

Basic Principles of Cigarette Design and Function

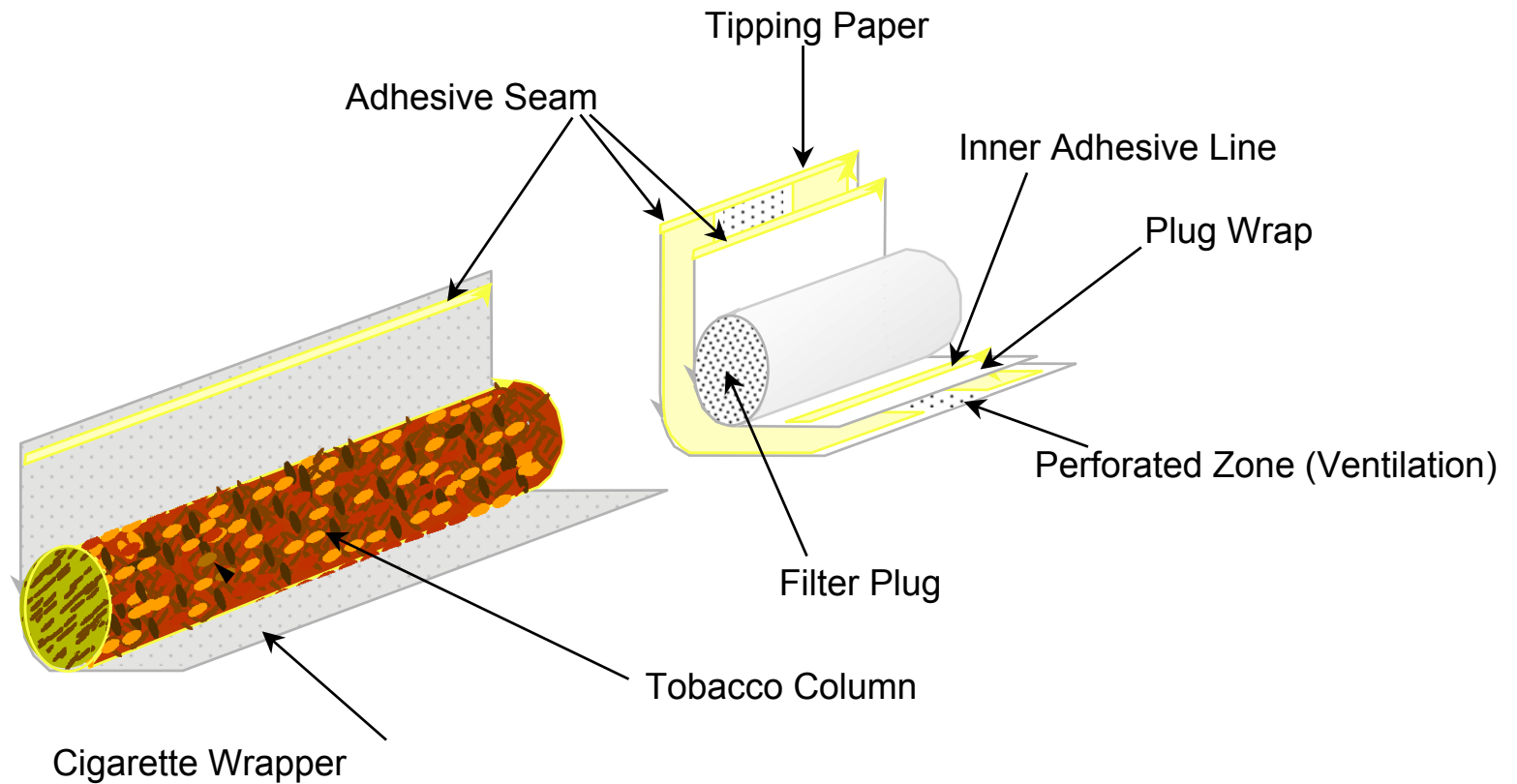
Ken Podraza Ph.D.

Director

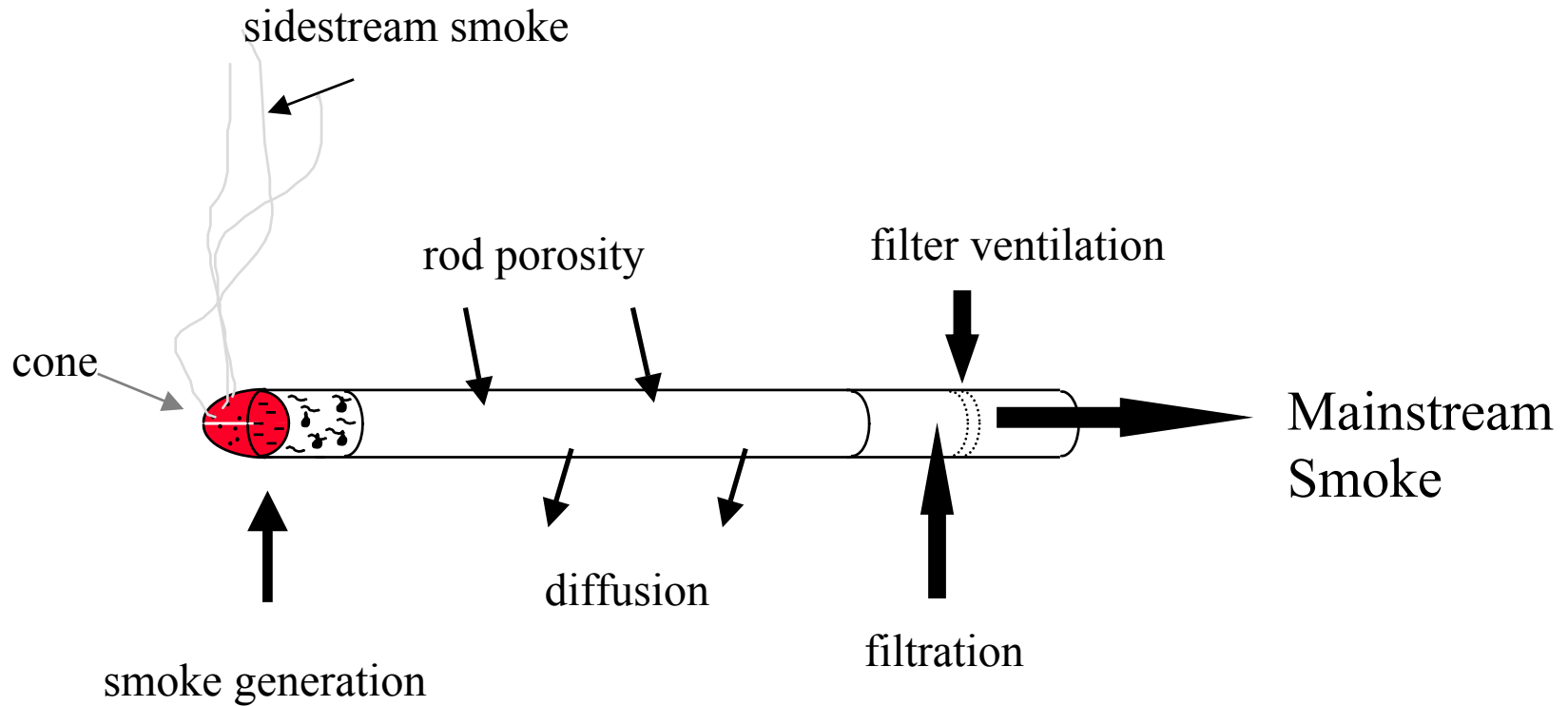
Product Integrity

Philip Morris USA

Cigarette Construction



Processes Related to Cigarette Construction



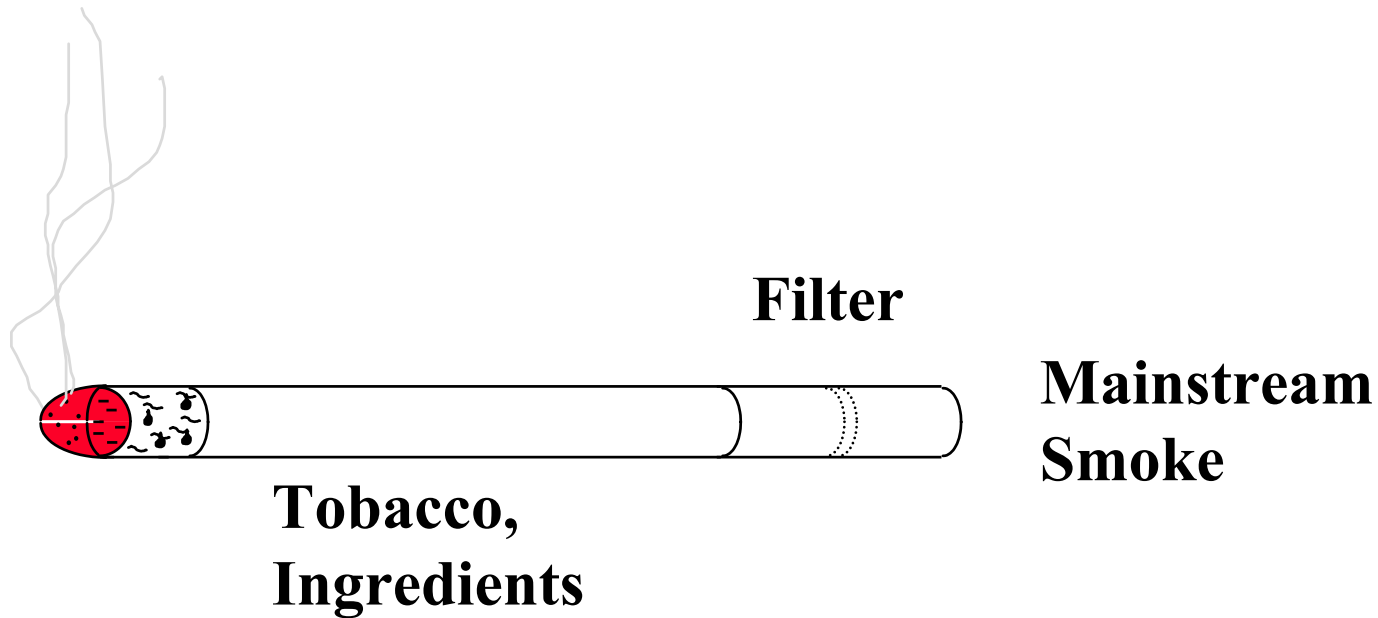
Processes of Smoke Formation



**Mainstream
Smoke**

**Combustion
Pyrolysis
Distillation
Pyrosynthesis**

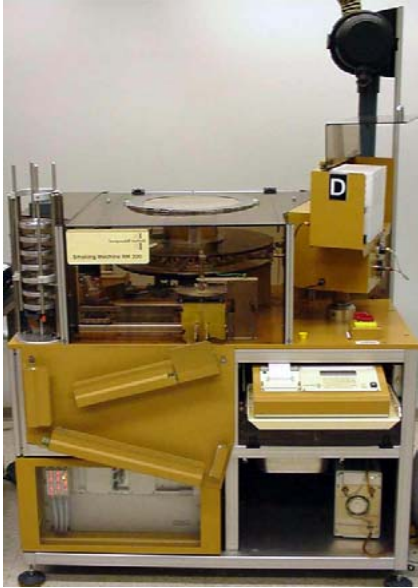
Mainstream Smoke



Mainstream Smoke Phases

- Particulate Phase
 - The phase of the cigarette smoke retained on a Cambridge filter pad during machine smoking
 - Consists of condensed droplets of material ranging in size from 0.2 - 0.4 microns
- Gas/Vapor Phase
 - The phase of the cigarette smoke that passes through a Cambridge filter pad during machine smoking
 - Consists of permanent gases and volatilized compounds
- Cambridge Filter Pad
 - Consists of a fiberglass sheet that collects greater than 99% of the 0.1 μm diameter particles

Mainstream Smoke Generated by Smoking Machines



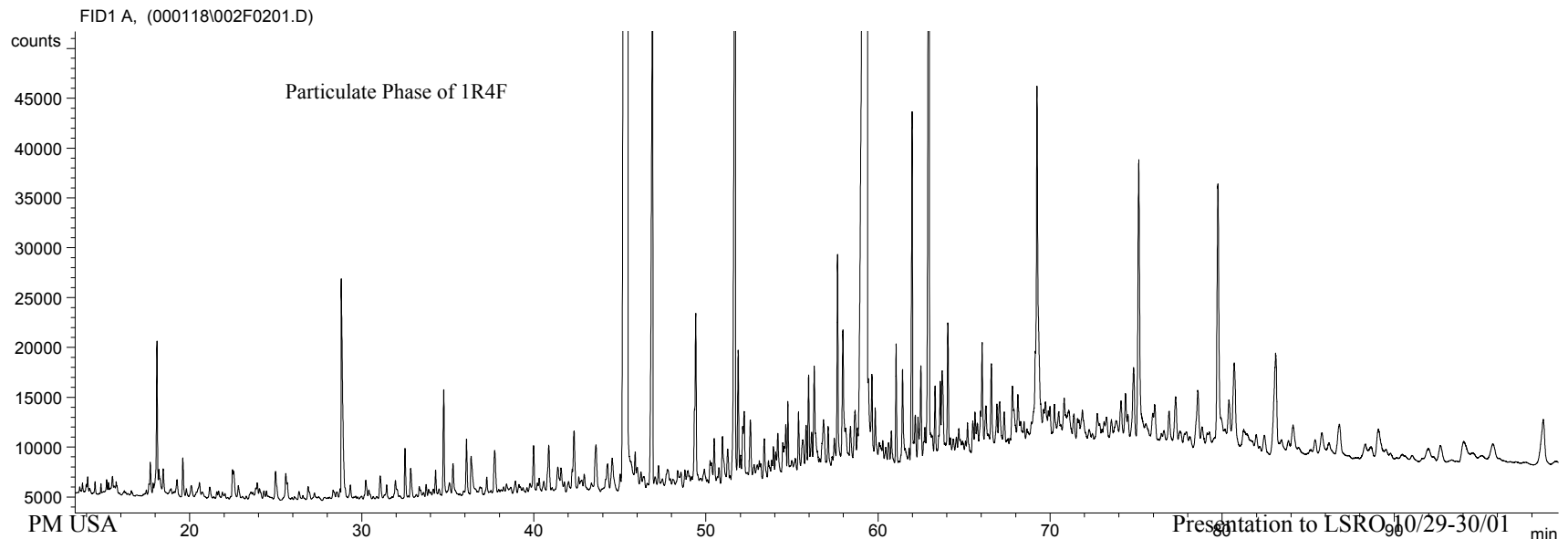
- Smoking Parameters
 - Federal Trade Commission (FTC) / International Organization for Standardization (ISO)
 - 35 mL Puff Volume
 - 2 Second Puff Duration
 - 60 Second Puff Interval

Mainstream Smoke Measurements

- Traditionally, used to determine “tar”, nicotine and carbon monoxide yields
 - “Tar” is the weight of the material collected on a Cambridge filter pad when a cigarette is smoked under a defined set of conditions (e.g. ISO or FTC) minus nicotine and water.
- Interlaboratory validated methods to measure “tar”, nicotine and carbon monoxide exist

Smoke Profile

- Approximately 4,000 identified constituents in smoke
- Difficult to identify an ingredient added to tobacco in the ppm concentration range



Other Smoke Constituents Measured in Benchmark Studies

- **Ammonia & Aromatic Amines**
 - Ammonia
 - 1-Aminonaphthalene
 - 2-Aminonaphthalene
 - 3-Aminobiphenyl
 - 4-Aminobiphenyl
- **Aldehydes and Ketones**
 - Formaldehyde
 - Acetaldehyde
 - Propionaldehyde
 - Butyraldehyde
 - Acrolein
 - Crotonaldehyde
 - Acetone
 - Methyl Ethyl Ketone
- **Miscellaneous**
 - “Tar”
- **Aromatic Hydrocarbons**
 - Benzene
 - Toluene
 - Styrene
- **Gases**
 - Carbon Monoxide
 - Hydrogen Cyanide
 - Nitric Oxide
- **Heterocycles**
 - Pyridine
 - Quinoline
- **Metals**
 - Arsenic
 - Cadmium
 - Chromium
 - Lead
 - Mercury
 - Nickel
 - Selenium
- **Phenols**
 - Phenol
 - Catechol
 - Resorcinol
 - Hydroquinone
 - Cresols
- **Tobacco Specific Nitrosamines**
 - NAB
 - NAT
 - NNK
 - NNN
- **Unsaturated Compounds**
 - Acrylonitrile
 - 1,3-Butadiene
 - Isoprene
- **Polycyclic Aromatic Hydrocarbon**
 - Benzo(a)pyrene

Alternate Smoking Parameters

- Massachusetts
 - 45 mL Puff Volume
 - 2 Second Puff Duration
 - 30 Second Puff Interval
 - 50% Ventilation Holes Blocked
- Canadian (Extreme)
 - 55 mL Puff Volume
 - 2 Second Puff Duration
 - 30 Second Puff
 - 100% Ventilation Holes Blocked

Constituent Yield Methodology

- Interlaboratory validated methods do not exist

Machine Cigarette Smoking Compared to Consumer Smoking

- Machine smoking
 - Standardized method (*e.g.* FTC, ISO) useful to assure consistency in manufacturing and inter-brand comparison for “tar”, nicotine and carbon monoxide
- Consumer smoking
 - Actual exposure to smokers is not measured by a smoking machine

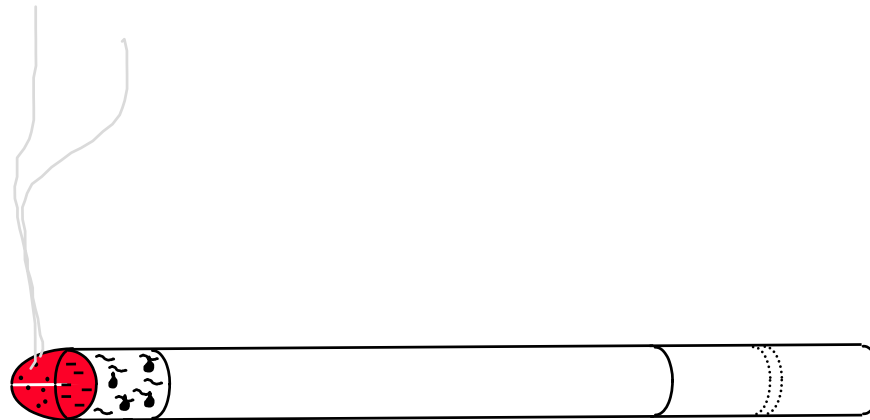
Variability

- All measurements show some variability in their results
- There are a number of sources contributing to this variability including:
 - the method itself
 - inherent product variability
 - the sampling procedure

Mainstream Smoke Summary

- Smoking machine derived mainstream smoke
- Actual exposure to smokers is not measured by a smoking machine
- Ingredients added to tobacco and part of smoke are not typically measured due to the analytical difficulty
 - Complex smoke matrix
 - Low concentration of ingredients used

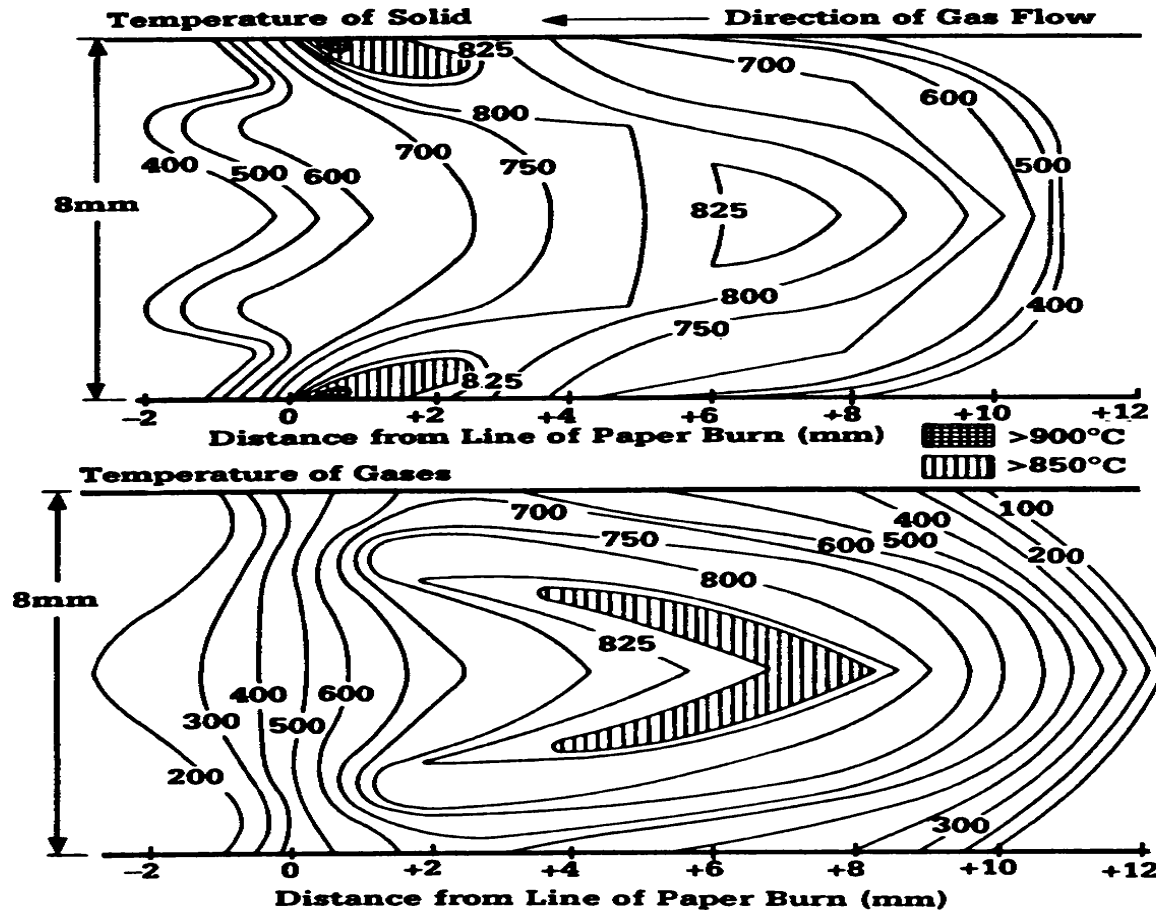
Processes of Smoke Formation



**Mainstream
Smoke**

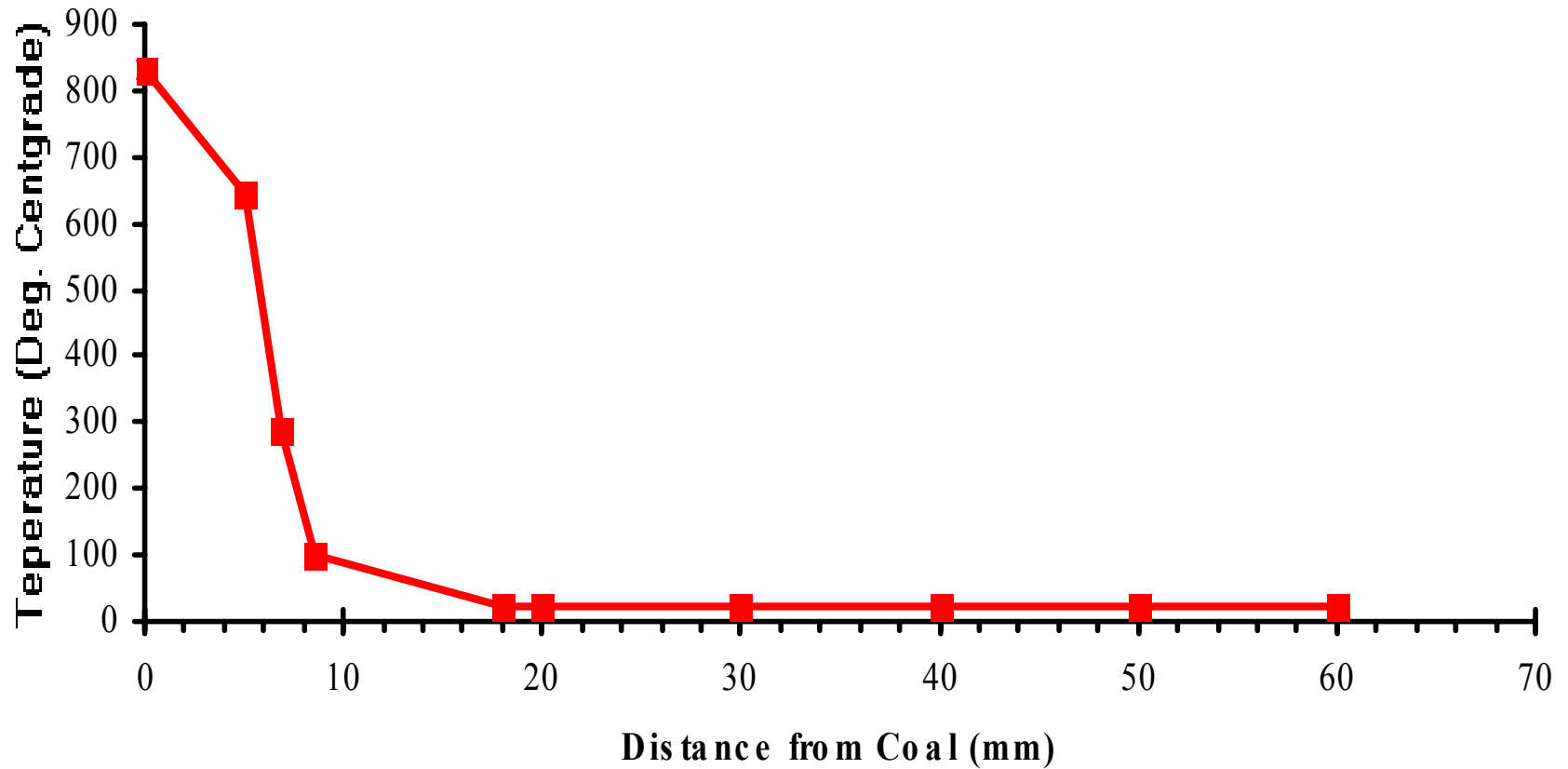
**Combustion
Pyrolysis
Distillation
Pyrosynthesis**

The Burning Cigarette



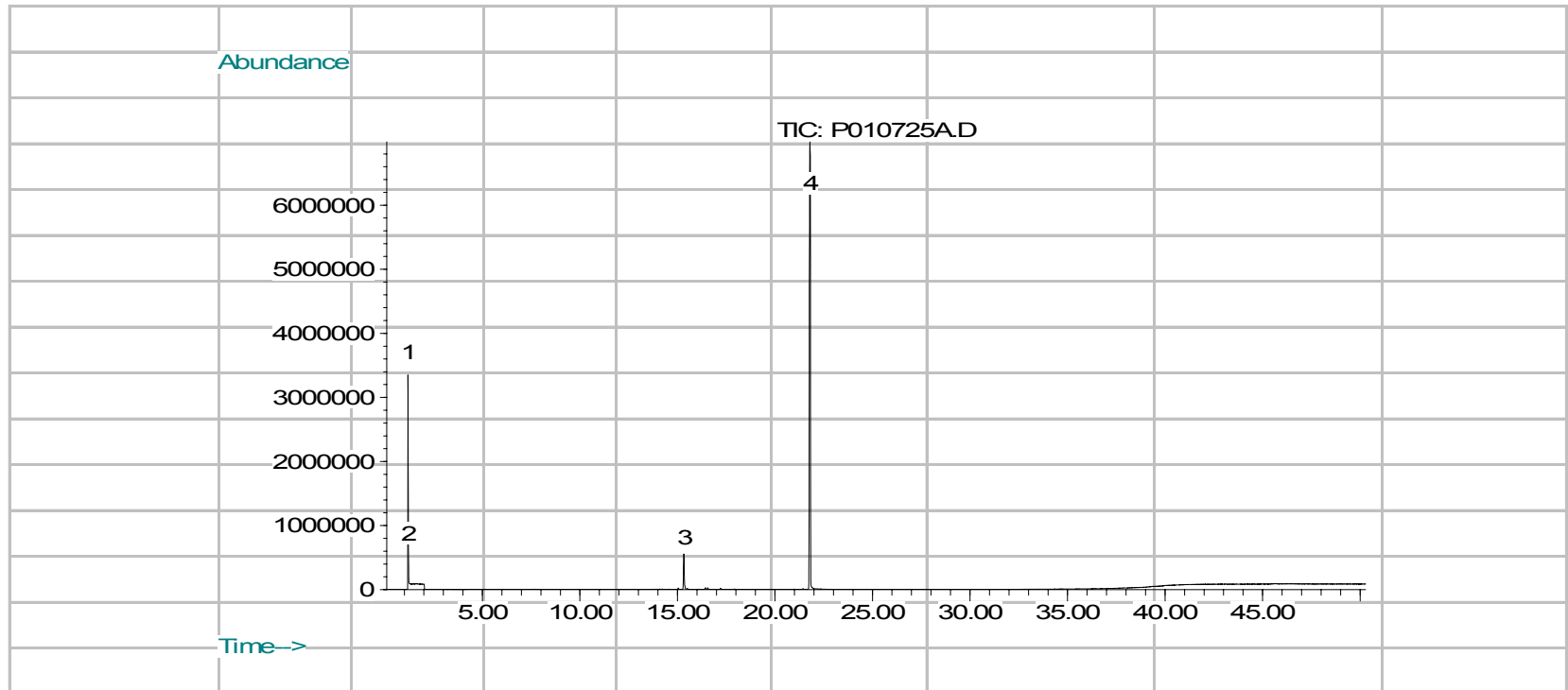
Smoke Formation Temperature Profile

Temperature Profile



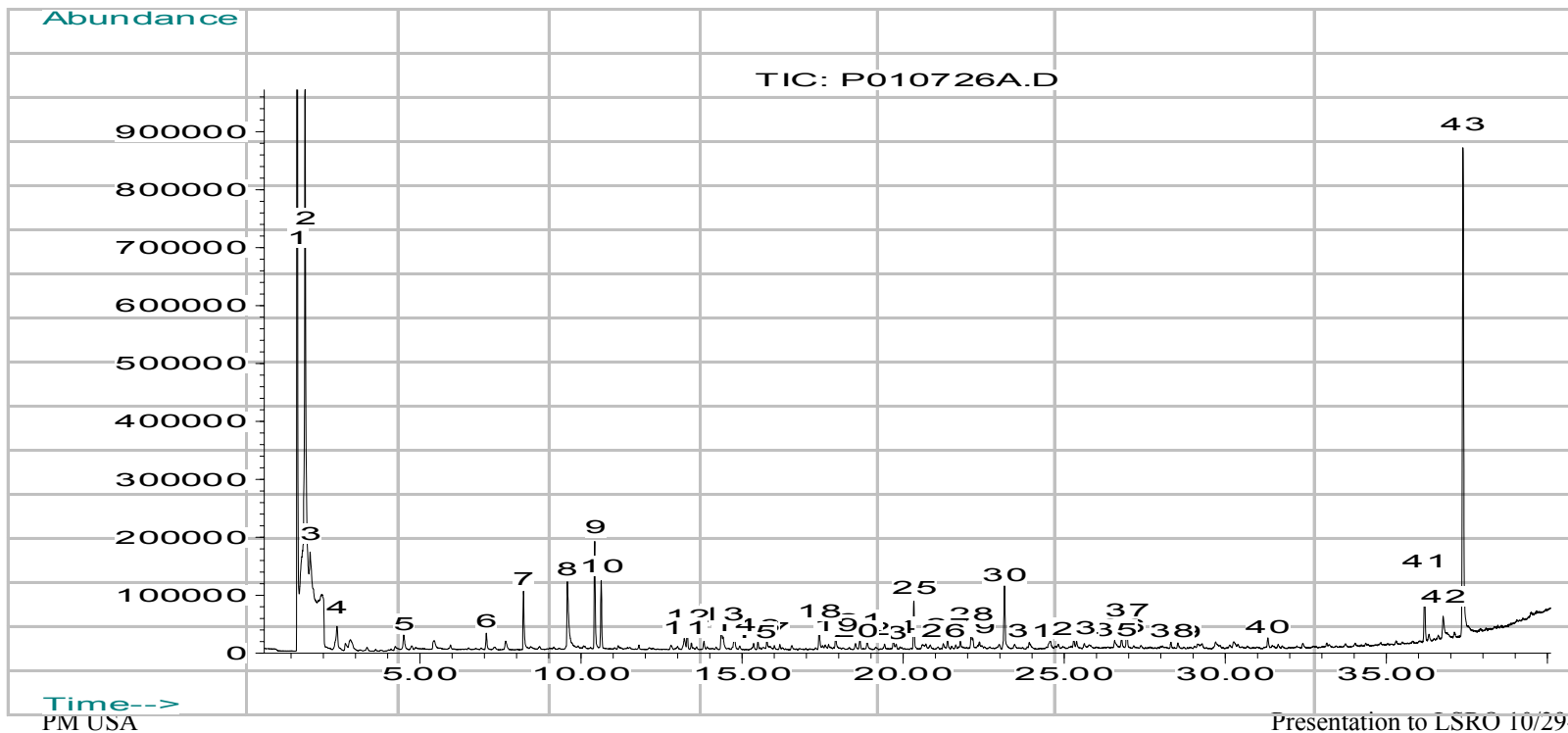
Distillation Process

- Transfer of a compound into the smoke stream unchanged
- Analytical Pyrolysis of Menthol



Combustion Process

- Transformation of a compound into one or more other substances by heat in the presence of oxygen
 - Formation of CO_2 , CO , H_2O and degradation fragments
- Analytical pyrolysis of Cocoa



Pyrolysis Process

- Transformation of a compound into one or more other substances by heat in a low oxygen concentration environment
 - Decomposition into smaller fragments
 - Isomerization

Pyrosynthesis Process

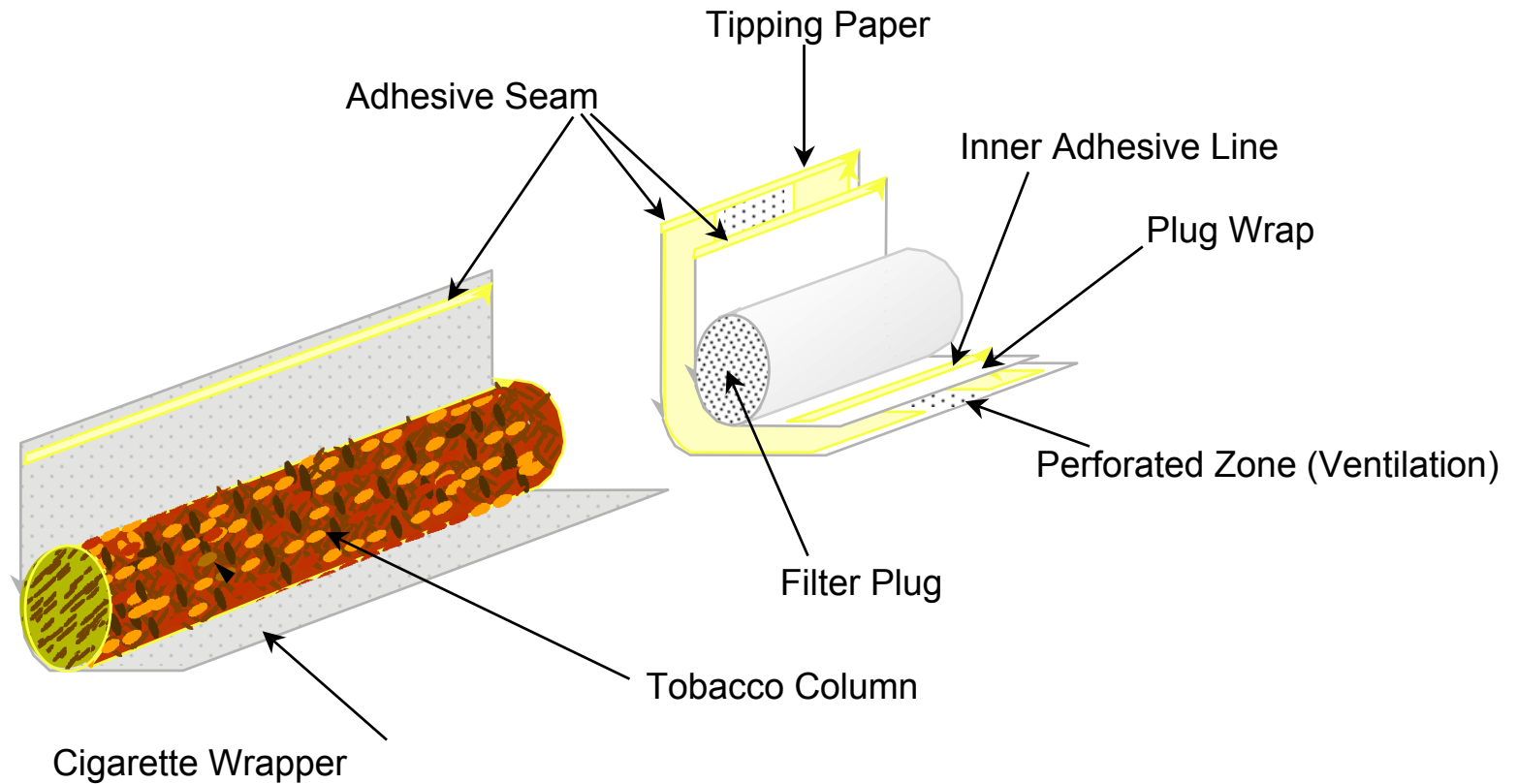
- Formation of smoke components during the combustion, pyrolysis and distillation processes

Process of Smoke Formation

Summary

- Mainstream smoke is produced by a number of processes
- Specific process which impacts an ingredient is dependent on the physical properties of the specific ingredient

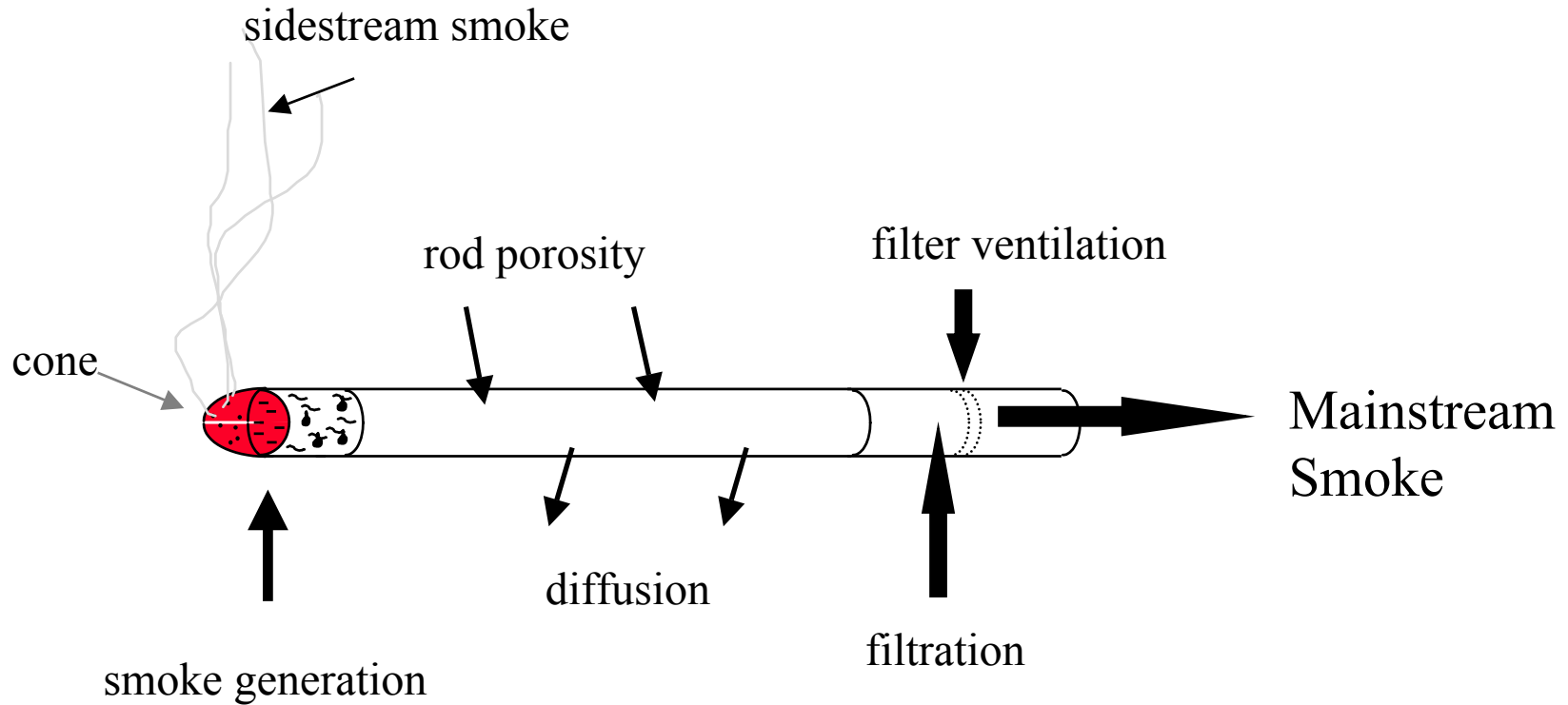
Cigarette Construction



Principal Cigarette Construction Parameters Controlling Smoke Yields

- Type of Tobacco
- Tobacco Weight (Density)
- Cigarette Paper
- Filter Type
 - Efficiency (retention)
- Filter Ventilation
- Cigarette Geometry
 - Circumference
 - Length

Processes Related to Cigarette Construction



Principal Cigarette Construction Parameters Controlling Smoke Yields

- Type of Tobacco
- Tobacco Weight (Density)
- Cigarette Paper
- Filter Type
 - Efficiency (retention)
- Filter Ventilation
- Cigarette Geometry
 - Circumference
 - Length

Types of Tobacco

<u>BURLEY</u>	<u>BRIGHT</u>	<u>ORIENTAL</u>	<u>EXPANDED</u>	<u>RECON</u>	<u>STEMS</u>
Air Cured	Flue Cured	Air Cured	Bright Burley Oriental	Flue Cured Type Burley Type	Expanded Stems Flue Cured
High Filling Power	Moderate Filling Power	Low Filling Power	Excellent Filling Power (2X)		Mod. - High Filling Power
Excellent Burn	Variable Burn	Very Slow Burn	Fast Burn		Fast Burn

Tobacco Variability

- Natural product
 - Grown in many parts of the world
- Crop year variation
 - Weather
- Multiple crop years are used in US blended cigarettes

Typical US Blend

<u>Components</u>	<u>%</u>
Burley	25 - 35
Bright	25 - 35
Oriental	3 - 5
Reconstituted	10 - 25
Stems	3 - 10
	<hr/>
	100

Tobacco Weight (Density)

- US commercial brands have approximately 400 mg to 1 gram of tobacco
- Reduced tobacco weight reduces machine smoked yield of smoke components, but also can reduce the physical stability of the cigarette
 - Compensate by using a higher filling power tobacco
 - Use expanded tobacco

Cigarette Paper

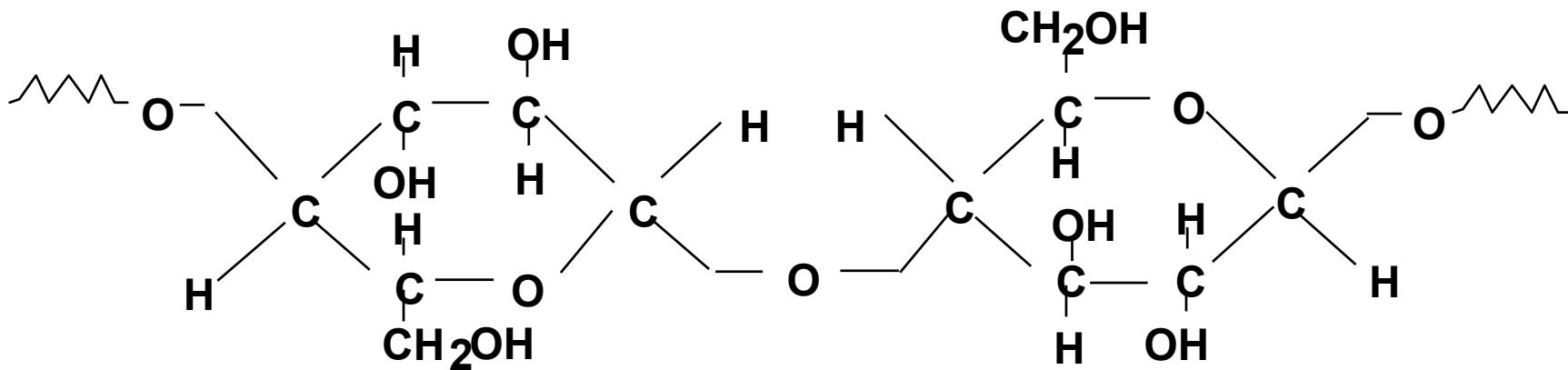
- Cigarette papers are constructed of:
 - Flax or wood fibers
 - Typically calcium carbonate as a color enhancing agent
 - Sodium and potassium citrate as burn rate modifiers
- Resulting paper has a certain permeability
 - Measure of the volume of air that flows through a specified area of cigarette paper in a given unit of time--CORESTA units

Cigarette Paper Properties

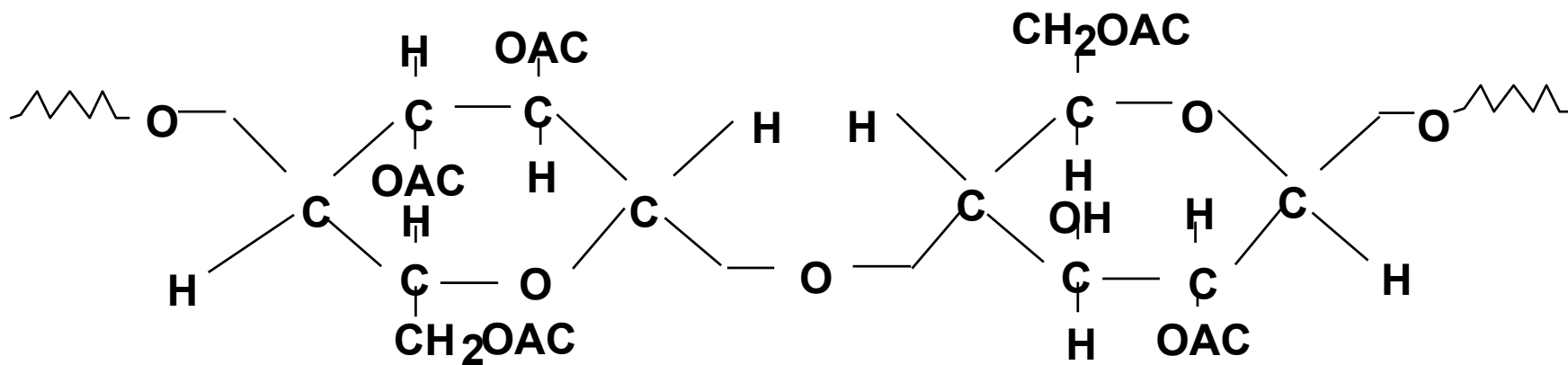
- US commercial brands have paper permeability between 14 and 51 CORESTA units
- Increased potassium and sodium citrate results in faster burning papers and reduces machine smoked tar yield per cigarette by reducing the number of puffs
- Increased cigarette paper permeability decreases the amount of tobacco consumed during a puff and reduces machine smoked tar yield

Filter Types

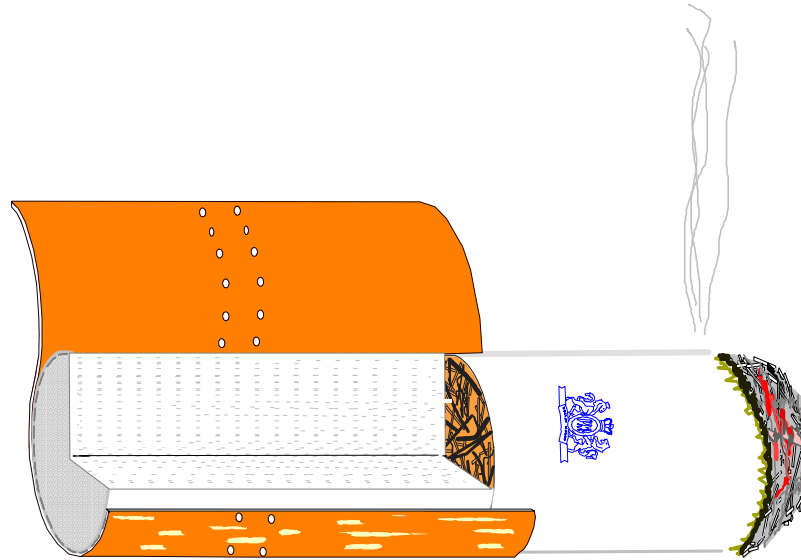
- Cellulose Acetate
 - Most common
 - Made of cellulose acetate
- Paper
 - Offers higher smoke component removal efficiency, at the same pressure drop, but poor visual appearance
 - Made of pure cellulose
- Combination carbon filter
 - A combination of a cellulose acetate or paper filter with carbon

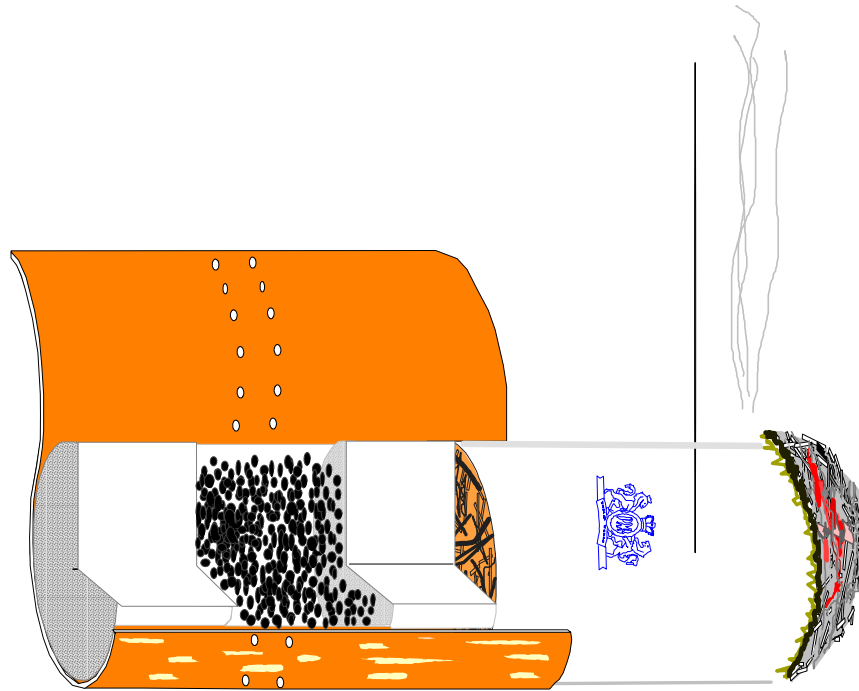


ACETYLATION

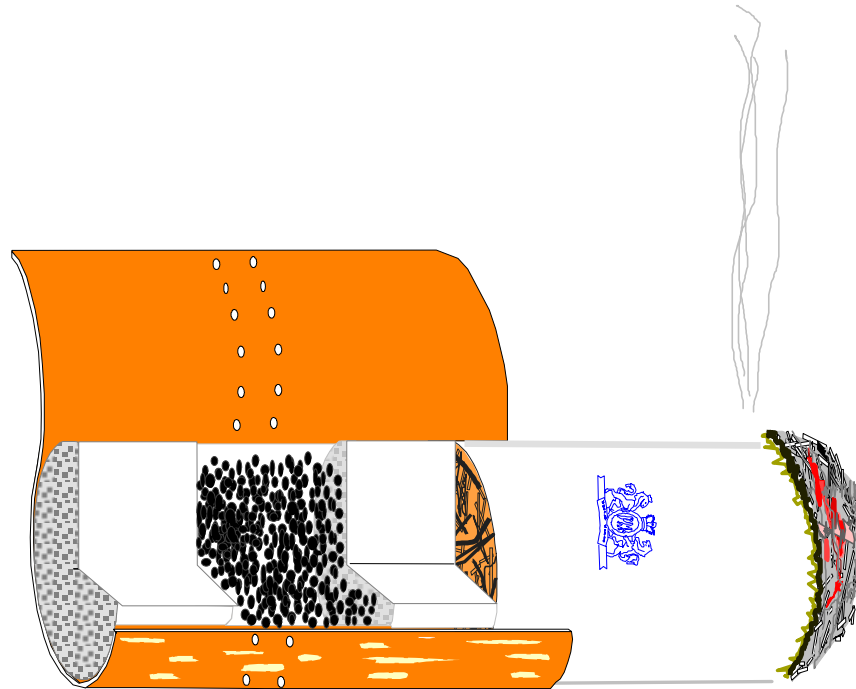


Single Component Filter





Cavity Filter (plug space plug)



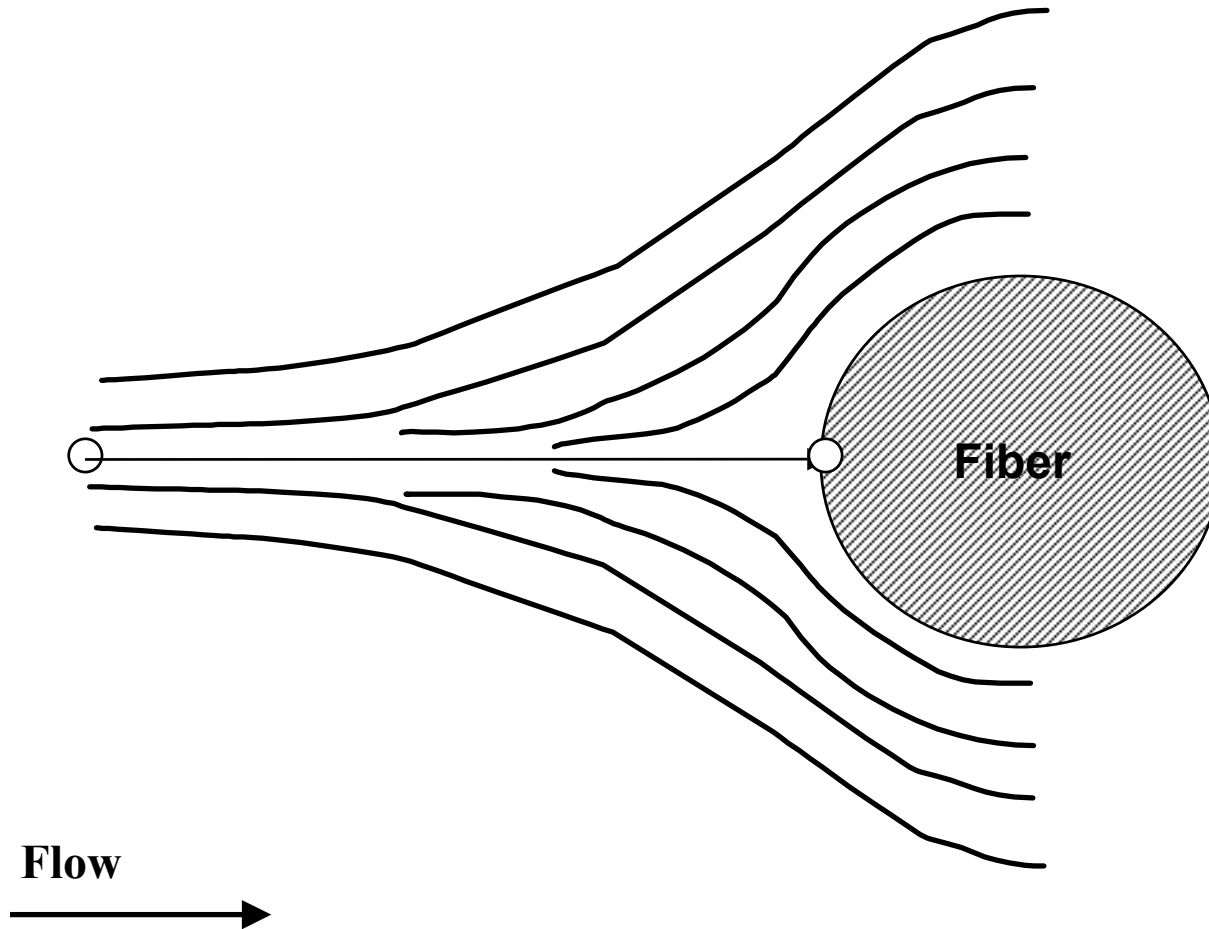
Resistance to Draw (RTD) or Filter Pressure Drop

- The amount of suction that must be used to pull smoke through the filter
- Measure of pressure required to force air through the filter at the rate of 17.5 mL/sec

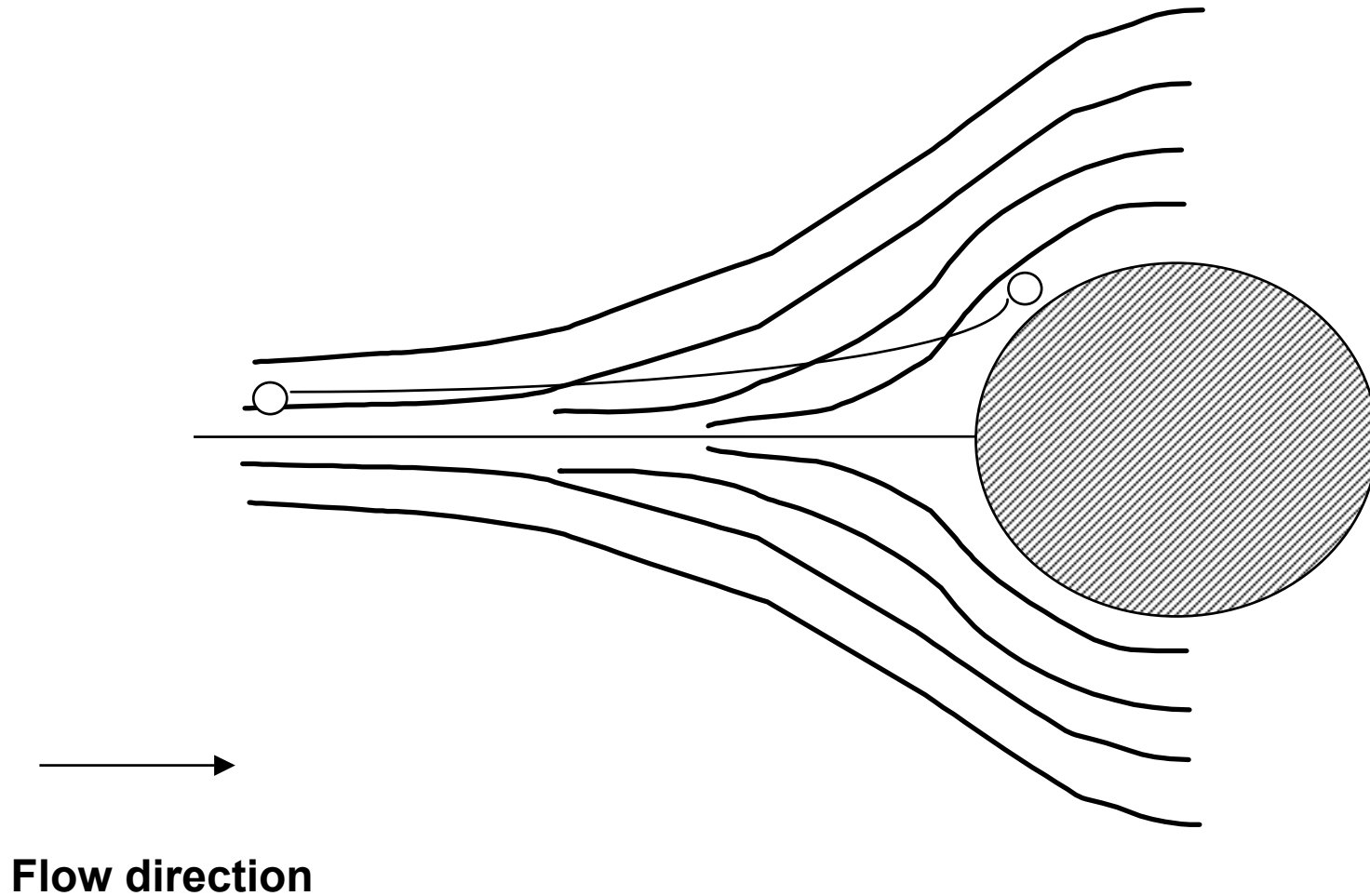
Filter Efficiency (Retention)

- The percentage of the incoming smoke components that are removed by the filter
- As the pressure drop increases for a given filter rod configuration, filtration efficiency increases due to a reduction in mainstream smoke velocity

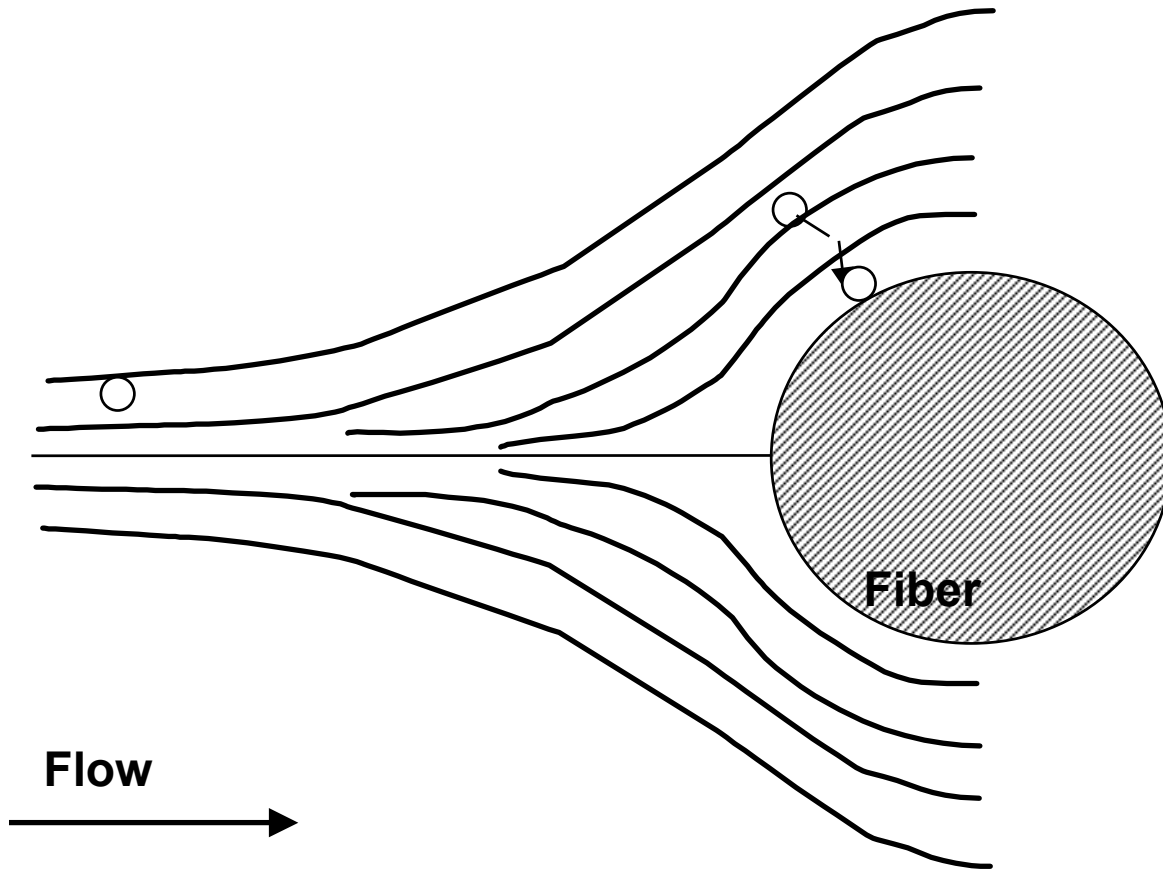
Direct Interception



Inertial Impaction



Diffusion



Filter Efficiency (Retention)

- Particulate phase materials can be removed to some degree with a cellulose acetate or paper filter while gases (e.g., CO) are not removed
- Use of a combination carbon filter can also reduce some gas phase materials but not CO

Filter Ventilation

- US commercial brands range from 0 to 81% ventilation
- Increased ventilation causes:
 - Reduction in per-puff machine smoke concentration due to dilution with air from the atmosphere
 - Improved filtration efficiency of tobacco column and filter due to reduced aerosol velocity
 - Decreased tobacco burned during a smoking machine puff resulting in increased puff count
 - Increased diffusion of the gas phase out of the tobacco column

Cigarette Geometry

- Circumference
 - US commercial brands are 17 mm to 27 mm, most are 25 mm
 - Reduced circumference increases Resistance To Draw (RTD)
- Length
 - US commercial brands are 70 to 120 mm, most are 85 or 100 mm
 - Longer length has the potential for more tobacco to be burned

	Marlboro King, HP EU GBS	Raffles 100, HP UK GBS
Smoke Constituent		
Tar, mg/cig	13	12
Nicotine, mg/cig	0.9	1.2
CO, mg/cig	11	13
Formaldehyde, ug/cig	38	41
Acetaldehyde, ug/cig	540	643
Acetone, ug/cig	287	335
Acrolein, ug/cig	51	60
Propionaldehyde, ug/cig	50	56
Crotonaldehyde, ug/cig	20	28
MEK, ug/cig	66	78
Butylaldehyde, ug/cig	34	48
Hydroquinone, ug,cig	54	75
Resorcinol, ug/cig	1	1
Catechol, ug/cig	50	73
Phenol, ug/cig	15	24
m+p-Catechol, ug/cig	10	13
o-Catechol, ug/cig	3	6
Benzo(a)pyrene, ng/cig	11	13
1-Aminonaphthalene, ng/cig	18	18
2-Aminonaphthalene, ng,cig	11	10
3-Aminobiphenyl, ng/cig	3	2
4-Aminobiphenyl, ng/cig	2	2
NO, ug/cig	156	118
HCN, ug/cig	114	135
Ammonia, ug/cig	18	12
1,3-Butadiene, ug/cig	46	54
Isoprene, ug/cig	385	466
Acrylonitrile, ug/cig	11	11
Benzene, ug/cig	44	44
Toluene, ug/cig	68	68
Styrene, ug/cig	9	10
Pyridine, ug/cig	12	13
Quinoline, ug/cig	0.3	0.6
NNN, ng/cig	189	27
NAT, ng/cig	160	43
NAB, ng/cig	19	7
NNK, ng,cig	104	34
pH	6.2	6.2
Mercury, ng/cig	3	4
Cadmium, ng/cig	51	34
Lead, ng/cig	20	17
Chromium, ng/cig	BDL	NQ
Nickel, ng/cig	BDL	BDL
Arsenic, ng/cig	NQ	NQ
Selenium, ng/cig	BDL	BDL
GBS - Global Benchmarking Study		
BBS - Brazil Benchmarking Study		
ABS - Australian Constituent Study		

Cigarette Construction Summary

- Mainstream smoke concentration, including ingredient smoke concentration, is influenced by:
 - dilution air
 - filtration by tobacco
 - filtration by the filter or additive
 - outward diffusion

Overall Summary

- A cigarette is surprisingly complex with many inter-related parts
- Cigarettes are constructed with a natural, somewhat variable, biological matrix - tobacco
- Mainstream smoke formation is dynamic
- Mainstream smoke components, including ingredients, are impacted by a number of processes
- Mainstream smoke components and ingredient concentrations are influenced by:
 - dilution air
 - filtration by tobacco
 - filtration by the filter or additive
 - outward diffusion
- Approximately 4,000 constituents have been identified in smoke
- Difficult to identify an ingredient added to tobacco due to the complex nature of smoke and low concentration of ingredients used