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Tobacco, Cigarettes and Cigarette Smoke

An Overview

Otmar Geiss, Dimitrios Kotzias

Institute for Health and Consumer Protection
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Preface

DG JRC's Institute for Health and Consumer Protection (IHCP) is acting upon DG SANCO's request to serve as reference point for issues related to the implementation of the Tobacco Directive. The field of activities covers the characterization of ingredients in cigarette brands, the study of diverse smoking regimes and collaboration with other international organizations to establish technical guidelines for the measurement of emissions during the burning of tobacco products, as well as the evaluation of data lists on tobacco ingredients that national authorities transmit to DG SANCO within the frame of the Tobacco Directive's requirements.

JRC-IHCP is hosting the Network of Government Laboratories for Tobacco and Tobacco Products (GoToLab) with the aim to establish a close collaboration between relevant Member State authorities and the JRC on tobacco control to develop validated measurement methods and techniques.

JRC-IHCP has also provided substantial support to Commission Services for the preparation of the Green Paper on Environmental Tobacco Smoke (ETS), particularly on the impact of various air change rates on the levels of ETS components.

This technical note provides an overview of the origin and mode of treatment of tobacco, tobacco ingredients and pesticide residues found in tobacco leaves. This note also reports on experiments carried out at the JRC-IHCP related to the chemistry of tobacco constituents and it gives information on analytical methodologies used for measuring tar, nicotine and carbon monoxide.

Dimitrios Kotzias

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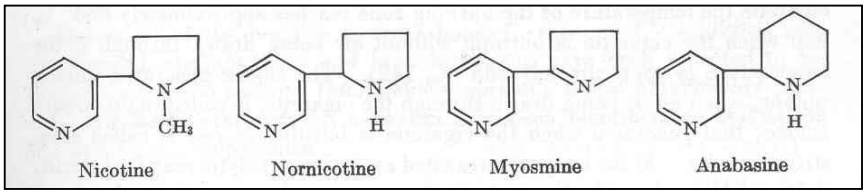
Chemistry of Tobacco

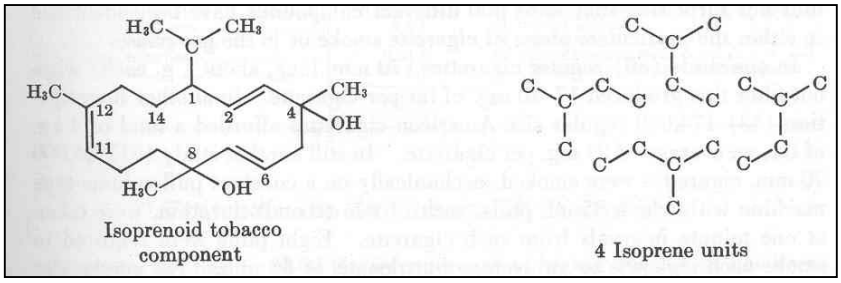
A tobacco leaf contains a complex mixture of chemical components: cellulose products, starches, proteins, sugars, alkaloids, pectic substances, hydrocarbons, phenols, fatty acids, isoprenoids, sterols and inorganic minerals.

Two groups are <u>specific</u> to tobacco:

The alkaloid nicotine and the related companion substances nornicotine, myosmine and anabasine. These nitrogen-containing substances are all basic and hence extractable with acid.



Seven members of a second group of compounds fairly distinctive to tobacco have been isolated and characterised. They are described as isoprenoids.



Composition of smoke-ready Tobacco

Water	12-14 %

<u>In dried tobacco</u>

Cellulose	7-16 %	Starch	2-7 %
Sugar	0-22 %	Ashes(most Ca/K)	9-25 %
Triglycerides	1 %	Organic Acids	7-25 %
Proteins	3.5-20 %	Waxes	2.5-8 %
Nicotine	0.6-5.5 %		

Pectinic Substances, Polyphenoles, Flavones, Carotinoides, etheric Oils, Paraffinans
Sterines : 7-12 %

Composition of tobacco smoke

Tobacco smoke components are distributed between the particulate phase and the vapour (or gas) phase of the smoke aerosol. The following definitions of particulate phase and vapour phase mention a Cambridge filter pad. Cambridge filters are used in smoke analytical procedures. They are glass fibre filters stabilised by an organic binder, manufactured by the Cambridge Filter Corporation, Syracuse, New York.

The filter is 99.9% efficient in trapping aerosol particles larger than 0.1µm in diameter. In general, substances with a molecular weight below about 60 g/mol tend to be predominantly present in the vapour phase and substances with a molecular weight above 200 g/mol tend to be wholly present in the particulate phase.

a) Particulate phase and condensable substances

Definition Particulate Phase

The portion of smoke which is retained on a Cambridge filter pad at room temperature. Substances with MW > 200 g/mol

Cigarette smoke is a heterogeneous mixture of gases, uncondensed vapours and liquid particulate matter.

As it enters the mouth, the smoke is a concentrated aerosol with millions of particles per cubic centimetre. The median size of the particles is about 0.5 micron.

For the purposes of investigating chemical composition and biological properties, smoke is separated into a particulate phase and a gas phase; the gas phase is frequently subdivided into materials which condense at liquid-air temperature and those which do not.

An important factor determining the composition of cigarette smoke is the temperature in the burning zone. While air is being drawn through the cigarette, the temperature of the burning zone reaches approximately 884 °C; when the cigarette is burning without air being drawn through it, the temperature is approximately 835 °C.

Extensive pyrolytic reactions occur at the cited temperatures. Some of the constituents of tobacco are stable enough to distil unchanged, but many others suffer extensive reactions involving oxidation, dehydrogenation, cracking, rearrangement and condensation.

The large number and variety of compounds in tobacco smoke tar recalls the composition of the tar formed by carbonisation of coal, which in many cases is conducted at temperatures lower than those of a burning cigarette.

Compound	µg/Cig.	Compound	µg/Cig.
Nicotine	100-3000	Scopoletin	15-30
Nornicotine	5-150	Other Polyphenols	
Anatabine	5-15	Cyclotenes	40-70
Anabasine	5-12	Quinones	0.5
Other tobacco alkaloids		Solanesol	600-1000
Bipyridils	10-30	Neophytadienes	200-350
n-Hentriacontane	100	Limonene	30-60
Total non-volatile HC	300-400	Other Terpenes	
Naphthalene	2-4	Palmitic Acid	100-150
Naphthalenes	3-6	Stearic Acid	50-75
Phenanthrene	0.2-0.4	Oleic Acid	40-110
Anthracenes	0.05-0.1	Linoleic Acid	150-250
Fluorenes	0.6-1.0	Linolenic Acid	150-250
Pyrenes	0.3-0.5	Lactic Acid	60-80
Fluoranthenes	0.3-0.45	Indole	10-15
Carcinogen PAH	0.1-0.25	Skatole	12-16
Phenol	80-160	Other Indoles	
Other Phenols	60-180	Quinolines	2-4
Catechol	200-400	Other aza-arenes	
Other Catechols	100-200	Benzofuranes	200-300
Other Dihydroxybenzenes	200-400		

Major constituents of the particulate matter of the mainstream smoke of non filtered cigarettes (other than higher Polycyclics)

Carcinogenic Hydrocarbons and Heteorcyclics in Particulate Phase

Benzo[a]pyrene is one of the most potent of all known carcinogens.
Most of the carcinogenic compounds identified in cigarette smoke are not present in the native tobacco leaf but are formed by pyrolysis at the high burning temperature of cigarettes. It appears that the pyrolysis of many organic materials can lead to the formation of components which are carcinogenic to mice. Cigarette paper consists essentially of cellulose. Pyrolysis of cellulose has been shown to produce benzo[a]pyrene.

PAHs	***N-Nitrosamines***
Benz[a]anthracene	N-Nitrosodimethylamine
Benzo[b]fluoranthene	N-Nitrosoethylmethylamine
Benzo[j]fluoranthene	N-Nitrosodiethylamine
Benzo[k]fluoranthene	N-Nitrosopyrrolidine
Benzo[a]pyrene	N-Nitrosodiethanolamine
Dibenz[a,h]anthracene	N-Nitrosoarcosine
Dibenzo[a,i]pyrene	N-Nitrosonornicotine
Dibenzo[a,l]pyrene	4-(Methylnitrosamino)-3-(pyridyl)-1-butanone
Indeno[1,2,3-cd]pyrene	N'-Nitrosoanabasine
5-Methylchrysene	N'-Nitrosamorpholine
Aza-arenes	***Aromatic Amines***
Quinoline	2-Toluidine
Dibenz[a,h]acridine	2-Naphthylamine
Dibenz[a,j]acridine	4-Aminobiphenyl
7H-Dibenzo[c,g]-carbazole	

b) The Gaseous Phase (not condensable)

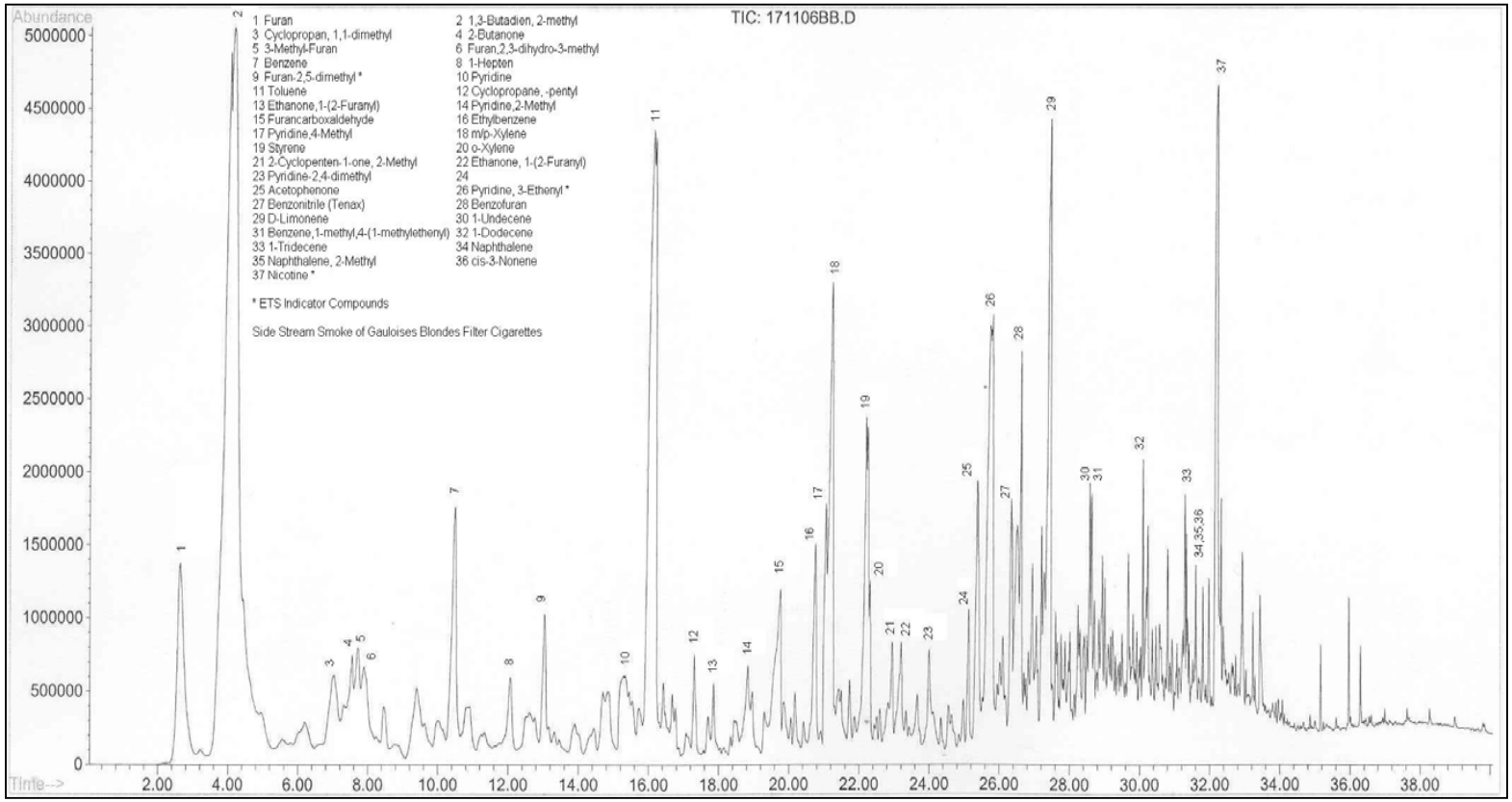
Definition gaseous phase

For the purposes of a generally accepted definition, the portion of smoke that passes through a Cambridge filter pad at room temperature is called the vapour phase. Substances with MW < 60 g/mol

The gas phase accounts for 60 percent of total cigarette smoke.

Compound	Concentration/Cigarette (% of total effluent)	Compound	Concentration/Cigarette (% of total effluent)
Nitrogen	280-120 mg (56-64 %)	Methyl- formate	20-30 µg
Oxygen	50-70 mg (11-14 %)	Other volatile Acids	5-10 µg
Carbon Dioxide	45-65 mg (9-13 %)	Formaldehyde	20-100 µg
Carbon Monoxide	14-23 mg (2-5 %)	Acetaldehyde	400-1400 µg
Water	7-12 mg (1.5–2.5 %)	Acrolein	60-140 µg
Argon	5 mg (1 %)	Other Volatile Aldheydes	80-140 µg
Hydrogen	0.5-1.0 mg	Acetone	100-650 µg
Ammonia	10-130 µg	Other volatile Ketones	50-100 µg
Nitrogen Oxides NOx	100-680 µg	Methanol	80-100 µg
Hydrogen Cyanide	400-500 µg	Other Volatile Alcohols	10-30 µg
Hydrogen Sulfide	20-90 µg	Acetonitrile	100-150 µg
Methane	1.0-2.0 mg	Other Volatile Nitriles	50-80 µg
Other volatile Alkanes	1.0-1.6 mg	Furan	20-40 µg
Volatile Alkenes	0.4-0.5 mg	Other Volatile Furanes	45-125 µg
Isoprene	0.2-0.4 mg	Pyridine	20-200 µg
Butadiene	25-40 µg	Picolines	15-80 µg
Acetylene	20-35 µg	3-Vinylpyridine	7-30 µg
Benzene	6-70 µg	Other volatile Pyridines	20-60 µg
Toluene	5-90 µg	Pyrrole	0.1-10 µg
Styrene	10 µg	Pyrrolidine	10-18 µg
Other aromatic hydrocarbons	15-35 µg	N-Methylpyrrolidine	2.0-3.0 µg
Formic Acid	200-600 µg	Volatile Pyrazines	3.0-8.0 µg
Acetic Acid	300-1700 µg	Methylamine	4-10 µg
Propionic Acid	100-300 µg	Other aliphatic Amines	3-10 µg

Major constituents of the vapour phase of the mainstream smoke of nonfiltered cigarettes



Gaseous phase of side stream smoke sampled on Tenax TA

Chemical composition of tobacco-smoke and its related health risks

A considerable amount of epidemiological research over the past 50 years has shown tobacco smoking to be the cause of a variety of serious diseases such as lung cancer, emphysema, chronic bronchitis and heart disease.

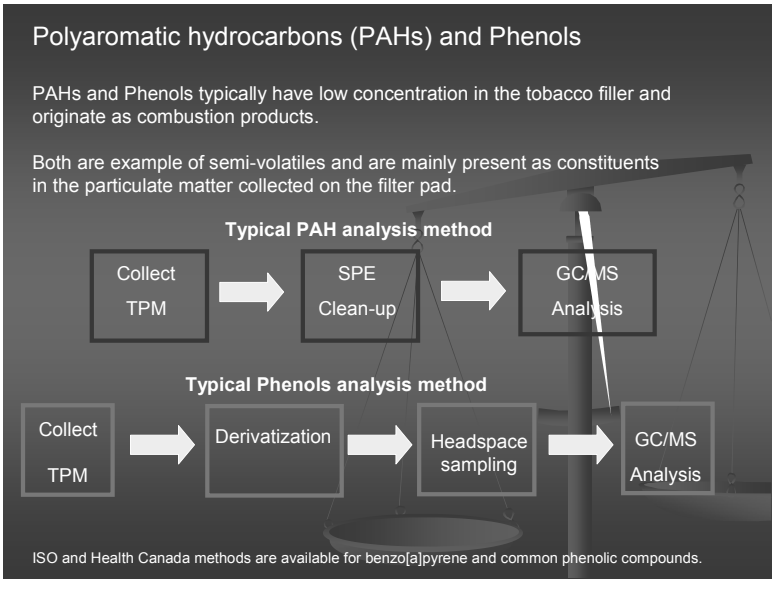
Since the 1950s, the tobacco industry has collaborated with public health bodies to modify cigarettes with the aim to reduce the risks. One crucial element of this work has been the development of a greater understanding of smoke chemistry.

Since Doll and Hill's paper in 1950[20] there have been many attempts to isolate the substances in smoke that may be responsible for the adverse health risks associated with smoking. The earliest substances identified were benzo[a]pyrene (BaP) and other polynuclear aromatic hydrocarbons, which were known to produce tumours in animal experiments.

Benzo[a]pyrene

PAHs are formed by pyrolysis and pyrosynthetic reactions of long-chained hydrocarbons, terpenes, phytosterols such as stigmasterol, paraffins, sugars, amino acids, celluloses and reactions involving primary hydrocarbon radicals. Cigarette paper consists essentially of cellulose. Pyrolysis of cellulose has been shown to produce benzo[a]pyrene.

In the 1950s and 1960s the tobacco industry undertook a considerable amount of work to reduce or eliminate BaP and PAHs in smoke by filtration and various cigarette design modifications, but no method was found to reduce BaP selectively from "tar".



PAHs Analytics

O'Conner, R., Watson, C., Product Testing and Monitoring [26]

Moreover, as analytical techniques advanced, other classes of carcinogens were discovered in smoke. In particular, in the 1960s the presence of nitrosamines in cigarettes came to be regarded by some as a more significant set of carcinogens than BaP and the PAHs.

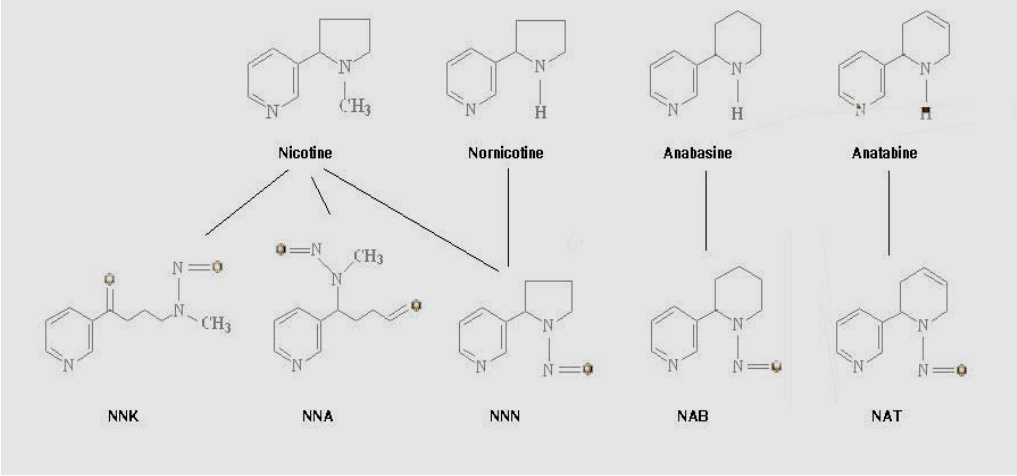
Tobacco specific nitrosamines (TSNA) are only found in tobacco products[21] and they are highly carcinogenic. There is no safe level of exposure to the most potent of the TSNA carcinogens. Besides the TSNA, non-tobacco specific nitrosamines are also formed during the smoking process.

Nitrosamines contain the organic functional group N-N=O, and are formed by the nitrosation (addition of an N=O group) of secondary and tertiary amines. The nitrosating agent is nitrite, derived from tobacco nitrate by the action of bacteria and tobacco enzymes during curing. In tobacco, these amines are nicotine, nornicotine, anabasine, and anatabine (alkaloids).

When tobacco burns during cigarette smoking, the tobacco specific nitrosamines can transfer to smoke and decompose thermally; additional nitrosamines can form pyrosynthetically.

TSNA are created during fermentation, curing and burning of the tobacco leaf.

Chemical formation of TSNA : Nitrosation of tobacco alkaloids to form tobacco specific nitrosamines



Tobacco specific nitrosamines and their carcinogenic rating

Name	Acronym	Carcinogenity
N-nitrosonornicotine	NNN	Group 1 IARC
4-(methylnitrosamino(-1-(3-pyridil)-1-butanone	NNK	Group 1 IARC
4-(methylnitrosamino)-1-(3-pyridyl)-1-butanol	NNAL	
N'-nitrosoanatabine	NAT	Group 3 IARC
N'-nitrosoanabasine	NAB	Group 3 IARC
4-(methylnitrosamino)-4-(3-pyridyl)-1-butanol	NNA	Group 3 IARC
4-(methylbitrosamino)-4-(3-pyridyl)-1-butanol	iso-NNAL	
4-(methylnitrosamino)-4-(3-pyridyl)butyric acid	iso_NNAC	

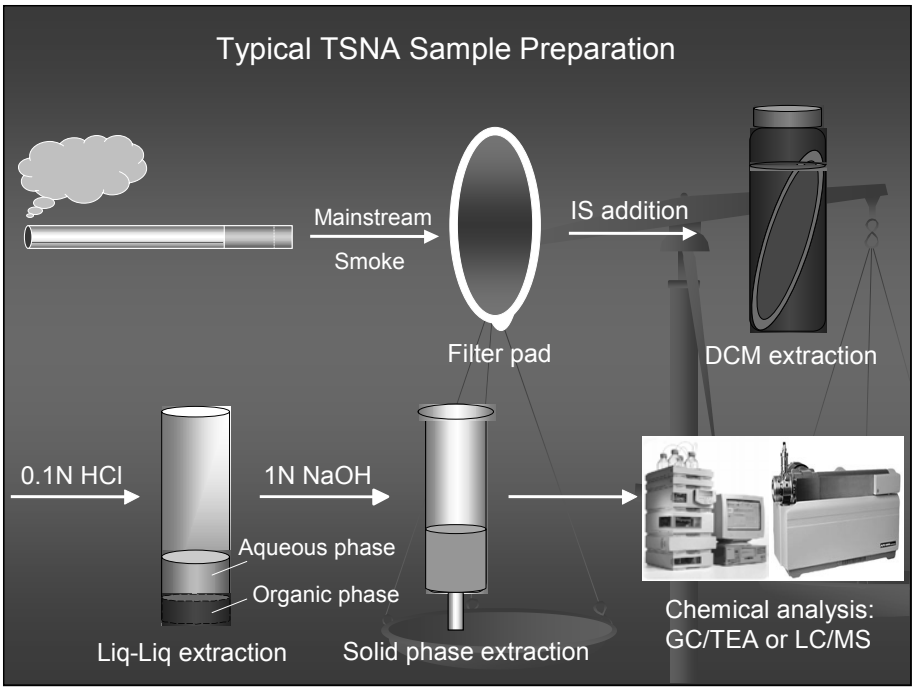
The most comprehensive lists of tobacco smoke constituents relevant to smoking related diseases have been drawn up by Dietrich Hoffmann and co-workers of the American Health Foundation in New York [22]:

Constituent class and examples	Amount/cigarette	Phase	Type of toxicity
PAHs			
Benzo[a]pyrene	ng	P	C
Aza-arenes			
Quinoline	ng	P	C
Heterocyclic compounds			
Nicotine	mg	P	T
Pyridine	µg	P	T
Aromatic Amines			
2-Napthylamine, 4-aminobiphenyl	ng	P	C
N-heterocyclic amines			
Amino pyridoindoles and imidazoles	ng	P	C
N-Nitrosamines			
NNK	ng	P	C
Volatile nitrosamines	ng	V	C
Aldehydes			
Formaldehyde	µg	V	C
Acetaldehyde	µg	V	C
Acrolein	µg	V/P	T
Crotonaldehyde	µg	V/P	T
Volatile Hydrocarbons			
1,3-Butadiene	µg	V	C
Isoprene	µg	V	C
Benzene	µg	V/P	C
Styrene	µg	P	SC
Miscellaneous Organic			

Compounds			
Ethylene Oxide	µg	V	C
Methanol	µg	V	T
Phenol, Catechol	µg	P	TP
Acetamid, Maleic Hydrazide	µg	P	SC
Inorganic Compounds			
CO	mg	V	T
NOx, CS2, HCN, H2S	µg	V	T
Metals (Ni, Cd, Co, Cr, Pb)	ng	P	C

P = Particulate Phase V = Vapour Phase V/P = between Vapour and particulate Phases
C = Carcinogen SC = Suspected Carcinogen T = Toxic TP = Tumour Promotor

TSNA – Analytics



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