Background Information on Persistent Organic Pollutants

Presented

at the

Training Workshop on Safe and Effective Inventory of PCBs and PCBs-containing Electrical Equipment in Power Installations

Held at

Rapha Hotel Limited, Umuahia Abia State

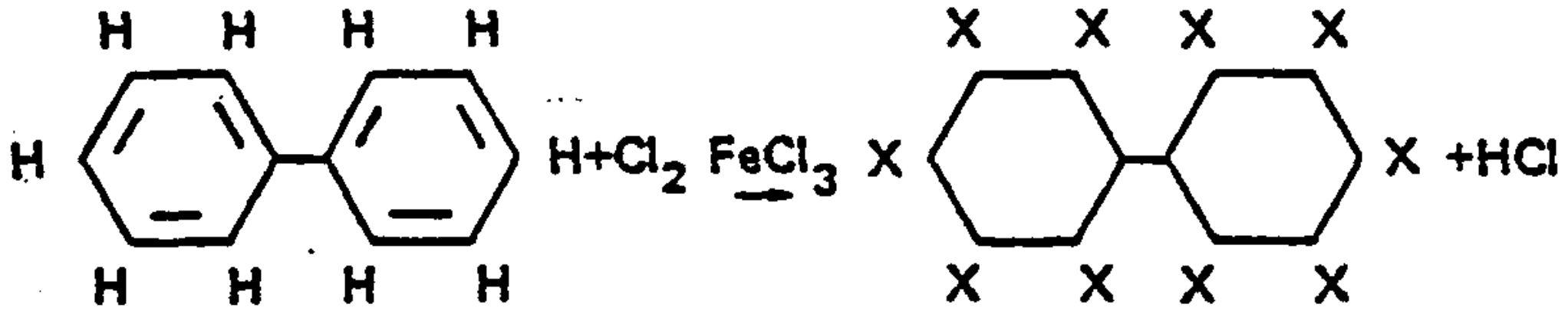
(Wednesday, 6th to Friday, 8th October 2021)

Presentation Highlights

- Introduction
- The Use of Dielectrics in Electrical Equipment
- Applications of PCBs as a Dielectric Fluid in Electrical Equipment
- PCBs Exposure Risks
- PCBs Exposure Risks Control Actions

Introduction

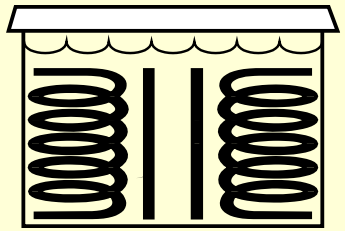
- Polychlorinated biphenyls (PCBs) are a class of aromatic chemical compounds, in which some or all hydrogen atoms attached to the biphenyl ring are substituted by chlorine atoms.
- PCBs, as a group, was discovered in the late 1800s and became prevalent in the late 1920s as its technical benefits were recognised. Its commercial production rose from 1930s to 1980s.
- The general chemical formula for PCBs is $C_{12}H_{10-n}Cl_n$, in which "n" is the number of hydrogen substituted with chlorine. 1 to all 10 of the hydrogen atoms can be replaced with chlorines.
- PCBs can be categorized based on degrees of chlorination in 10 homologue groups, ranging from monochlorobiphenyls to decachlorobiphenyls.
- More than 60% of the PCBs are tetra- to hexachlorophenyls.



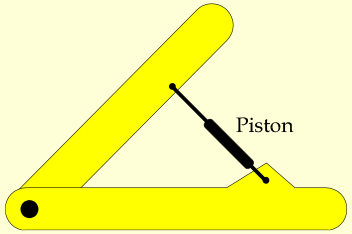
Synthesis of Polychlorinated biphenyls

Introduction (Cont'd)

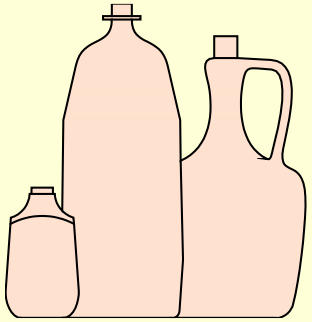
- PCBs are mixtures of individual isomers in which the chlorine content is between 21 and 68%.
- In theory there are 209 PCB congeners, although only about 130 have been found in commercial PCB formulations (Holoubek, 2000).
- PCB formulations are therefore 'cocktails of congeners', processed based on the manufacturers' 'recipes'.
- They do not react with both acids and alkalis and are relatively heat-stable, oil-miscible, water-immiscible, have high boiling point, low flammability and good insulating properties.
- These unique properties have made PCBs to be accepted for multipurpose industrial and chemical applications, for about a century.



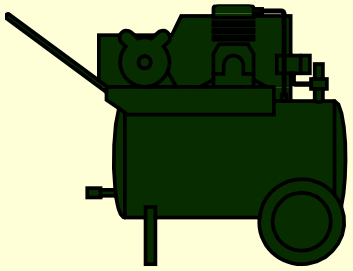
Coolants in Transformers



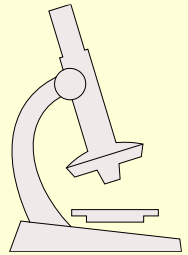
Hydraulic fluid



Plasticizer

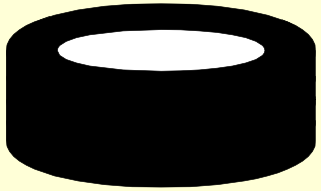


Vacuum pump fluid

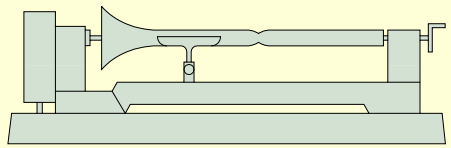


Microscopy

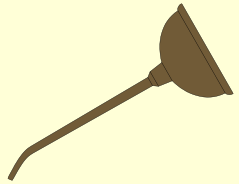
(mounting media & immersion oil)



Gaskets & Damping felt

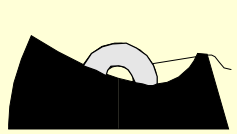


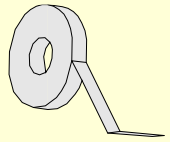
Cutting oils



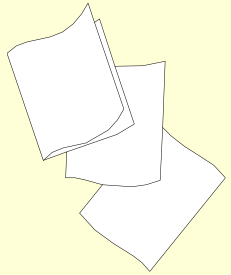
Lubricants

Some Applications of PCBs

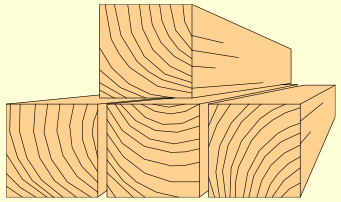




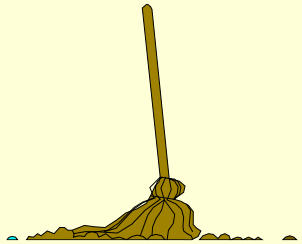
Adhesives



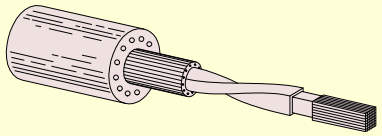
Carbonless copy paper



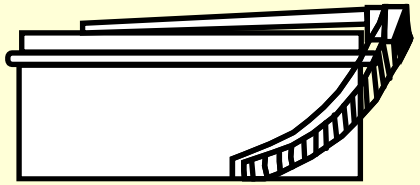
Construction materials



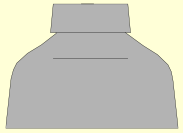
Dedusting Agents

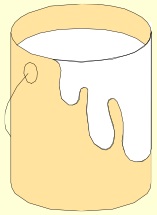


Electric cable insulation

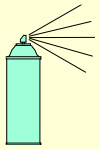


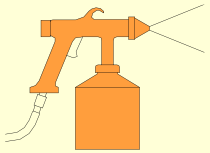
Fuel tank coatings



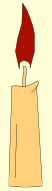


Inks and paint pigments





Pesticide extenders



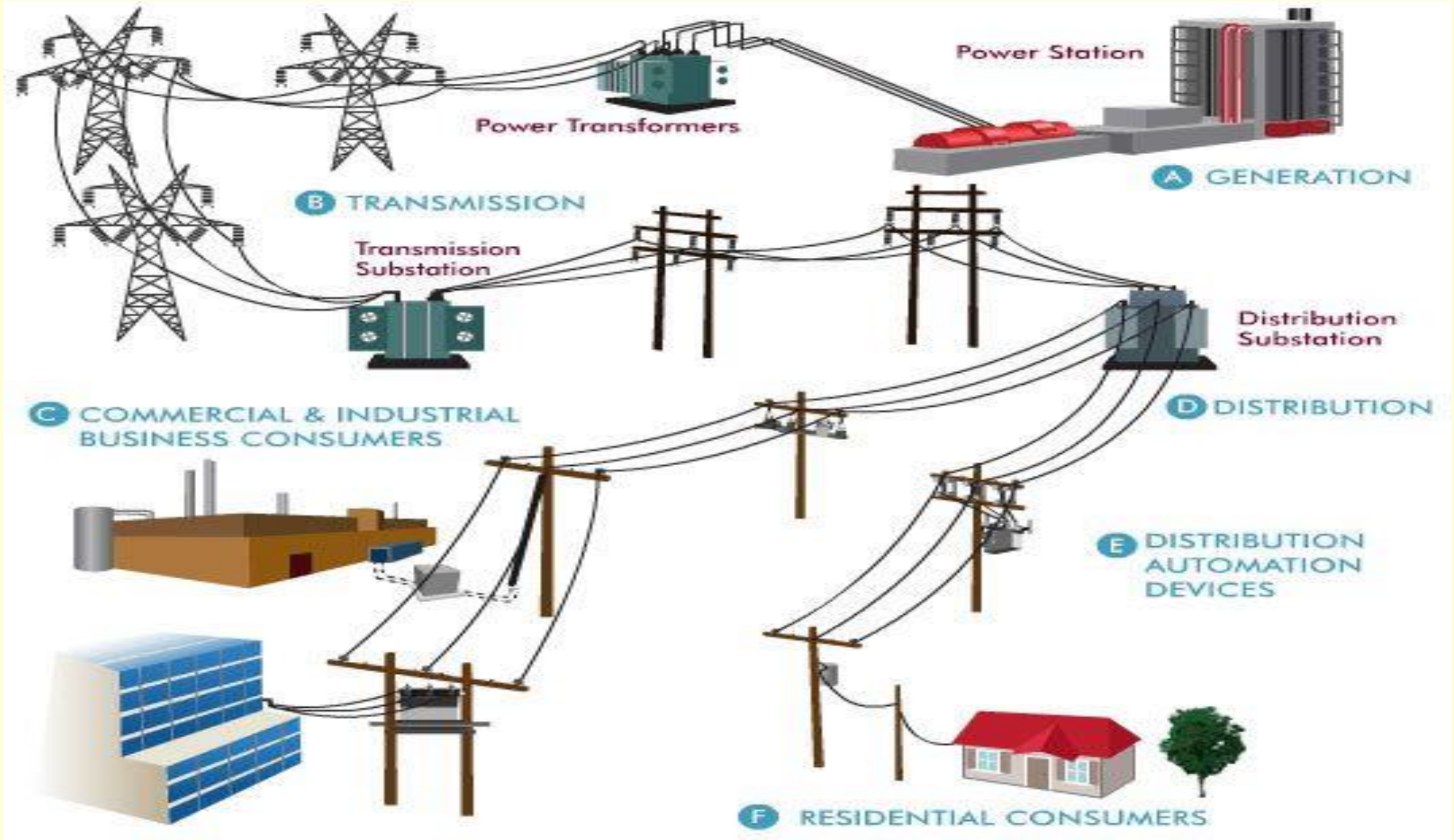
Casting Wax

Some Applications of PCBs

Application of PCBs in the Power Sector

The Use of Dielectrics in Electrical Equipment

- Electrical equipment such as transformers, capacitors and switchgears contain a great deal of current-carrying wires, which resistances are directly proportional to their lengths.
- Due to resistances in the current-carrying wires, substantial amount of electrical energy, in the range of 0.3 to 0.6 percent of the load on the transformer (for example) is lost.
- This energy loss (including eddy current) manifests as heat, which if not cooled or removed, could lead to the burning of electrical insulation or the wire windings could short circuit and melt.
- An electrical transformer must be kept cool using an efficient dielectric material, to guarantee their efficient performances and integrities, best achieved at lower temperatures and less energy losses.



Typical Electric Power Supply System
Source: Electrical Technology, 2020

A Distribution Substation
Source: Edvard Csanyi, 2021

Transformer Main Parts

1. Three-limb core
2. LV Winding
3. HV Winding
4. Tapped Winding
5. Tap Leads
6. LV Bushings
7. HV Bushings
8. Clamping Frame
9. On-Load Tap Changer
10. Motor Drive
11. Tank
12. Conservator
13. Radiators

Source: Pinterest, 2021

The Use of Dielectrics in Electrical Equipment (cont'd)

- The primary function of the dielectric material is to absorb the heat produced in the windings and core, transfer the heat to cooling fins and provide electrical insulation within the transformer or any other electrical equipment.
- **The ideal fluid must have good thermal stability (high boiling point, heat capacity, noninflammability, etc), chemical stability (low solvency, non-corrosive, low degradability, etc), poor electrical conductivity (resistance to corona effect), low toxicity, low cost and readily available.**
- Dielectrics can be vacuum, liquid, solids or gases
- **In the past, the dielectric that closely met the foregoing requirements was the one containing polychlorinated biphenyls, also known as chlorinated biphenyls, chlorinated diphenyls, chlorobiphenyls or polychlorobiphenyls.**

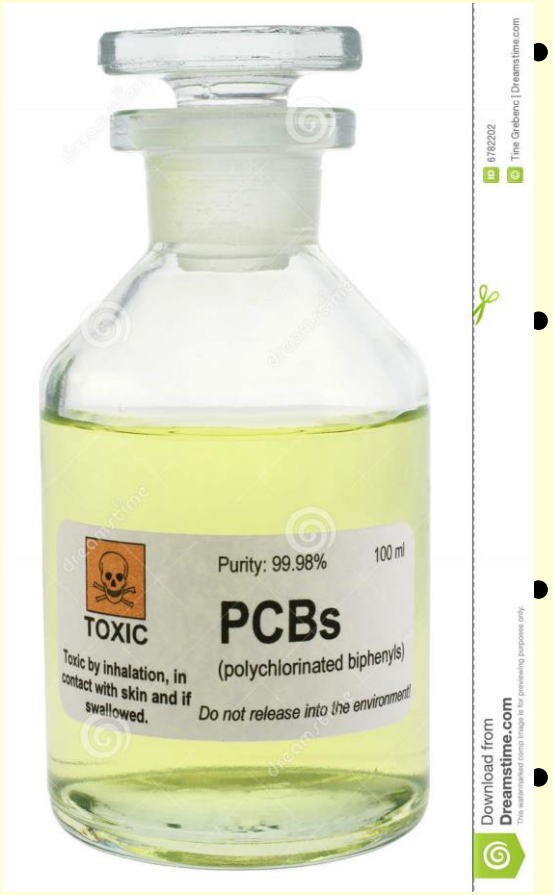
Application of PCBs As Dielectric Fluid In Electrical Equipment

- As indicated in slide 13, PCBs largely meet requirements for a good dielectric material; namely: thermal stability, chemical stability, poor electrical conductivity, cost-effectiveness, availability, except that they are highly toxic.
- Registered trade names for some commercial brands of PCBs include Aroclor, Chlorinol, Askarel, Dykanol, Pyranol (USA), Pyralene (France), Clophen (Germany), Kannechlor (Japan), Delor (Czechoslovakia), Sovol, Trichlorobiphenyls, Sovtol (USSR), among others.
- Items of electrical equipment filled with PCBs as liquid dielectric are ubiquitous, in almost all sectors of human endeavours, namely: Electricity Installations, Industries, Public Utilities, Commercial Facilities, Institutional facilities, among others.
- Nevertheless, the physical and chemical properties that have made PCBs valuable commercially/industrially also make them detrimental to the environment and public health.

PCBs Exposure Risks

- PCBs exposure risks to human health and the environment may arise from unintentional production of PCBs in certain Chemical Process Industries, use, storage of legacy stock , transportation and disposal of PCBs, PCBs-containing-equipment, cross-contaminated equipment, among others.
- Due to an ineffective stewardship, booming activities of the informal sector have led to rising cases of illicit uses of PCBs as ‘miracle oil’ for the cure of arthritis, cosmetic treatment of bodies for soft and bleaching effects and hair conditioner, welding coolant, as well as, illicit additive for the adulteration of cooking oils.

PCBs Exposure Risks (Cont'd)



- It is estimated that over 90% of these transformers are contaminated to levels less than 50 parts per million (ppm) (APARG, 1995).
- The source of this contamination is lack of segregation or cross-contamination of PCBs-lean transformers during retrofilling.
- The permissible level of PCBs in a dielectric fluid is 50ppm.
- The following slide shows classification of transformer oil, based on PCBs concentration.

PCB Level Classification

PCB content levels mg/kg	PCB level	PCB levels, common names
< 1	0	PCB-free material
1 – 10	1	Non-PCB material
11 – 20	2	Non-PCB material
21 – 50	3	Non-PCB material
51 – 500	4	PCB-contaminated material
> 500	5	PCB material

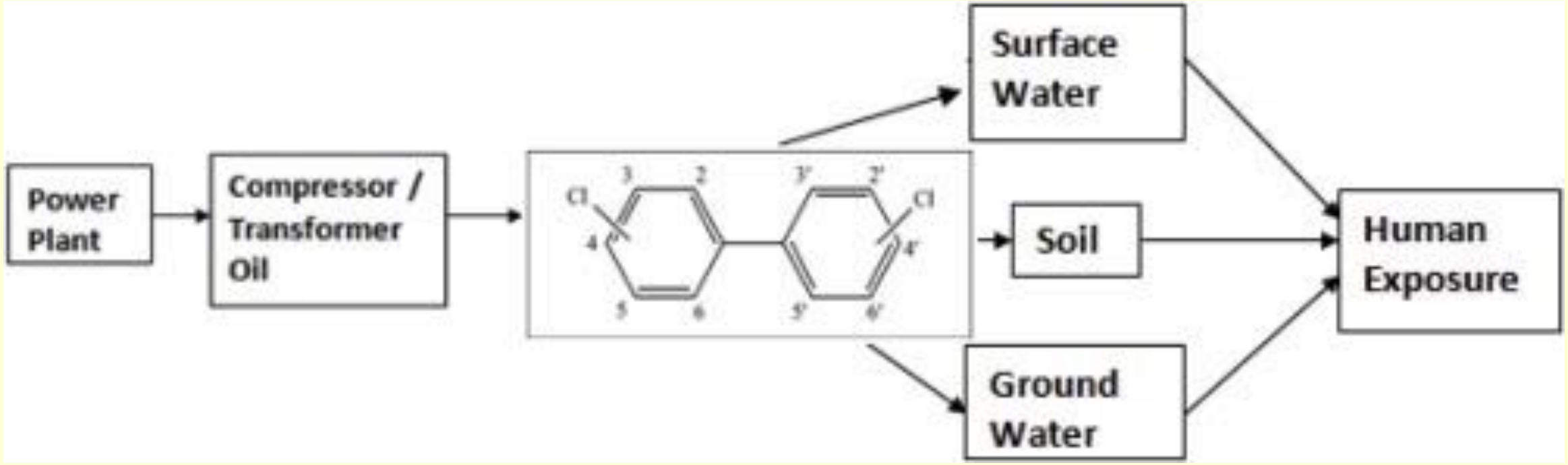
Source: Eskom, 2018

PCBs Exposure Risks (Cont'd)

- These PCBs hotspots are associated with detrimental environmental and public health exposure risk, typical of Persistent Organic Pollutants (POPs).
- PCBs remains a toxic legacy to the environment and our health and everyone is likely to have PCB quantities in his or her body (adapted from UN Environment, 2003).
- Human exposure to PCBs can occur as a result of environmental conditions (PCBs spills, PCBs in air), nutrition (eating contaminated food, use of contaminated waterbodies for irrigation or domestic chores), occupation (handling PCBs-dielectric or contaminated items, workplace safety issues), etc.
- It is estimated that over 90 % of these transformers are contaminated to levels less than 50 parts per million (ppm) (APARG, 1995). The source of this contamination is dearth of segregation or cross-contamination of PCBs-lean transformers during retrofilling.

PCBs Exposure Risks (Cont'd)

- A large number of scientific investigations have revealed dangerous effects of PCBs on the environment and human health, due to its toxicity, persistence and tendency to bioaccumulate, biomagnify and be transported globally.
- PCBs can settle in the fatty tissue and liver of the humans and animals, to manifest in cancers, some skin diseases, damage to reproductive, neurological and immune systems, fatigue, headaches, thyroid problems, increased risk for type 2 diabetes, among others.



PCBs Exposure Route

IMPACTS OF PCBs ON HUMAN HEALTH

Liver disorders

Elevation of serum triglycerides,
Induction of mixed function oxidases

Failure of reproduction

Reduced sperm counts, accumulation in breast milk, neurobehavioral deficits in newborns, conception rates, reduced birth weight

Risk of Cancers

Every commercial PCB mixture tested caused cancer,
Increases in rare liver cancers and malignant melanoma

Hormone system

Several PCB metabolites induce gene mutations, chromosome breaks, chromosome loss and polyploidization in cells in culture.

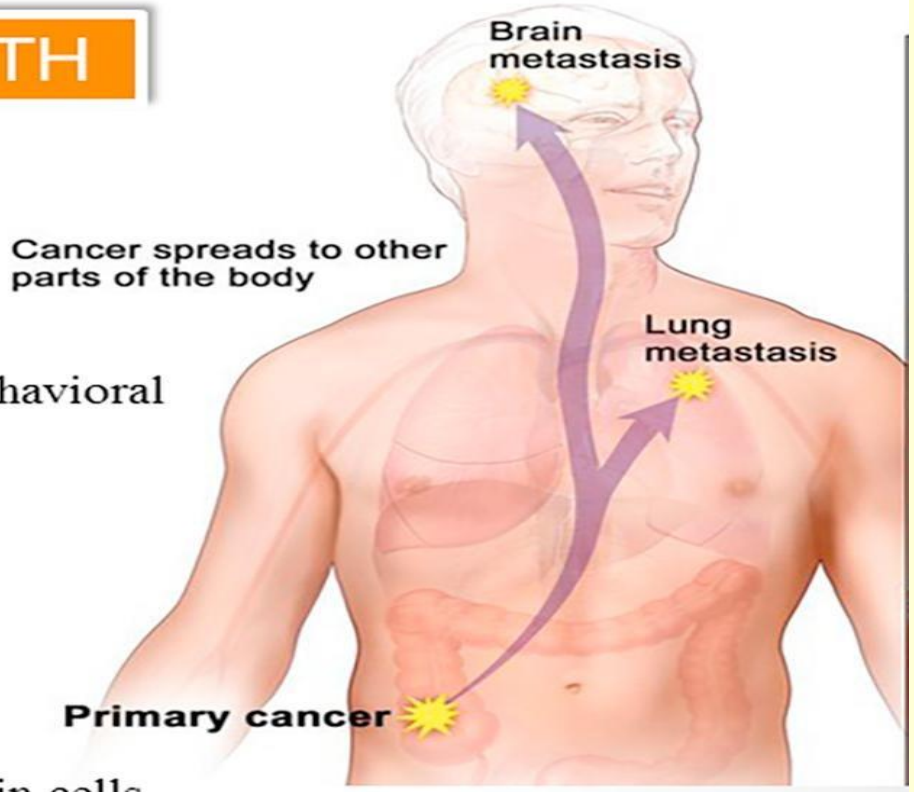
Suppress immune system

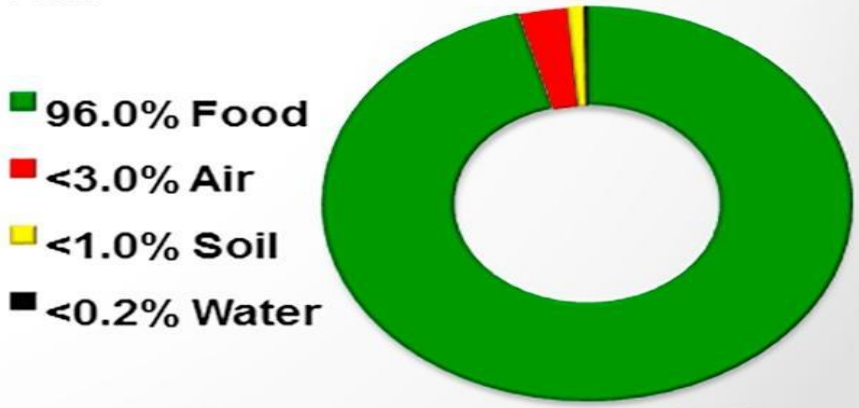
Decreases in IgA and IgM antibody levels,
decreases in monocyte and granulocyte counts,
decreases in natural killer cell count

Carcinogenic effects

EPA and DHHs consider PCBs a carcinogen for human
Based on animal studies data.

- Also, IARC classified PCBs as Group-I carcinogen to humans.





Human exposure to PCBs via food, water, air and soil

Source: Reddy, et al, 2019

PCBs Exposure Risks Control Actions

- Considering validated body of scientific evidences on deleterious impacts of PCBs of the environment and human health, the genre of hazardous chemicals was listed among the 'dirty dozen' during adoption of the Stockholm Convention on POPs in 2001.
- Parties to the Convention have been mandated to cease production & use of PCBs and equipment containing the chemical by 2025 AND ensure sound disposal of waste generated therefrom by 2028 (Part II of Annex A to the Stockholm Convention).
- To achieve this, the following national and sectoral control actions need be taken.

PCBs Exposure Risks Control Actions (Cont'd)

- Complete inventories of all PCBs and PCBs-containing/contaminated equipment.
  - This will enable the facility/industry identify and document locations, types and quantities of PCBs and PCBs-containing electrical equipment in its system
  - To achieve this, there must be identification and confirmatory laboratory analyses of the dielectrics and the electrical equipment containing same.
  - Appropriate labelling for ease of documentation;
  - Temporary Storage for safe/secure containment;
  - Development of the PCBs Management Plan
  - Development of PCBs Database.

PCBs Exposure Risks Control Actions (Cont'd)

- At all stages of PCBs and PCBs-containing equipment management, it is necessary for responsible persons to be kitted with compatible safety hard hats, full face shield or chemical-resistant goggles (tight-fitting), rubberized protective suit, gloves (gauntlet type to provide forearm protection) and rubberized boots.
  - All rubberized clothing should be made of PCB-resistant material, such as nitrile rubber or, if cost permits, Tyvek, Saranex, or Viton.
  - All contaminated protective equipment and clothing should be thoroughly cleaned; if possible, or properly disposed of, since some materials deteriorate after exposure and lose their protective efficiency.

PCBs Exposure Risks Control Actions (Cont'd)

- Improve the capacity and increase the knowledge of facility operators on proper maintenance of equipment, to avoid further contamination.
  - Education and Awareness programmes for facility/industry personnel on PCBs and its safe and secure management;
  - Operationalisation of PCBs Management Plan;
  - Development of Sustainability Plan

PCBs Exposure Risks Control Actions (Cont'd)

- Research and Development, targeted at discovery and introduction of environmentally safe, technically and economically feasible, equally effective (vis-a-viz requirements for a good dielectric), accessible, and available alternatives to PCBs.
  - A few candidate alternative dielectrics are in the market, which are based on mineral oils, vegetable oils, silicone, paraffinic hydrocarbons, among others.
  - However, their potentials to supersede PCBs in enhancing equipment performance/integrity and fire safety have not been adequately documented.
  - Some items of 'dry' electrical equipment are also being produced, which need be tested and used overtime to ascertain their efficacy and better performances when compared to PCBs-filled types.
  - Knowledge capitalisation, experience sharing research and development community can be expedient.

PCBs Exposure Risks Control Actions (Cont'd)

- Establishment of Standard Storage Facilities for Discontinued PCBs-containing/contaminated electrical equipment
  - Design, building and maintenance of Standard PCBs Storage Warehouses, for temporary containment, equipped with hardware and software Safety and Security Components.
  - Neighbouring facilities can share and jointly maintain the facilities.
  - Safety and Security provisions need be incorporated to Storage design
  - Labelling and Caution Signs need be conspicuously displayed at the site.
  - Proper documentation of stocked items in bin cards and in the international stock management system.
- Treatment of collected PCB oils and disposal of PCBs-containing/contaminated electrical equipment in an environmentally sound manner.
- There are many commercially available Destruction and Treatment Technologies for sound management of PCBs which are variously based on physical, chemical and or thermal processes.

Thank You