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International HCH & Pesticides Association

The Legacy of Lindane HCH Isomer Production

Main Report

A Global Overview of Residue Management, Formulation and Disposal

by John Vijgen

IHPA
International HCH & Pesticides Association

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Photo: HCH residuals (white hills) deposited next to a railway.

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1. Summary

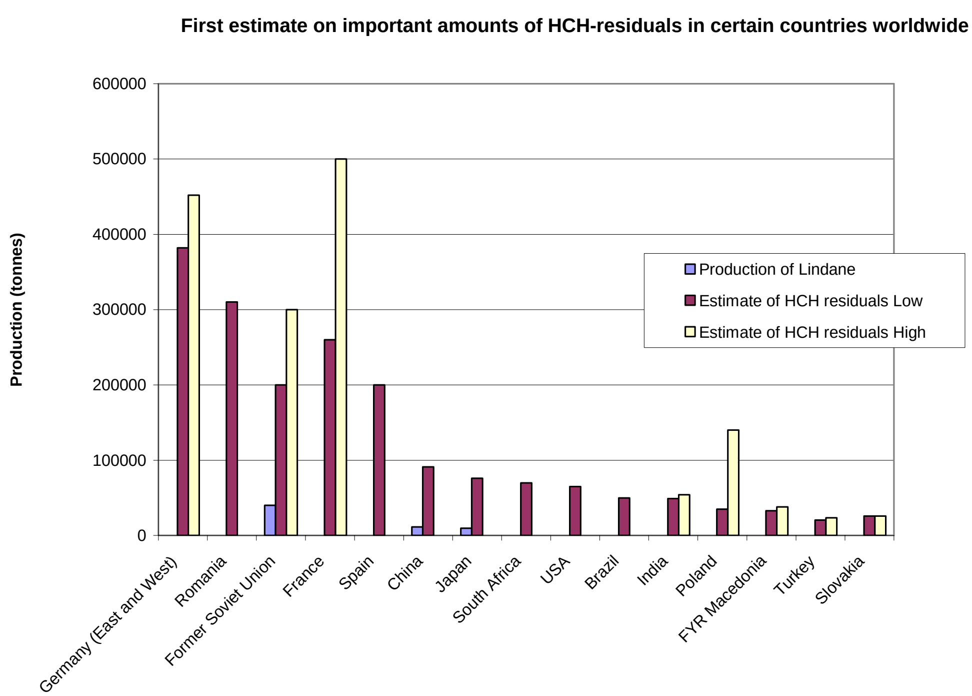
This report describes the various aspects of the production, management, formulation, storage and disposal of hexachlorocyclohexane (HCH) isomers with particular emphasis on the alpha, beta, delta and gamma (Lindane) isomers.

The production of Lindane is inefficient as for each ton of Lindane 8-12 tons of isomers are produced. These isomers have ended mostly as hazardous waste which were wildly and uncontrolled dumped at many places in the world. Although attempts have been made to use these residuals for the production of TCB, HCl and other derivates most of the attempts have been unsuccessful.

A global review has been made, in order to estimate the global amount of HCH-isomers. Two approaches have been used for the estimates.

The first approach is based on the collection of information from production sites, production capacities and produced amounts and information on waste amounts occurring. This is a kind of minimum approach as a number of sites are still unknown and if known the information is, specifically from the 50s and 60s, very difficult to access and often lacking.

By collecting data on production an approach has been made to estimate the possible amounts of residuals. For each ton of Lindane produced around 8 tons of HCH-residuals was estimated. (Further details see Chapter 6).



In Annex III, an overview has been made of all information collected of the various countries. The overview is not claimed to be complete, but comprise a first rough status on the situation. From these numbers first indications on total amounts of HCH-residuals has been established. These assumptions have been gathered in the following Figure and a separate Table in Annex V.

The second approach is based on the collection of usage data and its evaluation by experienced scientists in the field of POPs and HCH monitoring like Breivik, Holoubek, Li and others. Hence, Yi-Fan Li and the author have in close cooperation made a report on the global Lindane use (See Annex IV). In this report global and continental estimates have been made.

The second approach based on usage data as described in Annex IV resulted in the following data comprising an overview of usage data per Continent is indicated.

Lindane usage in different continents from 1950 to 2000.

Continent	**Usage (1 000 tons)**	**%**
Europe	287.16	63.32
Asia	73.20	16.14
America	63.57	14.02
Africa	28.54	6.29
Oceania	1.032	0.23
Total	435.50	100

It is estimated that global Lindane use for agricultural purposes amounts to around 450 000 tons for the period from 1950 to 2000. Additional use of Lindane on livestock, forestry, human health etc. has also to be considered and for the total global use around 600 000 tons has been estimated.

On that base a simple calculation on the total amount of possible residuals (factor 8 assumed for each ton of Lindane produced) 4.8 Mio tons of HCH-residuals could be present world-wide.

In summary both approaches can give a good first estimate on the range of the total HCH-residuals problem varying from 1.7-1.9 Mio to 4.8 Mio tons.

In order to describe the nature and the extent of the problem, some photos have been included below.

Photo: Dumping of HCH-residuals at former Lindane factory in 50s

Photo: Huge piles of HCH-residuals in Eastern Europe (ca. 250 000 tons)

Photo: Former Eastern Germany, HCH residuals (white embankments next to a railway).
Copyright: Picture MDSR

Photo: Large HCH-waste storage Anno 2005 (taken by John Vijgen)

*Photo: HCH residuals in France (*Public Prosecutor of *Canton Basel-Stadt (Switzerland), produced on behalf of the Canton's laboratory of Basel-Stadt, 2.11.1972)*

The nature of the HCH residuals problem is further described by the following two examples:

1.1 The Legacy of "technical" HCH Production in the Basque Country of Spain

For more than forty years, technical HCH[1] was produced by two companies located in the Basque Country in northern central Spain. Starting in 1953, Lindane was extracted from the technical HCH mixture, leaving behind huge amounts of waste HCH isomers. See photo below. The authorities in the Basque Country have calculated that 82 000 tons of waste HCH isomers have been dumped at more than thirty sites in their region.

Dumping of waste isomers stopped in 1987, when the Basque authorities banned this practice. Due to the mixing of waste HCH isomers with soils and other wastes, the authorities estimate that there are between 500 000 and 1 Mio tons of contaminated residues in their region. In addition to environmental problems and unacceptable risks to inhabitants this imposes, the contamination has also in the past,

[1] Terminology for this chemical compound has evolved since its discovery. In this context "technical HCH" means the production mixture of all hexachlorocyclohexane isomers. HCH means all isomers except the gamma-isomer, which is extracted from the Technical HCH to produce the pesticidally active compound Lindane

hindered important development projects in areas near the sites where the isomers were dumped.

The authorities developed a strategy to manage the contamination. Over a period of 10 years they conducted inventories and constructed two secure hazardous waste landfills for the contaminated soils; one for 176 000 tons and the other for 480 000 tons of waste residues and contaminated soil. In addition, a process called the base catalyzed dechlorination (BCD) process was developed to treat 3 500 tons of HCH waste isomers.

Current Status: The Basque Country Region of Spain spent over a decade and an estimated 50 mio EUR to build the two secure landfills for wastes and contaminated soils. Of that total amount 8.4 mio EUR was spent on the base catalyzed dechlorination process.

Lessons learned: The revenues generated from the sale of Lindane may be outweighed by costs associated with the clean up of waste isomers. If the waste HCH isomers had been promptly treated once produced, then contamination may have been minimized and the high costs of remediation and damage to the environment may have been avoided.

Photo of waste HCH isomers being collected inside a former Lindane production facility in Basque Country Region of Spain. (Source: IHOBE, Basque Country)

1.2 The Legacy of "technical" HCH Production in the Netherlands

Technical HCH was produced in the Netherlands, primarily between 1947 and 1952. Technical HCH production occurred at five sites at various times during this period. Very little information is available on the amounts of Technical HCH produced.

In the early 1950s there was a shift in the market place to the use of Lindane rather than Technical HCH. Therefore the production facilities started extracting

Lindane from Technical HCH. The change led to a problem with accumulation and disposal of waste isomers. For every ton of Lindane produced, there are 6-10 tons of unwanted waste HCH isomers that must be disposed of or otherwise managed. Typically, the waste isomers were stored in piles next to the production site, while industry attempted to make use of these by-products.

One of the Dutch Lindane production facilities was located in the eastern part of the Netherlands. The production at this facility resulted in the production of more than 5 500 tons of waste isomers requiring disposal. In 1956, 1 500 tons of HCH isomers were sold by the facility to another producer in the Netherlands for reprocessing. The rest remained stored next to the production site.

In the 1950s and 1960s, a portion of the remaining waste isomers in the storage were illegally collected and mixed with soil for construction purposes and hence dumped at numerous locations. Approximately 290 sites have been identified in a predominantly agricultural area in the eastern region of the Netherlands. In 1974 there was a massive fish kill in a canal next to a site where some of the isomers were stored. This time incident resulted in public outcry and in 1975 the Dutch regional government put pressure on the new owners of the facility to pay for the complete removal of 4 000 tons of waste isomers. These were consequently shipped to Germany for disposal (see photo).

At the end of the 1980s, the Dutch government authorized a large project to manage the regional contamination issue. In 1988, a temporary storage site was established on top of a former landfill site. About 200 000 tons of soil excavated from the most contaminated areas of the region, were stored at this site. At the time no adequate technology was available to treat soil contaminated with waste isomers, and the Dutch government invited companies to develop technologies to treat the isomers and investigated their efficiency. By the beginning of 2002, all waste isomers at the temporary storage site have been treated, and the site is now capped, secured, and used by the farming community for summer festivals.

<u>Current Status:</u> The Dutch government spent approximately 27 mio EUR to clean up soil highly contaminated with waste HCH isomers in the eastern region of the Netherlands. Currently there are additionally 200 000 tons of less contaminated soils remaining that may need remediation in the future.

<u>Lesson Learned:</u> The revenues generated from the sale of Lindane may be outweighed by costs associated with the clean up of the inordinately high volume of waste isomers. If the waste HCH isomers had been secured or promptly treated once produced, then the contamination may have been minimized and the high costs of remediation and damage to the environment may have been avoided.

Photo: taken during the excavation of the waste isomers to be shipped for disposal at German saltmines (taken by K. Tibbe by order of Akzo Zout Chemie Nederland bv)

Photo from the mid-1990s of a temporary storage site for 200 000 tons of soil contaminated with waste HCH isomers.

1.3 Conclusions

Based on the results obtained it can be concluded that the international society is confronted with a huge heritage of toxic materials in the form of by-products from Lindane production. Although the exact the amounts of HCH-residuals are not known, a first estimate is in the range varying from 1.6-1.9 to 4.8 mio tons. The extent of this problem is thereby far beyond present estimates on obsolete pesticides in Africa (55 000 tons) and in the Eastern European region (500 000 tons).

With the exception of certain locations in the Western world, which are "contained and controlled", it can be expected that most locations are causing environmental danger and impacts on the environmental quality have taken place over the last decades, and are still taking place today. Appropriate measures must therefore take place.

During the years the production has rapidly decreased, now leaving only a small number of producing countries (China, India and Romania). Exact information on existing production capacities is missing, but it is estimated that between 1 300 and 2 000 (maximum) tons are produced at present (See also chapter 5.7).

2. Introduction

In the last years an intensive discussion has taken place regarding the dangers and effects of Lindane. It has been largely unknown to the public that the production of Lindane has created huge amounts of waste at the former production sites. These sites and the fate of the waste as well as the consequences for humans and the environment have virtually been forgotten. This report makes a first effort to quantify the extent of the waste and the related problems.

IHPA wants to stress that the objective of the report is NOT to accuse former producers, but merely to draw attention to this large global problem and thereby call for a concerted action of all international stakeholders to work jointly towards sustainable solutions for the legacy of Lindane isomer production.

3. Data Collection

Information available from papers submitted to the seven International HCH and Pesticides Forums held since 1992 has provided a valuable basis for answering the questions related to wastes from the Lindane isomer production.

The information is a first step in compiling a comprehensive list of countries, which are affected by Lindane production.

Furthermore a questionnaire was developed and sent to stakeholders in the Forum network. At first more than 50 organizations, mainly governmental, industry and individual persons were contacted.

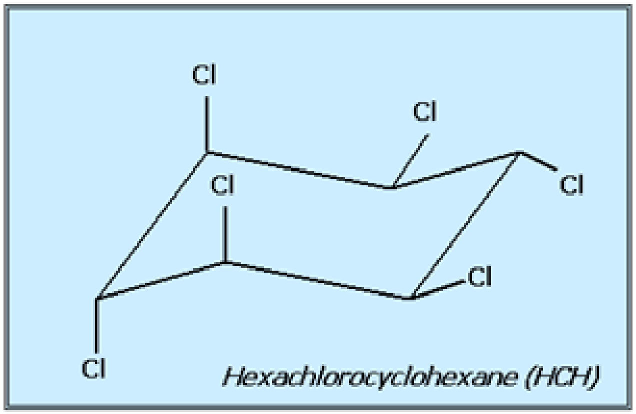
The result of the questionnaire was highly disappointing, as from over 50 recipients only Albania, Australia, Austria, Belgium, Brazil, Hungary, Japan, Pakistan, Poland answered officially. Intensive efforts in France, being one of the major producers, comprising repeated requests and phone-calls to various ministries and regional authorities, were never answered.

Efforts to interview persons and organizations gave similar limited results as the questionnaire, and it is proven that the HCH and Lindane issues are still very sensitive to public and authorities, interpreted as fear of raising unmanageable concerns and reactions.

Extensive help was given by US EPA and the work was facilitated by their extensive database.

A second round addressing 30 governments was made again in October and November 2004 in a last attempt to improve the quality of the information. This effort provided some supplementary information.

Repeated requests to the governments of China and India to obtain information on the ongoing Lindane production have never been answered, and therefore only a rough estimate has been made in this report.



The HCH molecule

4. What is HCH and Lindane

Hexachlorocyclohexane or the abbreviation HCH is identified as a monocyclic chlorinated hydrocarbon. HCH was in 1825 discovered by Faraday, who just had discovered benzene. By reacting benzene with chlorine in bright sunlight, HCH was discovered. The insecticidal properties of HCH were however first mentioned by Bender in a patent paper. HCH was first patented in the 1940s.

Neither Faraday nor the Dutch chemist Van der Linden, who in 1912 isolated the pure gamma-isomer from a HCH mixture, realized the insecticidal potential of the compounds they produced (Amadori, 1993).

Dupire conducted detailed investigations on the insecticidal properties in 1940, and HCH was first used to combat the Colorado beetle (Stoffbericht, 1993). In 1942 Slade proved that gamma-HCH was the sole carrier of the insecticidal properties of technical HCH (Stoffbericht, 1993). HCH has been produced commercially since 1947 in Germany.

The common name of Hexachlorocyclohexane is “benzene hexachloride”, which is incorrect according to the IUPAC rules (Galvan, 1999). Nevertheless it is still widely used, especially in the form of its abbreviation “BHC”, notably in the USA. The name BHC is however approved by the ISO. The Hexachlorocyclohexane compound is called “HCH” by the WHO, but BHC by UN FAO (de Bruin, 1979).

Technical HCH consists mainly of a mixture of various stereo-isomers, which are designated by Greek letters. As mentioned above, only one of these stereo-isomers, gamma-HCH, is the carrier of the insecticidal properties. The other ones are therefore sometimes collectively referred to as “inactive isomers”.

The raw product from the chlorination of benzene contains about 14% gamma-HCH and 86 % of inactive isomers, i.e. 65-70% alpha, 7-10% beta, 14-15% gamma, approximately 7% delta, 1-2% epsilon-HCH, and 1-2% other components. Therefore, in the production of one ton of technical HCH, 140 kg is gamma-HCH and 860 kg is “inactive isomers”. The latter is potentially waste and gamma-HCH and 860 kg is “inactive isomers”. The latter is potentially waste and predestined for disposal.

The basic compound cyclohexane is often represented by a hexagon. The cyclohexane ring does not lie in one plane, because the angles of the bonds tend to be tetrahedral, but takes another configuration forming a “puckered” ring. The main puckered rings are the “boat” and the “chair” (the predominant one) (de Bruin, 1979).

The manufacturing process can be designed in such fashion that part of the inactive isomers are removed. The product thus obtained has a higher content of gamma-isomer, and this product is known as “enriched HCH” or in particular in the USA, as “refined BHC”.

It is possible to extract and purify the active gamma-HCH. If the purity is 99.0% or more it may be called “Lindane”, which is an accepted common name for this substance. Lindane is also called “gamma-HCH, or “gamma BHC” and by FAO “gamma BHC (technical grade)” (de Bruin, 1979).

5. Production processes for HCH

5.1 Introduction to the Marketplace

HCH and Lindane have been rapidly introduced on a large scale due to their universal insecticidal properties. Contrary to DDT, Lindane has a rapid initial impact (knock-down effect), but because of its volatility, it is less persistent than DDT (Amadori, 1993). After the introduction of DDT, the development of HCH and Lindane had promising market opportunities in the search for alternatives to DDT. The only problem was a very typical smell of the HCH product, which is taken up by the treated crop.

5.2 Technical HCH or isomer mixture

Raw materials are benzene and chlorine. Benzene is chlorinated under free radical conditions, and if care is taken that compounds, which could catalyze substitutive chlorination, are absent, nearly all chlorine is “added” to the “double bounds” of the benzene ring.

In practice this reaction is carried out by dissolving chlorine into benzene in such a concentration that there is an excess of benzene. The solution is then passed through a thin-layer photo reactor where it is irradiated by intensive light sources having a high ultraviolet content. Because of the excess of benzene the product formed remains dissolved at higher temperatures. Great care is taken that the reaction mixture at no point can come in contact with materials, which might catalyze substitution, such as iron.

It has to be mentioned that chlorination of benzene will only lead to a complete reaction under specific conditions. Contaminants in benzene (such as thiophene), too high temperatures, presence of undesirable radicals, too low light output are leading to undesirable substitution products such as chlorobenzenes with different degree of chlorination, which have a negative impact on the process to gain pure and also odourless Lindane. During the first years of the production, when the technical HCH was used directly, this did not matter so much. However at the later stage during the Lindane production this played a very important role. First the chlorination under irradiation led to a mix of isomers, which was practically free of chlorobenzenes, and a content of 13-14% gamma HCH. Investigations of competing products under similar analytic methods, confirmed that it was not possible to achieve higher contents.

After washing to remove any untreated chlorine and traces of HCl that might have been formed during the process, the excess benzene is stripped off and re-turned to storage. The molten product from the bottom of the distillation still is run onto a flaker, i.e. a cooled moving metal belt, on which it solidifies (de Bruin, 1979).

Technical and enriched HCH are obsolete products in Western Europe. The very strong and disagreeable smell, which is taken up by the crop, makes technical HCH practically useless for food crops. In Germany the application of technical HCH was terminated due to creation of non-desirable taste in food. In the years 1973 to 1975 it was furthermore replaced by Lindane in the application for wood protection.

5.3 Enriched HCH

To manufacture enriched HCH, the warm reaction mixture is first cooled. Part of the inactive isomers, mainly alpha-HCH crystallizes, and these crystals are re-moved. The excess benzene from the remaining solution is then stripped off, and the molten enriched HCH, which contains typically 40% gamma-isomer, is then flaked. Already in 1979, enriched HCH was no longer manufactured in the EU or in the USA.

5.4 Lindane

Starting material is technical HCH. This is extracted with methanol at 15-25 º C and the un-dissolved inactive isomers are filtered off. From the remaining solu-tion, which contains nearly all the gamma-HCH originally present in the technical product, methanol is distilled off at 80 -100 º C. Upon cooling, gamma-HCH crys-tallizes from the concentrated solution. The methanol and the mother liquors are recycled, and the raw gamma-HCH is further purified by a series of crystallization processes until the required purity has been obtained.

The production of Lindane created huge amounts of isomers waste. The total quantity of waste was about 8 times the Lindane output (Bodenstein, G., 1972), meaning that for each ton of Lindane produced 8 tons of waste has been created. As one can imagine this have large environmental consequences (See Chapter 5.7, 6 and 7).

Other experts mention higher amounts of isomer waste, such as 10 tons (Krum, 1982) and 10 to 12 tons per ton of Lindane produced (Treger, Oct 2004)

It is important to emphasize that the alpha-, beta-, gamma-, delta and epsilon-isomers differ not only in their melting points, but especially in their solubility in the solvents applied. All Lindane producers used these characteristic in their methods for the enrichment of the gamma-HCH for the production of a Lindane which was free of contaminants. During the fractionated crystallization, aromatic and aliphatical solvents partly alternately have been applied. This was done in order to eliminate/separate the crystallized isomers with gamma contents lower than 1% (anonymous, 2004).

It also has to be noted that for the manufacture of the pure gamma HCH, the isolation of the gamma requires a lot of specific know-how, as the quality and output are important economical factors. The right adjustment of the concentration before the first crystallization is vital, as actually the alpha-residuals have the lower solubility in the methanol solution, and therefore it has to suspend the first. Gamma has however a faster crystallization velocity, and therefore comes out of the solution first (Gamma-jump). However one must consider that this adjustment is very sensitive.

In certain cases, the methanol and mother liquids still having 15-25% of Lindane, have been mixed with diesel oil and used in Africa for aerial spraying as treatment against grasshoppers (anonymous, 2004).

An issue which is not clarified but worthwhile to mention is the possible creation of dioxins during the Lindane production. The author is not able - based on the present information - to assess the issue, but has inserted the presently available information from Rippen (12/96) who refers to measurements of original residuals with dioxin contents between 0.8 and 300 ug I-TEQ/kg resp. 0.7 and 430 ug BGA-TEQ/kg. As there are hardly any other measurements made on dioxin contents of HCH-residuals, it is not possible to verify these data further.

5.5 Variations in the production of HCH

A number of manufacturers have applied various variations to the before mentioned production method. Some of these are described in Annex II of this report.

5.6 Use of HCH isomers including Lindane as an intermediary in the production of any other chemical / pesticide products

There have been attempts to re-use the inactive isomers, and this has led to the formation of 1,2,4-trichlorobenzene (75%), which from 1954 and onwards formed the basis for the production of 2,4,5-trichlorophenoxyacetic acid (2-4-5-T) and from 1969 and onwards for the manufacturing of 2,5-Dichloro-4-bromphenol-oxy-phosphoric acid (insecticide Bromophos). 2,4,5-T was used in large amounts by USA in the Vietnam war (anonymous 1990).

A number of the Lindane manufacturers have dehydrohalogenated the inactive isomers by heating and catalysis. This leads to total dehydrohalogenation of HCH under formation of trichlorobenzene, the 1,2,4-isomer (60-66%), 1,2,3-isomer (32-38% and 1,3,5-isomer (ca. 2%) and chlorhydric acid (HCl). The mechanism of this elimination is such that all isomers have more or less the same elimination rate; the difference is no more than a factor 3. There is one exception, however and that is the beta-isomer, which reacts about 7000 times more slowly than the others. This is caused by the specific configuration of beta-HCH. Care must therefore be taken that all beta-HCH is completely dehydrohalogenated. The trichlorobenzene is purified by distillation. In the 1980s it was still a valuable raw material for many other organic chemicals (de Bruin, 1979, IPCS, 1991).

In 1972 Bodenstein quoted that "Lindane manufacturers equipped for the production of these compounds are therefore in a relatively happy situation with regard to their waste problems. In the future it is no longer economically justifiable to bury or burn these waste which have a very high content of a homogeneous organic complex and of chlorine. Efforts to investigate possibilities for usage of trichlorobenzene, which originates as a primary product during processing of Lindane wastes have lately been met with remarkable success." (Ulmann, 1972)

When the Vietnam war ended the market for 2,4,5-T collapsed. The manufacturing of a Lindane quality from which all of the original smell had removed proved to be much more difficult than anticipated, and the second step in the making of 2,4,5-T (conversion to 2,4,5-trichlorphenol, also used for the making of hexachlorophene – Seveso) gave rise to some very severe accidents in which notorious dioxins were formed. The productions therefore had to be stopped. Due to the great number of HCH and Lindane producers in those years prices went down considerably, and one Lindane plant after the other was discontinued. Only a few manufacturers remain.

Most of the described methods have been given up very early and no appropriate application or ingenuous use for the residuals has been found (Stoffbericht, 1993, Amadori, 1993). Consequently, most of the waste products have been dumped over the last 50 years.

A limited number of production plants information as regards to applied industrial processes has been collected. Some of them are described in Annex II.

5.7 Environmental issues

As described below, most of the residuals from the production processes have been dumped over the last 50 years under the state-of-the-art techniques available. In this context it shall be noted that originally the residuals were considered harmless and insoluble in water. No objections have therefore been raised to the practice of using residuals for construction purposes, e.g. filling up unwanted holes or pits wherever they were encountered (Amadori, 1993, Holoubek et al, 2004).

In one case, which does not have to be representative for all cases but may be illustrative for certain situations, some 10-thousands of tons have been deposited at the end of the 50s and the following information from the responsible authorities could be collected:

According to the responsible regional authorities and the construction supervising authorities until 1958 there was no legal order for authorization of fill-up measures that could be applied. Therefore no authorization was needed for the disposal works. On the other hand in legal water permits in 1960-61, a specific requirement was made stating that the bottom of the deposition should be sufficiently above the highest from the neighbouring river influenced groundwater level. A copy of the permit (excluding name of Industry) has been translated and is included in the report (See Annex VIII).

Permits issued at that time were according to the “state of the art” of the science and technology, and based on expert opinion and reports of the various institutes. In 1974 the same water authorities reviewed the situation and required the manufacturer to investigate regularly the groundwater in monitoring and production wells on HCH-isomers.

In the past, a large number of manufacturers of Lindane and/or enriched HCH have deposited the inactive isomers which were removed during the production process. These residues, depending on the method of storage, have often been dispersed by wind in the surrounding environment, and/or leakage to groundwater and/or surface waters and sediments have taken place (Schmidt et al 1997, Fitz, 1999, Schmidt, 1999, Zimmermann et al, 1999). Based on simple calculations of the ratio of gamma-HCH to other HCH residues, the amount of inactive isomers deposited are enormous. World-wide estimates amount to at least several million of tons, and this has created large environmental problems. Annex III is highlighting acknowledged problems.

Today, residues are found at many locations: in the soil of inundated regions, at places where the wind has spread flour-like residues which have been stored in the open air in large heaps, on legal and illegal dumps mixed with household garbage, and in abandoned brown-coal mines and quarries (Amadori, 1993, Lehmann et al, 1999, Schmidt, 1999).

Apart from the residues being the main environmental problem, especially in the early stages of production of HCH and Lindane, problems have furthermore arised from emissions from production plant stacks and from process water being emitted into filtration ponds, directly into rivers or into sewage systems (Grinwis 1993, Amadori 1997, Schulz et al, 1997, Schmidt, 1999, Lehmann et al, 1999, Zimmermann et al, 1999, Fitz, 1999).

5.8 Current production

In the last years the production has rapidly decreased leaving only a small number of producing countries. Exact information is missing as the questionnaires sent to the concerned countries were never returned, - even after repeated efforts. It is however assessed that,

- China has a continuous production of around 1000 tons per year (Annex IV)
- Ghana has been formulating Lindane and stopped in January 2002, but an accumulation of Lindane stocks has been reported (Buffin et al 2002)
- India has a decreasing production. According to Jensen, one major producer had no production of Lindane for the first 9 months of 2004. The Lindane production capacity is 3 t /day, but only 300 kg/day is produced for a period of 6 months/year, because production is demand driven. This means that the plant runs now at 5% of its capacity. A second company is still producing, and the amounts are not known.
- It is not certain if Romania has still a very small production or has stopped the Lindane production, but certain is that the producer still sells either

> from the present left-over stock or from a still ongoing small production. It is also reported that the Romanian producer has its own relatively new incineration plant for destruction of hazardous waste.

Romania, India and China are the only countries in the world still producing Lindane. The production between 1990 and 1995 is 3 222 tons per year. In 1997, the global demand was around 3 000 tons, of which nearly half stemmed from Europe. In spite of the prohibition Europe was the main consumer. Canada and the United States are other large consumers with approximately 700 tons (Ecoportal).

6. Overview historical HCH/Lindane production and occurring HCH-residuals

In order to make an estimate of the extent of the problem of the HCH-residuals two approaches have been followed:

1. Collection of information from production sites, production capacities and produced amounts and information on waste amounts occurring. This approach can be regarded as a minimum approach, as a number of the sites are still unknown and if known, the information (especially from the 1960s) is very difficult to access.

By collecting data on production an approach has been made to estimate the possible amounts of residuals. For the calculation of the residuals a simple estimate has been made using 8 tons as a conversion faction between Lindane produced and HCH-waste emerging. The number has been referred to by many authors, and only the situation the FSU has apparently been different. As explained by Treger in 2004, 10 to 12 tons per ton Lindane has been the Lindan/HCH-residual ratio. The amounts of waste at former production sites herewith speak for themselves, assuming the waste is still there and not transported to e.g. landfill sites.

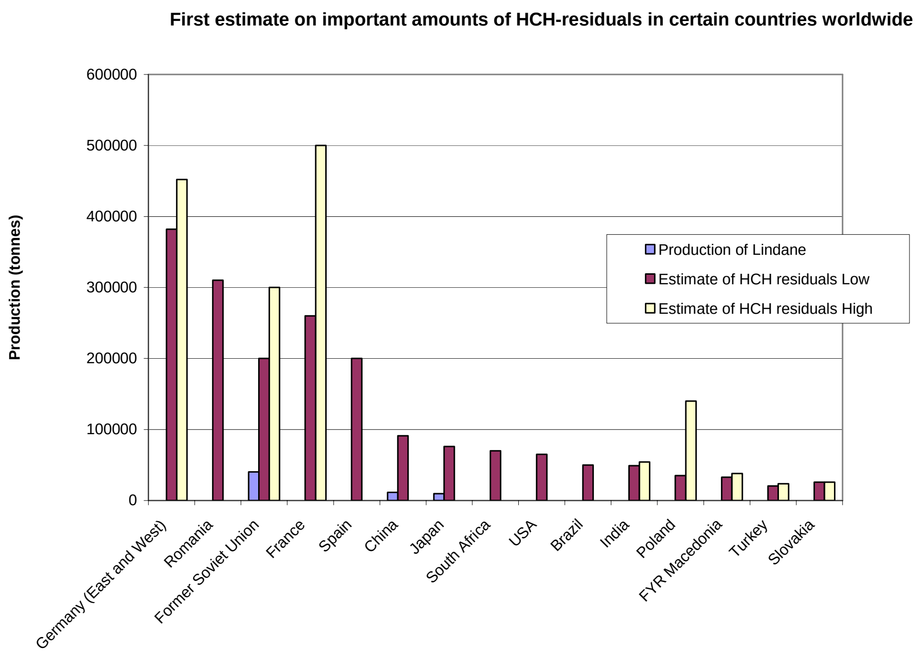
There has been no attempt to calculate amounts of soil contaminated with HCH (BHC). However for 2 cases the consequences and their financial implications of poor management of HCH waste have been described in Chapter 7.

In Annex III, an overview has been made of all information collected of the various countries. The overview is not claimed to be complete, but a first rough indication of the situation. From these numbers first indications on total amounts of HCH-residuals has been established. The assumptions have been gathered in a separate Table in Annex V.

2. Collection of usage data and its evaluation by experienced scientists in the field of POPs and HCH monitoring like Breivik, Holoubek, Li and others. Hence, Yi-Fan Li and the author have in close cooperation made a report on the global Lindane use (See Annex IV). In this report global and continental estimates have been made.

The first approach on residuals resulted in an amount of approximately 1.7 mio tons to 1.9 mio tons. The overview of the most important countries with HCH-residuals is shown in the Figure overleaf.

The second approach based on usage data as described in Annex IV resulted in the following data. An overview of usage data per Continent is indicated.



Lindane usage in different continents from 1950 to 2000.

Continent	**Usage (1 000 t)**	**Percentage**
Europe	287.16	63.32
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It is estimated that global Lindane use for agricultural use amounts to around 450 000 tons for the period from 1950 to 2000. Additional use of Lindane on live-stock, forestry, human health and other purposes has also to be considered and for the total global use around 600 000 tons has been estimated.

On that base a simple calculation on the total amount of possible residuals (factor 8 assumed for each ton of Lindane produced) 4.8 Mio tons of HCH-residuals could be present on worldwide.

As mentioned above, it is estimated that a minimum of 1.7 mio tons to 1.9 mio tons is occurring. The amount can be much higher but due to the difficulty of gathering information, the minimum range must be seen as a base (see Annex III). On the other hand certain amounts of HCH have been used for the production of mainly TCB and others. It could not yet be estimated how much HCH has been used for this purpose, but amounts up to several hundred thousands of tons could well be possible. These amounts would then reduce the potential amount of HCH-residuals. In Annex II examples from Germany, France, Czech Republic, Russia and China have been gathered.

7. Remediation and clean up efforts of former HCH/Lindane production and formulation sites

Some very important cases from The Netherlands and The Basque Country (Spain) are described in the following.

7.1 Lessons Learned from clean-up actions in The Netherlands and in the Basque Country

As an example the experiences of two major problem-owing countries have been briefly described in the following section.

The Netherlands:
At the end of the 1980s in the Eastern part of The Netherlands it became clear that a large number of agriculture areas (till present, a list of around 290 suspected sites has been compiled (VROM Press Release, 20.02.04)) were polluted with HCH-residuals stemming from a neighbouring production facility. From the original waste pile of 5 500 tons, around 4 000 tons was removed by the Dutch government and financed by the owner, as a large fish catastrophe occurred in the adjacent canal, which was attributed to the HCH-residuals. During a number of years considerable amounts of waste were illegally transported and dumped at many clay and sandpits in the surrounding being predominantly an agricultural area. At many of these locations cattle has been grazing and agricultural products had been grown. The issue became thus a regional problem and the government decided to set up a large project to deal with the issue. At the end of the 1980s, a temporary storage site was established where over a number of years around 200 000 tons of soil, being excavated at the most contaminated areas, was stored. As at that time no proper technology was able to treat HCH, the government invited companies to try their technology in order to prove its feasibility. Finally all HCH from the site has been treated at the beginning of 2002.

Till present another 200 000 tons of less contaminated areas have remained untreated.

The total costs for the actions executed are around 27 mio EUR. Due to the fact that is not clear if and when the remaining contaminations will be treated it cannot be concluded what the final costs will be.

Estimating that from the original amount of 5 500 tons of HCH residuals, 4 000 tons being transported to Eastern Germany an amount of around 1 500 tons. 1 500 tons being spread in the region has created a damage of around 27 mio EUR. It may be obvious that a direct elimination and destruction or even encapsulation of these 1 500 tons would have been a fraction of the money spent till present for the region clean-up.

Basque country:
Also the Basque Country in Spain has been devastated with the remnants of 2 former Lindane production plants, which had been left without any control.

After the closure large amounts of HCH-residuals were being swept by into the surrounding of the factory. At the same time large amounts of residuals, a total amount of 82 000 tons had been deposited, at a large number of uncontrolled dumping sites. Finally due to their mixing with soils and other wastes, between 500 000 and 1 mio tons of soils have been contaminated in the region, leaving the Basque country with its biggest environmental problem for the last decade.

Over a period of 10 years the country made inventories, developed their own specific technology for the elimination of HCH waste and built 2 huge landfill sites where these enormous amounts were encapsulated. Costs till present amount to 50 mio EUR.

Both examples show that, if (at least some containment) measures would have been taken during the production large amounts of money could have been saved.

Similar experiences have been made in Aragon in Spain, while France is now facing the first dangers due to large-scale dumpings of HCH residuals are appearing. For example the drinking water supply of a medium-size town in is now threatened.

7.2 Options for future solutions

Comparing to other POPs and hazardous waste problems, the HCH-residuals differ significantly as the extent of the problem is huge and as an environmentally sound disposal by means of destruction will be necessary. However the enormous financial burden needed to achieve this will be a main barrier. On the other hand, the former practice of simple encapsulation is considered far from sustainable and will leave a huge number of time bombs in the global landscape.

A possible strategy could be to bring together a joint effort of international and financial organisations, as e.g. EU, GEF, World Bank, Industry and others, to set up demonstration projects. This could be accompanied by joint-cooperation of scientists, chemical industry and practitioners aiming at bringing the HCH-residuals, consisting largely of chlorine, back into industrial production. This strategy could in fact bring forward economical solutions at the lowest possible price and the guarantee that the residuals will be eliminated permanently.

8. Note from the Author

Assessing former Lindane production and its environmental impacts, we have to understand that even though the environmental consequences have been large, many of the former production facilities have been approved by appropriate Authorities according the state-of-the-art and legal framework of the time.

In countries where environmental concerns were still to be developed, production facilities operated without any or only limited authority requirements.

Annex VI includes anonymised copies of old permits where producers have made agreements with authorities on how to manage disposal of residuals.

The report has mainly used public available materials and in case of sensitive information the sources have been anonymised. All assessments and evaluations are under responsibility of the Author. Annex IV is elaborated by Mr. Yi Fan Li whom I thank for a valuable and interesting cooperation.

I would like to thank all those persons, who have spent their time voluntarily to read through the text, helped with information collection and brought in valuable know how and experience. Only through their effort, I have been able to write this report.

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