FORENSIC TOXICOLOGY:
FROM CRIME SCENE TO VIRTUAL LAB

MODULE 1
CHAPTER 6: Volatile Organic Compounds (VOCs)

FORENSIC SCIENCE | MOVERS AND SHAKERS

Forensic chemist Maiken Ueland examines emissions from human remains

University of Technology Sydney scientist explains how volatile organic compounds from human decomposition can help find victims of crimes and mass disasters

ENVIRONMENT

Scientists search for death's aroma

Identifying the unique volatile compounds emanating from human corpses could aid cadaver searches after natural disasters and in homicide cases

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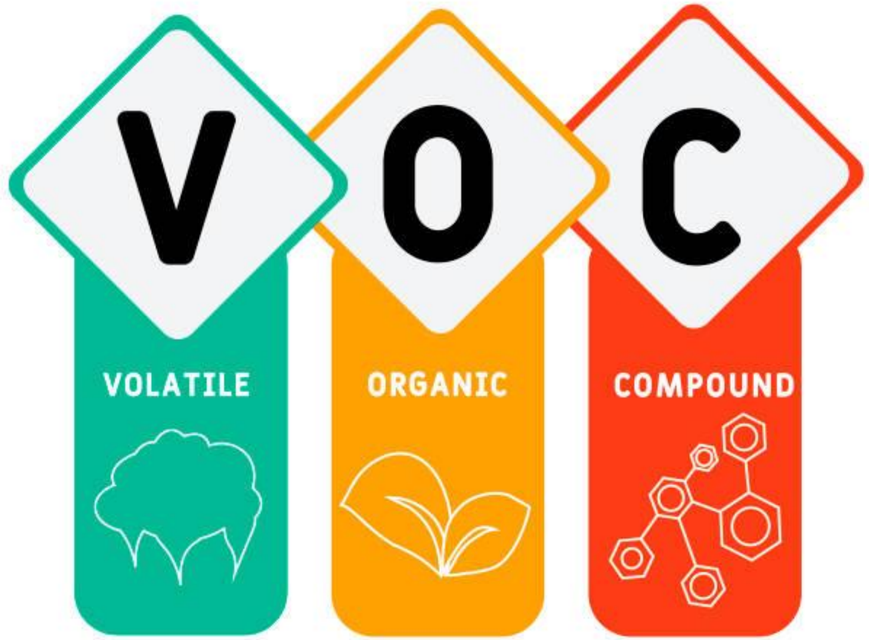
01.

INTRODUCTION

01.

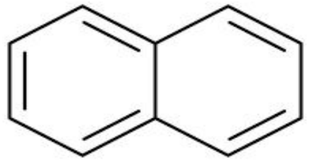
WHAT ARE VOLATILE ORGANIC COMPOUNDS?

- Volatile organic compounds (VOCs) are gases and vapours that are emitted into the air by products or processes
- Some are harmful by themselves, and can cause cancer
- In addition, they can react with other gases and form other air pollutants after they are in the air
- VOCs are also emitted during human decomposition



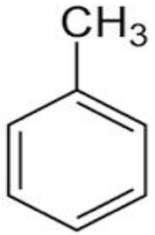
01.

EXAMPLES OF VOCS

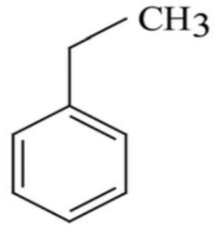


Naphthalene

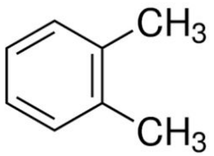
Benzene



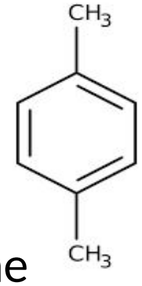
Toluene



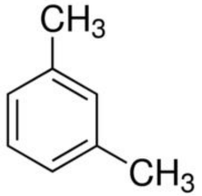
Ethylbenzene



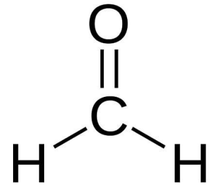
o-xylene



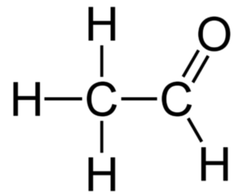
p-xylene



m-xylene



Formaldehyde



Acetaldehyde

02.

SOURCES OF VOCS

02.

SOURCES OF VOCS

Activities

- Tobacco smoke
- Dry-cleaned clothing
- Glues & Permanent markers
- Wood burning stoves
- Office printers and copiers

Building Materials

- Paint
- Varnishes & Finishes
- Caulks & Sealants
- Adhesives
- Flooring & Carpet

Outdoor Sources

- Gasoline
- Diesel emissions
- Wood burning
- Oil and gas extraction and processing
- Industrial emissions

Home & Personal Care

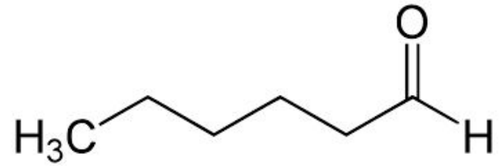
- Cleaners & Disinfectants
- Furniture
- Pesticides
- Air fresheners
- Cosmetics & Deodorants
- Fuel oil, gasoline

02. VOCS FROM DECOMPOSITION

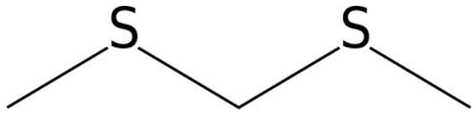
The odor of decomposition is now associated with a **wide range** of VOCs

The most commonly reported VOCs from decomposition odor are **polysulfide compounds** including **dimethyl sulphide** (DMS), **dimethyl disulphide** (DMDS) and **dimethyl trisulfide** (DMTS)

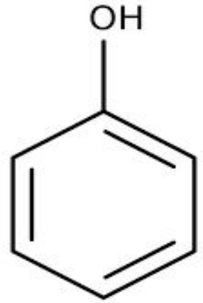
Other common compound classes include **ketones, phenols, indoles,** and **aldehydes**



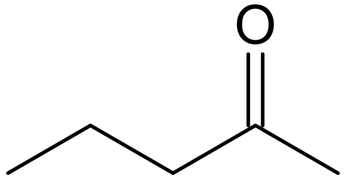
Hexanal



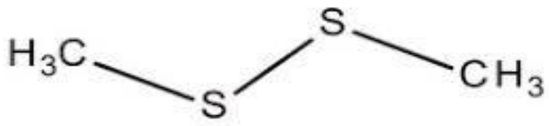
2,4-dithiapentane



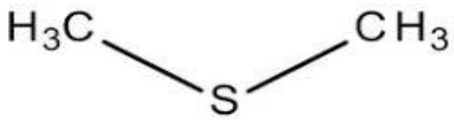
Phenol



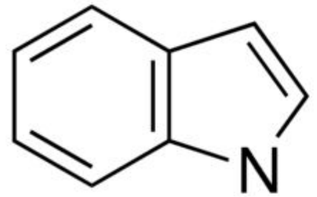
2-pentanone



Dimethyl disulfide



Dimethyl sulphide



Indole

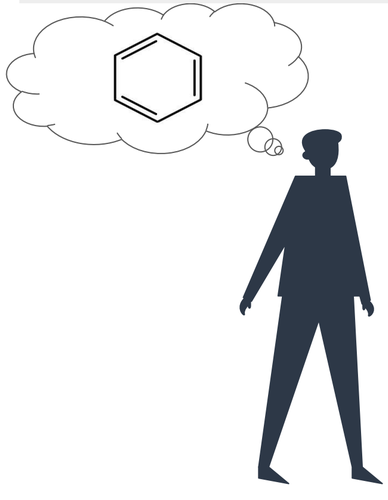
03.

FORENSICS OF VOCS

03.
ABUSE OF VOLATILE ORGANIC COMPOUNDS

A concerning aspect of human exposure to the vapour of volatile substances is the **deliberate self administration** in order to achieve intoxication

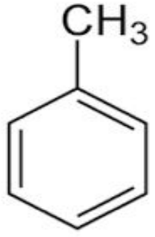
The potential of VOCs to be abused is directly related to their ability to produce **intoxication**

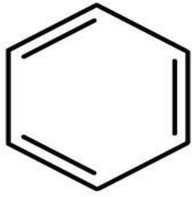


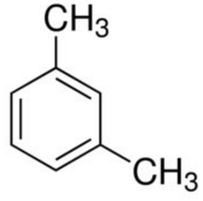
Repeated abuse may result in **psychological dependence** or other harmful effects

If inhaled or ingested in sufficient quantities, many VOCs can produce effects similar to those of **central nervous system depressants** such as ethanol and barbituants

03.
ABUSE OF VOCS







What does it look like?

Many common glues, gases, and aerosols which, when inhaled, can cause harm, including butane gas lighter refills, air fresheners, tubes of glue, and cleaning fluids

How does it feel?

VOCs are depressants, meaning they slow down the brain and body's responses and produce a similar effect to that of alcohol. Effects vary from person to person and depend on the specific VOC used.

How do people take it?

VOCs are often inhaled from a container or holder. It is difficult to control the dose, and could result in fatality. The risk increases if this is done in an enclosed space.

How does it make people behave?

Inhalation of VOCs can cause mood swings, aggressive behaviour, hallucinations, vomiting, and blackouts

03.

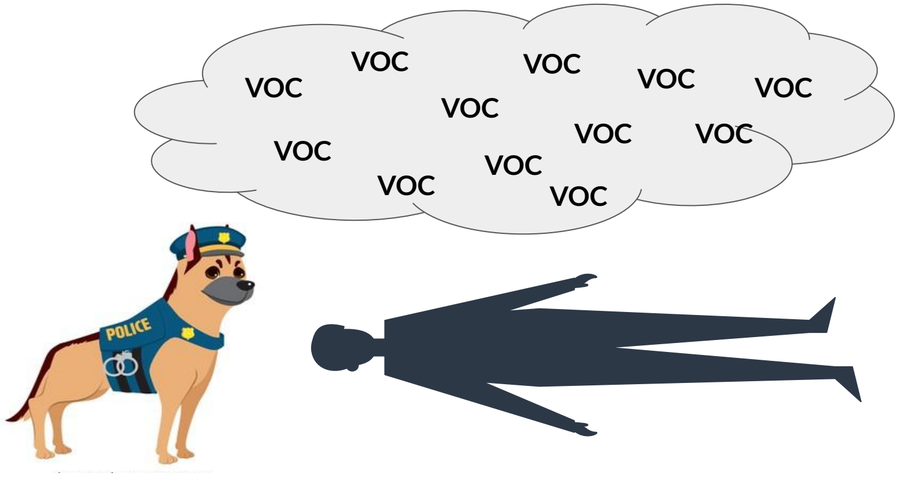
DECOMPOSITION AND VOCS

1

The process of decomposition produces a **variety of chemicals** as soft tissues and their component parts are degraded.

2

These decomposition byproducts include **VOCs** responsible for the **odour** of decomposition



3

Human remains detection (HRD) canines use this **odour signature** to locate human remains during police investigations and recovery missions in the event of a mass disaster

4

Currently, it is **unknown** which **compound**s or **combinations of compounds** are **recognized** by the HRD canines

5

GCxGC-TOFMS has been used to generate a **characteristic profile** of decomposition VOCs across the various stages decomposition.

6

This profile is comprised of numerous chemical families, particularly **alcohols**, **carboxylic acids**, **aromatics** and **sulfides**

04.

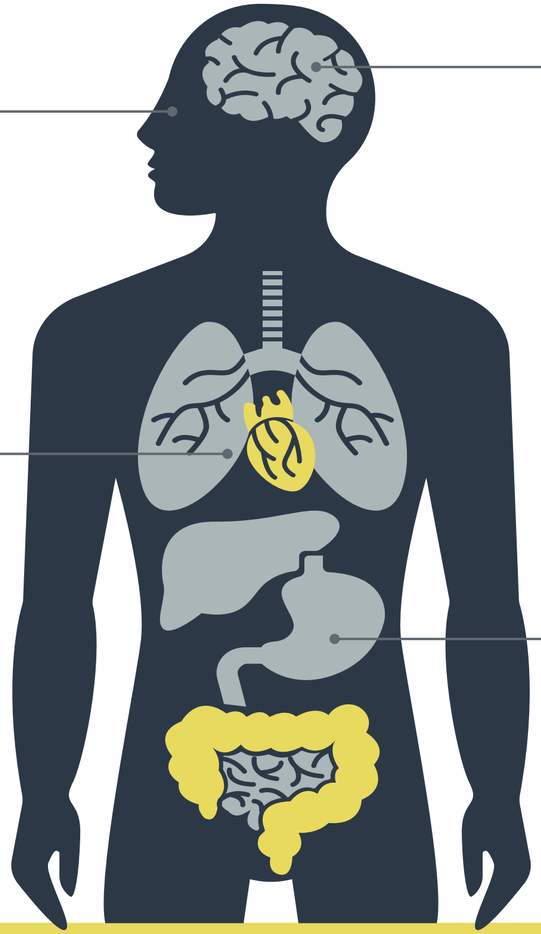
EFFECTS OF VOCS ON THE BODY

04.

SHORT TERM EFFECTS

Eye, nose and throat irritation

Worsening asthma symptoms



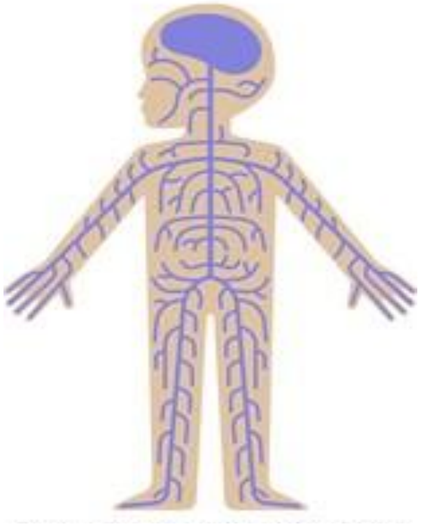
Headaches, dizziness

Nausea and vomiting

04.

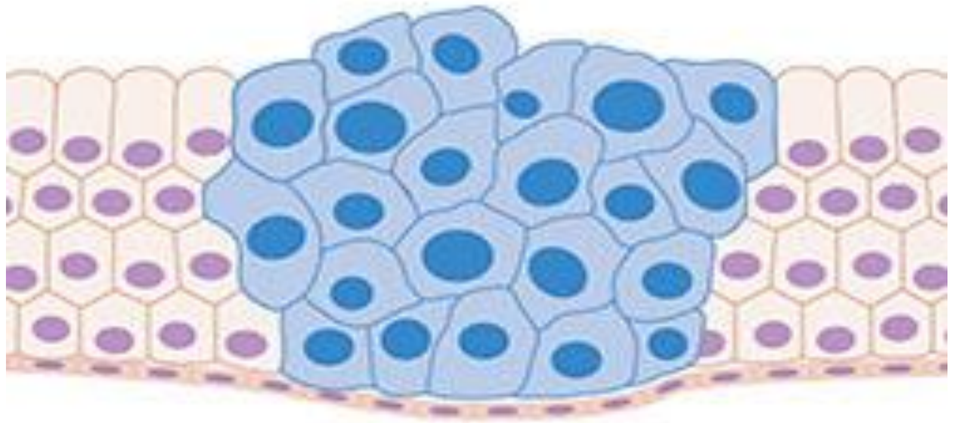
LONG TERM EFFECTS OF VOCS

Chronic exposure (years to a lifetime)



Liver and kidney damage

Central nervous system damage

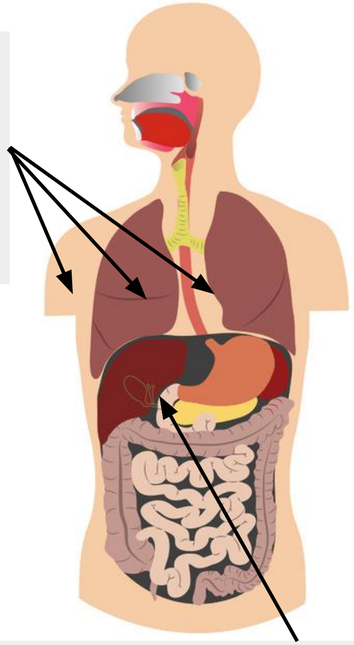


Cancer

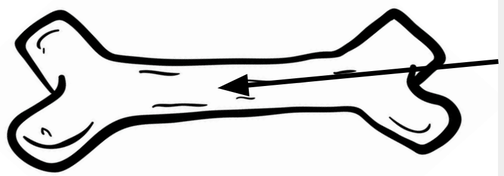
04.

EFFECTS OF BENZENE

Benzene can enter the body through your **lungs**, **GI tract**, and across the **skin**



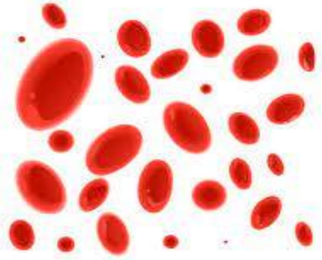
Once in the bloodstream, benzene travels throughout your body and can be temporarily stored in the **bone marrow** and **fat**



Benzene is converted to metabolites in the **liver** and **bone marrow**. Some of the harmful effects of benzene exposure are **caused by** these **metabolites**

Benzene causes cells to not work correctly

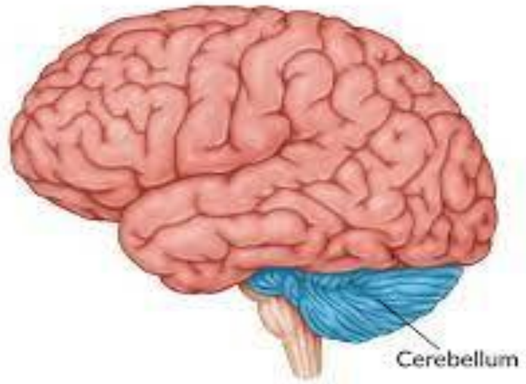
1. It can cause bone marrow not to produce enough **red blood cells**, which can lead to **anemia**



2. It can also damage the **immune system** by changing blood levels of antibodies and causing the **loss** of **white blood cells**

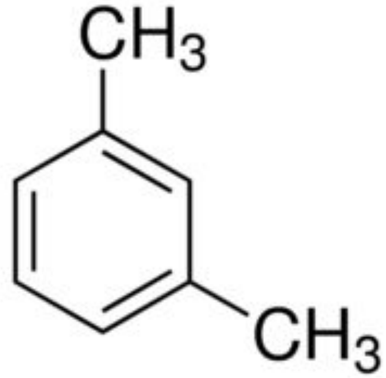
04.

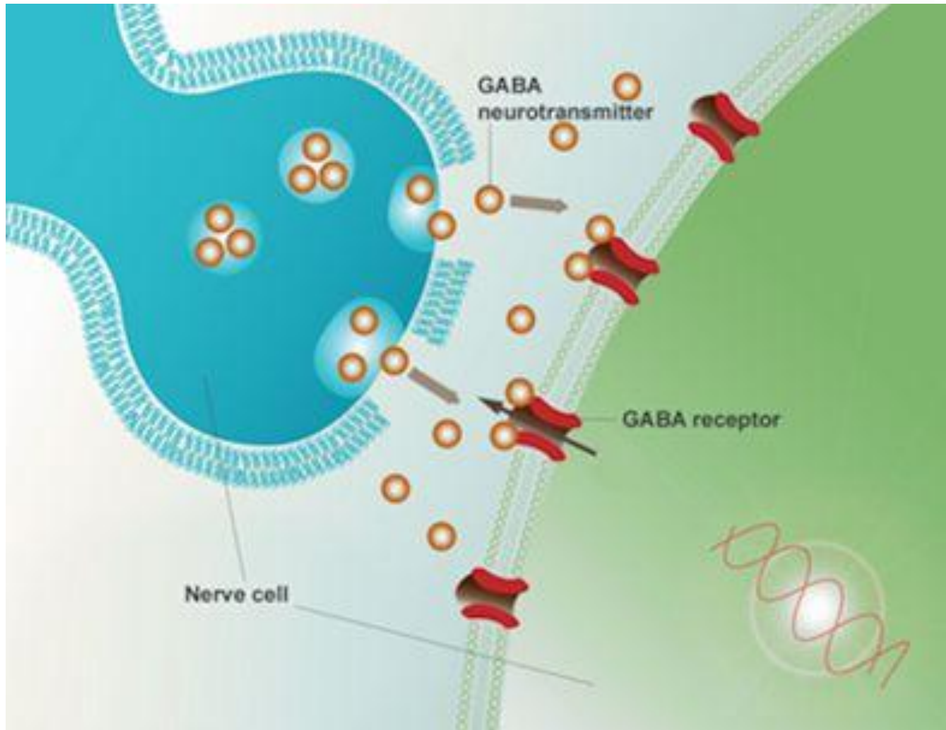
MECHANISMS OF TOXICITY - XYLENE



1. High concentrations of **m-xylene** in the **cerebellum** has been associated with increased GABAα release and/or enhanced GABA receptor function, consequently **increasing the receptor binding activity** of GABAα

2. The increased receptor binding activity of GABAα in the cerebellum is consistent with the **adverse effect** of m-xylene on **motor coordination**

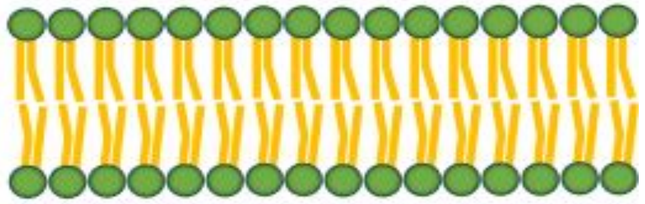




04.

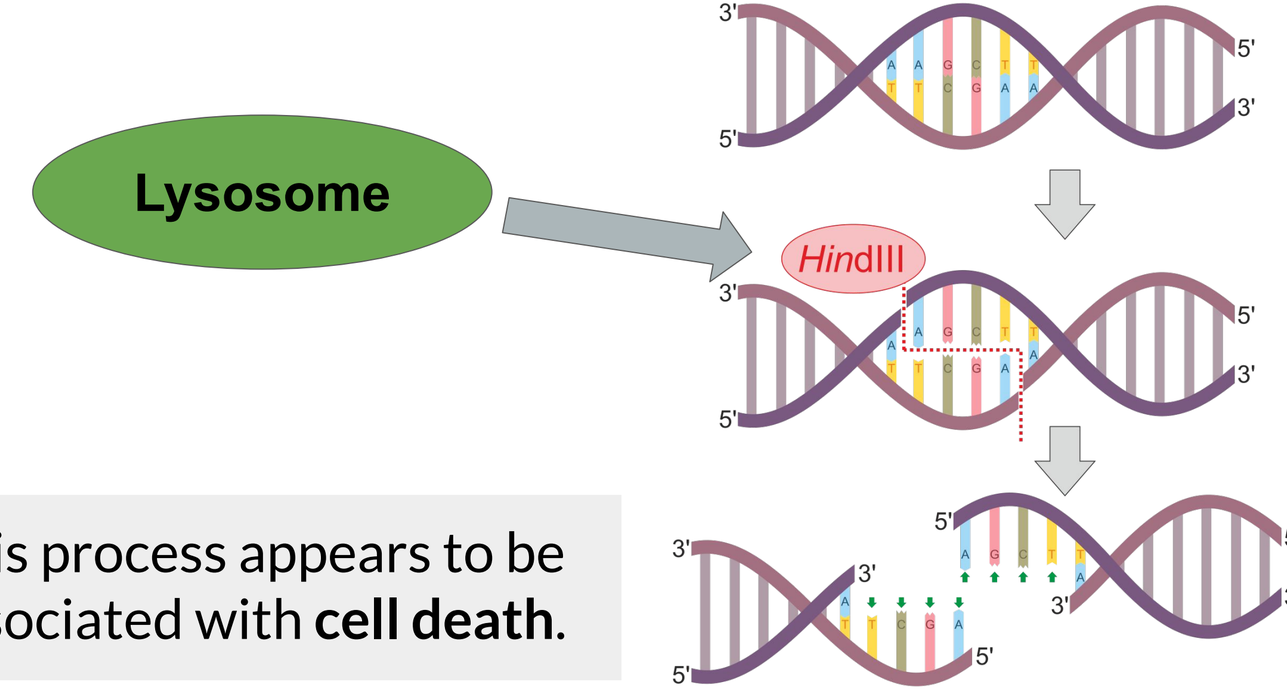
MECHANISMS OF TOXICITY - XYLENE

The **lipophilic** effects of xylene, which **dissolve lipid membranes**, are responsible for the irritant effects on the **eyes, mucous membranes** and **skin**



The lipophilicity of xylene is also responsible for its **narcotic** and **anaesthetic** properties

Xylene may impair the integrity of cell membranes, causing the **release of nucleases** from membrane bound **lysosomal stores**, resulting in the f**ragmentation of DNA.**



This process appears to be associated with **cell death**.

05.

PHARMACOKINETICS OF VOCS

05. PHARMACOKINETICS

Exposure is **NOT** a static process

Internal dose levels change with time depending on many **physical**, **chemical**, and **metabolic** processes

The rate that VOCs enter and leave the body through the lungs is a function of the partitioning of the individual compounds between **lipid** and **aqueous** sites in the body

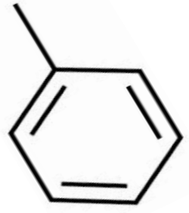
Compounds that are **lipophilic** will be eliminated **quickly**

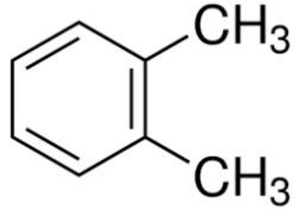
Compounds with **greater lipid solubility** will deposit in fat and be eliminated **slowly**

05.

Pharmacokinetic data of some volatile compounds

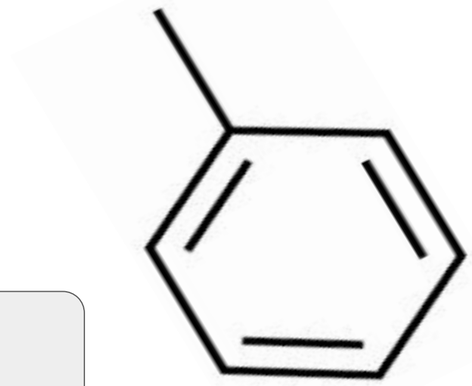
Compound	Inhaled dose absorbed (%)	Proportion absorbed dose eliminated unchanged (%)	Proportion absorbed dose metabolized (%)	Half-life (h)
Benzene	46	12	80	9-24
Toluene	53	<20	80	7.5
Xylene	64	5	>90	20-30



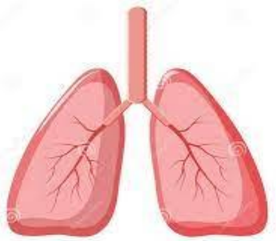


05.

ABSORPTION OF TOLUENE



Nearly 100% of toluene is absorbed following a single oral exposure



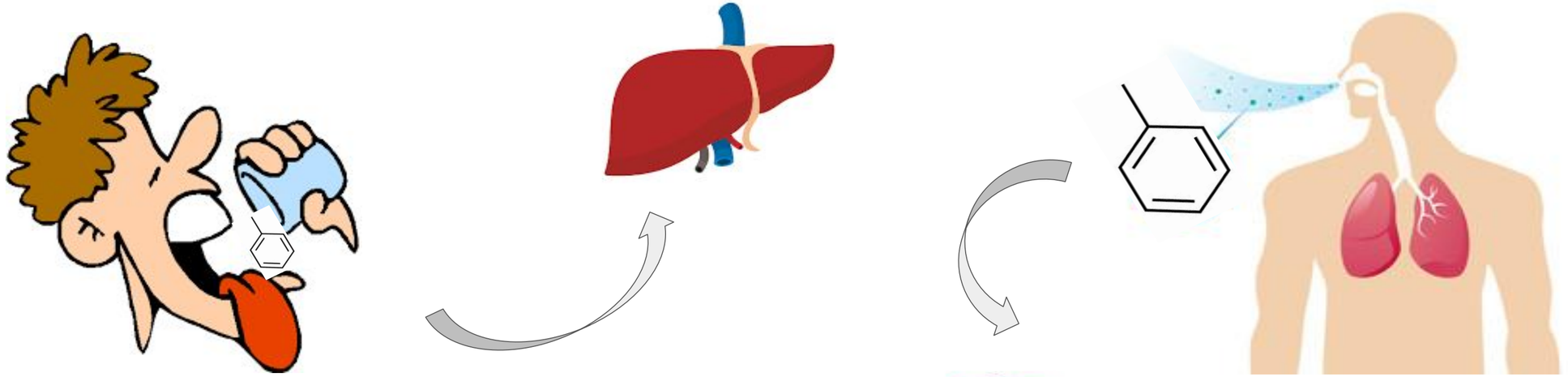
Studies have reported an average uptake (percent inspired air) of about 55% in subjects exposed to 300 mg/m3 for 2 hours, and the value dropped to 50% during the next 2 hours of exposure at rest

Toluene is absorbed slowly through the skin, with absorption rates ranging from 14 to 23 mg/cm3 per hour

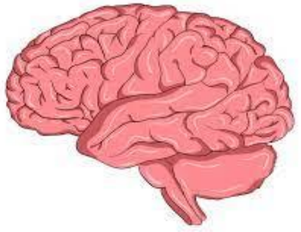
05.

DISTRIBUTION OF TOLUENE

Toluene that is absorbed into the blood is distributed throughout the body



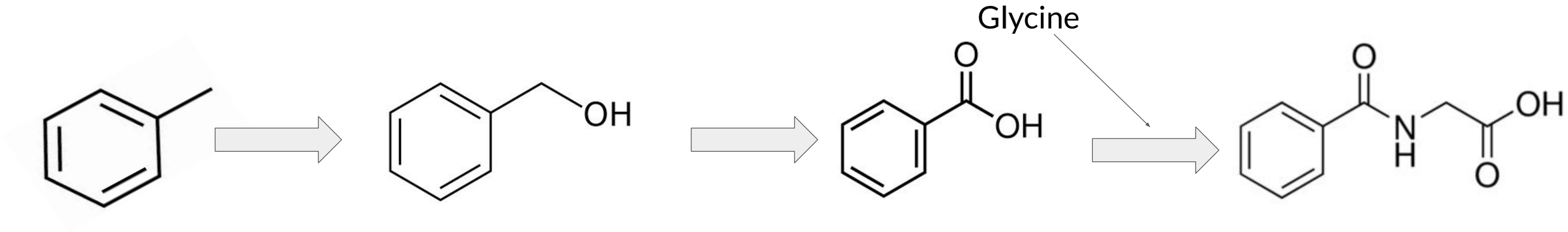
Following **oral exposure**, the **liver** contains the greatest concentrations of toluene



More toluene accumulates in the **brain** than the liver following **inhalation exposure**

05.

METABOLISM OF TOLUENE



Toluene

Benzyl alcohol

Benzoic acid

Hippuric acid

1

The primary route of **toluene** metabolism begins with the **hydroxylation** of the methyl group to form **benzyl alcohol**

2

Benzyl alcohol is then **oxidized** to **benzoic acid**

3

Finally, **benzoic acid** is conjugated with **glycine** to form **hippuric acid**

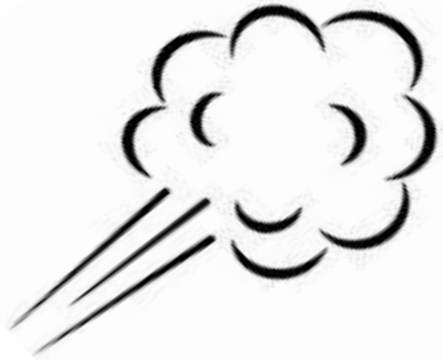
06.

VOCS IN BIOLOGICAL FLUIDS

06. ELIMINATION OF TOLUENE

The release of toluene from the **adipose tissue** has a half-life of **80 hrs**, meaning toluene can be detected in the blood up to **two weeks** following exposure

The **majority** of toluene in the body is eliminated in the **urine**, mainly as metabolites



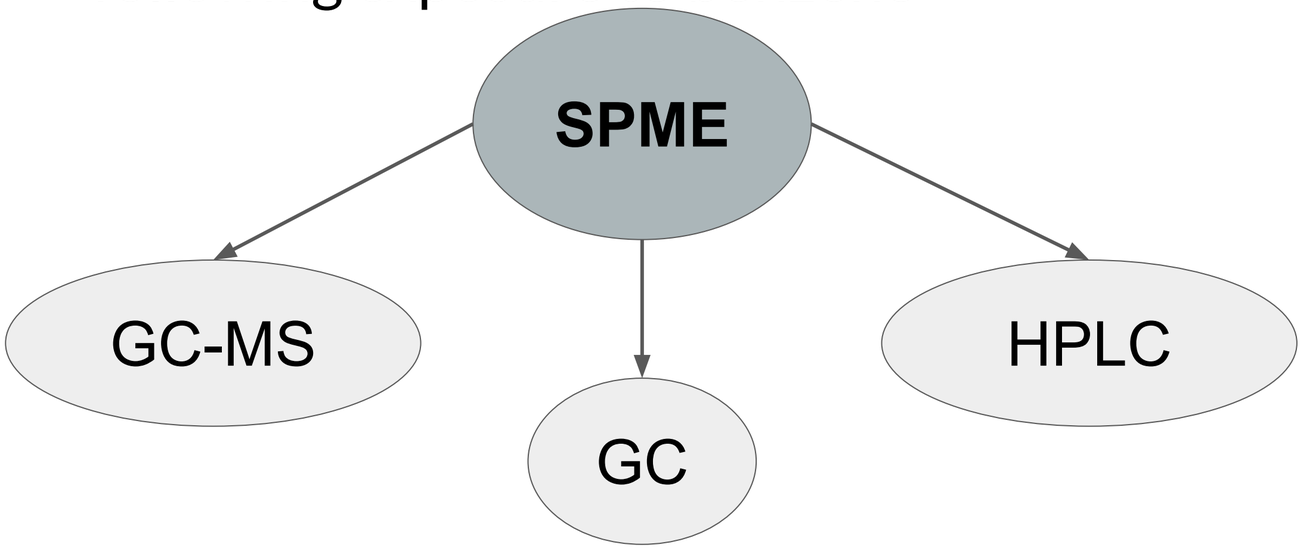
A lesser, but significant amount of inhaled toluene is removed in **expired air**

Elimination from the blood is rapid with three-phase elimination half times of **3, 40,** and **738 min** following a **single inhalation exposure**

06.

DETECTION OF BENZENE USING IN BLOOD AND URINE

Benzene and its major metabolite phenol can be detected in the blood and the urine following exposure to benzene



LOD (ng / 0.5 mL)

Blood	Urine
Benzene = 5	Benzene = 2
Phenol = 10	Phenol = 5

The limit of detection for benzene and phenol using SPME-GC is **lower in urine** than blood

Benzene and **phenol** can be extracted from blood and urine using headspace **solid-phase microextraction** (SPME), and are analyzed using **gas chromatography** (GC), **high-performance liquid chromatography** (HPLC), and **gas chromatography-mass spectrometry** (GC-MS)

06.

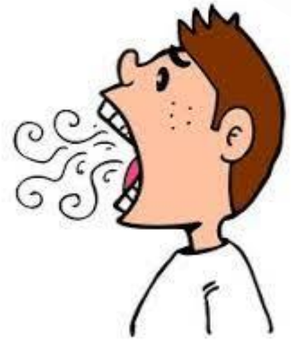
METHODS TO DETECT, IDENTIFY, AND QUANTIFY VOCS

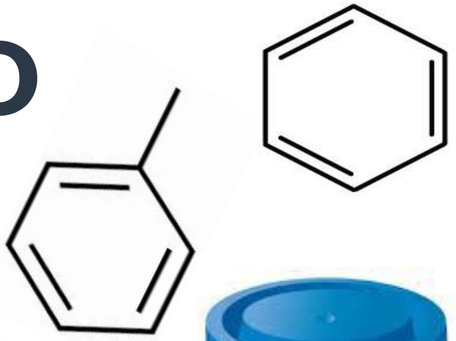
FID
Flame Ionization Detector

ECD
Electron Capture Detector

MS
Mass Spectrometry

GC



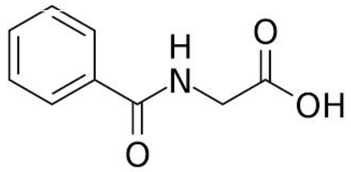


Gas chromatography (GC) can be paired with one of three detectors to **detect, quantify,** and **identify** volatile organic compounds in **biological samples,** mainly the blood, breath, and urine

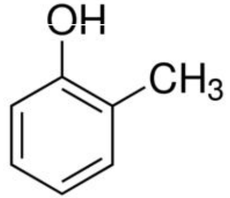
06. DETECTION OF TOLUENE

Measurements of toluene in blood and exhaled air provide evidence of **toluene exposure**

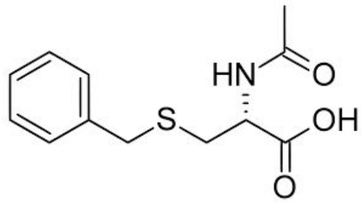
Toluene and its **metabolites** in the urine can also be used to monitor toluene exposure



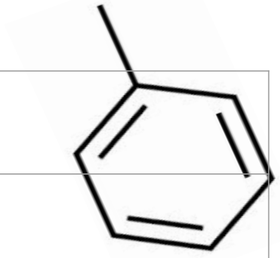
Hippuric acid



***o*-cresol**



Benzylmercapturic acid



Sample Matrix	Method
Blood (toluene)	GC
Breath (toluene)	GC/FID
Urine (toluene)	GC/FID, HPLC, 1H NMR
Urine (Hippuric acid)	HPLC/UV
Urine (*o*-cresol)	HPLC/UV
Urine (Benzylmercapturic acid)	HPLC/FI

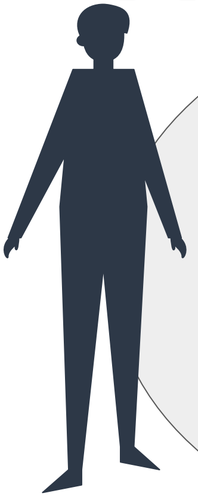
There are a variety of methods used to detect toluene and its metabolites in biological matrices

07.

CANLII CASE STUDY

07.

WORKPLACE SAFETY AND INSURANCE APPEALS TRIBUNAL DECISION NO. 887/17



Issue

The worker seeks entitlement for **myelodysplastic syndrome (MDS)**

Background

The worker, a heavy equipment operator, was **diagnosed with MDS** in 2005 at 73 years old. His previous claim of entitlement for his MDS condition was denied. He claimed this condition was a **result of workplace exposure.** The worker passed away in March 2013 as a **result of MDS.** The current appeal is initiated by a representative

Initial Findings:

1. There is **some evidence** of correlation between exposure to **diesel exhaust** and the **development of MDS.**
2. **Benzene** is the component identified as being associated with the development of MDS

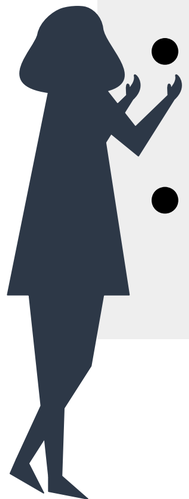
07.

EXPERT REPORT

Dr. Verma gave a report regarding the claim that the worker's MDS was a result of workplace exposure

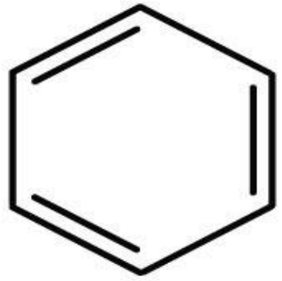
Main Points:

- **Unable** to find a mortality or morbidity study specifically dealing with **heavy equipment operators** and **MDS**
- **Benzene** levels in **diesel fuel** are quite **low**, ranging from 0.006 to 0.02%
- The worker's exposure was likely 0.005 ppm, about **1/50th** of the level associated with **increased risk of MDS**
- No known cause of MDS, but **risk factors** include **smoking**, and the worker smoked for **25 years**



07.

OUTCOME



It was concluded that the worker **does not have entitlement** for MDS. Dr. Verma's report was heavily relied upon, and this report indicates a **lack of evidence** to support a relationship between the worker's occupation and the development of MDS. The worker's workplace exposure to **benzene** was **very minimal** as compared to what would lead to the development of MDS.

08.

LIST OF REFERENCES

08.

REFERENCES

1. Scientists search for death's aroma
2. Forensic chemist Maiken Ueland examines emissions from human remains
3. Volatile Organic Compounds | American Lung Association
4. Odor of Death: An Overview of Current Knowledge on Characterization and Applications | BioScience | Oxford Academic
5. VOLATILE SUBSTANCE ABUSE
6. Glues, gases and aerosols | Effects and Risks | FRANK
7. Analysis of the Volatile Organic Compounds Produced by the Decomposition of Pig Carcasses and Human Remains
8. Volatile Organic Compounds (VOCs) in Your Home - EH: Minnesota Department of Health
9. TOXICOLOGICAL PROFILE FOR BENZENE
10. Facts About Benzene
11. TOXICOLOGICAL PROFILE FOR XYLENE
12. Gamma-aminobutyric acid (GABA) - JMol version
13. Nuclease - Wikipedia
14. Measurement of volatile organic compounds in human blood. | Environmental Health Perspectives | Vol. 104, No. suppl 5
15. VOLATILE SUBSTANCE ABUSE
16. TOLUENE
17. Determination of Benzene and Phenol in Body Fluids by Headspace Solid-Phase Microextraction（SPME）and Capillary Gas Chromatography
18. Volatile Organic Compounds (VOC) Analysis | Thermo Fisher Scientific - US
19. Toxicological Profile for Toluene
20. Decision No. 887/17, 2018 ONWSIAT 718 (CanLII)