Category		Title
NFR	2.K	Consumption of persistent organic pollutants and heavy metals
SNAP	060502 060504 060507	Refrigeration and air conditioning equipment Foam blowing (except 060304) Electrical equipment
ISIC		
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Coordinator

Jeroen Kuenen

Contents

1 Overview

Emissions from the consumption of persistent organic pollutants (POPs) and heavy metals are in many cases considered to be insignificant (where contribution to the total national emissions is less than 1 % of national emissions). For some POPs, however, e.g. polychlorinated biphenyls (PCBs), use in electrical equipment could be an important source. Berdowski *et al*. (1997) estimated that as much as 94 % of all PCB emissions come from the use of electrical equipment.

The present chapter does not provide guidance on the use of pesticides in agriculture. Specific information on this activity is given in chapter 3.I Agriculture other.

All other use of POPs that may be significant for national emission inventories is dealt with in the relevant chapters throughout the Guidebook. The present chapter therefore focuses mainly on the use of electrical equipment and the PCB emissions from this source.

2 Description of sources

2.1 Process description

The present chapter deals with emissions from the consumption of POPs and heavy metals. These are used in e.g. refrigerators, air conditioning equipment and electrical equipment.

2.2 Techniques

2.2.1 Electrical equipment and PCB use

Electrical equipment is one of the major sources of PCB emissions, mainly from capacitors and transformers.

The majority (70 %) of capacitors used are power capacitors; high frequency capacitors have the next highest usage (Gulevich and Kireev (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 two typical sizes, weighing 28–35 kg and 54–60 kg, of which 10 and 19 kg are PCBs respectively (Kakareka *et al.*, 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 has 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 *et al.*, 2000).

2.2.2 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.

2.2.3 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.

2.2.4 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 three fractions:

- ferrous metal, which is recycled to steel producers;
- a non-ferrous metal enriched 'heavy' fraction, which is mainly landfilled;
- 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) and is mainly landfilled.

There is the potential for PCB release both from landfilled fragmentiser wastes 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.

2.2.5 Disposal of electrical equipment containing PCBs

Large quantities of PCBs have been landfilled 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.

2.3 Emissions

All kinds of POPs and heavy metals may be emitted, however only emissions of PCB are generally significant on a national level.

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

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

Mercury (Hg) emissions arise mainly from the use of batteries, measuring and control equipment (including laboratory and hospital equipment), electrical equipment and lighting. Other products (e.g. paints, pharmaceuticals, other medical/health problems and dental amalgams) may also be a source of Hg emissions but are unlikely to be very significant on a national level.

2.4 Controls

Many of the known PCB-filled transformers are nowadays owned by organisations that operate to strict safety and environmental standards. In such cases, the environmental impact of leaks from the transformers should therefore be minimised. These transformers can be landfilled after being drained and flushed, and the PCBs are accessible for controlled disposal, usually by incineration.

Options to reduce mercury emissions are:

- banning or phasing out the production and sale of products containing or needing metallic mercury for their functioning;
- limitating the amount of mercury in products.

Since 1990, mercury consumption in primary batteries has been reduced significantly due to the introduction of the Directive 91/157/EEC on batteries and accumulators containing certain dangerous substances. This directive came into force in 1994. As a result, the majority of Hg emissions from batteries in the EU now originates from special purpose mercury button cells.

3 Methods

3.1 Choice of method

Only a Tier 1 default approach is presented in this chapter.

3.2 Tier 1 default approach

3.2.1 Algorithm

The Tier 1 approach for emissions from this source category uses the general equation:

$$E_{pollutant} = AR_{production} \times EF_{pollutant} \quad (1)$$

This equation is applied at the national level, using annual national statistics on the consumption of POPs and heavy metals.

The Tier 1 emission factors assume an averaged or typical technology and abatement implementation in the country and integrate all sub-processes.

3.2.2 Default emission factors

Default emission factors are presented in the table below. Only emission factors for PCB and Hg are available from literature. All other emission factors can in most cases be considered to be insignificant. No additional information is available.

To derive the Tier 1 emission factor for PCB, a typical average value of the information given in the Tier 3 section of this chapter has been calculated.

The emission factors for Hg and PCB should be used with some caution, as they are based on relatively old studies with a very large uncertainty and hence may overestimate total emissions for this sector.

Table 3.1 Tier 1 emission factors for source category 2.K Consumption of persistent organic pollutants and heavy metals

Tier 1 default emission factors					
	Code	Name			
NFR Source Category	2.K	Consumption of POPs and HMs			
Fuel	NA				
Not applicable	NOx, CO, NMVOC, SOx, NH3, TSP, PM10, PM2.5, BC, PCDD/F, Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Indeno(1,2,3-cd)pyrene				
Not estimated	Pb, Cd, As, Cr, Cu, Ni, Se, Zn, HCB				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
Hg	0.01	g/capita	0.001	0.1	WS Atkins (1997)
PCB	0.1	g/capita	0.01	0.5	Berdowski (1997), Harrad (1993)

3.2.3 Activity data

In the Tier 1 approach, emissions can be calculated by using the default emission factors given in Table 3.1 above and the country's total population.

3.3 Tier 2 technology-specific approach

Not available for this source category.

3.4 Tier 3 emission modelling and use of facility data

The present sub-section presents a Tier 3 approach for estimating the emissions of PCBs from the use of electrical equipment. This involves a review of the estimated number of transformers and capacitors in a country and an analysis of the proportion of these that contain PCBs and the proportion that 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, i.e. 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.

It is good practice for the inventory to detail transformers and capacitors separately, with an indication of their type, dielectric type, equipment number, year of manufacture and 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 because 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 a 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 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 ton to 4.1 ton (Kakareka *et al*., 2000).

Concerning the emission factors presented in Table 3.2, 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 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 3.4 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 the rate of evaporation decreases with increased levels of 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 3.2 Emission factors for leaks from transformers and capacitors

Equipment / process	Emission factor	Data quality	Country or region	Reference
Leaks from transformers	0.006 - 0.5 g/capita/year ([a])	E	Europe	Berdowski *et al*. (1997)

(a) Recommended emission factor 0.13 g/capita/year

Table 3.3 Emission factors for fragmentising operations (recycling of ferrous scrap)

Equipment / process	Emission factor	Data quality	Country or region	Reference
Fragmentiser operations (recycling of ferrous scrap)	0.004 g/capita/year	E	UK	Harrad *et al*. (1993)
Fragmentiser operations (recycling of ferrous scrap)	0.25 g/t of ferrous scrap recycled	E	UK	Harrad *et al*. (1993)

Table 3.4 Leaks (releases) and emission factors of PCBs from electrical equipment (kg/tonne)

Equipment	Leaks (releases)	Emission to air	Country or region	Reference
Transformers	0.06	-	Europe	Berdowski *et al*. (1997)
	0.3	-	North America	USEPA (1987)
	0.3	0.06	CIS countries	Kakareka *et al*. (2000)
Capacitors	1.6	-	Europe	Berdowski *et al*. (1997)
	4.2	-	North America	USEPA (1987)
	2.0	0.8	CIS countries	Kakareka *et al.* (2000)

The majority of PCB emissions arise from electrical transformers and capacitors in poor condition and the nature of this source means that 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 this section 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 of relatively low importance.

4 Data quality

There are no source-specific issues in this source category.

5 Glossary

POP	Persistent organic pollutant
Capacitor	A device for accumulating and holding a charge of electricity. Some were made with PCBs as the dielectric fluid.
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.
Dielectric fluid	Insulating material used in electrical equipment, separating the conduction surfaces (sometimes containing PCBs).

6 References

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7 Point of enquiry

Enquiries concerning this chapter should be directed to the relevant leader(s) of the Task Force on Emission Inventories and Projection's expert panel on combustion and industry. Please refer to the TFEIP website (www.tfeip-secretariat.org) for the contact details of the current expert panel leaders.