

Replacement of PCB (poly-chlorinated biphenyls) and HCB (hexachlorobenzene) - the Swedish experience.

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Background

■ *Assignment:*

- *Chemical and technical alternatives to PCB and HCB (besides pesticides), that are used today in Sweden.*
- *In which parts of industry and purpose of use.*
- *Estimated quantities and costs for the replacement of use.*

■ *Information sources:*

- *Personal contacts.*
- *Technical and scientific reports.*
- *Computerised information retrieval.*

Use of PCB in Sweden

- *Restricted since 1972.*
- *In 1978 it was decided that no new permits to use PCB in new products should be issued.*
- *Transformers or capacitors containing PCB and with a higher rating than two kilovolt-amperes (reactive) may not be used after the 31st of December 1994.*

Use of PCB in Sweden cont.

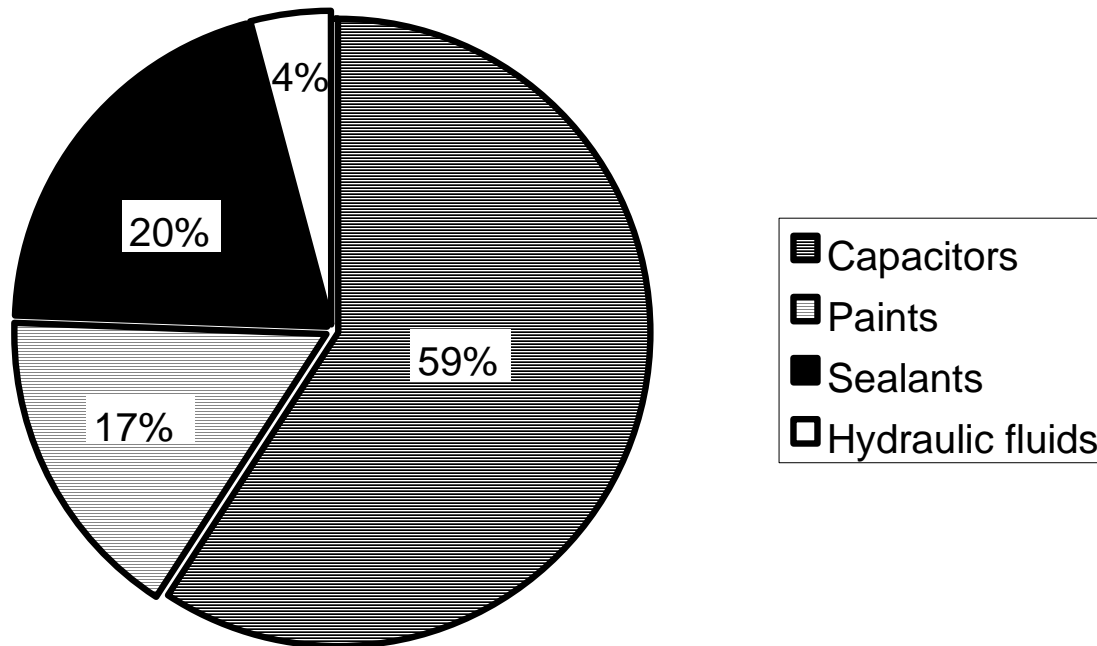
- *The use of PCB in Sweden at the end of the 1960s was about 600 and in the mid 1970s 450 metric tonnes annually*
- *The total import between 1957-1980 has been estimated to roughly 8,000-10,000 metric tonnes.*
- *A substantial part of the import, probably more than 50%, was re-exported in goods.*

Use of PCB in Sweden cont.

The main purposes for use of PCB was the same in Sweden as in other industrialised countries:

- *Dielectric fluid in power transformers and capacitors.*
- *Hydraulic fluid in machinery.*
- *Heat-exchanger fluid.*
- *Plasticiser in paints, plastics, and sealants.*

Use of PCB in Sweden cont.



Distribution of the net use of PCB in Sweden in 1970, estimated to 210 metric tonnes annually.

Use of PCB in Sweden cont.

Situation today:

- *The new use of PCB has discontinued since 1978.*
- *The remaining part in the power sector of the industry has been removed.*
- *Substantial amounts of PCB remains in use within goods and products manufactured and sold before 1978.*
- *I have roughly estimated the total quantity still in use in Sweden to 190-650 metric tonnes.*

Chemical and technical alternatives to PCB

- *Focus on the Swedish experience.*
- *Difficult to obtain reliable data, since replacement of most product groups took place already in the early 1970s.*
- *Phase-out was swift and done by the industry case by case.*
- *Documentation was not given a priority at that time.*

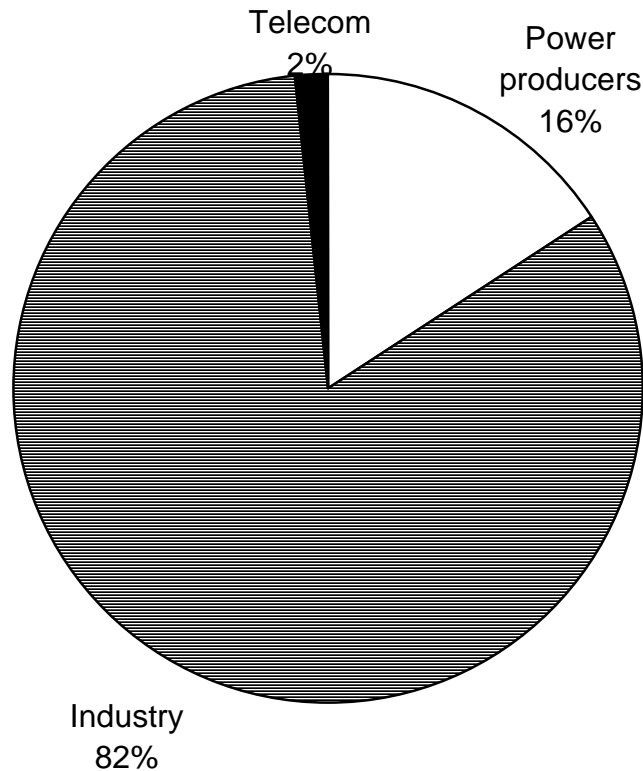
Dielectric fluids

- *Dielectric fluids was the product group of most importance on a quantitative basis.*
- *PCB was used as isolation fluid in both capacitors and transformers, because of the suitable electrical and thermal properties.*
- *In 1970 the total annual net use of PCB for these purposes was estimated to 125 metric tonnes.*
- *Since 1978 consumption of new PCB ceased, and the PCB containing installations has continuously been replaced over the time period until now.*

Transformers

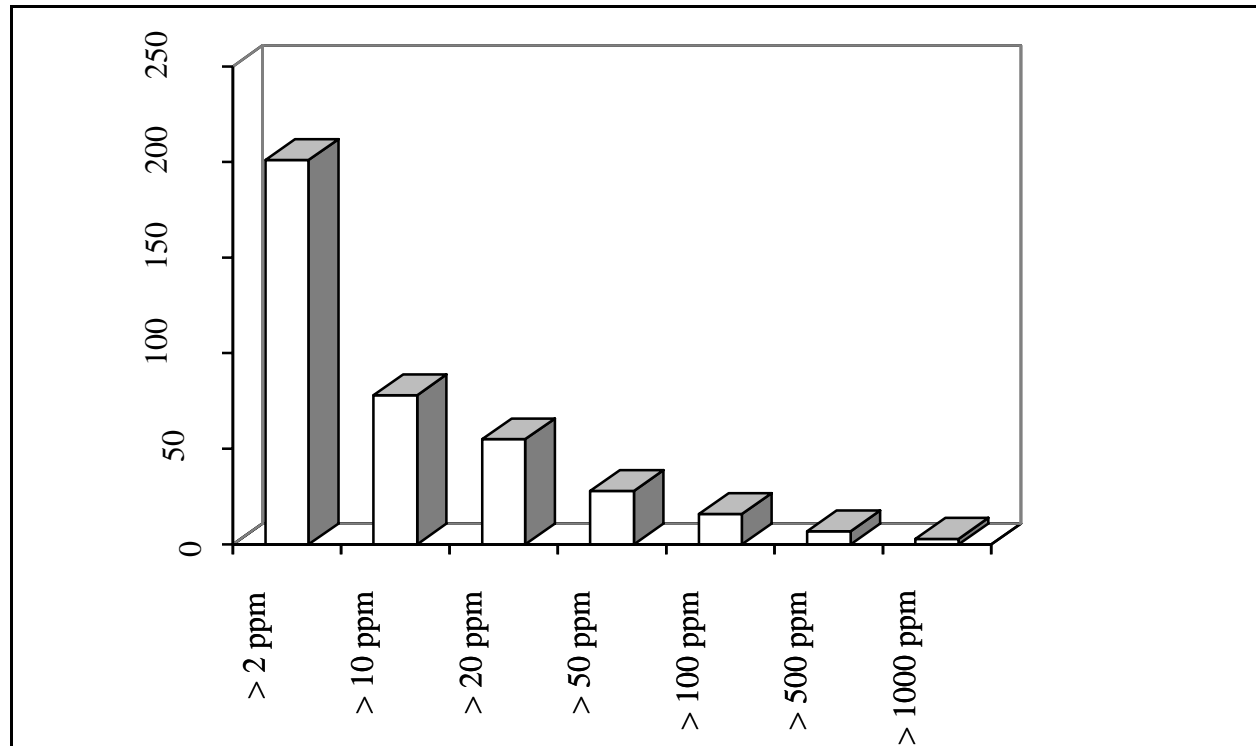
- *Transformers containing PCB as isolation fluid were never manufactured in Sweden.*
- *The problem of PCB contaminated transformer oils has also been less severe in Sweden, and has made it possible to adopt very stringent limits regarding the definition of PCB contamination.*

Transformers cont.



172 transformers containing approximately 77 metric tonnes of PCB were in use in 1983.

PCB contamination in transformer oil.



Summary of chemical analyses carried out by Vattenfall of oils for in 2,548 transformers in 1986-1989.

The practical limit applied in Sweden to consider oil contaminated with PCB is 2 ppm (mg/kg).

Alternatives

- Chemical alternatives most frequently used as transformer fluids includes **mineral and silicone oils**, but a number of other alternatives are mentioned in the literature.
- Technical alternative: Dry isolated transformers has also been mentioned as an alternative to PCB filled transformers. Dry isolated transformers avoids the problems of fire but are less suitable from every other point of view, e.g. sensitivity to overload and voltage spikes, compared to oil filled transformers.

Other chemical alternatives as transformer fluid

Some examples of chemical alternatives to PCB in transformers that have been considered and are mentioned in the literature.

Trade name(s)	Type of substance(s)
	Mineral oil
	Silicone oil
Pyralene, Pyrochlor, Inerteen	Mixtures of chlorobenzenes and chlorobiphenyls
	Chlorinated diphenylether
Chloroalkylenes	Chloralkylène
Iralec	Chlorinated diphenylethane
R-TempR	Mixture of hydrocarbons and additives, isopropyl biphenyl and perchloroethylene
	Tetrachloroethylene
	Chlorofluorocarbons
Formel	Mixture of halocarbons
	Tri/terachlorobenzene

It should however be noted that many of these "alternatives" lack commercial interest today.

Cost of replacing a PCB filled transformer

- *Table based on calculations made in 1985.*
- *The cost of destruction of PCB amount to about 40% of this cost-estimate.*

Cost of replacing an average PCB-filled transformer (SEK).

Cost price	110,000
Installation	15,000
Destruction cost	<u>75,000</u>
Total	200,000

Retrofilling

- *In many other countries the limit value for PCB contaminated dielectric fluid is 50 mg/kg.*
- *That have made it possible to use equipment for retrofilling of the dielectric fluid and continued operation of the transformers.*
- *As an example more than 80 million litres of PCB contaminated mineral oil in the USA and Canada have been dechlorinated and purified by means of the PCB-X process. More than 10,000 transformers have been reclassified.*

Capacitors

- *Capacitors containing PCB as isolation fluid was manufactured in Sweden before 1978.*
- *The use for this purpose accounted for about 80% of the import of PCB.*

Chemical alternatives

- *A number of chemical compounds are mentioned in the literature as chemical alternatives for PCB as capacitor fluid.*
- *In addition to the examples already mentioned, in the table on transformer fluids, one can add different organic esters like glyceryl triacetoxystearate, butyl stearate, butyl sebacate, butyl naphthenate and tetrahydrofurfuryl oleate, ethylene glycol and silicate ester base fluid.*
- *Phthalates, esterbased materials and triaromatics have been evaluated among others by the Swedish capacitor manufacturer ABB (Asea Brown Boveri AB).*

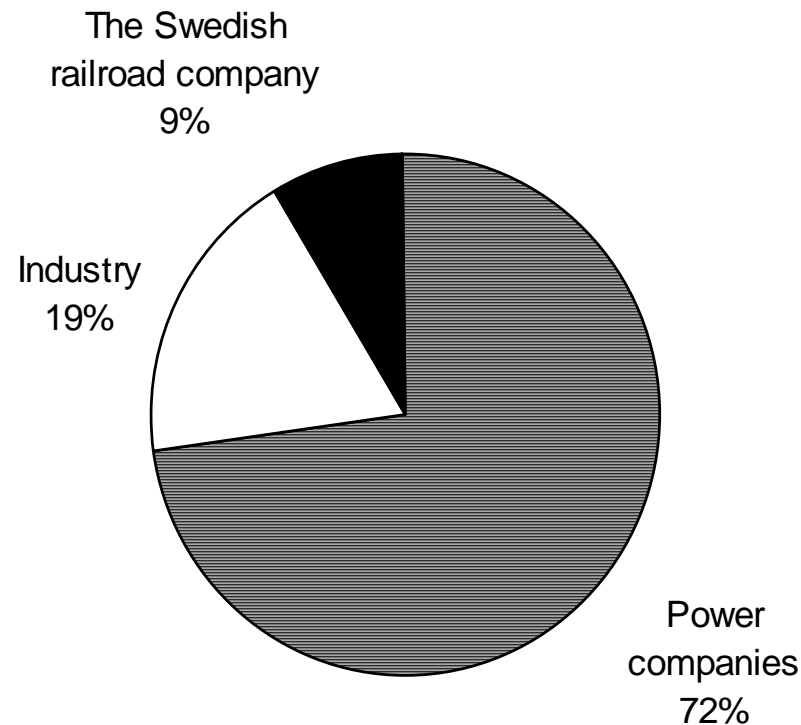
Chemical alternatives cont.

- *The main characteristics that are difficult to fulfil for many PCB alternatives are thermal and hydrolytic stability combined with a somewhat polar property. Many esterbased materials, except hindered esters, are therefore not suitable. Aromatics are preferred due to the ability to bind hydrogen.*
- *Many of the "alternatives" mentioned in literature can therefore be presumed to be without any commercial interest today, in this field of application.*

Chemical alternatives cont.

- *The capacitor fluids most frequently used today in Sweden are **dodecylbenzene** and a mixture of **methyl(phenylmethyl)benzene** and **methylbis(phenylmethyl)benzene**.*
- *The amounts of these chemicals imported to Sweden are approximately of the same magnitude as the estimated PCB use for the same purpose in 1971.*
- *A diaryl alkane is the main component in another important product on the international market.*
- *Chemicals used as PCB substitutes are produced by chemical companies in the United States, Japan, France and Italy. Examples of producers of PCB alternatives as capacitor fluids today are Elf Ato Chem in France and Nippon Oil in Japan.*

Distribution of PCB containing capacitors 1981/83 in Sweden



92,700 capacitors containing approx. 1,410 metric tonnes.

Cost of replacing a PCB filled capacitors

- *Table based on calculations made in 1985.*
- *The cost of destruction of PCB amount to about 17% of the total cost-estimate.*

Cost of replacing average PCB-filled capacitors (SEK).

Type	150 kVA	50 kVA
Cost price	4,500	3,500
Installation	1,500	1,500
Destruction cost	1,200	1,000
Energy saving	-1,000*	-700*
Total	approx. 7,000	approx. 5,800

* The value of the energy saving is uncertain. Therefore only a part of it is taken into account.

Cost of replacing a PCB filled capacitors cont.

- *The total costs for the replacement of PCB containing power capacitors by the distributor Svenska Kraftnät, and formerly Vattenfall, has more recently been estimated to approximately 150 MSEK.*
- *The cost for PCB-destruction was 68 MSEK (45%).*
- *The cost for destruction of the PCB-waste, today around 25 SEK/kg in Sweden, is the major cost factor if the extension in technical life-time and energy savings is also taken into account.*

Sealants

- *Sealants was the product group of second most importance on a quantitative basis.*
- *In 1970 the total annual use of PCB for these purposes, as plasticiser (softener), was estimated to 40-45 metric tonnes.*
- *Since the restrictions in 1972 new consumption ceased.*
- *It is estimated that 150-600 metric tonnes remains in buildings and this makes sealants the largest source of PCB in Sweden since the use in power installations has been phased out.*

Sealants cont.

- *The major application of sealants based on poly-sulfide Thiokol-rubber was in buildings constructed with pre-fabricated concrete elements. Up to the early 1970s PCB was added as plasticiser in these sealants.*
- *Chlorinated paraffins have been used as replacement for PCB as plasticiser in these sealants.*
- *Phthalates, dioctyl phthalate, have also been mentioned as chemical alternatives.*
- *Polysulfide sealants of the Thikol-type has now been replaced by other materials, mainly polyurethans, in the building industry. Plasticisers are not needed in these materials.*
- *Polysulfides used nowadays in isolation glass fabrication does not contain any plasticiser.*

Paints and flooring

- *Paints was the product group of third most importance on a quantitative basis. In 1970 the total annual use of PCB in these products was estimated to 35 metric tonnes. Since the restrictions in 1972 new use ceased.*
- *PCB was primarily used as plasticiser in PVC (polyvinyl chloride) and chlorinated rubber paints and in bottom coats for ships.*
- *Two major paint manufacturers in Sweden have been interviewed about previous use of PCB and substitutes, but neither of these had any knowledge about the issue.*
- *PCB was also used in concentrations up to 20% in the binder in non-slip floors of the Acrydur type. It was substituted with chlorinated paraffins. The Swedish supplier has not been able to specify the plasticisers that are used today.*

Hydraulic fluids

- *In 1970 the total annual use of PCB in hydraulic fluids was estimated to 8-10 metric tonnes. Since the restrictions in 1972 new consumption ceased.*
- *Hydraulic fluids with PCB (20-99%) were mainly used in applications where fire-safety was a main concern. The iron-, steel- and casting industry was identified as important areas of use.*
- *Contacts with steel manufacturing companies and the Swedish Steel Producers Association (Jernkontoret) has not revealed any data about previous applications and substitutes.*
- *Non-chlorinated fire persistent hydraulic fluids are now available, and the Swedish steel company SSAB Tunnplåt AB uses a vegetable based oil (turnip oil) in their Borlänge plant.*

Heat-exchange fluids

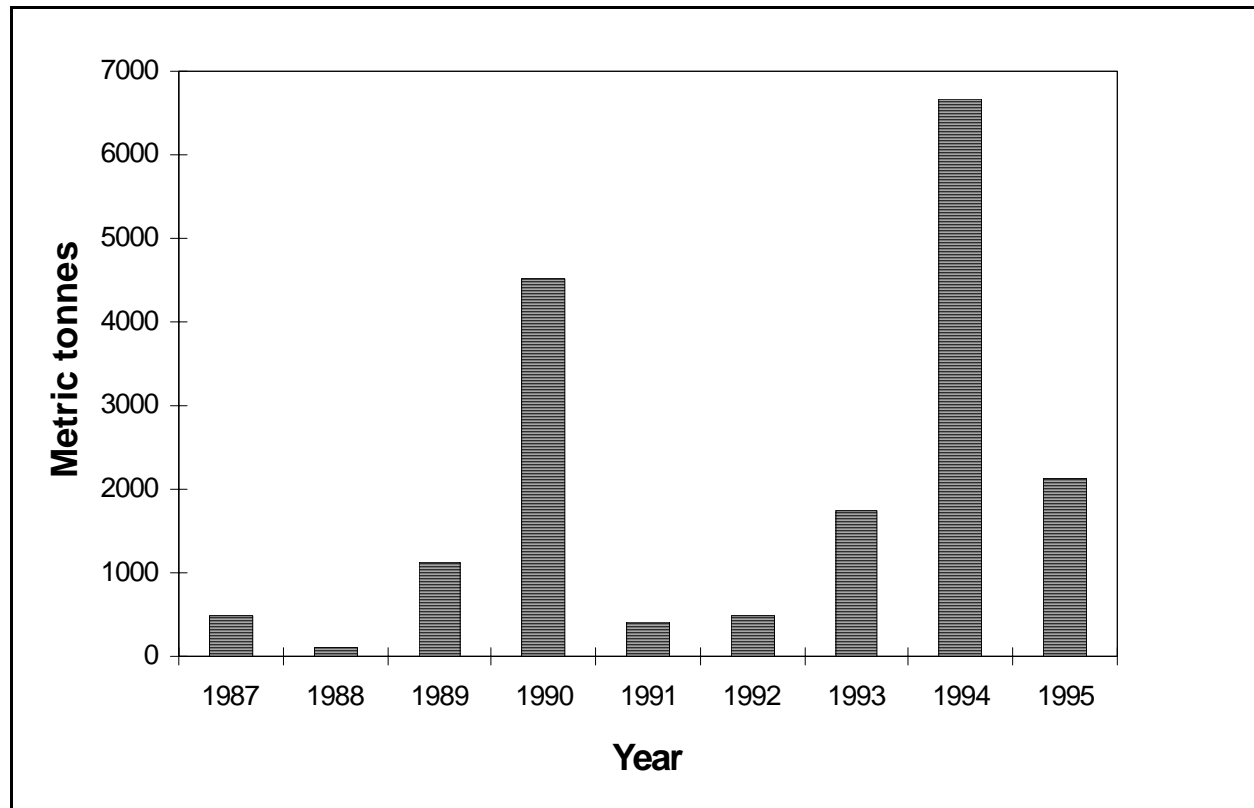
- *In 1970 the installed amount of PCB as heat-exchange fluids was estimated to 8-10 metric tonnes. Since the restrictions in 1972 these fluids have been replaced and new consumption ceased.*
- *Mineral oils and some organics, e.g. biphenyl, diphenyl oxide and terphenyl, are used as high temperature heat transfer fluids today. These chemicals have a broad temperature range of operation, good thermal stabilities and low vapour pressures and are therefore the likely substitutes for PCB.*

Other uses

- *PCB was also used in many other materials and products e.g. non-carbon copying paper and electric cables. The total use in these materials and products was probably of a minor quantitative importance but still cause contamination problems.*
- *PCB used in non-carbon copying paper as a solvent (microencapsulation of dyes) was replaced with a number of different organics such as isopropyl-substituted biphenyls, 1,1-diarylethanes, hydrogenated terphenyls and phthalates.*
- *PCB was used in electric cables as plasticiser and as flame retardant for PVC, but this is not likely to have occurred in the manufacture of cable sheathing in Sweden. Substitutes include chlorinated paraffins and other halogenated organic compounds as well as inorganics like antimony trioxide and aluminium trihydrate.*

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Destruction of PCB containing waste



PCB containing waste received at SAKAB hazardous waste treatment plant in 1987-1995.

Destruction cont.

- *The diagram gives an idea about the amounts of PCB waste that must be handled.*
- *Many industrialised countries have treatment facilities for hazardous waste, including PCB waste.*
- *Replies to our inquiry, to previous participants in our training programme on hazardous waste, indicates however that substantial amounts of PCB is stored in many low-income countries around the globe.*

Chemical and technical alternatives to HCB (hexachlorobenzene)

- HCB is not produced in Sweden, and is not likely to be manufactured anywhere else according to a Swedish report published in 1992.
- In the same report the global emissions of HCB from other sources, such as electrolytic and combustion processes, are estimated to be below 10,000 metric tonnes annually.
- Contradictory data is presented in a paper from Greenpeace International in 1995.
- Our own database searches has not revealed any current production figures.

Use of HCB

- *Pesticide (not a part of the present assignment).*
- *Military pyrotechnics.*
- *Fluxing agent in aluminium smelting.*
- *Porosity control in the manufacture of graphite electrodes.*
- *Peptising agent in the rubber industry*
- *Intermediate in dye manufacture and organic synthesis.*
- *HCB is also formed as a by-product, often in minute quantities, from many industrial chemical processes involving chlorine.*

Military pyrotechnics

- *We have not been able to identify any military use or manufacture of products with HCB in Sweden.*
- *HCB can be used for smoke generating grenades, but in Sweden hexachloroethane is used instead.*

Aluminium smelting

- *Chlorine gas was used as fluxing agent in aluminium smelting during the 1940s and 1950s. One of its functions is to remove magnesium.*
- *Out of safety reasons chlorine gas was substituted with chemicals such as carbon tetrachloride, hexachloroethane and HCB. The consumption amounted to a few kg per metric tonne of aluminium.*
- *By the end of the 1970s there was a switch back to chlorine gas. This is not a drawback in the processing, as long as the workplace safety can be handled.*

Graphite electrode production

- *HCB was used to increase the strength of the graphite electrode and this method was also evaluated by the Swedish manufacturer Haggraf.*
- *Later, when environmental concern arouse regarding HCB, tin chloride was also tested.*
- *During the last years of operation in the 1980s neither of these chemicals were used without quality problems.*
- *HCB is not used today anywhere in Europe for graphite electrode production.*
- *Chemical substitution for HCB in this application is obviously not necessary.*

Rubbers

- *Peptising agents are used to control the molecular weight in rubber production.*
- *According to the literature HCB has been used as a peptising agent in the production of nitroso and styrene rubbers for tires.*
- *We have not found any indication that HCB has been used in the Swedish rubber industry.*

Intermediate in organic synthesis

- *HCB may be used in the production of pentachlorophenol, aromatic fluorocarbons and as an intermediate in other synthesis.*
- *We have not been able to identify any such previous or present use of HCB in the Swedish chemical industry.*

Conclusions

PCB

- *The transfer to new chemical products and technical solutions was accomplished without too many obstacles in most sectors of the industry. Destruction costs for PCB has been a main cost factor.*
- *PCB containing material in buildings and the contamination of PCB in other products is the main concern today. It is obvious that measures to deal with these problems may cost many times more than the actual replacement already accomplished.*
- *Substantial amounts of PCB is now stored in many countries around the globe. Destruction capability and capacity are therefore the keys to a successful and final solution to the PCB problem.*

Conclusions cont.

PCB, alternatives

- *The chemical and technical properties of PCB are to some extent unique, but chemical or technical alternatives were in most cases already available when the Swedish phase-out began in the early 1970s.*
- *The replacement of PCB as dielectric fluid in capacitors is an exception, and in this case the replacement was more complicated and time consuming.*
- *Today competing chemical and technical products without PCB are commercially available in all areas of application, including the power sector. Lack of alternatives is therefore not a limiting factor anymore and can not be an argument against replacement.*
- *The choice between alternatives can instead focus on the technical and environmental qualities of the products in question.*

Conclusions cont.

HCB

- *Minor amounts of HCB (hexachlorobenzene) has been used in some parts of the Swedish industry.*
- *HCB has not been manufactured in Sweden and previous use has been replaced.*
- *However, it seems premature to neglect HCB as an organic micro-pollutant of environmental concern if the international production still is substantial.*