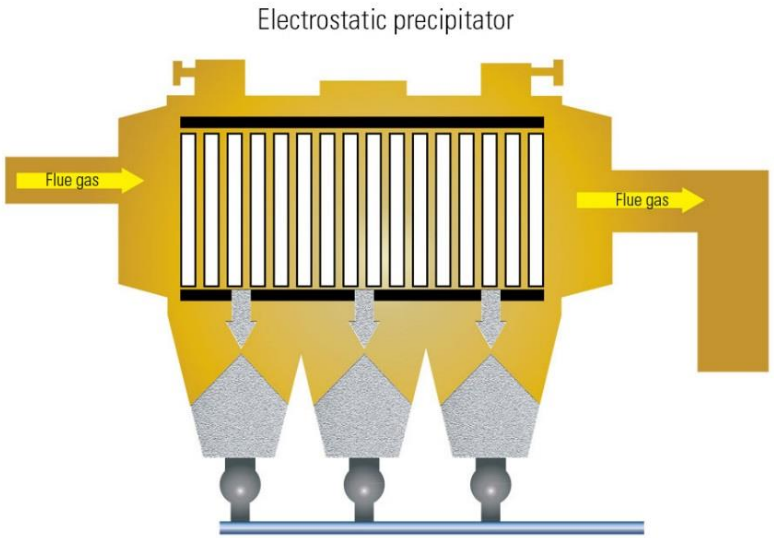
Aerosol control for smaller particles

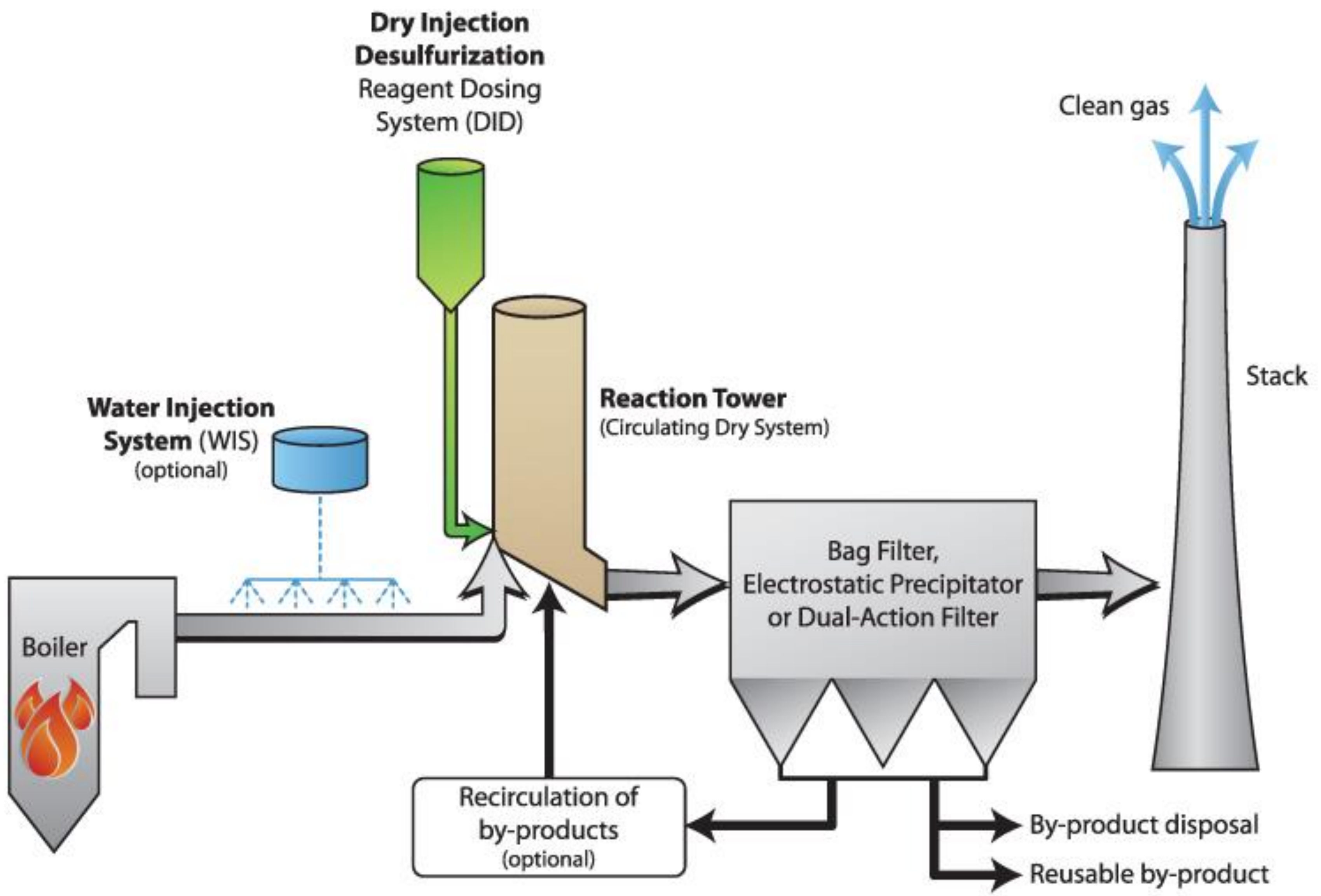
Wet Scrubber



Electrostatic Precipitator






Dry Injection
Desulfurization
Reagent Dosing
System (DID)
Clean gas
Stack
Reaction Tower
(Circulating Dry System)
Water Injection
System (WIS)
(optional)
Bag Filter,
Electrostatic Precipitator
or Dual-Action Filter
Boiler
Recirculation of
by-products
(optional)
By-product disposal
Reusable by-product

Cyclone Collection (Particle Removal) Efficiency Formula

$$\eta = \frac{1}{1 + (d_{pc}/d_p)^2}$$

η – *fractional particle collection efficiency*
d_{pc} – *diameter of particle collected with* 50% *efficiency in m*
d_p – *diameter of particle of interest in m*

Size distribution of aerosols in engine exhaust