SNAP CODE: **N/A**

SOURCE ACTIVITY TITLE: **ELECTRICAL EQUIPMENT CONTAINING PCBS**

NOSE CODE: **112.09.13**

NFR CODE:

1 ACTIVITIES INCLUDED

This chapter covers emissions to atmosphere from electrical equipment containing PCBs. It covers emissions which result from existing electrical equipment containing PCBs, through leaks or spills, and from the recycling of this equipment by fragmentising / shredding.

This chapter does not cover emissions from landfill, from the burning of electrical equipment containing PCBs through accidental or deliberate fires (SNAP 09), from the processes of utilisation of electrical equipment, and emissions from open applications of PCBs.

2 CONTRIBUTION TO TOTAL EMISSIONS

The major use of PCBs, and so the main source of secondary environmental pollution by PCBs, is electrical equipment. In the UK, for example, it is estimated that over 90% of PCB emissions arise from leaks from transformers and capacitors and from fragmentising operations (APARG, 1995). Recent estimates of the European emissions in 1990 indicate that as much as 94% of PCB emissions come from this source (Berdowski et al., 1997). Electrical equipment containing PCBs is unlikely to be a significant source of any pollutant other than PCBs.

Table 2.1 Contribution to total emissions of the CORINAIR90 inventory

Source-activity	SNAP-code	Contribution to total emissions [%]							
		SO_2	NO_x	NMVOC	CH_4	CO	CO_2	N_2O	NH_3
Electrical equipment containing PCBs		-	-	-	-	-	-	-	-

- = no emissions are reported

Table 2.2 Contribution to total POP and heavy metal emissions of the OSPARCOM HELCOM-UNECE emission inventory *(up to 39 countries)*

Source-activity	SNAP-code	Contribution to total emissions (including emissions from nature) [%]									
		As	Cr	Cu	Pb	Cd	Hg	PCBs	PCDD/Fs	HCB	PCP
Electrical equipment		0	0	0	0	0	0	94	0	0	0

- = no emissions are reported

3 GENERAL

3.1 Description

PCBs are synthetic organic compounds, which mix well with organic solvents and plastics, etc. They are stable to strong acids and alkalis. This high chemical stability, together with their electrical stability (particularly at variable voltage), as well as their resistance to degradation at high temperatures, have in the past resulted in a range of industrial applications. PCBs were widely used as dielectric fluids for a long period (approx. from 1929 to 1988), mainly in industrial transformers and capacitors.

The main difficulty in compiling an inventory of PCB emissions is the tracking and identification of PCB-containing equipment, since there are no relevant readily available statistics.

3.2 Definitions

Capacitor - a device for accumulating and holding a charge of electricity. Some were made with PCBs as the dielectric fluid.

Dielectric fluid - insulating material used in electrical equipment, separating the conduction surfaces (sometimes containing PCBs).

Fragmentising operations - the breaking up of household appliances (e.g. cookers, refrigerators) for recycling.

PCBs - polychlorinated biphenyls. A subset of the synthetic organic chemicals known as chlorinated hydrocarbons; this includes any chemical substance of the biphenyl molecule that has been chlorinated to varying degrees. The chemical formula for PCBs can be represented as $C_{12}H_{(10-n)}Cl_n$, where n is number of chlorine atoms within the range of 1-10. A total of 209 individual isomers exist; these range from liquids to high-melting crystalline solids.

Transformer - a device that is used to raise and lower voltage. PCB-containing transformers are typically located in electricity facilities and industrial sites.

3.3 Activities

3.3.1 Electrical equipment and PCB use

The main use of PCBs has been as dielectric insulating materials in electrical equipment such as capacitors and transformers (see Table 3.1). Most countries have not manufactured PCBs for many years, but many of the old appliances still exist; the useful life of such appliances is 20-30 years.

Table 3.1 Use of PCBs in USA, Germany, Japan and Russia

Country	% of total PCBs used as dielectric fluids	Reference
USA	until 1971, 61%; after 1971, 100%	USEPA, 1987
Germany	55.5%	Dobson and van Esch, 1993
Japan	66%	Neumeier, 1998
Russia	75%	Kakareka et al., 2000

The majority (70%) of capacitors are used as power capacitors; high frequency capacitors have the next highest usage (Gulevich, 1981, data for the former USSR). Power capacitors are used in high and low voltage transmission lines or in high frequency transmission units for a variety of purposes, such as:

- to increase the capacity factor of industrial electrical units;
- to increase the capacity factor of induction electrical and thermal units;
- to compensate for reactive resistance of long-distance power transmissions;
- to take off power from high voltage transmission lines;
- to filter traction substation;
- to generate impulse current and voltage;
- to start capacitor electric motors;
- in mine electric locomotives;
- in ultrasonic units.

They can be used both as separate units and in the form of complex capacitor units or batteries.

Power capacitors produced in different countries have similar size parameters. Large high voltage capacitors typically weigh 54 kg, of which 11 kg are PCBs (USEPA, 1987); power factor correction capacitors produced in the USSR have 2 typical sizes, weighing 28-35 kg and 54-60 kg, of which 10 and 19 kg are PCBs respectively (Kakareka, 2000).

Small capacitors include motor start capacitors and ballast capacitors. Motor start capacitors are used with single phase motors to provide starting torque; these capacitors can be found also in household electrical appliances including refrigerators, cookers, washing machines, air conditioners, dishwashers, etc (UNEP, 1999). Many such appliances are still in use but it is difficult to establish what proportion of these goods have PCB-containing components. Ballast capacitors are found within fluorescent, mercury, and sodium lighting fixtures, and neon lights; they typically weigh 1.6 kg, of which 0.05 kg are PCBs (USEPA, 1987).

Transformers are used for electric power transformation in power transmission lines and in power energy receipt and use units. The transformer is a very important component in different types of electrical circuits, from small-signal electronic circuits to high-voltage power transmission systems. The physical size and shape of transformers, and therefore the volume of PCBs in them, vary greatly. Transformers can range in size from not much bigger than a pea up to the size of a small house (UNEP 1999); the volume of PCBs typically ranges from 0.2 to 4.1 tonnes (Kakareka, 2000).

3.3.2 PCBs as dielectric fluid

Commercial products known generically as PCBs are mixtures of individual isomers in which the chlorine content is between 21 and 68%. Registered trade names for some commercial brands of PCBs are: Aroclor, Chlorinol, Askarel, Dykanol, Pyranol (USA), Pyralene (France), Clophen (Germany), Kannechlor (Japan), Delor (Czechoslovakia), Sovol, Trichlorobiphenyls, Sovtol (USSR). Arochlor is the best known of the PCB formulation and has served as a standard. Example characteristics are shown in Table 3.2.

Table 3.2 Chlorinated liquid dielectric characteristics (Kakareka, 2000)

Name	Composition	Density at 20°C, kg/m^3	Chlorine content, %
For capacitors			
Sovol	Pentachlorobiphenyl	1.55	54.6
TCB	Trichlorobiphenyl	1.4	42
Aroclor 1232	Dichlorobiphenyl	1.27-1.28	32
Aroclor 1242	Trichlorobiphenyl	1.38-1.39	42
Aroclor 1248	Tetrachlorobiphenyl	1.405-1.415	48
Aroclor 1254	Pentachlorobiphenyl	1.495-1.505	54
Clophen A-30	Trichlorobiphenyl	1.35	42
Pyralene 1460	Polychlorobiphenyls+Polychlorobenzenes	1.41	
Pyralene 1499	Trichlorobiphenyl	1.38	42
Pyralene 2000	Dichlorobiphenyl	1.29	32
Pyralene 3010	Trichlorobiphenyl	1.38	42
Pyralene 5000	Pentachlorobiphenyl	1.55	54
For transformers			
Askarel	Polychlorobiphenyls (60-70%) + Chlorobenzene (30-40%)		
Sovtol-10	Pentachlorobiphenyl (90%) + Trichlorobenzene (10%)	1.52-1.54	
Hexol	Pentachlorobiphenyl (20%) + Hexachlorobutadiene (80%)	1.64	

3.3.3 Leaks from transformers and capacitors

The majority of emissions of PCBs arise from leaks from electrical transformers and capacitors which contain PCBs and which are in a poor condition and/or are poorly maintained.

It is likely that the oil of some transformers that were not originally deliberately filled with PCBs has become contaminated with PCBs. However, it is estimated that over 90% of these transformers are contaminated to levels less than 50 ppm (APARG 1995). The source of this contamination is likely to be the lack of segregation in the past of oil and PCB filling lines at manufacturers' works, and the subsequent use of recycled oil.

3.3.4 Fragmentising operations

Some small capacitors containing PCBs will be landfilled with household waste, but most will be in appliances that will be partly recycled by fragmentising. This is the process by which domestic electrical appliances are shredded and the fragments separated into the following 3 fractions:

- ferrous metal, which is recycled to steel producers;

- a non-ferrous metal enriched 'heavy' fraction, which is mainly disposed to landfill following processing to remove the non-ferrous metals;
- a 'light' or 'dirt' fraction that consists largely of non-metallic waste materials (e.g. wood, glass, plastic etc), which is mainly disposed to landfill.

There is the potential for PCB release both from fragmentiser wastes disposed to landfill and from the fragmentiser process itself, as well as during metal processes when recycled ferrous metal is used. The release of PCBs to atmosphere greatly depends on the process temperatures.

3.3.5 Disposal of electrical equipment containing PCBs

Large quantities of PCBs have been disposed to landfill in the past, mainly in the form of electrical components or fragmentiser residues, but discarded electrical equipment known to contain PCBs is now often disposed of by chemical waste incinerators. However, emissions from disposal of electrical equipment are not covered by this chapter.

3.4 Emissions

The major source of PCBs arises from leaks of dielectric fluid containing PCBs from large electrical transformers and capacitors which are in poor condition. PCB emissions from transformers and capacitors during normal operation are negligible (section 3.3.3).

In addition, fragmentising operations are also likely to be significant sources of PCBs where electrical appliances containing PCBs are involved (section 3.3.4).

3.5 Controls

Not all PCB-filled transformers are identifiable, although many of the ones that are known are owned by organisations that operate to rigorous safety standards. In such cases the environmental impact of leaks from the transformers has therefore been minimised. These transformers can be landfilled after being drained and flushed, and the PCBs are accessible for controlled disposal, usually by incineration.

4 SIMPLER METHODOLOGY

There are limited data available on emissions of PCBs from electrical equipment and therefore the simple methodology is based on emission factors which have been developed by calculation, using population as the activity. The emissions can be estimated using the equations below. Default emission factors are given in Section 8.

Transformers and Capacitors

Atmospheric emission of PCBs from transformers/capacitors
= (per capita emission factor) x (population)

Fragmentising Operations

Atmospheric emission of PCBs from fragmentising operations
= (per capita emission factor) x (population)

For the emission of PCBs from fragmentising operations, the emission can also be estimated using an emission factor based on the quantity of ferrous scrap recycled, using the equation:

Atmospheric emission of PCBs from fragmentising operations
= (emission factor per unit mass of ferrous metal recycled) x (mass of ferrous metal recycled)

5 DETAILED METHODOLOGY

The detailed methodology involves a review of the estimated number of transformers and capacitors in a country and an analysis of the proportion of these which contain PCBs and the proportion which have the potential to leak. This analysis would therefore require a more detailed audit of electrical equipment within a country.

Similarly, for fragmentising operations, the detailed methodology involves an analysis of the types of ferrous scrap recycled, and requires more detailed knowledge of the quantity of PCBs within the different types of ferrous scrap.

The first stage in the inventory of electrical equipment with PCBs requires the identification of power capacitors and power transformers, ie those devices where most of the PCBs have been used. This group alone can consist of thousands of appliances distributed over hundreds of users, so their full inventory is a very complicated task. As the first approximation a selective inventory of main users can be proposed.

This inventory should detail separately transformers and capacitors, with an indication of their type, dielectric type, equipment number, year of manufacture, producer. Electrical equipment that was in operation, in reserve or damaged must also be taken into account. It is not always possible to determine the capacitor type and the year of its manufacture; there are problems of dielectric type determination (often it is defined under a general name ‘synthetic’). It is difficult to track equipment as in many cases capacitors have no registration certificates, as there are no regulations for PCB-containing equipment operation; also some equipment may have been stored at dumps or used for other purposes.

The second stage of PCB inventory includes calculation of the volume of dielectric fluids. The amount of dielectrics in large capacitors varies depending on its type from 2.7 kg to 22-24 kg; most of the widely used power capacitors contain 14 kg of PCBs. The volume of PCBs in transformers varies depending on its type from 0.2 t to 4.1 t (Kakareka, 2000).

Default emission factors are given in Section 8.

6 RELEVANT ACTIVITY STATISTICS

6.1 Simple methodology

The simple methodology for estimating PCB emissions from leaks from transformers and capacitors requires knowledge of the population in a country. This information will be available from national statistics offices.

The simple methodology for estimating PCB emissions from fragmentising operations requires knowledge of the population or the quantity of ferrous scrap recycled in a country.

6.2 Detailed methodology

The detailed methodology for estimating PCB emissions from leaks from transformers and capacitors requires detailed knowledge of the quantities of transformers and capacitors which contain PCBs and their state of maintenance. This information might be available from national Electricity Associations.

The detailed methodology for estimating PCB emissions from fragmentising operations requires knowledge of the quantities and types of ferrous scrap recycled and the quantity of PCBs in the types of ferrous scrap.

7 POINT SOURCE CRITERIA

Although leaks from electrical equipment sites might be significant, limited information is likely to be available on the location and scale of leaks. Therefore electrical equipment should be treated as area sources unless reliable site specific data are available.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

Concerning emission factors presented in Table 8.1, Berdowski et al. (1997) have calculated emissions of PCBs due to leaks from transformers and capacitors for each of the European countries in 1990. The range of the per capita emission factors is large; almost two orders of magnitude. This indicates a difficulty in choosing a proper emission factor and the high uncertainty of emission estimates on the basis of these emission factors.

Table 8.3 gives default emission factors for calculating emissions to air from the amount of leakage of PCBs. The process of evaporation is very complex and has not been well studied, although it is known that rate of evaporation decreases with increase of level chlorination of PCB; therefore Trichlorobiphenyl, which is used in, and leaks from, capacitors, will evaporate more rapidly than Pentachlorobiphenyl (Sovtol-10 or other brand) from transformers.

Table 8.1 Emission factors for leaks from transformers and capacitors

Compound	Equipment / process	Abatement type	Abatement efficiency	Fuel type	Emission factor	Data Quality	Country or region	Reference
Total PCBs	Leaks from transformers	None	N/A	N/A	**0.006 - 0.5 g/capita/year** [1]	**E**	Europe	Berdowski et al. (1997)

[1] Recommended emission factor 0.13 g/capita/year

Table 8.2 Emission factors for fragmentising operations (recycling of ferrous scrap)

Compound	Equipment / process	Abatement type	Abatement efficiency	Fuel type	Emission factor	Data Quality	Country or region	Reference
Total PCBs	Fragmentiser operations (recycling of ferrous scrap)	None	N/A	N/A	**0.004 g/capita/year**	**E**	UK	Harrad et al. (1993)
Total PCBs	Fragmentiser operations (recycling of ferrous scrap)	None	N/A	N/A	**0.25 g/t of ferrous scrap recycled**	**E**	UK	Harrad et al. (1993)

Table 8.3 Leaks (releases) and emission factors of PCBs from electrical equipment, kg/t

Equipment	Leaks (releases)	Emission to air	Country or region	Reference
Transformers	0.06	-	Europe	TNO, 1995
	0.3	-	North America	USEPA, 1997
	0.3	0.06	CIS countries	Belarusian report to EMEP, 2000
Capacitors	1.6	-	Europe	TNO, 1995
	4.2	-	North America	USEPA, 1997
	2.0	0.8	CIS countries	Belarusian report to EMEP, 2000

9 SPECIES PROFILES

No information is available on the PCB species profiles from electrical equipment.

10 UNCERTAINTY ESTIMATES

The majority of PCB emissions arise from electrical transformers and capacitors in poor condition, and by the nature of this source emissions are difficult to estimate. The use of per capita emission factors is uncertain because the emission factors are likely to vary significantly between countries. For example the quantity of PCBs remaining in electrical equipment will vary as well as the standard of maintenance and quality of safety procedures to prevent leaks.

The emission factors in Section 8 are based on calculations rather than measurement. The emission factors therefore have a data quality of E.

A key uncertainty is that, although the approximate quantity of PCBs produced in the past is known, the exact quantity of PCBs still in existence is unknown. Other uncertainties include the possibility of double counting in the total PCB inventory as PCB emissions from landfill are likely to include emissions that arise from electrical equipment disposed to landfill. However, this uncertainty is less important compared with those described above.

11 WEAKEST ASPECTS / PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

The weakest aspect of the methodology is the emission factors, which are very uncertain for the reasons described in Section 10. The emission factors can be improved by improving the knowledge of the quantity of PCBs in existing electrical equipment and the rate of leakage.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

PCB emissions from electrical equipment can be assumed to be spatially disaggregated according to population unless reliable data are available on leaks from specific sites.

13 TEMPORAL DISAGGREGATION CRITERIA

Until better information becomes available, emissions may be considered to occur evenly through out the diurnal and annual cycles. However, as electrical equipment containing PCBs continues to be replaced, emissions will in reality decrease with time.

14 ADDITIONAL COMMENTS

There are no additional comments.

15 SUPPLEMENTARY DOCUMENTS

Supplementary documents are not required.

16 VERIFICATION PROCEDURES

Verification procedures are in line with the priority requirements for improvement described in section 11, i.e. improved knowledge of the quantity of PCBs in existing electrical equipment and the rate of leakage is required to verify the emission factors. In addition, the research into the variation in leakage between countries could verify whether the use of per capita emission factors is reliable.

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