

***ALKOR DRAKA IBERICA'S
MANAGEMENT TEAM POSITION PAPER
BARCELONA - SPAIN***

About Environmental issues of PVC

A
n
t
r
o
p

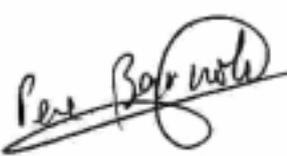
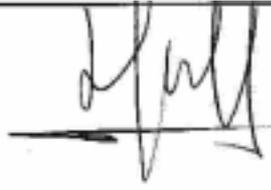
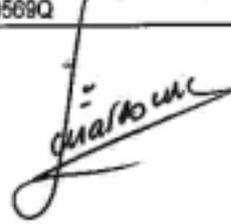
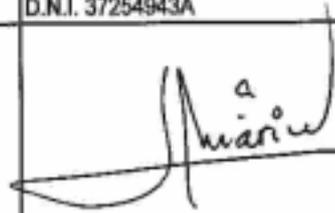
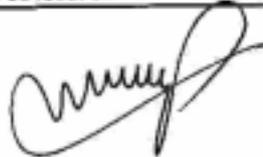
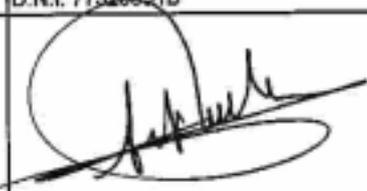
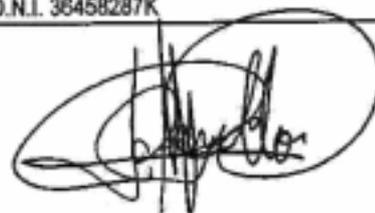
		
Agometa, José María D.N.I. 40764688F	Barnola, Pere D.N.I. 38707168P	Borrell, Joan D.N.I. 07753027A
		
Del-Castillo, Luis D.N.I. 37242850P	España, José Antonio D.N.I. 40350569Q	Freixes, Joan D.N.I. 37254943A
		
Hernández, Esteban D.N.I. 38489671E	Maresma, Francisco D.N.I. 77526651B	Marín, José D.N.I. 46003467V
		
Mayneris, Josep D.N.I. 38703894T	Molins, Antonio D.N.I. 36458287K	Orms, Pere D.N.I. 36501764M
		
Pallas, José Antonio D.N.I. 35034736D	Perello, Jesús María D.N.I. 37698528X	Ris, Abel D.N.I. 38470728P
		
Rodríguez, José Luis D.N.I. 39030188Q	Romero, Armando D.N.I. 18847307A	Romeu, Ricardo D.N.I. 38480437B
		
Santamaria, Juan-Ignacio D.N.I. 38002965V	Truan, Rafael D.N.I. 14270688R	Vizcarra, Ramón D.N.I. 37610961G

TABLE OF CONTENTS

1.	Introduction.....	4
2.	The PVC industry and its products	6
2.1.	<i>PVC material and its applications</i>	6
2.2.	<i>Production processes of PVC and PVC compounds</i>	7
2.3.	<i>Structure and description of the PVC industry</i>	9
3.	The use of additives in PVC	11
3.1.	<i>Range and types of additives</i>	11
3.2.	<i>Stabilisers</i>	11
3.3.	<i>Plasticisers</i>	18
4.	The waste management of PVC.....	23
4.1.	<i>Current situation and future developments</i>	24
4.2.	<i>Mechanical recycling</i>	26
4.3.	<i>Chemical recycling</i>	35
4.4.	<i>Other recycling and recovery technologies including co-incineration</i>	37
4.5.	<i>Incineration</i>	38
4.6.	<i>Landfill</i>	44
5.	Other horizontal aspects on PVC.....	46
6.	Conclusion	47

GREEN PAPER

Environmental issues of PVC

1. INTRODUCTION

The Commission has committed itself to assess the impact of PVC on the environment, including related human health issues, in an integrated approach. In the Proposal for a Directive on end of life vehicles¹, it is stated that “*the Commission will consider the evidence regarding the environmental aspects relating to the presence of PVC in waste streams; on the basis of the evidence, the Commission will review its policy regarding the presence of PVC in waste streams and will come forward with proposals to address problems which may arise in this regard.*” In the Council Common Position on that Proposal², it is further stated that “*the Commission is currently examining the environmental impacts of PVC. The Commission will, on the basis of this work, make proposals as appropriate as to the use of PVC including considerations for vehicles*”. **(a)**

(a). To make some comparisons possible, a so called 'Life Cycle Analysis' (LCA) can be made, which compares different materials, or methods (e.g. reuse against recycling), for the same purpose on a lot of environmental impacts like air- and water pollution, energy use, waste management, etc... Although this method is still under continuous progress of refinement and not yet ideal, if properly carried out, it is the only method where you can compare materials in a scientific way on environmental impact. See Annexe 9

PVC has been at the centre of a controversial debate during much of the last decades. A number of diverging scientific, technical and economic opinions have been expressed on the question of PVC and its effects on human health and the environment. **(b).**

(b) Bruce N. Ames (1990) et al. Division of Biochemistry and Molecular Biology (University of California), see Annexe 4, say:

The administration of chemicals at the maximum tolerated dose (MTD) in standard animal cancer tests is postulated to increase cell division (mitogenesis), which in turn increases

¹ COM (97) 358 final
² EC 39/1999

rates of mutagenesis and thus carcinogenesis. The animal data are consistent with this mechanism, because a high proportion - about half - of all chemicals tested (whether natural or synthetic) are indeed rodent carcinogens. We conclude that at the low doses of most human exposures where cell killing does not occur, the hazards to humans of rodent carcinogens may be much lower than is commonly assumed.

But: The major preventable risk factors for cancer that have been identified thus far are tobacco, dietary imbalances, hormones, infections, and high dose exposures in an occupational setting as has been discussed extensively in the literature. What is chiefly needed is to take seriously the control of the major hazards that have been reliably identified, without diverting attention from these major causes by a succession of highly publicized scares about factors that may well be of little or no importance as causes of human disease. Moreover, we need to make progress towards the identification of at least a few more major causes, and to understand better the hormonal determinants of breast cancer, the viral determinants of cervical cancer, and the dietary determinants of stomach and colon cancer. In this context, the most important contribution that animal studies can offer is insight into possible mechanisms (e.g. more studies on mitogenesis), and into the complex natural world in which we live and in which life expectancy is still increasing.

Some Member States have recommended or adopted measures related to specific aspects of the PVC life cycle. These measures are not identical and some of them may have consequences for the internal market. An integrated approach is therefore necessary to assess the whole life cycle of PVC in order to develop the necessary measures to ensure a high level of protection of human health and the environment as well as the proper functioning of the internal market.

The two objectives of this document are, firstly, to present and assess on a scientific basis, the various environmental issues including related human health aspects that occur during the life cycle of PVC and, secondly, to consider, in view of sustainable development, a number of options to reduce those impacts that need to be addressed. This should serve as a basis for a consultation with stakeholders in order to identify practical solutions to health and environmental issues raised by PVC.

2. THE PVC INDUSTRY AND ITS PRODUCTS

2.1. *PVC material and its applications*

Polyvinyl chloride (PVC) is a synthetic polymer material (or resin), which is built up by the repetitive addition of the monomer vinyl chloride (VCM) with the formula $\text{CH}_2=\text{CHCl}$. PVC has thus the same structure as polyethylene except for the presence of chlorine. The chlorine in PVC represents 57% of the weight of the pure polymer resin. 35% of chlorine from the chloralkali electrolysis eventually ends up in PVC, which thus constitutes the largest single use.

Pure PVC is a rigid material, which is mechanically tough, fairly good weather resistant, water and chemicals resistant, electrically insulating, but relatively unstable to heat and light. Heat and ultraviolet light lead to a loss of chlorine in the form of hydrogen chloride (HCl). This can be avoided through the addition of stabilisers. Stabilisers are often composed of salts of metals like lead, barium, calcium or cadmium, or organotin compounds³.

The mechanical properties of PVC can be modified through the addition of low molecular weight compounds that mix with the polymer matrix. Addition of these so-called plasticisers in various amounts generates materials with an important versatility of properties that has led to the use of PVC in a vast range of applications. The main types of plasticisers used are esters of organic acids, mainly phthalates and adipates⁴.

The main distinction between the numerous applications is between « rigid PVC » (accounting for about two thirds of total use) and « flexible PVC » (accounting for about one third).

The following table presents the main applications of PVC in Europe and the percentage of overall use. The great number of applications is characterised by a wide range of lifetimes ranging from several months to more than 50 years for some construction products. The main applications of PVC in Europe are in the building sector, which accounts for 57% of all uses and where products also have the longest average lifetimes.

Table 1: Main use categories of PVC in Europe (1999)⁵

Use / application	Percentage	Average life-time (years)
Building	57	10 to 50
Packaging	9	1
Furniture	1	17
Other household appliances	18	11
Electric/Electronic	7	21
Automotive	7	12
Others	1	2-10

³ More details and quantities will be discussed in section 3.

⁴ More details and quantities will be discussed in section 3.

⁵ Prognos, Mechanical recycling of PVC wastes, Study for DG XI, January 2000

2.2. *Production processes of PVC and PVC compounds*

Mass production and use of PVC took off in the 1950s and 1960s, whereas the first industrial production started in the 1930s.

World production of PVC today is at more than 20 million tonnes per year - up from 3 million tonnes in 1965 - which corresponds to about one fifth of the total plastic production. PVC is thus one of the most important synthetic materials. Production is mainly located in the US, Western Europe and Asia. Production in Western Europe in 1998 was 5.5 million tonnes (about 26% of the world production). Average growth rates of PVC production in recent years have been between 2 and 10%, with differences per region (higher in Asia, lower in Europe) and per application (higher for rigid, lower for flexible). Prices for virgin PVC are extremely cyclical due to variations in supply and demand and prices for the raw materials.

Two main processes are used to produce PVC: suspension polymerisation of VCM (80%) and emulsion polymerisation (10%).

The production of VCM from ethylene and chlorine, or ethylene and HCl respectively, takes place to a great extent in closed industrial processes. Emissions of chlorine, ethylene, ethylene dichloride, HCl, VCM and chlorinated by-products including dioxines to the working environment or the outdoor environment can occur (air and water). Several of these chemicals are well known toxic substances⁶ and strict emission control measures are therefore necessary. Several Community Directives apply to PVC and VCM production processes⁷.

As in other sectors of the chemical industry, continuous improvements in the production processes have taken place over the years. Best available technologies for the production of VCM and suspension PVC have been established, which have led to the adoption of a number of relevant emission limits in OSPAR Decisions (Convention for the protection of the marine environment of the north-east Atlantic)⁸. A voluntary commitment was already signed in 1995 by the Association of European PVC producers (ECVM). In this industry charter for production of VCM and PVC (suspension), strict emission limits for a number of chemicals were set, which had to be complied with by 1998. Compliance was verified through an independent audit, which attested an overall compliance of 88% with all standards. ECVM has expressed its intention to achieve full compliance as soon as possible. In

⁶ According to Dir. 67/548/EEC, VCM is classified as carcinogenic category 1, EDC as carcinogenic category 2, HCl as corrosive and irritant to the respiratory system,

⁷ Protection of the health of workers exposed to vinyl chloride monomer. Council Directive 78/610/EEC of 29.6.78 (OJ L 197 of 22.7.1978, p. 12)

The provisions of Directive 96/61/EC concerning integrated prevention and reduction of pollution, Directive 76/464/EEC and 86/280/EEC on discharges of certain dangerous substances and Directive 84/360/EEC on the combating of air pollution from industrial plants apply to PVC and VCM production processes. Directive 91/61/EC establishes the application of best available techniques (BAT) as the general rule for emission limits. Information concerning BAT for large volume organic chemicals will be published by the Commission in 2001/2002, as part of the BAT information exchange being organised pursuant to Article 16 (2) of Directive 96/61/EC. It is possible that new emission limits will then be adopted in accordance with Article 18 of the Directive.

⁸ Decisions 98/4 and 98/5 enter into force on 9 February 1999 for new plants and on 1 January 2006 for existing plants. The Commission, in its Proposal for a Council Decision [COM(1999) 190 final], proposes that these Decisions are approved on behalf of the Community

addition to the charter for VCM and suspension PVC production, ECVI signed in 1998 a charter for the production of emulsion PVC with strict emission limits for VCM to air and water, and VCM content of the final polymer. Those companies, which, although already complying with existing national and local regulations or requirements, do not yet comply with the stricter limits of the voluntary charter, committed themselves to do so by 2003. An independent external verification is scheduled for early 2004. ©.

©. How carcinogenic is a PVC-factory?

If you look at the air releases of a chlorine-VCM-PVC-factory, there is (in Europe) less than 100 g of VCM that is emitted per ton of PVC. A factory that makes 500,000 tonnes of PVC gives a maximum emission of about 50 tonnes of VCM per year. This seems to be rather much, but this is in fact only 6 kg/h, widespread over a large factory. This is within the factory below all concentration limits for the workers and outside the factory far below all limits for the inhabitants. Compare this with a truck: a diesel motor emits about 4 kg of soot per ton of fuel. A full loaded truck uses approximately 33 kg of fuel per hour and emits 100 g of soot (into the smallest streets of towns). The carcinogenic potency of soot is in fact 13 times higher than of VCM, but the limits for soot outside factories are 4 times stricter. That means that a large chlorine-VCM-PVC factory is not more carcinogenic for the general public than about one truck...

Raw PVC is processed into finished products in several steps. The addition of the necessary additives is called PVC-compounding. PVC is a thermoplastic material, i.e. upon heating it melts and can then be brought into many forms and shapes through various processes. After cooling, the material regains its original properties. A large number of different methods that use this principle are employed in the transformation of PVC, notably extrusion, calendaring, injection moulding, blow moulding, rotation moulding, thermoforming, and film blowing.

During compounding and further transformation, emissions of a number of dangerous substances and therefore exposure of workers can occur. Compounding of PVC powder and additives (also in powder form or liquid) is usually carried out in closed equipment. Exposure of workers can occur when dosing the compounds in the mixer. This can be eliminated or reduced to a minimum in accordance with the provisions of Council Directive 98/24/EC⁹ on the protection of the health and safety of workers from the risks related to chemical agents at work. (d).

In cases of over-heating during conversion of PVC through heating, forming and cooling, there is a risk of emission of a number of degradation compounds, where

⁹ JO L 131 of 5.5.1998, p. 11

HCl is the most important one. However, the amounts generated are small and have a low potential of adverse effects on the environment. The amounts of VCM rest monomer emitted during the conversion are considered to be very low¹⁰. The emissions of stabilisers and plasticisers are also small if appropriate measures are taken. In general, workforce protection measures have to be taken, in order to comply with the existing legislation on workers and environment protection¹¹.
¹². (d).

(d). The same protection measures than in other Industrial activities...steel , aluminium, paper other plastics as PET, PP, PE, ABS...

2.3. *Structure and description of the PVC industry*

Recent statistics produced by the PVC industry estimate that the total PVC producing and transforming industry in Western Europe comprises more than 21.000 companies with more than 530.000 jobs and a turnover of more than 72 billion €. The industry can be roughly divided into four groups: PVC polymer producers, stabiliser producers, plasticiser producers, and PVC transformers.

PVC polymer is produced by a relatively small number of companies, mostly located in Europe, the US, and Japan. Production capacity in developing countries is growing steadily as well. Annual consumption in Western Europe is slightly higher than production, and since the early 1990s, imports have been higher than exports leading to a small net import of about 230.000 tonnes in 1998 (when domestic production was around 5.5 million tonnes)¹³. Several manufacturers are integrated in the chlorine or petrochemical industry and also produce ethylene, chlorine and VCM monomer. In 1999, there were 10 companies producing VCM and PVC, operating 52 plants on 40 sites in 10 Member States and Norway and employing about 10,000 people.

Eleven European companies (22 plants) produce more than 98% of the stabilisers sold in Europe. They employ around 5.000 people for a production of 160.000 tonnes of stabiliser formulations and a turnover of about 380 million €.

In 1999 there were about 20 companies producing about 1 million tonnes of plasticisers in Europe, the three biggest accounting for about 40% of overall capacity¹⁴. The number is decreasing: smaller companies are abandoning the products or are being bought by big companies. It is estimated that about 6,500 people are employed by this industry. The production trend from 1990 to 1995 was an annual increase of 1.5%. Western Europe is a net exporter of plasticisers.

The transformation of PVC into final products, which requires two or three different manufacturing operations, is essentially done in more than 21,000 small and medium

¹⁰ Danish Environmental Protection Agency, Environmental Project No. 313, Environmental Aspects of PVC, 1995.

¹¹ Danish Environmental Protection Agency, op.cit.

¹² Agence danoise pour la protection de l'environnement, Opus cité.

¹³ Source: ECVM, based on data provided by EUROSTAT.

¹⁴ Information received from the European Council for Plasticisers and Intermediates

sized enterprises. Ninety per cent of these SMEs have less than 100 employees, 5% have between 100 and 500 employees, and 5% have more than 500 employees. Table 2 summarises the information regarding the number of companies, production and employment of the whole PVC industry chain.

Table 2: PVC industry: companies, production, employment¹⁵

Products	Companies	Production (tonnes)	Employment
Total PVC	21,199	7,900,000	530,000
Flexible products	10,321	3,700,000	260,000
Rigid products	10,878	4,200,000	270,000

¹⁵ Information received from the association of European Plastic Converters (EuPC)

3. THE USE OF ADDITIVES IN PVC

3.1. *Range and types of additives.*

In order to provide the range of properties needed in the finished products, PVC polymer is mixed with a number of additives. Depending on the intended application, the composition of the PVC compound (i.e. resin + additives) can vary largely due to the different quantities of additives that are incorporated into the polymer as fillers, stabilisers, lubricants, plasticisers, pigments or flame retardant. A very large number of different formulations of PVC compounds are used to manufacture products. The use of plasticisers (mainly phthalates) and stabilisers in rather high quantities constitutes a specific characteristic of PVC manufacturing compared to other types of plastics. All other types of additives are also used to varying extent with other plastic materials. **(e)**.

(e) All alternatives use almost always additives to give the properties wanted for a specific purpose, PVC not being an exception. Anti-oxydants, pesticides, fungicides, stabilisers, dyes, plasticisers, etc... are used in foods, steel, aluminium, paper, plastics, paints, etc...As long as that doesn't give unacceptable impacts on environment or health, that is not a problem. For instance the polyolefin's need the same quantity of additives to arrive PVC advantages (fire retardants...).

3.2. The most important categories of additives, which need to be assessed scientifically in terms of hazardous characteristics and risks to human health and the environment, are stabilisers, in particular those containing heavy metals such as lead and cadmium, and plasticisers, mainly the phthalates. **(f) (b)**.

f). And why not additives for the aluminium, other plastics , paper, inks, pigments, ...

3.3. *Stabilisers*

Stabilisers are added to the PVC polymer in order to prevent degradation by heat and light. Different types of stabilisers are used and their content in the final product varies according to the technical requirements of the intended application .

Lead stabilisers are currently the most widely used, in particular lead sulphate and lead phosphite. About 112,000 tonnes¹⁶ of lead stabilisers were used in Europe in 1998, containing about 51.000 t of lead metal and representing 70%¹⁷ of the overall stabiliser consumption. With an overall consumption of lead of about 1.6 million

¹⁶ Donnelly, J.P. (1999): Risk Assessment of PVC Stabilisers during Production and the Product Life Cycle. Proceedings of OSPARCOM workshop

¹⁷ European Industry Position Paper on PVC and Stabilisers. ECVM. Document produced by the ECVM in conjunction with ELSA and ORTEP, 1997

tonnes in Europe in 1995¹⁸, lead stabilisers thus account for about 3% of the total consumption. Lead stabilisers are used mainly in pipes, profiles and cables.

Cadmium stabilisers are still being used by some producers as stabilisers in PVC window frames, where their use is still permitted by Community legislation. In Europe, use of cadmium has largely decreased from about 600 t/a in 1992¹⁹ to 100 t/a in 1997 and 50 t/a in 1998. (g).

(g) Cadmium levels in soils have increased because of cadmium emission from metallurgical industries, mining and smelting operations, and incineration of plastic containers and batteries. Addition of sewage sludge and phosphate fertilizers to soil has also contributed to the increased levels of cadmium. Internationella Miljöinstitutet Lund, Sweden September 1997.

Landfills / Wastes sources of cadmium: Since the majority of batteries are disposed of as domestic waste, the hazardous substances are dispersed into the environment via waste incineration plants or landfills. Metals and the Environment, Swedish EPA,(1993).

About 14,500 tonnes of mixed metal solid stabilisers and 16,400 tonnes of liquid stabilisers were used in 1998 in Europe^{20,21}. Among these types of stabilisers, calcium/zinc and barium/zinc systems are the most commonly used.

Organotin compounds represent, with a consumption of 15,000 tonnes²² about 9.3% of the European consumption of stabilisers. Various types of organotins, in particular mixtures of mono- and di-organotin compounds, are used as stabilisers, mostly in rigid packaging film, bottles, roofing, and clear rigid construction sheeting.

According to Council Directive 67/548/EEC on the classification and labelling of dangerous substances as amended²³, most lead compounds including those used in PVC are classified as toxic to reproduction, harmful, dangerous for the environment (ecotoxic) and presenting a danger of cumulative effects. Lead is persistent and certain lead compounds accumulate in certain organisms. (h).

(h) There is no reason to ban (heavy) metal stabilisers in PVC, the environment and health impacts are negligible.

¹⁸ Eurometaux, Annual report 1999.

¹⁹ OSPARCOM workshop on cadmium 1997

²⁰ Figures provided by the European Stabilisers Producers Association (ESPA)

²¹ Donnelly, J.P. (1999): Risk Assessment of PVC Stabilisers during Production and the Product Life Cycle. Proceedings of OSPARCOM workshop

²² Donnelly, J.P. (1999): op.cit.

²³ OJ L 196, 16/08/1967, p. 1. (Lead compounds have been classified through Commission Directive 98/98/EC of 15 December 1998 (25th Adaptation to technical progress), OJ L 355, 30.12.1998 p. 1.

There are other real problems if you compare the impact of lead in PVC with its use in a lot of other purposes.

More significant sources of lead in the aquatic environment derive from leaded petrol, and dumped lead/acid batteries.

Detailed calculations on the environmental impact of lead leaching from PVC sewage waste and vent pipes have been reported by Burn and Schafer (1997), who concluded that the use of lead stabilisers in PVC pipe was not a significant source of lead in sewage effluent nor in the resultant biosolids which are used for fertiliser applications.

Most cadmium compounds are classified according to Council Directive 67/548/EEC as harmful and dangerous for the environment (ecotoxic). Other cadmium compounds are classified as being harmful, toxic or very toxic. Some compounds are also classified as carcinogens (category 2). Cadmium is persistent and certain cadmium compounds accumulate in certain organisms.

Data on the organotin compounds used as stabilisers in PVC show that dioctyl tin is toxic to the immune system. Such immunotoxic effects have not been observed for the other organotin compounds used as PVC stabilisers (dimethyl tin, dodecyl tin, monobutyl tin). Dioctyltin compounds present a possible environmental risk locally in the aquatic environment.

A distinction has to be made between the hazards and risks from chemical substances. At present, no comprehensive risk assessments have been completed on the use of cadmium and lead compounds as stabilisers in PVC products. Under Council Regulation 793/93 of 23 March 1993 on the evaluation and control of the risks of existing substances²⁴, a risk assessment is being finalised on cadmium and cadmium oxide. For lead, the Scientific Committee on Toxicity, Ecotoxicity, and the Environment (CSTEE) has recently adopted an opinion regarding a draft ban on the use of lead in products in Denmark²⁵. The CSTEE is currently working on the issue of risks from the use of lead in general and an opinion, building *inter alia* on a study to be commissioned by the services of the Commission, should be adopted by mid-2001 on both the environmental and human health risks of lead. **.(i)**

(i) Lead.-In Sweden, shotgun pellets and bullets and fishing line sinkers consume nearly three times the amount of lead that is used in PVC (KEMI, 1994). See Annexe 5.

When incinerated, the amount of any metal used as stabiliser in PVC will nearly not change the total amount of heavy metals that has to be washed out of the stack gases.

²⁴ OJ L 84, 05/04/1993, p.1

²⁵ CSTEE opinion on lead – notification 98/595/DK. Opinion expressed at the 15th CSTEE plenary meeting, Brussels, 5th of May 2000.

No leaching has been seen from PVC pipes in soils or landfills, neither any breakdown of rigid PVC itself. But, if we assume that PVC anyway will breakdown in 100,000 years or so, that extra risk of lead leaching would be negligible:

- **Natural lead content of soil: 20-50 mg/kg.**
- **Maximum allowed by different countries: 200-1000 mg/kg**

When the lead content from one meter of 110 mm (4.3") PVC pipe migrates in the adjacent soil that would augment the background lead content of soil with:

- **0.4 mg/kg if only the surface layer breaks down and lead migrates within 0.5 m of the pipe.**
- **7 mg/kg if the entire lead content migrates in the adjacent 1 m³ of soil.**

The migration speed of metals in general is less than 1.5 m in more than 600 years, with sandstone as exception: 4.5 m in 690 years.

The contribution of lead stabilisers leached from PVC products to the level of lead in the environment is relatively small compared to contributions from other sources, and could be eliminated by using less-toxic Ca/Zn stabiliser systems.

As for most heavy metals, cadmium and lead are emitted to the environment by many sources other than their use in products, that contribute significantly more to the dispersion of these heavy metals in the environment, e.g. industrial activities, petrol, fertilisers and sewage sludge. Also, both heavy metals are used in numerous products. The most important uses for lead and cadmium in terms of quantity are in batteries and accumulators. Apart from the use in batteries, PVC stabilisers represent one of the main applications of lead.

The main points of interest for the discussion of the potential risks from lead or cadmium stabilisers in PVC are the following:

- **Lead and cadmium stabilisers in PVC will most probably remain bound in PVC during the use phase and thus will not contribute significantly to exposure. A potential contamination of the environment by the use of lead or cadmium stabilisers in PVC can take place during the production and waste phase.**
- **During the phases of production and of waste treatment, a number of specific protection and prevention measures need to be taken in order to eliminate or**

reduce to a minimum the exposure of workers, in accordance with the EU's legislation on workers health and safety.

- No exact data are available on the contribution of lead stabilisers in PVC to the overall lead load in municipal solid waste being landfilled or incinerated. Various calculations and estimates have led to widely varying results: 1%, 3%, 6%, 10%²⁶ and 28%²⁷. For cadmium it is estimated that about 10% of cadmium in waste incinerators or landfill originate from PVC²⁸.

Few experimental investigations have been carried out on the behaviour in landfills of PVC waste containing lead and cadmium. It can be expected that lead and cadmium compounds would stay encapsulated in rigid PVC waste. For lead in flexible PVC, the situation is less certain. In particular, one study²⁹ has shown a 10% release of lead stabiliser from one type of *flexible* PVC cable containing a mixture of various plasticisers. The contribution of PVC to the lead content found in landfill leachates has not been investigated. **(j)**.

(j). ¿How many studies will be necessary to close the discussions about PVC: 10, 300, 1000?. ¿Have you a methodology?. ¿Do you applied the same approach for the other products?.,

During the incineration of PVC and other wastes, practically all lead and cadmium ends up in the bottom and fly ashes of the incinerators. Due to a high contamination with heavy metals, fly ashes and residues, which are generally mixed, have to be disposed of in controlled landfills. Bottom ashes are either re-used or land filled. A dispersion of heavy metals into the environment therefore cannot be excluded but this seems unlikely in the short term.

Given the scientific uncertainties described above, the effect of substitution of lead or cadmium to the overall environmental emissions cannot be precisely quantified at present. However, it is questionable whether a general substitution of these stabilisers would have a major effect on the overall emissions of lead or cadmium to the environment. On the other hand, according to some analyses, the long term use of lead stabilisers would contribute to an increase of lead concentrations in the environment³⁰ through the waste management phase.

Due to the issues raised by the presence of hazardous substances in waste, the Community waste management strategy³¹ has stated that "*preventive measures might lead to the need for EC-wide rules to limit the presence of heavy metals in products*

²⁶ Bertin Technologies, The influence of PVC on quantity and hazardousness of flue gas residues from incineration, Study for DG XI, April 2000

²⁷ Argus in association with University Rostock, The Behaviour of PVC in Landfill, Study for DG ENV, February 2000.

²⁸ Bertin Technologies, op. cit.

²⁹ Mersiowski et al. Long-Term Behaviour of PVC Products under Soil-Buried and Landfill Conditions, Technical University Hamburg-Harburg, July 1999.

³⁰ Swedish National Chemicals Inspectorate, Additives in PVC, Marking of PVC, report of a Government Commission, 1997

³¹ COM(96)399

or in the production process or ban specific substances, in order to prevent, at later stage, the generation of hazardous waste. This might be the case where neither the reuse nor the recovery or the safe disposal of that substance is an environmentally acceptable solution.”

The protection of man and the environment from risks related to exposure to cadmium has been an issue in Community policy for several years. On 25 January 1988 the Council of the European Communities adopted a Resolution³² on a Community action programme to combat environmental pollution by cadmium. The Council stresses that the uses of cadmium should be limited to cases where suitable alternatives do not exist.

With regard to the use of cadmium in stabilisers for PVC, Directive 91/338/EEC already restricts the use of cadmium as a stabiliser in a number of PVC applications. However, the use of cadmium in PVC profiles is still allowed. Sweden, Austria and the Netherlands have banned all the uses of cadmium in stabilisers and Directive 1999/51/EC provides for a general derogation to Sweden and Austria to apply stricter rules concerning cadmium.

No Community legislation exists on the use of lead compounds as stabilisers. Denmark³³, Sweden³⁴, Austria³⁵ and Germany³⁶, have called for further restrictions, mandatory or voluntary, on the use of lead and cadmium, in particular as stabilisers in PVC.

Moreover, as previously mentioned, a risk assessment is being carried out on cadmium as well as a scientific evaluation on lead by the CSTEE. Decisions on potential risk reduction measures should be based on all existing scientific evaluations. They should be reviewed in the light of new scientific developments, including the results of potential future risk assessments.

Potential substitutes of lead and cadmium are already being used, the main substitutes being calcium-zinc stabilisers and tin organic stabilisers. Calcium/Zinc compounds do have a more advantageous hazard profile than lead and cadmium compounds and are currently not classified as dangerous. Technical reasons (product quality, standards, testing requirements) and economic grounds (higher costs) currently prevent the general substitution of lead stabilisers. It is expected that in the coming years the price difference between lead stabilisers and calcium/zinc stabilisers will decrease due to new production capacities being currently installed. Tin stabilisers have less favourable properties with regard to the environment and humans.

³² OJ C 30, 4. 2. 1988, p. 1.

³³ Notification of Denmark of a draft legislation on the restriction of the use of lead in products

³⁴ Swedish National Chemicals Inspectorate, Additives in PVC, Marking of PVC, report of a Government Commission, 1997

³⁵ Austrian national legislation on the ban of cadmium in PVC

³⁶ Kommission Human-Biomonitoring des Deutschen Umweltbundesamts “Bleireferenz und Human-Biomonitoring-Werte”, 1996

Report of the Bundestag Enquête Kommission “The products of industrial society; Perspectives on sustainability management of material streams”, recommendations regarding PVC, July 1994

In March 2000, the PVC industry (PVC manufacturers, PVC additive producers and PVC converters represented by their European associations (ECVM, ECPI, ESPA, EuPC³⁷) combined to sign a voluntary commitment with the declared objective to “*meet the challenge of sustainable development*”, through adopting “*an integrated approach to deliver the concept of responsible cradle to grave management.*”

The signatories represent more than 98% of PVC polymer, additives and compound producers, and between 60 to 80% of the transformers of window frames and pipes.

The voluntary commitment addresses different impacts of PVC on the environment, and includes a plan for the various actions envisaged: reduction of emissions at the production stage, limitations on the use of cadmium, progressive implementation of recycling targets, as well as financial commitments involving the creation of a fund designed to finance relevant research projects. The main actions envisaged relate to:

- specific obligations, details of which are indicated at appropriate points in this document, covering the period 2000-2010;
- quantitative and progressive objectives for recycling certain waste streams and phasing out cadmium;
- publication of an annual report to be made available to interested parties;
- verification and evaluation of the results by an independent third party, first in 2003, and later in 2008;
- revision of objectives in order to take into account technical and scientific progress as well as the suggestions of interested parties.

The signing and entry into force of this commitment represents an important step which need to be assessed in function of the effectiveness criteria mentioned in the Communication of the Commission to the Council and to the European Parliament concerning agreements in the area of the environment (COM(96)561 final).

The success of this approach will require a constant progression in the efforts realised in the specific areas covered by the agreement and, in particular, reduction in the production and use of certain additives, more ambitious target quantities for recycling, industry’s contribution to added costs of incineration, and a fully operational funding mechanism.

As regards cadmium, industry has committed itself to phase out the use of cadmium stabilisers in 2001. This commitment does not cover the imports of PVC from third countries, which might still contain cadmium.

Concerning the use of lead, the European Stabilisers Producers Association (ESPA) has committed itself to carry out “*initial risk assessments on lead-based stabilisers under the CEFIC and ICCA programmes ‘confidence in chemicals’ by 2004*”.

³⁷

ECVM is the European Council of Vinyl Manufacturers; ECPI the European Council for Plasticisers and Intermediates; ESPA the European Stabilisers Producers Association and EuPC the European Plastics Converters.

ESPA has committed itself to produce yearly statistics showing which stabilisers are purchased by converters. ESPA anticipates that the 120,000 tonnes of lead used in PVC in 1999 will decrease to 80,000 tonnes in 2010 and has stated that it “*will support this trend by developing suitable alternatives*”. The PVC stabiliser industry does not at present take measures to phase out the use of lead in PVC, other than to “*continue to research and develop alternative stabilisers to the lead-based systems*”.

(k).If the rest of the world consider the Scientifics evidences that we show you, Europe industries well be forced to close or delocalise activities. The products will be imported without restrictions outside Europe. We do not understand.

Issues for consideration

The Commission considers, on the basis of the above-mentioned analysis, that the contamination of the environment by lead and cadmium should be avoided as much as possible. The Commission is in favour of a reduction of the use of cadmium and lead as stabilisers in PVC products. A number of measures could be envisaged and should be assessed in the light of their potential environmental and economic implications.

- 1. Legislative phase-out or other risk reduction measures for cadmium and/or lead with the possibility of temporary derogations*
- 2. Implementation of the voluntary commitment of the PVC industry on cadmium*
- 3. Development of further voluntary commitments for lead.*

Question n°1:

Which set of measures should be implemented to address the issue of the use of lead and cadmium in new PVC? According to which timeframe?.

3.4. Plasticisers

Plasticisers are necessary to manufacture flexible PVC products. In Western Europe about one million tonnes of phthalates are produced each year, of which approximately 900,000 tonnes are used to plasticise PVC. In 1997, 93% of the PVC plasticisers were phthalates. The most common phthalates are: bis-2-ethylhexyl phthalate (DEHP), diisodecyl phthalate (DIDP) and diisononyl phthalate (DINP). In recent years the use of DEHP has decreased, while that of DIDP and DINP has increased. The quantities of plasticisers added to the PVC polymer vary depending on required properties. Depending on the final use, plasticiser contents vary between 15 and 60%, with typical ranges for most flexible applications around 35 to 40%.

Other plasticisers, in particular adipates, trimellitates, organophosphates and epoxidised soybean oil can also be used as softeners in PVC. These plasticisers represent only a small fraction of the use of plasticisers. Information on the impact of these plasticisers on the environment and on human health from their use in PVC is limited and further data would need to be acquired for a proper assessment. This

section will therefore concentrate on phthalates, the most important plasticisers in term of quantity and the main plasticisers currently assessed in term of environmental and health risks.

Phthalates are high production volume chemicals, five of which have been put, due to their potential risks to human health and the environment, on the first three priority lists for risk assessment in accordance with Regulation 793/93 on existing substances. The risk assessments on these five substances are carried out by Member State rapporteurs³⁸. The risk assessments on DEHP, DIDP, DINP, DBP have been or are expected to be completed in 2000 and in 2001 for BBP.

DEHP, DINP and DIDP have a potential for bioaccumulation. The risk assessments under Regulation 793/93 have concluded that no concern exists for the accumulation potential of DBP, DINP and DIDP, whereas the potential effects on the environment are still being assessed for DEHP and BBP. Long-chain length phthalates have a low biodegradability under normal conditions of sewage treatment and are only partly degraded in usual leachate and sewage treatment plants, where they accumulate on suspended solids. Certain phthalates as well as their metabolites and degradation products can cause adverse effects on human health (in particular on liver and kidney for DINP and on testicles for DEHP). Potential endocrine disrupting properties are being evaluated.

All the phthalates used in large quantities in PVC applications are ubiquitous in the environment today. Transport in the air and leaching out from certain applications seem to be the major routes by which phthalates enter the environment. Phthalates are found in high concentrations mostly in sediments and in sewage sludge. In Denmark, it has been reported that the concentrations of certain phthalates can exceed the national limit values fixed for the use of sewage sludge in agriculture.

The risks due to the use of phthalates in certain soft PVC toys and childcare articles have been assessed by the Scientific Committee on Toxicity, Ecotoxicity and the Environment (CSTEE). Phthalates leach out from toys and child care articles, when sucked by small children. In its opinions, the Scientific Committee on Toxicity, Ecotoxicity and Environment has expressed its concern about the risks resulting from the exposure of small children to two phthalates (DINP and DEHP) used in these products, due to the potential adverse effects on liver, kidney and testicles. The Commission has adopted on 10 November 1999 a Proposal for a Directive and on 7 December 1999 a Decision under the emergency procedure of Directive 92/59/EC in order to ban of the use of phthalates in certain toys and childcare articles intended to be put in the mouth.

Without waiting for the final stage of the above mentioned risk assessment process, three Member States have already started to draw up risk management strategies based on the global objective to reduce the use of phthalates. The Swedish Government has presented a bill on "Swedish environmental quality objectives"

³⁸ The five phthalates are : Bis(2-ethylhexyl) phthalate (DEHP), rapporteur Sweden; Di-'isononyl''phthalate (DINP), rapporteur France; Di-'isodecyl''phthalate (DIDP), rapporteur France; Dibutylphthalate (DBP), rapporteur the Netherlands; Butyl Benzyl Phthalates (BBP), rapporteur Norway

which aims at reducing the use of the main phthalate DEHP³⁹. The Danish government has adopted an action plan to reduce the use of phthalates by 50% over the next 10 years. The sustainability of flexible PVC has also been assessed by the German Umweltbundesamt⁴⁰, which recommends a phase-out of flexible PVC, for those applications where safer alternatives are available, due to the permanent loss of softeners, in particular phthalates, into the environment. **(I)**

(I). There is the possibility that there may be plasticiser emissions to the external environment during the processing of flexible PVC into finished products. Cadogan (1994) estimated that these constitute 0.02 to 0.07 % of the plasticiser used, and most of these emissions are to air (Christiansen *et al.*,1990).

Nielsen *et al.* (1985) found no dose related health effects following phthalate exposure during PVC processing.

Huber *et al.*(1996) reviewed the information available on the hepatocarcinogenic potential of DEHP in rodents and its implications on human risk, and concluded that an actual threat to humans by DEHP seems rather unlikely.

MD Meek *et al.* (1997), examined the alleged in vitro and in vivo estrogenic activities of eight commercial phthalates esters and concluded: no significant responses were observed with the phthalate esters in any of the in vitro assays. In vivo, none of the eight phthalate esters significantly induced uterine wet weight or vaginal epithelial cell cornification in rats treated with oral doses.

More recently, Scholz, N.J., Menzel and B., Thölmann: SETAC 18th Annual Meeting San Francisco 1997b, reviewed the Biodegradation and Bioaccumulation of Phthalate Esters. Literature results apparently show evidence of high concentrations in biota. The ubiquitous presence of phthalates in the environment and the alleged persistence in biodegradation tests has raised concern about this group of substances. However, recent results did not only demonstrate that phthalates are readily biodegradable but

³⁹ The Swedish Government states that “the use of DEHP and other plasticizers with harmful effects in PVC for outdoor use in coated woven fabrics and coated plate and for corrosion protection in cars should be phased out on a voluntary basis by 2001. Other uses of DEHP as a plasticizer in PVC, with the exception of medical products and drugs, should be phased out on a voluntary basis by 2001.”

⁴⁰ Deutsches Umweltbundesamt, Handlungsfelder und Kriterien für eine vorsorgende nachhaltige Stoffpolitik am Beispiel PVC, 1999

also that they bioaccumulate to very much lesser degree than anticipated.

On February 2000 the International Agency for Research on Cancer (IARC) with a working group of 28 experts from 12 countries met in Lyon to evaluate or re-evaluate the evidence for carcinogenicity of sixteen industrial chemicals, all of them organic compounds. The working group considered that in light of a large body of other relevant data, including evidence from genetically engineered mice, DEHP met criteria previously established for evaluation of such substances (IARC Technical Report No. 24, 1995 Consensus Report). DEHP was downgraded from Group 2B to Group 3, *not classifiable as to carcinogenicity to humans*. In making its overall evaluation of the possible carcinogenicity to humans of DEHP, the working group took into consideration that (a) DEHP produces liver tumours in rats and mice by a non-DNA-reactive mechanism involving peroxisome proliferation; (b) peroxisome proliferation and hepatocellular proliferation have been demonstrated under the conditions of the carcinogenicity studies of DEHP in mice and rats; and (c) peroxisome proliferation has not been documented in human hepatocyte cultures exposed to DEHP nor in the livers of exposed non-human primates. Therefore, the mechanism by which DEHP increases the incidence of hepatocellular tumours in rats and mice is not relevant to humans.

Svenska Dagbladet Page: 2 (editorial) *Subject: Campaign against plastic not serious* Date: July 11, 2000. Convincing scientific documentation that proves that softeners are dangerous to humans does not exist. But rats and mice did develop cancer after having been stuffed with softeners in laboratory tests. To draw conclusions about human health on the basis of these tests is not credible. Bruce Ames, one of the world's most respected cancer scientists has concluded that *almost half of all chemicals that have been tested are poisonous when administered to mice in high dosages*. This goes for both chemicals that are man-made and chemicals that exist naturally. After years of extensive research, the International Agency for Research on Cancer, which is linked to the UN's WHO, has reached the conclusion that the softener DEHP is not carcinogenic to humans. Per-Arne Arvidsson of the Moderate Party was rapporteur on the PVC question within the European Parliament. Other Moderates

decided to follow his restrictive recommendations except for one item – the proposal to implement a “...review of other applications of PVC products especially when it concerns PVC products used within the medical world”.

Cadogan (1996) reviewed the occurrence of phthalates in the environment, as well as their degradation, bioaccumulation and aquatic toxicity. He concluded that the levels of phthalates in the environment are decreasing, and that phthalates pose no significant health risk to humans.

Møller *et al.*, (1995) discuss the environmental effects of phthalate plasticisers in detail, and point out that since DEHP has a global distribution pattern, evaporation is most likely to be the major route to the environment. The phthalate esters are strongly adsorbed by particulate matter, and only very slightly soluble in water. Accordingly, more will be found in sediments and soil than in water. The atmospheric photodegradation of DEHP appears to be rapid, but hydrolysis at neutral pH is very slow. DEHP biodegrades under aerobic conditions, but only very slowly in an anaerobic environment.

A very detailed review of the literature on the environmental fate of phthalate esters was published in 1997 by Staples *et al.* Photodegradation via free radical attack is expected to be the dominant degradation pathway in the atmosphere with predicted half-lives of ca. 1 day for most of the phthalates investigated. For phthalates released to surface waters, soils and sediments, biodegradation is expected to be the dominant degradation mechanism, with half-lives ranging from 1 to 14 days in waters, and from 1 week to several months in soils. Longer half-lives are expected in anaerobic, nutrient-poor, or cold environments.

Sundmark (1995a) reported on the environmental risks from phthalates, and concluded that phthalate emissions from PVC processing or use were not an environmental problem in Norway, where some 10,000 t.p.a. of phthalates are used.

Yushimasa Kurata *et al.* (1997, Mitsubishi Chemical Safety Institute, Japan) studied the sub chronic Toxicity of DEHP in common marmosets for longterm at high dose . No changes such as the increase of liver mass, hepatocyte hypertrophy,

and peroxisome proliferation, which were observed in rodents, were noted.

I. Mersiowsky *et al* (University of Hamburg-Harburg 1999) investigated the long-term behaviour of various PVC products in laboratory scale landfill simulation assays in order to assess whether a degradation of the PVC polymer or a loss of plasticisers occurred. A preliminary assessment of the environmental impact for PVC in landfills was performed, indicating no risk to the environment.

At the present time, there is little evidence, if any, to indicate that phthalates have a significant effect on the environment. There is the additional difficulty of extrapolating the results from animal experimentation to human health risks.

Issues for consideration

The use of phthalates in PVC applications raises issues, described above, which could be addressed through a number of measures, including legislative or voluntary risk reduction measures. These potential measures should be assessed in the light of their environmental and economic implications.

Question n°2:

Should specific measures be taken for the use of phthalates as plasticisers in PVC? If so, when and through which instruments?

4. THE WASTE MANAGEMENT OF PVC

Four studies have been commissioned by the services of the Commission in order to assess the technical aspects of the main waste management options for PVC waste: mechanical recycling⁴¹, chemical recycling⁴², incineration⁴³ and landfilling⁴⁴.

The management of PVC waste should be assessed in the context of the European waste management policy. The Communication from the Commission on the review of the Community strategy for waste management⁴⁵ has confirmed “*the hierarchy of principles that prevention of waste shall remain the first priority, followed by recovery and finally by the safe disposal of waste*”. It is further stated that “*preference should be given, where environmentally sound, to the recovery of material over energy recovery operations. This general rule is based on the fact that material recovery has a greater effect on waste prevention than energy recovery. It*

⁴¹ Prognos, Mechanical recycling of PVC wastes, Study for DG XI, January 2000

⁴² TNO, Chemical recycling of plastics waste (PVC and other resins), Study for DG III, December 1999

⁴³ Bertin Technologies, The influence of PVC on quantity and hazardousness of flue gas residues from incineration, Study for DG XI, April 2000

⁴⁴ Argus in association with University Rostock, The Behaviour of PVC in Landfill, Study for DG ENV, February 2000.

⁴⁵ COM(96) 399 final

will nevertheless be necessary to take into account the environmental, economic, and scientific effects of either option. The evaluation of these effects could lead, in certain cases, to preference being given to the energy recovery option.” In its Resolution⁴⁶ of 24 February 1997, the Council has endorsed this hierarchy of principles.(m)

(m) See Annexe 7 for an overview of the energy use of different materials, based on figures from a scientific institute in The Netherlands.

The energy and crude oil use of PVC is the lowest of all plastics. Steel and aluminium don't use crude oil as raw material, but steel needs coal and aluminium uses also coal and lots of electrical energy. The amount of crude oil should not be overemphasised, all plastics in the world do use only 4% of all crude oil, 94% is directly used for energy, the rest for other purposes.

It is quite normal that the energy and crude oil use of PVC is the lowest, because 57% of PVC comes from salt, an extremely abundant material on earth. Of course you need energy to split salt into chlorine and sodium hydroxyde, but in many cases this is done by combined heat/energy power plants, with very high yield on energy and you have two valuable products for the same energy. Sometimes you even have three products: chlorine is first used to make another product, like polycarbonate (PC) or polyurethane (PU), before it is used to make DCE/VCM/PVC. That means that in such cases the energy use of PVC and of the other products is even lower.

4.1. *Current situation and future developments*

Current situation

The total quantity of PVC waste is a function of PVC consumption. However, due to lifespans, which can reach up to 50 years and more for some applications such as pipes and profiles, there is a “time-lag” between PVC consumption and PVC presence in the waste stream. PVC products reached significant market share in the 1960's. Considering lifespans of about 30 years and more, a significant increase of PVC waste quantities is expected to start around 2010.

Due to the fact that PVC is used in a wide range of applications, data on PVC waste arisings in the EU are uncertain. The most recent and detailed data available on PVC waste quantities are estimations carried out by industry and are based on calculations using production quantities per year and average lifespan of products.

⁴⁶

97/C 76/01

It is estimated that in 1999 the total annual PVC waste quantity was about 4.1 million tonnes in the Community, which can be divided into 3.6 million tonnes of post-consumer PVC waste and 0.5 million tonnes of pre-consumer PVC waste. Pre-consumer wastes are generated during the production of intermediate and final PVC products as well as during the handling and installation of PVC products. The present composition of PVC waste is two thirds flexible PVC and one third rigid PVC.

About one million tonnes of PVC is present in the construction and demolition waste stream. One million tonnes of PVC can be found in the municipal solid waste stream, which comprises wastes collected from households as well as similar wastes collected from commercial and industrial operations. About 700,000 tonnes of PVC packaging waste are generated and about 700,000 tonnes of PVC are found in end of life vehicles and electrical and electronic equipment.

At present the main waste management route in the Community for all types of post-consumer waste is landfilling. This is therefore also the case for post-consumer PVC waste. About 2.6 to 2.9 million tonnes of PVC waste are currently landfilled every year. Mechanical recycling is applied to only a small fraction of the post-consumer waste (about 100,000 tonnes). Approximately 600,000 tonnes of PVC are incinerated per year in the Community.

Future developments: baseline scenario

This scenario⁴⁷ describes the situation with regard to the quantities of PVC waste and the main waste management routes expected in the years 2000, 2010 and 2020, with the assumption that no PVC-specific measures will be taken except for those legal, administrative and voluntary measures in force or in preparation at Community and at national levels. It is assumed under this scenario that existing and future Directives on landfilling, incineration, packaging, end of life vehicles and electric and electronic waste will be implemented.

The key element in the management of post-consumer PVC waste is the expected increase in PVC waste quantities. Predictions of future PVC waste arisings are subject to uncertainties but it is expected that the volume of PVC waste will increase significantly by 30% in 2010 and by 80% in 2020, in particular due to the important increase of waste quantities from long lifespan products. Post-consumer wastes will increase from about 3.6 million tonnes at present to about 4.7 million tonnes in 2010 and 6.2 million tonnes in 2020. PVC pre-consumer wastes will increase from 0.5 to 0.9 million tonnes.

Compared to the current situation, it is expected that the composition of PVC post-consumer waste arisings by product group will change. The share of PVC building waste and waste from household and commercial products will increase, whereas the contribution of packaging is expected to decrease significantly. The proportion of flexible PVC waste will also decrease.

In the context of the baseline PVC waste scenario, changes in waste management legislation and practices are expected to have the following effects:

⁴⁷ Prognos, op. cit.

- The landfill Directive will bring some important changes to waste management mainly due to the expected increasing landfill costs. Some Member States, in particular Germany, Austria, the Netherlands and Denmark have announced national policies for banning the landfilling of untreated organic wastes, including plastics, with the exception of PVC waste for Denmark.
- Recycling is expected to increase significantly over the next decades, in particular for those waste streams for which recycling targets will be set. Energy recovery is also expected to increase for waste, which cannot be recycled.

How this will affect the treatment of PVC waste will be discussed in more detail in the following sections on the main waste management options.

4.2. Mechanical recycling

Mechanical recycling refers to recycling processes where PVC waste is treated only mechanically, mainly through shredding, sieving, and grinding. The resulting recyclates (in powder form) can be processed into new products. Depending on the degree of contamination and the composition of the collected material, the quality of the PVC recyclates can vary a lot. The quality of the recyclates determines the degree, to which virgin material can be substituted by recyclates: “high-quality” recyclates can be re-used in the same types of PVC applications, whereas “low-quality” recyclates from mixed waste fractions can only be “down-cycled” into products usually made from other material.

Recycling of post-consumer waste is still at a low level in the EU and the quantities recycled represent less than 3% of the total⁴⁸. About 100,000 tonnes are currently recycled per year in the EU. A major part of the post-consumer PVC waste recycling (about 70%) is down-cycling in the area of cable wastes (about 38,000 tonnes) and packaging waste (about 19,000 tonnes).

High-quality mechanical recycling for post-consumer wastes is still in a preliminary stage and exists only for few product groups and with low quantities (about 3.600 tonnes of rigid profiles, 5,500 tonnes of PVC pipes and 550 tonnes of flooring).

There appears to be no Member States where the recycling rate of post-consumer waste is significantly higher than the EU average. In some countries, collection schemes have been established, usually through voluntary approaches. However, the recycling rate is usually below 5% and is largely based on the down-cycling of packaging and cables.

As far as pre-consumer wastes are concerned, about 420,000 tonnes of PVC were recycled in 1998, representing about 85% of pre-consumer PVC waste arising. Mechanical recycling of pre-consumer waste exists in all Member States and can be considered as a profitable economic activity.

A number of life cycle assessments⁴⁹ on some specific PVC products have shown that mechanical recycling provides an environmental advantage for production

⁴⁸ Prognos, op. cit.

⁴⁹ Prognos, op. cit..

waste, cut-offs and post-consumer PVC waste, which can be separated. The environmental advantages of the down-cycling of mixed plastics for the production of products which substitute concrete, wood or other non-plastic applications are less certain. **(n)**

(n) There seems to be no commercially viable alternative to the use of plasticised PVC in electrical cable insulation. As pointed out by Hogan (1983), PVC provides a low cost material for low voltage insulation. This results from its low material cost and its fast extrusion speed. It also has excellent mechanical properties and abrasion resistance at normal operating temperatures, and excellent moisture, chemical, flame and weathering resistance.

KEMI (1996) suggest that polyethylene and polypropylene can constitute alternatives to PVC for cable insulation, albeit at 3-5 times the cost. However, these materials are not self-extinguishing, and increase the cable rigidity. In so doing, the likelihood of cracking during installation and use is increased.

The alternatives to rigid PVC in pipe and fittings in the building sector are concrete, polyethylene, polypropylene, ductile iron, vitreous clay, and fibreglass reinforced plastics. The choice of pipe is determined by price, design pressure, and the effects of chemical and biological activity. In acid soils, for example, cement and iron-based pipes can corrode. Polyolefins have lower melting temperatures, and heavy pipe materials are worse from a work-environment point of view. Detailed life cycle analyses (LCA) for vitreous clay and concrete products could not be found in the literature. An extensive review of LCA studies on PVC packaging has been reported by Smit (1994).

An LCA by van den Berg *et al.* (1996) compared iron, polyethylene and PVC piping for low pressure gas distribution systems in Holland.

Using a cradle-to-grave approach, their conclusions were that in terms of all of these environmental themes, PVC was better than or equal to the other materials considered.

The other LCA located in the course of the present study was that by Finnveden *et al.* (1996), which dealt with concrete, cast iron, polyolefin and PVC pipes. Due to a lack of reliability

in the basic information and a lack of comparable data for all pipe materials, the authors were unable to draw any sound conclusions. In the majority of assessment methods, PVC pipe ended up between the other alternatives (KEMI, 1996).

Although little detailed comparative, conclusive LCA information is available, it does not seem that PVC in its major building product applications has significantly more effect on the environment than alternative materials.

All alternatives for PVC, give pollution during production, transport, recycling and/or incineration. In many cases, they use more energy and more scarce raw materials than PVC and in many cases they give more important air and water emissions than the production, transport, use, recycling, incineration and accidental fires of PVC.

However, the presence of additives classified as hazardous, such as lead, cadmium and PCBs, in large PVC waste streams raises specific issues for their potential recycling. The recycling of PVC waste containing heavy metals results in a dilution of these substances in a greater quantity of PVC, since it is necessary to add virgin material. The heavy metals are not directly released into the environment during the recycling process and the renewed service life. The recycling of PVC material containing these heavy metals postpones the final disposal to a later stage. Although it could be difficult to control the use of recycled PVC containing lead and cadmium, for technical reasons it is unlikely that PVC waste from various applications would be recycled together in case of high quality recycling. Due to the product-specific additives formulations, recyclers would prefer recycling into similar applications. Additional measures, such as restrictions of the uncontrolled sale of recyclates containing heavy metals or its down-cycling, could be envisaged. A prohibition of the recycling of PVC waste containing heavy metals would eliminate the mechanical recycling of post-consumer PVC wastes from building applications - the waste stream with the highest potential for high-quality recycling - as they virtually all contain lead or cadmium. It should be noted that, except for Denmark, Member States, which have banned the use of cadmium as stabilisers, allow the recycling of PVC waste containing cadmium. The problem of PCBs in PVC cable waste has been addressed in Directive EC/96/59 on the disposal of PCB and PCT, which provides that cables containing more than 50 ppm of PCBs are considered as PCBs and have therefore to be decontaminated or disposed of in accordance with the provisions established under this Directive. **(o)**

(o) PVC is a very versatile material, it is used in ten thousands of applications, so it is nearly impossible to give a complete comparison for all these applications. Rigid PVC is used as building material in window frames, waste water pipes, etc..., etc... It doesn't rust nor rot and it has a very long lifespan. PVC drinking water supplies were tested after 37 years underground: No difference was found, compared with

new pipes. So, for this application it will have a lifetime of more than a hundred years.

Soft PVC sheet can be applied to strengthen the dikes in The Netherlands at a much lower price, at much higher speed and with a four times longer lifespan - up to 200 years - than steel reinforcements. Electrical cables, isolated with PVC can withstand sunlight and all outside weather conditions for tens of years, while the alternatives had to be renewed after eight years, because of dangerous short circuits in rain, caused by cracked polymers. So we can go on for many lines...

Of course, all good properties can turn into bad, if that is on behalf of the environment. We have seen no big problems for PVC when produced, there are even less when in use. PVC needs practically no maintenance. This was one of the reasons for the Gothenburg (Sweden) hospitals to choose for vinyl instead of linoleum floorings. Although the production of linoleum uses near only renewable raw materials (linseed oil), it is less favorable in use: before the application of vinyl they had to use 6 tons of cleaning agents per year, after that, 0.5 tons and they will reduce it to near zero.

The same is true for wooden window frames: Wood is a 100% renewable raw material, but, besides production emissions (2/3 of the wood ends as production waste, which is mainly burned!), wooden window frames have to be painted, or treated. This makes the use of wood and PVC for window frames equally good (or bad) for the environment.

PVC was accused to have many negative aspects for health and environment. We do not agree:

PVC softeners, like phtalates, are linked to cancer and estrogenic properties. That may be the case, if you give massive doses to rats - up to an equivalent of 500 g/day for an adult human - but after hundreds of tests, not for primates (apes and humans), because differences in metabolism. PVC, including phtalates, is the only thoroughly tested plastic which is permitted for bloodbags. In fact, you ingest near 0.1 g of phtalates per year by using PVC, the toxic equivalent of drinking 0.01 g of alcohol.. per year.

PVC was accused to give remaining VCM in food and water, which can cause cancer, it turned out that water from PVC-bottles gives (an insignificant) 1.9% less cancer, compared with water from glass bottles in a mega-experiment. PVC was accused to be the origin of sudden childrens dead, it turned out to be the contrary: one of the many possible causes is the use of matrasses which catch a lot of dust. PVC and other plastic layers prevent that.

PVC was accused to give irritations and allergic reactions, it turned out to be the contrary: a lot of hospitals, especially build for allergy patients are using PVC as building material, because a lot of natural materials like certain types of wood and not well treated natural rubber (latex) can give severe allergic reactions.

PVC can have a negative influence on the recycling of other plastics in mixed plastic waste. When PVC is processed with other plastics, such as in the packaging waste stream, the processing temperature is limited to the range of PVC-processing, which is a relatively low range compared to other plastics. Due to similar densities, polyethylene terephthalate (PET) and PVC waste are difficult to separate and the presence of PVC puts additional costs on some PET recycling schemes such as the PET bottles. In some cases, the PVC industry has recognised this issue and contributes to this additional cost. **(p)**.

(p) When we look at the air- and water pollution, we need some normation to make different kinds of pollution comparable. In almost all LCA's they use the method of 'critical volumes', that is the volume of air or water you need to dilute the measured amount from the emission of a certain polluter to below the legal limits in force.

All critical volumes for all individual emissions are then added together to give the total critical volume of a product. In this way, the total air and water pollution of different emissions and products can be compared.

In fact, the produced figures count for the amount *and* for the toxicity of the emission: more or more toxic pollutants need more air or water to be diluted until under the normation, that gives a higher critical volume.

There are some drawbacks on this method: legal limits can differ very much from country to country, based on differences in assumed (eco)toxicologic properties.

Sometimes limits are based on political grounds and not on toxicological grounds. But if properly used, this method gives a rough idea, where the problems are.

From the same source as for energy use we give in Annexe 8 the figures for critical volumes to air and water by production of one kg of a material. These figures are in fact not complete and outdated. Not complete, because the energy emissions were not included. Why, that was not clear, until we saw the difference: electrical power for salt-chlorine-PVC plants is mainly produced by the use of natural gas, while most refineries use their own waste. This gives for the biggest refinery in The Netherlands already 1,200 tonnes of soot per year for a work up of 21 million tonnes of crude oil. As you know the difference in carcinogenity (and persistence!) between soot and the most important pollutants from a PVC factory: VCM and DCE, taking into account the energy production would give a lot more air pollution for the 100% oil based products!.

Also outdated, because the DCE-VCM-PVC factories in The Netherlands since 1991 have installed a lot of new equipment to reduce the air emissions of DCE with a tenfold and of VCM with a fivefold, while not much changed at the biggest refinery...

Of course, here too it is important, how much material you need for a certain application and for some applications more important (e.g. aluminium and plastics in cars), how much - or less - pollution is coming from the use of these products.

As in the case of other materials, the recycling of PVC is also limited by the overall recycling costs. Economic profitability is reached when the net recycling costs (i.e. the overall costs for collection, separation and processing minus the revenues from sale of the recyclates) are lower than the prices for alternative waste management routes for related PVC wastes. If economic profitability cannot be reached, the recycling of PVC waste will not take place under free market conditions, unless there are legal obligations or voluntary measures enforcing or promoting the recycling of PVC. Collection represents the major bottleneck regarding the availability of waste and costs.

High-quality recycling of post-consumer waste (in particular pipes, profiles, flooring) is at present not profitable, as the net recycling costs are well above the costs for landfilling or incineration. In addition, there are further costs for the waste owner for separation of wastes at the construction sites.

Low-quality recycling of post-consumer PVC waste, such as for packaging waste, is not economically profitable. Economic profitability is not likely to be reached for other waste streams suitable for low-quality recycling, such as office supplies, printing films. Cable insulation is the only post-consumer waste, which can be recycled at competitive costs, due to the presence of valuable metals, such as copper.

In conclusion, the recycling of pre-consumer waste can, in principle, be profitable. However, post-consumer PVC waste recycling is far from reaching economic competitiveness. In addition to the establishment of recycling schemes with a broad regional coverage, financial incentives are necessary for a separate collection of PVC wastes. Also, PVC is often present as a component in composite materials, or mixed in contaminated waste streams, which require specific collection and sorting operations. The price of virgin material, which is highly volatile (between 0.5 and 0.8 €/kg), has a large influence on the profitability of recycling. In addition, the prices for landfilling and incineration are low. Nevertheless, in the coming years, it can be expected that the economic conditions for recycling are likely to improve, in particular due to the increasing costs for landfilling and incineration. (q).

(q) Møller *et al.* (1995) reviewed the limited number of studies that have been carried out on PVC waste management, and pointed out that the leaching of heavy metals from PVC is small compared to the amount of heavy metals present as a result of the corrosion of the metal contained in ordinary municipal waste. PVC is a very resistant material both to water and to most chemicals, and its degradation in landfills will be very slow.

One study found that no degradation had occurred in PVC that had been buried for 25 years. (Hjertberg and Gevert, 1995.).

Hjertberg (1995), in a theoretical study on the degradation of PVC, concluded that rigid PVC will not degrade at a practically important rate, and plasticised PVC will degrade slowly with the PVC chain remaining intact.

Ejlertson and Svensson (1995) commented on the paucity of information on the subject of PVC degradation in landfills, and could not find any report of organochlorine compound formation from that source. There is the possibility that landfill leachate may contain traces of plasticisers. However, Lundberg *et al.* (1992) point out that “because of their high affinity for organic soil particles and their low water solubility this is not likely to be a major route into the environment.”

The Swedish EPA (Naturvårdsverket, 1996) states that current knowledge indicates that emissions from land-filled

PVC sources do not constitute a major environmental problem.

Future developments and policy orientations

In the baseline scenario about 9% of the total PVC waste could be mechanically recycled in 2010 and 2020, representing about 400,000 tonnes of PVC waste in 2010 and 550,000 tonnes in 2020⁵⁰. The recycling rates vary according to the specific waste streams considered.

- For high quality recycling, the following recycling rates could be reached for construction and demolition PVC wastes: about 25% for pipes, about 40% for window profiles and about 12% for flooring.
- For low-quality recycling, the recycling rates would be about 65% for cables present in the construction and demolition waste stream, about 30% for waste from electronic and electronic equipment and about 20% for packaging.
- Other waste streams such as household and commercial wastes are not likely to be recycled according to the assumptions made in this scenario.

Compared to this baseline scenario, maximum recycling potentials have been estimated⁵¹, which represent the PVC quantities, which can be recycled, taking into account the technical and economic limits of PVC recycling. According to this scenario, the potential for post-consumer waste is about 800,000 tonnes in 2010 and 1.2 millions tonnes in 2020, representing a recycling rate of about 18%. This means that the mechanical recycling of PVC waste could contribute only to the management of about one fifth of PVC post-consumer waste. Other waste management routes will therefore remain important.

In its commitment of March 2000, the PVC industry has made quantified commitments regarding the mechanical recycling of pipes, fittings and window frames. For pipes, the commitment is “to recycle at least 50% of the collected available quantity of pipes and fitting waste by 2005”. For window profiles, the commitment is “to recycle at least 50% of the collectable available quantity of window profiles waste by 2005”. These targets are not based on waste generated but on waste collected. According to the PVC industry, in 2005 the annually recycled quantities are estimated as follows: 15,000 tonnes for pipes and 15,000 tonnes for window profiles. However, the following large PVC waste streams, which could be used for high quality recycling, are not covered by the commitment: rigid profiles other than window profiles (about 240,000 tonnes in 2005), flooring calandered (about 240,000 tonnes in 2005) and flexible profiles and hoses (about 120,000 tonnes in 2005). Nonetheless, in its commitment, the PVC industry has stated that in the case of other potential applications such as PVC cables, flooring and roofing membranes, “*more work is needed in developing suitable logistics, technologies and reuse applications*”.

⁵⁰ Prognos, op. cit.

⁵¹ Prognos, op. cit.

In addition, the industry has committed itself to supporting these developments including the achievement of higher mechanical recycling targets “as soon as possible.”.

Issues for consideration:

The Commission considers, on the basis of the above-mentioned analysis and given the present low recycling rate, that recycling of PVC should be increased. This could be achieved through a range of measures, which could be used separately or in combination. Their potential environmental and economic implications should be assessed. These potential measures include:

- 1. Mandatory collection and recycling targets for some relevant PVC waste streams***
- 2. Voluntary commitment of the industry to improve and finance, totally or partially, the collection and the recycling of some relevant PVC waste streams***
- 3. Recommendations to Member States with the objective of establishing and developing separate collection of PVC waste and other demolition waste***
- 4. Development of appropriate standards that allow the use of recycled PVC materials***
- 5. Marking of plastic products as a useful tool to facilitate the separation of PVC waste from the general waste stream and development of other methods for plastic identification and sorting.***
- 6. Development of innovative recycling processes for certain post-consumer PVC waste***

Question n°3:

Which set of measures would be the most effective to reach the objective of an increase of PVC recycling?

The recycling of PVC waste containing heavy metals raises specific issues due to the potential dilution of heavy metals into new and possibly wider range of products. Some potential measures could be envisaged to address these issues. These measures should be assessed in the light of their potential environmental and economic implications. They include:

- 1. Legislative instruments to restrict the mechanical recycling of PVC waste containing lead and cadmium***
- 2. Specific conditions for this recycling, such as recycling in the same type of application, the control of the placing on the market of recyclates, the marking of the recycled products and the control of the use of heavy metals***
- 3. No specific conditions for this recycling.***

Question n°4:

Should specific measures be attached to the mechanical recycling of PVC waste containing lead and cadmium? If so, which ones?

4.3. *Chemical recycling*

Chemical recycling denotes a number of processes, by which the polymer molecules that constitute plastic materials are broken up into smaller molecules. These can either be monomers that can be used directly to produce new polymers or other substances that can be used elsewhere as starting materials in processes of the basic chemical industry.

In the case of PVC, in addition to the breaking up of the backbone of the polymer molecules, the chlorine attached to the chains is set free in the form of hydrogen chloride (HCl). Depending on process technology, HCl can be re-used after purification or has to be neutralised to form various products that either can be used or have to be disposed of.

In practice, during the last 5 years, there have been only a limited number of initiatives that have resulted in the construction of industrial plants, or may lead to the realisation of such plants in the near future. Chemical recycling processes can be categorised according to their capacity to handle waste with high or low chlorine content, 4 to 5% being the maximum PVC content that can be handled by technologies for low chlorine content. Of the three operational purpose-built chemical recycling plants for waste with low chlorine content, two have been shut down due to economic and supply reasons. For PVC-rich waste there is currently one incineration-based technology with HCl recovery operational, two pilots will become operational in the coming years.

According to several life cycle assessments (LCA), some chemical recycling processes would score considerably better with regards to energy use and global warming than municipal solid waste incineration and landfilling. In addition, in some processes chlorine is recovered, thus avoiding new production through energy-intensive chloralkali-electrolysis. The available LCAs did not allow a clear preference to be made for one of the chemical recycling technologies analysed. Direct mechanical recycling of PVC-rich waste is preferable in environmental terms, particularly if it concerns recycling to high-quality products, and does not involve extensive sorting and pre-treatment⁵²

Together with the organic parts in PVC, plasticisers are transformed into feedstock material as well. Stabilisers containing heavy metals mostly end up in solid residues that will most probably have to be landfilled. For most of the dedicated chemical recycling technologies, emissions of problematic substances other than solid residues are low⁵³. No firm conclusions can be drawn with regard to the formation of dioxins. As a general rule, reducing conditions and high temperatures promote the breakdown and prevent the formation of dioxines, and this is the case for the operating conditions of some processes.

It seems that chemical recycling of PVC-rich waste is unattractive in economic terms in those situations where mechanical recycling has proven already to be technically

⁵² TNO, op.cit.

⁵³ TNO, op.cit.

feasible, with the possible exception of flooring. This would imply that chemical recycling plants for PVC-rich waste would have to concentrate on those flows for which mechanical recycling is not feasible, e.g. for types of waste that cannot be mechanically recycled as they would require additional separation steps, contain too many problematic impurities, or because of other restrictions linked to environmental concerns.

Chemical recycling has to compete with other waste management practices in the EU, mainly based on landfill and incineration. Landfill and incineration have the lowest gate fees. Purpose-built chemical recycling plants will also face an important competition from blast furnace operations and cement kilns, which could absorb a large quantity of mixed plastics waste with limited PVC content.

When looking at the various waste streams, it appears that in the current situation for categories like agricultural waste, industrial waste and non-packaging household waste, chemical recycling, although technically feasible, will have problems to compete in the absence of legal or other steering instruments. As for automotive and electrical and electronic waste, the PVC content in the mixed plastics waste seem to be too high to make them suitable for most chemical recycling options for mixed plastics waste with low chlorine content, but too low for economically viable separation and subsequent treatment in plants for PVC-rich waste.

Overall, it can be concluded that the successful operation of dedicated chemical recycling plants is mainly dependent on the economic aspects and in present circumstances there are important question marks over the viability of such operations.

Future developments and policy orientations

Chemical recycling has a potential mostly for those wastes for which mechanical recycling is not an option, and when legal or other instruments are effective in steering the waste away from the most cost-effective competitors (such as cement kilns, municipal solid waste incinerators and landfill).

For 2010, the total PVC waste quantities, which could be chemically recycled in the baseline scenario, are about 80,000 tonnes as a fraction in mixed plastics waste with low chlorine content (mostly from packaging) and about 160.000 tonnes in mixed plastics fractions with higher PVC content, mostly from automotive and electric and electronic waste.

The PVC-industry committed to invest 3 million € by 2001 in a pilot plant, with the objective to recover the chlorine and hydrocarbons content of PVC coated fabrics. The outcome of this pilot will be known by mid 2002, when the decision to build a commercial plant will be made.

Issues for consideration:

The Commission notes with interest the efforts described above to develop further chemical recycling technologies. In this context, potential measures could be envisaged in order to encourage these developments. Their potential environmental and economic implications should be assessed. Such measures

include:

- 1. Further voluntary initiatives from the PVC industry*
- 2. Recommendations for targets for chemical recycling for those waste streams where mechanical recycling is not possible*
- 3. Setting of mandatory targets for chemical recycling.*

Question n°5:

Which set of measures would be most appropriate for chemical recycling of PVC waste?

4.4. Other recycling and recovery technologies including co-incineration

A newly developed dissolution-precipitation process is based on physical principles without destruction of the polymer molecules to feedstock compounds. The process was developed specifically for composite materials containing PVC and other components. PVC is separated from the components that make up the composite through selective dissolution, and then the entire PVC compound is regenerated through precipitation. PVC and the other components can then be re-used.

Currently, an experimental installation is operational and a pilot plant is planned to be operational in 2001. The technology works in a closed circuit system, where the solvent is recycled.

The process deals with selectively collected PVC products. The quality has to be about the same as for mechanical recycling, which means that the costs of making the material available are comparable. The developers of this process expect that the technology could deal with rather complicated formulations, such as tarpaulins, cables, pharmaceutical blister packs, floor coatings, car dashboards, and could compete financially with some of the other recycling options.

Mixed plastic waste is used by one German steel producer as a reducing agent in blast furnaces in the production of raw iron. Mixed plastic waste is also used in cement kilns as a substitute to coal, oil or gas for the generation of heat.

The evaluation of the environmental performance of the use of mixed plastic waste in blast furnaces and cement kilns is somewhat controversial. According to some life cycle analyses, blast furnaces and cement kilns score better with regards to energy used and global warming than municipal solid waste incineration. With regards to the potential contribution of PVC to the emissions of dioxins, it is rather difficult to draw firm conclusions and further research would be necessary.

Blast furnaces and cement kilns can treat mixed plastic waste without the need for high capital investment, thus offering low gate fees. The use of mixed plastic waste in cement kilns and blast furnaces represents serious competition for other waste management installations. On the other hand, the use of mixed plastic waste in cement kilns and blast furnaces is restricted by its content in chlorine, as chlorine can have negative effects on the quality of the produced cement or iron and the potential corrosion of the equipment due to the formation of HCl. A tolerance of some 2-3%

of PVC or less is possible⁵⁴. Theoretically, co-combustion in cement kilns of mixed plastic waste with low PVC content could, however, become important in the future.

4.5. *Incineration*

PVC waste, if incinerated, is mainly treated in municipal waste incinerators. PVC waste is also present in hospital waste incinerators since PVC applications are used in hospitals. Approximately 600,000 tonnes of PVC are incinerated per year in the Community. PVC represents about 10% of the plastic fraction incinerated and about 0.7% of the total quantity of waste incinerated⁵⁵.

PVC waste contributes between 38% and 66% of the chlorine content in waste streams being incinerated. The other main sources of chlorine are putrescibles (about 17%) and paper (10%). On average it can be estimated that about 50% of the chlorine input into the incinerators are due to the presence of PVC.

Upon incineration, PVC waste generates hydrochloric acid (HCl) in the flue gas, which needs to be neutralised except when a special technology is employed where HCl is reused. At the moment, this specific technology is used only in 5 plants in Germany and 3 plants are in construction. All acid gases generated during the incineration of municipal solid waste (in addition to HCl mainly sulphur oxides) have to be neutralised prior to emission of the remaining gas to the atmosphere. Community legislation⁵⁶ already requires emission limit values for hydrochloric acid. These limits are currently being revised into more stringent limits⁵⁷.

In order to reach these emission limit values for HCl, neutralisation agents, in particular lime, are injected in order to neutralise the acidic components of the flue gas. The four main neutralisation processes are the dry, semi-dry, semi-wet wet and wet processes, which are presented in more details in annex 1.

An assessment⁵⁸ of the quantities of flue gas cleaning residues resulting from the incineration of PVC waste concluded that the incineration of 1kg of PVC generates on average⁵⁹ between 1 and 1.4 kg of residues for the dry process with lime, semi-dry and semi-wet wet processes. With the use of sodium hydrogen-carbonate as neutralisation agents in semi-dry process, 1 kg of PVC generates about 0.8 kg of residues. In case of wet processes, between 0.4 and 0.9 kg of residues dissolved in liquid effluent is generated. There is an important difference between the amounts of neutralisation agent required and residues produced between soft and rigid PVC. Flexible PVC contains less chlorine than rigid PVC. The amounts of neutralisation

⁵⁴ Or some 1-1.5% chlorine. Values may vary per installation, and legal demands may vary per country.

⁵⁵ Bertin Technologies, op. cit.

⁵⁶ Directive 89/369/EEC on the prevention of air pollution from new municipal waste incineration plants requires emission limit values for hydrochloric acid between 50 and 250 mg/Nm³ depending on the capacity of the incineration plant.

⁵⁷ The Proposal for a Directive on the incineration of waste [COM(1998) 558 final] as well as the Common Position on this Proposal [98/289 COD of 25 November 1999] foresees a strict emission limit value for HCl of 10 mg/Nm³, which will become in 2005 the emission limit value for existing and new incinerators in the Community.

⁵⁸ Bertin Technologies, op. cit.

⁵⁹ The average figure apply to a PVC material mix with 45% chlorine, i.e. composed of 70% rigid PVC (containing 53% chlorine) and 30% flexible PVC (containing 25% chlorine)

agents required and of residues generated are therefore lower for flexible PVC than for rigid PVC (1 kg of soft PVC⁶⁰ generates between 0.5 and 0.78 kg of residues). More details can be found in the following table.

Table 3: Estimated quantities of residues generated by the incineration of 1 kg of PVC waste⁶¹

		DRY		SEMI-DRY	WET	SEMI WET – WET
Neutralisation Agent		Lime	BICAR	Lime	Lime	Lime
Cl kg per kg of PVC	Min	0.25				
	Max	0.53				
	Average	0.45				
Residues (kg) (per kg PVC)	Min	0,78	0,46	0,70	0	0.54
	Max	1.65	0.97	1.48	0	1.15
	Average	1,40	0,82	1,26	0	1
Liquid effluent (dry material) (kg per kg PVC)		0	0	0	0.42 to 0.88	0

The flue gas cleaning residues are classified as **hazardous waste**⁶². The residues are generated separately (in particular in semi-wet and wet systems) or mixed with fly ash. The residues contain the neutralisation salts, the excess neutralisation agent as well as pollutants such as heavy metals and dioxins that were not destructed. Landfilling of the residues is, with some exceptions, the only option used within the Member States.

Several processes have been devised to recover calcium chloride and sodium chloride from the residues of the dry and semidry processes, but few of them are currently used commercially. Except in some specific cases, it is uncertain whether such technologies can be commonly used in order to recover a substantial quantity of residues. These technologies would be “end of the pipe” solutions, less preferable than a preventive measure aimed at reducing at source the quantity of residues generated.

PVC at current levels in the municipal solid waste stream has the following effects on the flue gas cleaning residues in comparison to incineration of municipal solid waste without PVC⁶³:

- PVC incineration contributes to an increase of the quantity of flue gas cleaning residues (about 37% for the dry systems, 34% for semi dry systems and 42% for semi wet-wet⁶⁴).

⁶⁰ For these calculations, soft PVC contains 25% chlorine

⁶¹ Bertin Technologies, op.cit.

⁶² According to Council Decision 94/904/EC establishing a list of hazardous waste, all solid wastes from gas treatment are classified as hazardous (code 190107), OJ L 356, 31.12.1994, p.14.

⁶³ Bertin Technologies, op. cit.

The scenario considered is based on the incineration of 1 million tonnes of waste with and without PVC, respectively, and the landfilling of the resulting residues.

⁶⁴ Bertin Technologies, op. cit.

- PVC incineration contributes to an increase of the content of leachable salts in the residues by a factor of two. These are primarily chlorides of calcium, sodium, and potassium.
- The incineration of PVC increases the amount of leachates from the residues put into landfill (about 19% for dry systems, 18% for semi dry systems, 15% for the semi wet-wet systems and 4% for wet systems). The leachates need to be treated prior to any discharge.
- There is a theoretical possibility that the leaching of, for example cadmium, may increase due to increased chloride complexation caused by PVC incineration but data would be needed to substantiate this.
- In the current temperature range of combustion steps for municipal solid waste incineration, the higher chlorine content has no significant effects on the transfer of heavy metals and trace elements from bottom ash to gas treatment residues.

The potential influence of the incineration of PVC waste on the emissions of dioxins has been at the centre of a major scientific debate since PVC is currently the largest contributor of chlorine into incinerators. The contribution of incinerators to the total emissions of dioxins in the Community was about 40% between 1993 and 1995⁶⁵.

It has been suggested that the reduction of the chlorine content in the waste can contribute to the reduction of dioxin formation, even though the actual mechanism is not fully understood. The influence on the reduction is also expected to be a second or third order relationship⁶⁶. It is most likely that the main incineration parameters, such as the temperature and the oxygen concentration, have a major influence on the dioxin formation.

Whilst at the current levels of chlorine in municipal waste, there does not seem to be a direct quantitative relationship between chlorine content and dioxin formation, it is possible that an increase of chlorine content in the waste stream above a certain threshold could contribute to an increase of the dioxin formation in incinerators. The threshold of 1% of chlorine has been suggested⁶⁷ but uncertainties remain on the level of this threshold⁶⁸. Further assessment should be carried out in order to assess the threshold above which the chlorine content would influence the formation of dioxins. This threshold could be exceeded due to increasing quantities of waste containing chlorine.

⁶⁵ Identification of relevant industrial sources of dioxins and furans in Europe, Landesumweltamt Nordrhein-Westfalen, Essen, 1997

⁶⁶ Danish Environmental Protection Agency, Environmental aspects of PVC, 1996

⁶⁷ Wikstrom, 1996, influence of level and form of chlorine on the formation of chlorinated dioxins, dibenzofurans and benzenes during the combustion of an artificial fuel in a laboratory reactor.

⁶⁸ Danish Environmental Protection Agency, Dioxins emissions from waste incineration, Environmental Project 117, 1989

Danish Environmental Protection Agency, The effects of chlorine content on the formation of dioxin, Project 118, 1989

Danish Environmental Protection Agency, Dioxins – sources, levels and exposures in Denmark, Working report N°50/1997

At present, not all incinerators in the Community are already operating according to state-of-the-art air-emission standards for dioxins. The Proposal for a Directive on the incineration of waste⁶⁹ foresees an emission limit value of 0,1 ng/m³. This shall decrease the emissions of dioxins from incinerators.

The potential link between the incineration of PVC and the corrosion of the equipment of incinerators has also been debated. Some operators claim that the steam pressure and consequently the energy efficiency could be higher with a lower chlorine presence in the waste stream. The absence of PVC could therefore enable a higher efficiency of the energy recovery system. This question needs further research. It should be noted that the incineration with energy recovery of PVC waste generates higher energy than the incineration of general municipal solid waste since the calorific value of PVC waste is higher⁷⁰.

PVC waste incineration increases the operating costs of the incinerators due to the use of neutralisation agents to neutralise the acid flue gas and the additional costs for the waste management of the resulting residues. The total additional financial costs related to the incineration of PVC vary depending on the Member State, the neutralisation processes and the waste management of the residues. It is estimated that the additional costs of incinerating PVC compared to municipal solid waste is from about 20 € per tonne for wet systems to more than 300 € per tonne for dry systems⁷¹. Differences depend upon the technology used and the type of PVC incinerated (flexible or rigid). More details on these costs can be found in annex 2. These additional costs are at present not borne specifically by new PVC products or by PVC waste, but are included in the overall incineration cost of waste.

A study⁷² has been commissioned to assess the economic implications of diverting PVC waste away from incineration. The report analyses three scenarios in comparison to the baseline scenario (see annex 3 for details). In the first and the second scenarios, recycling rates increase to 15% and 22% respectively in 2020, with a proportionate decrease in the amount of PVC sent to incineration and landfill. With regard to incineration this means a cumulative diversion of about 1,700 ktonnes for scenario 1 (mainly construction waste) and 3,800 ktonnes for scenario 2 in the time period 2000 to 2020. In the third scenario recycling rates are unchanged against the baseline scenario, but the incineration rate is estimated as 28% in 2020 instead of 45% as forecasted in the baseline scenario as a result of the diversion of construction waste to landfill. This corresponds to the diversion of about 10,300 ktonnes in the time period 2000 to 2020.

⁶⁹ COM(1998) 558 final

⁷⁰ The average caloric value for flexible PVC is about 20 GJ/tonne, about 16 GJ/tonne for rigid PVC and about 10 GJ/tonne for municipal solid waste.

⁷¹ Bertin Technologies, op. cit.

⁷² AEA Technology, Economic evaluation of PVC waste management, a report produced for the European Commission Environment Directorate-General, June 2000. The study encompasses EU Member States + 6 Candidate countries. The reported figures relate to the average between the "high" and the "low" incineration scenarios. These scenarios are based on the assumption that landfilling of PVC waste would be significantly reduced in some countries such as Sweden, Austria, Germany and the Netherlands. The difference relates to the degree of reduction achieved. Values shown refer to a 4% discount rate.

The financial costs considered for scenarios 1 and 2 include the avoided cost of incineration (including “specific costs”⁷³) and the incurred net cost of the recycling process which depends on the waste stream diverted. The specific costs of incineration vary considerably depending upon the types of flue gas cleaning systems. Calculations in the report have been carried out for an “average” system distribution consisting of 25% semi dry-systems, 25% wet systems and 50% semi-wet wet systems. The results show that except in the case of rigid construction products (pipes, windows, cable trays and other rigid profiles) and cables, diversion of PVC waste from incineration to recycling results in a net increase in costs. The costs per tonne diverted have been estimated to be about 50 €/tonne for scenario 1 and about 190 €/tonne for scenario 2. Scenario 3 results in a net saving of about 90 €/tonne. These latter savings are mainly due to the lower cost of landfill and to the assumption that segregation of construction waste is generally carried out on site at the expense of the waste generator. Diversion of other waste streams to landfill (e.g. household and commercial waste) would result in much higher costs.

The main environmental burdens including the related human health impacts of the three scenarios have been assessed. To the extent possible, and therefore with a bias towards impacts of air pollution, the external costs associated to each scenario have been evaluated. The calculations for all the scenarios show environmental benefits. Considering what is regarded in the study as being the “best” estimate for each of the burdens evaluated, benefits have been estimated for the three scenarios to be respectively about 190, 140 and 50 € per tonne of waste diverted for the period 2000-2020. The major contribution to these results comes firstly from the avoided emissions from the manufacture of virgin PVC (in the case of high quality recycling) and secondly from the avoided emissions from incineration (including indirect emissions associated with the manufacture of neutralisation agents).

It can be seen from the comparison between the financial and the environmental analyses based on the best estimate that scenario 1 and scenario 3 show an overall benefit, as the costs per tonne diverted are lower than the benefits. The contrary is true for scenario 2, where the environmental benefit (although higher than in scenario 1 and 3) is nevertheless exceeded by the estimated cost.

A number of assumptions have been made to carry out these calculations. In particular, concerning the financial aspects, the cost elements were necessarily based on very few experiences of existing PVC post-consumer waste recycling schemes, which are still at a preliminary stage. These uncertainties are higher for scenario 2. As the price of recyclates is closely linked to the price of virgin PVC, increasing prices of the latter would lead to lower overall costs.

As indicated, the environmental analysis is biased towards the impacts of air pollution. However, it is likely that most of the externalities omitted (e.g. residues disposal) would increase the benefits of the diversion of PVC from incineration. The main exception relates to phthalate plasticisers. Landfilled flexible PVC would form a reservoir of these chemicals that could slowly leach out over time, whilst

⁷³

Incineration of PVC with municipal solid waste (MSW) incurs additional operating costs for the incinerator in terms of reagents to abate acid gas emissions and for the treatment and disposal of residues, although these are partly offset by increased energy sales due to the higher calorific value of PVC compared to MSW.

incineration presents the advantage of destroying them. Incineration also allows the recovery of the calorific value of phthalates. This factor has been included in the environmental analysis. (r)

(r) Wikström *et al.* (1996) studied the combustion of a synthetic fuel in a pilot reactor and found that there was no correlation between the quantities of dioxins formed and the chlorine content of the fuel when the chlorine content was below 1%; above this level, a positive correlation was found.

Lenoir *et al.* (1990) found that the addition of 2% sodium chloride to polyethylene produced no effect on the dioxin formation during combustion, whereas the addition of 3% PVC gave a moderate increase.

Seys (1997) cited ten studies that have demonstrated that the same amount of dioxin is emitted from incinerators burning MSW, with or without PVC present.

The Swedish EPA (Naturvårdsverket, 1996) state that incineration at MSW plants is not an environmental problem, and that the chlorine content of the PVC waste fraction does not affect the formation of dioxins as long as the chlorine load does not exceed 1%.

As pointed out by the Dutch government (VROM, 1998), improvements in combustion technology and flue gas treatment have led to reductions in both the formation and emission of dioxins, and that eliminating PVC from incinerators would have little or no effect on their dioxin emissions. Useful reviews of this area have been provided by Carroll (1996b) and Royston *et al.* (1993).

Pearson *et al.* (1997) studied the chronology of dioxin accumulation in sediment cores from the Great Lakes, and showed that the accumulation rates began increasing about 1940, peaked at 1970 \pm 10 years, and then declined to the present rates that are 30 - 70% of the maxima. A similar chronology is given by Alcock and Jones (1997).

Toshiro *et al.* (1990), for example, have measured dioxin in air samples over forest fires and concluded that large forest fires could produce significant amounts of dioxins.

Future developments and policy orientations

In the baseline scenario, the incineration of PVC waste would increase to about 2.5 millions tonnes in 2020 compared to about 600,000 tonnes at present. The number and capacity of incinerators employing wet, semi-wet wet and semi-dry flue gas neutralisation technologies will increase at the expense of those employing dry technologies.

Issues for consideration:

The Commission considers, on the basis of the above-mentioned analysis, that the incineration of PVC waste raises a number of issues. A range of measures could be envisaged to address these issues and should be assessed in the light of their potential environmental and economic implications. Such measures include:

- 1. Diversion of PVC waste, mandatory or not, as far as economically feasible, from incineration to preferably recycling or landfilling. This would require the introduction of collection schemes to ensure separate collection of PVC to be diverted***
- 2. Similar diversion only for rigid PVC***
- 3. Meeting the additional costs related to the incineration of (totally or partially), e.g. through internalisation of these costs in the price of new PVC products or direct financial contribution to operators of incineration plants***
- 4. Encouragement of the conversion of the flue gas cleaning technologies to processes that reduce the amounts of residues generated or allow the recycling of HCl instead of its neutralisation***
- 5. Further research on the potential relation between PVC incineration and dioxin formation.***

Question n°6:

Which set of measures would be most effective to address the issues linked to the incineration of PVC waste?

4.6. Landfill

Landfilling is the most common waste management route for PVC waste. Exact figures on the landfilling of PVC waste are not known and there are large differences between various estimations ranging up to 2.9 million tonnes of PVC waste being landfilled every year. It can be estimated that several million tonnes of PVC waste have already been landfilled during the past 30 years.

Member States will have to bring into force the provisions of Directive 1999/31/EC on the landfilling of waste in 2001. The Directive requires that landfill installations comply with a number of technical standards regarding the protection of soil and water including leachate collection, bottom sealing and gas emission control.

All materials in landfill including PVC are subject to different reactive conditions, which are determined by the parameters such as temperature, moisture, presence of oxygen, activity of micro-organisms and the interactions between parameters at different stages of the ageing process of landfills. Four main phases can be distinguished: short initial aerobic phase, anaerobic acidogenic phase (variable duration, longer than aerobic phase), anaerobic methanogenic phase (up to several centuries), final aerobic phase.

Investigations⁷⁴ have been carried out on both rigid and soft PVC samples mainly through laboratory equipment studies, examination of the effects of a biological treatment, and of microbiological tests.

The PVC polymer is generally regarded as being resistant under soil-buried and landfill conditions⁷⁵. However, an attack on the PVC polymer of a thin packaging foil has been detected⁷⁶. This remains an isolated result and the attack was observed under aerobic conditions and at 80°C, conditions which, if they occur in landfills, are transient.

Losses of plasticisers, especially phthalates, from flexible PVC are widely recognised in the literature. Results from studies on the degradability of phthalates under landfill conditions show that degradation of phthalates occurs, but may not be complete depending on conditions and type of phthalate. Both, phthalates and their degradation substances can be detected in landfill leachates. In addition, long-chain phthalates, such as DEHPs, are only partly degraded in usual leachate and sewage treatment plants and accumulate on suspended solids. Losses of phthalates could also contribute to gaseous emissions from landfills. As for other emissions from landfill, emissions resulting from the presence of PVC in landfills can last longer than the guarantee of the technical barrier and there is no evidence that the release of phthalates will come to a standstill after a given period of time.

Stabilisers are encapsulated in the matrix of rigid PVC waste. Hence, migration is expected to be low and would affect the surface of the PVC but not the bulk of the material. Concerning stabilisers in flexible PVC waste, a study⁷⁷ into the long-term behaviour of PVC waste under landfill condition showed a release of lead stabiliser from one specific PVC cable containing a combination of several plasticisers.

PVC products disposed of in landfills will certainly contribute to the formation of dioxins and furans during accidental landfill fires, but the quantitative contribution cannot currently be estimated due to the inherent difficulties in obtaining the necessary data.

In order to further assess and quantify the environmental impacts of the landfilling of PVC, further research would be necessary to study the potential degradation of PVC polymer, the release of stabilisers and plasticisers, as well as the environmental contribution of phthalates to the leachates and gaseous emissions from landfills.

⁷⁴ Argus in association with University Rotstock, op. cit.

⁷⁵ Mersiowski et al., op.cit.

⁷⁶ Argus in association with University Rotstock, op. cit.

⁷⁷ Mersiowski et al., op. cit.

The costs for landfilling PVC waste in Member States are those for landfilling municipal solid waste and show a wide range of tariffs⁷⁸. The prices or tariffs for landfills are influenced by a number of factors such as the standard of the landfill, the competition between different disposal routes, the type and nature of waste being accepted. Generally, no influence on prices or tariffs could be related or is expected due to the presence of PVC in municipal solid waste being landfilled.

Future developments and policy orientations

In the baseline scenario, it is expected that the quantities of PVC waste landfilled would remain constant at about 2.8 millions tonnes in 2020.

Issues for consideration:

The Commission considers, on the basis of the previous analysis, that the landfilling of flexible PVC waste raises some issues. A range of measures could be envisaged to address these issues. Environmental and economic implications of these measures should be considered. Such measures include:

- 1. Disposal of flexible PVC waste in controlled landfill sites with high emission standards as foreseen in the landfill Directive***
- 2. Further research on the leaching or emissions of additives.***

Question n°7:

Are specific measures concerning the landfilling of PVC waste necessary? If so, which ones?

5. OTHER HORIZONTAL ASPECTS ON PVC

The analysis in this document focuses on two main aspects : the use of additives in PVC and the management of PVC waste. In addition, more general and horizontal aspects arise in the context of a broad consultation on PVC.

Regarding the type of instruments to implement a horizontal Community strategy on PVC, a range of measures, mandatory and voluntary, is available:

- Voluntary approaches, including the implementation of existing voluntary commitments, at national and Community levels, as well as the development of new voluntary approaches. As mentioned previously, the European PVC industry has signed a voluntary commitment on the sustainable development of PVC. And while this can be seen as a first step there is still work to be done to ensure an effective participation by industry in achieving Community goals in this area. It should be underlined that the services of the Commission are currently preparing a Proposal for a framework Regulation concerning Community environmental agreements to be adopted by Council and Parliament.

⁷⁸

At present, the costs for landfilling municipal solid waste range from 8 € per tonne in Spain up to 200 € per tonne in Germany. The cost for landfilling mixed waste, such as unsorted construction and demolition waste containing organic components, is usually higher than for landfilling of inert waste. An average price of about 50 € per tonne is usual.

- Legislative measures, such as a Proposal for a Directive on PVC, could be proposed in order to address issues related to management of PVC waste and other legislative measures to deal with the use of additives on the basis of all existing scientific evaluation, including the results of risk assessments. Recommendations could also be adopted to develop the implementation of a Community strategy.
- A mix of instruments could be proposed, integrating voluntary commitments, recommendations and regulations including the adaptation of existing legislation. Such a set of instruments would be in line with an approach, which aims at combining voluntary and binding instruments.

Apart from an approach based on PVC waste management and additives, the question of a potential substitution policy for certain PVC applications has been raised in the context of promoting more sustainable products as part of an Integrated Product Policy. Such a substitution policy could be considered for specific applications, which can not be separated from the general waste stream and therefore are difficult to recycle such as in packaging, motor vehicles, electric and electronic equipment. A potential substitution policy would need to be underpinned by a comprehensive and objective assessment of the main environmental impacts both of PVC and of potential substitutes during their whole life cycle. The approach outlined in this document focuses on dealing with the environmental issues of PVC mainly through policies on additives and waste management.

Issues for consideration:

A number of issues regarding the environmental impacts of PVC have been identified, including the question of a horizontal approach and of appropriate instruments to address these issues. The Commission sees merit in developing a horizontal strategy on PVC. A number of instruments are available to implement such an approach. Environmental and economic implications, as well as the compatibility with the international obligations of the Community should be assessed.

Question 8:

Which are the appropriate instruments for developing a horizontal strategy on PVC? Should a PVC substitution policy for some specific applications be envisaged? If so, how?

6. CONCLUSION

A number of concerns regarding the impact of PVC on the environment, including related human health issues, have been identified and explained in this document. These are mostly related to the use of certain additives and to the management of PVC waste. In the light of the analysis, a number of options have been identified, which could ensure an effective approach on waste management and additives, to be based on an assessment of the environmental and economic implications, with a view

to reducing the impact on human health and the environment of PVC throughout its life cycle.

A public consultation on PVC is proposed on the basis of these options. The Commission hereby invites all interested parties to discuss and comment on this document. A public hearing will be organised in October 2000.

Comments may be sent directly to the Commission at the latest on 30 November 2000. Submissions should be sent to Mr Krämer, Head of the waste management unit (DG ENV) and Mr Schulte Braucks, Head of the chemicals unit (DG ENTR), 200 rue de la Loi / Wetstraat 200, B-1049 Bruxelles/Brussel, Belgium. Comments may alternatively be sent by e-mail to the following address: ENV-PVC@cec.eu.int. The various language versions of the Green Paper, the studies commissioned by the Commission as well as the comments on the Green Paper can be found at the following internet address: <http://europa.eu.int/comm/environment/pvc/index.htm>.

On the basis of the analyses developed in this document and the outcome of this consultation process, the Commission will present at the beginning of 2001 a Communication setting out a comprehensive Community strategy on the environmental issues of PVC.

References

Alcock, R.E. and Jones, K.C., (1996): *Env. Sci.Tech.* 30(11), 3133.

ASME, (1995): *"The relationship between chlorine in waste streams and dioxin emissions from waste combustor stacks"*. ASME Research report CRTD-Vol.36.

Baldwin, J., (1997): in *"Chemical Aspects of Plastics Recycling"*, Royal Society of Chemistry Special Publication No. 199.

Barton, P. *et al.*, (1997): *"PVCs in packaging and construction materials:- an assessment of their impact on human health and the environment"*. A report for the PVC Retail Working Group by the National Centre for Business & Ecology. (A university based centre in the UK.)

Bruce N. Ames and Lois Swirsky Gold. Division of Biochemistry and Molecular Biology University of California. *"Chemical Carcinogenesis: too many rodent carcinogens (promotion, mutagenesis, mitogenesis, animal cancer tests)*.

Burn, L.S. and Schafer, B.L., (1997): CSIRO DBCE Technical Report TR 97/1.

Cadogan, D.F. *et al.*, (1994): *Progress in Rubber and Plastics Technology*, 10 (1).

Cadogan, D.F., (1996): *"Phthalates: Their effect on man and the environment in perspective"*, PVC '96 Conference Proceedings, The Institute of Materials, London. p. 63.

Carroll, W.F., (1996b): *Organohalogen Compounds*, 27, 122.

Christiansen K. *et al.*, (1990): *"Environmental assessment of PVC and selected alternative materials"*. Environmental project no. 131. Danish Environmental Protection Agency.

Finnveden, G. *et al.*, (1996): *"Alternative materials to PVC. Listing and analysis of LCA's, etc., carried out regarding comparisons of PVC and alternative materials for different product groups"*. Institute for Water and Air protection Research, archive No. A96061 (for the Swedish National Environment protection Board).

Harrad S. and Jones K., (1992): *Chemistry in Britain*, 28(12), 1110.

Hjertberg T., (1995): *"Degradation of PVC in landfills - a theoretical evaluation"*, Report, Department of Polymer Technology, Chalmers University of Technology, Göteborg, Sweden.

Hjertberg, T. and Gevert, T., (1995): *"Evaluation of possible degradation of pipes and cable insulation of PVC"*. Report, Swedish National Testing and Research Institute.

HMIP (1995): *"A review of Dioxin Emissions in the UK"*. Research Report No.:

Hogan J.E., (1983): Kirk-Othmer Encyclopedia of Chemical Technology, third edition, 13, 571.Wiley, New York.

Huber, W.W. *et al.*, (1996): Critical Reviews in Toxicology, 26(4), 365.

I. Mersiowsky *et al* (*University of Hamburgo- Harburg 1999*) , Long-term behaviour of various PVC products in laboratory scale landfill.

The International Agency for Research on Cancer (IARC) (February 2000) with a working group of 28 experts from 12 countries met in Lyon to evaluate or re-evaluate the evidence for carcinogenicity of sixteen industrial chemicals, all of them organic compounds.

IARC Technical Report No. 24, 1995; Consensus Report.

Internationella Miljöinstitutet Lund, Sweden September 1997, Cadmium levels in soils.

KEMI (1996): *“Additives in PVC; Marking of PVC”*. (The Swedish National Chemicals Inspectorate.)

KEMI (1994): *“Phasing out Lead and Mercury”*. (The Swedish National Chemicals Inspectorate.) Report 8/94.

Lenoir D. *et al.*, (1990): Organohalogen Compounds, 4, 319.

Metals and the Environment, Swedish EPA,(1993), Landfills / Wastes sources of cadmium.

MD Meek *et al.* (1997), examined the alleged in vitro and in vivo estrogenic activities of eight commercial phthalates esters.

Møller S. *et al.*, (1995): *“Environmental aspects of PVC”*. Report, Environmental Project no. 313, Danish Environmental Protection Agency.

Naturvårdsverket (1996): *“PVC waste utilisation”*. (The Swedish National Environment Protection Board.)

Nielsen J. *et al.*, (1985): American Industrial Hygiene Assoc. Journal, 46, 643.

Pearson, R.F. *et al.*, (1997): Env. Sci. Tech., 31, 2903.

Royston, D. *et al.*, (1993): Proc. Chemeca '93, 2, 537.

Sack T.M., (1988b): Electr. Power Res. Inst. Report EPRI-EL-5944.

Seys, A., (1997): Paper presented at the sub-regional meeting on “Identification and Assessment of Releases of Persistent Organic Pollutants”, St.Petersburg, Russian Federation, July 1997.

Scholz, N.J., Menzel and B., Thölmann: SETAC 18th Annual Meeting San Francisco 1997b, The Biodegradation and Bioaccumulation of Phthalate Esters.

Smit et al., (1994): “Environmental aspects of PVC in packaging materials” with an annex on PVC incineration and dioxins. Report 2445/U94, TNO-KRI, Delft, the Netherlands.

Staples, C.A. et al., (1997): Chemosphere, 35(4), 667-749.

Sundmark H.B., (1995a): “Environmental risk assessment of phthalates used as plasticisers for PVC”. Report to the SFT (the Norwegian State Pollution Control Authority).

Sundmark H.B., (1995b): “Risk assessment of the use of lead stabilisers in PVC. Final draft,” Report to the SFT.

Swedish EPA (Naturvårdsverket, 1996), emissions from land-filled PVC sources.

Svenska Dagbladet Page: 2 (editorial) Subject: Campaign against plastic not serious Date: July 11, 2000.

Toshiro C., (1990): Chemosphere, 20, 1533.

UKEA (1997): “A Review of Dioxin Releases to Land and Water in the UK”. The United Kingdom Environment Agency AR&D Publication 3.

Van den Berg N.W. et al., (1996): “Environmental life cycle assessment of gas distribution systems”. Final report. Gastec N.V. and CML-S&P (Leiden University Centre of Environmental Science).

VROM (The Dutch Ministry of Housing, Spatial Planning, and the Environment) (1998): “Position Paper of the Netherlands on PVC”.

Wikström E. et al.,(1996): Environ. Sci. Technol., 30, 1637.

Yushimasa Kurata et al. (1997, Mitsubishi Chemical Safety Institute, Japan), The sub chronic Toxicity of DEHP in common marmosets for longterm at high dose.

ANNEX 1

Description of the various flue gas cleaning processes

Flue gas cleaning processes	Main characteristics
Dry process	<p>The neutralisation process consists of the injection of solid neutralisation agents. The most common neutralisation agent is lime ($\text{Ca}(\text{OH})_2$). Other agents are also used, in particular sodium hydrogen-carbonate (Bicar, NaHCO_3) or spongiacal hydrated lime.</p> <p>A chemical reaction transforms the acidic components of the flue gas into salts. The resulting residues of the neutralisation process are solid residues mainly composed of neutralisation salt: calcium chloride (CaCl_2), sodium chloride (NaCl), sulphates (CaSO_4, Na_2SO_4), excess of the neutralisation agents and heavy metals in various chemical forms. These residues are classified as hazardous waste.</p> <p>The dry process with classical lime is not likely to be able to comply with the strict emission limit value of 10 mg/Nm^3. The dry processes using specific neutralisation agents such as spongiacal hydrated lime and Bicar can comply with this limit.</p>
Semi-dry process	<p>The neutralisation process consists of the injection of a solution or a suspension of the neutralisation agent (lime) in water. The resulting reaction products are solid residues. They are composed of calcium chloride, sulphates and heavy metals, as well as unreacted lime added in excess. The residues are classified as hazardous waste.</p>
Wet process	<p>In this process, two successive scrubbers are operating. In the first (acid scrubber), most of the HCl is absorbed in water. The remaining HCl and SO_x are absorbed and neutralised in the second scrubber (neutral scrubber), which is generally fed with a soda (NaOH) solution.</p> <p>The resulting liquid effluents need to be treated prior to release into the environment. In the water treatment unit, heavy metals and sulphates are precipitated by the addition of lime. The precipitated heavy metals are separated by filtration (and need to be landfilled), while the treated saline wastewater is discharged. The effluent of the acidic scrubber is either neutralised and treated together with the effluent of the neutral scrubber or is purified and HCl reused.</p>
Semi-wet wet process	<p>Due to stricter regulations on the discharge of saline wastewater, many incineration plants are introducing evaporation to eliminate liquid discharges completely⁷⁹. Wet processes are therefore being converted to semi wet-wet processes generating dry solid residues. This is already the case for German and Austrian plants. This process is similar to the wet technique but the liquid effluent is then sprayed in the gas and the liquid evaporated. This system produces dry residues classified as hazardous waste.</p>

⁷⁹

Economic evaluation of the Draft Incineration Directive, a report produced for the European Commission, DG XI, AEA Technology, December 1996

It is difficult to present a detailed repartition of the various types of incinerators currently in activity. The following statistics⁸⁰ present the situation for the period 1993-1996 and for plants with a rather large capacity. About 15% of the total capacity use a dry process for gas treatment, for 25% a semi-dry process is employed, for about 20% semi-wet wet processes are in use and about 40% wet processes are used. The distribution of treatment capacities is different in the various Member States. In general, the capacities for dry processes have decreased to the advantage of other processes. The stricter emission requirements for incinerators as proposed in the Directive on waste incineration are likely to enhance this trend.

ANNEX 2

Additional cost for PVC incineration

The figures in the following table⁸¹ represent the range of additional costs for the incineration of PVC in comparison to municipal solid waste. The lower figures apply to flexible PVC containing 25% chlorine, the higher figures to rigid PVC containing 53% chlorine. The average figures apply to a PVC material mix with 45% chlorine, i.e. composed of 70% rigid PVC and 30% flexible PVC.

Average and range of additional cost for PVC incineration €/ton of PVC	Dry System		Semi-Dry	Wet	Semi-Wet, Wet
	Lime	Sodium Bicarbonate	Lime	Lime / NaOH	Lime / NaOH
Without stabilisation of the residues average and min/max value	196 95 – 234	274 144 – 327	165 84 – 206	19 -1 – 29	121 57 – 147
With stabilisation of the residues average and min/max value	290 154 – 347	334 172 – 396	244 127 – 305	19 -1 – 29	186 96 – 226

⁸⁰ European Energy from Waste Coalition, Energy from Waste Plants: Databook of European Sites, Report prepared by Juniper Consultancy Services Ltd, November 1997. This figure refers to plants with a capacity of more than 30,000 t/year

⁸¹ Bertin Technologies, op.cit.

ANNEX 3

PVC waste management scenarios established for the economic and environmental analysis⁸²

Scenarios of future waste management across the EU and six of the applicant countries have been developed in order to carry out the economic and environmental analysis. **The business as usual (BAU) scenario** is based on current destination of PVC waste across Western Europe as made available by EuPC and the present rate of MSW incineration. The present day incineration rate of main PVC waste streams is assumed to be in proportion to the general rate for MSW incineration. To estimate future destinations, a distinction has been made between Member States which will limit themselves to the strict implementation of the landfill directive and Member States which are likely to go beyond EU rules, substantially reducing the landfilling of raw organic waste (e.g. Austria, Germany, the Netherlands, Sweden) by increasing incineration. The first group of Member States are also expected to increase incineration capacity over the next two decades, but the final rate achieved is assumed to be lower because of the lower starting point and the poorer economic circumstances of some of the countries concerned. Accession countries have been included in this first group.

The obtained incineration rates have been applied to the remaining quantities after deduction of PVC waste that is mechanically recycled. Given the current limited state of its development, feedstock recycling has not been considered in the study. Mechanical recycling has been assumed to develop as predicted under the baseline scenario developed in the mechanical recycling study⁸³. Thus recycling of post-consumer PVC waste will increase from about 3 per cent today to about 9 per cent by 2020.

Three alternative scenarios for diversion of PVC from incineration have then been elaborated. The first two are based on the assumption that PVC diverted from incineration will go to mechanical recycling. In the third scenario, diverted waste is sent to landfill.

Scenario 1: This scenario is partly based on the “selective improvement scenario” proposed in the mechanical recycling study. It is assumed that recycling of most construction wastes suitable for high quality recycling is encouraged so that the average potential calculated in the mechanical recycling study is reached. Although suitable for high quality recycling, PVC in the household and commercial waste category as well as flexible profiles and hoses (construction category) have however been excluded as no precise cost estimate was available. It is reasonable to assume that development of recycling potential for these wastes is therefore further away than for the remaining wastes for which cost estimates were provided.

Scenario 2: This scenario models mechanical recycling for all suitable types of waste (construction, household and commercial, packaging, electric and electronic waste) achieving its absolute full potential in 2010 and continues at this rate until 2020. All waste streams are recycled at the *maximum* of recycling potential estimated in the mechanical recycling study.

Scenario 3: In this scenario recycling rates remain unchanged compared to the baseline scenario. PVC waste diverted from incineration is therefore sent to landfill. The analysis is limited to the diversion of construction waste to identify the main economic and environmental impacts of diverting from incineration to landfill. Segregation of PVC from the other waste streams considered in the study is likely to be more problematic from an economic and technical perspective.

⁸² AEA Technology, Economic evaluation of PVC waste management, draft report produced for the European Commission Environment Directorate-General, May 2000

⁸³ Prognos, op.cit.

ANNEXE 4

NATURE'S CHEMICALS AND SYNTHETIC CHEMICALS: COMPARATIVE TOXICOLOGY (carcinogens / mutagens / teratogens / clastogens / dioxin)

BRUCE N. AMES*, MARGIE PROFET, AND LOIS SWIRSKY GOLD

Division of Biochemistry and Molecular Biology

Barker Hall

University of California

Berkeley, California 94720

Abbreviations: TCDD = dioxin = 2,3,7,8-tetrachlorodibenzo-p- dioxin; IC = indolecarbinol * To whom correspondence should be addressed

For Proc. Natl. Acad. Sci. USA Classification: Medical Sciences Contributed by Bruce N. Ames July 17, 1990 Revised: August 15, 1990 (510) 642-5165 - phone (510) 643-7935 - fax .

ABSTRACT

The toxicology of synthetic chemicals is compared to that of natural chemicals, which represent the vast bulk of the chemicals to which humans are exposed. It is argued that animals have a broad array of inducible general defenses to combat the changing array of toxic chemicals in plant food (nature's pesticides) and that these defenses are effective against both natural and synthetic toxins. Synthetic toxins such as dioxin are compared to natural chemicals, such as indole carbinol (in broccoli) and alcohol. Trade-offs between synthetic and natural pesticides are discussed. The finding that in high dose tests a high proportion of both natural and synthetic chemicals are carcinogens, mutagens, teratogens, and clastogens (30 to 50% for each group) undermines current regulatory efforts to protect public health from synthetic chemicals based on these tests.

THE TOXICOLOGY OF SYNTHETIC AND NATURAL TOXINS IS SIMILAR

It is often assumed that, because plants are part of human evolutionary history, whereas synthetic chemicals are recent, the mechanisms that animals have evolved to cope with the toxicity of natural chemicals will fail to protect us against synthetic chemicals (1).- [- "For the first time in the history of the world, every human being is now subjected to contact with dangerous chemicals, from the moment of conception until death." Rachel Carson, Silent Spring, 1962.] We find this assumption flawed for several reasons.

Defenses that animals have evolved are mostly of a general type, as might be expected, since the number of natural chemicals that might have toxic effects is so large. General defenses offer protection not only against natural but also against synthetic chemicals, making humans well buffered against toxins (2-6). These defenses include the following: (a) The continuous shedding of cells exposed to toxins: the surface layers of the mouth, esophagus, stomach, intestine, colon, skin, and lungs are discarded every few days. (b) The induction of a wide variety of general detoxifying mechanisms, such as antioxidant defenses (7,8) or the glutathione transferases for detoxifying alkylating agents (9): human cells that are exposed to small doses of an oxidant, such as radiation or hydrogen peroxide, induce antioxidant defenses and become more resistant to higher doses (10-14).

These defenses can be induced by both synthetic oxidants (e.g., the herbicide paraquat) and by natural oxidants, and are effective against both. (c) The active excretion of planar hydrophobic molecules (natural or synthetic) out of liver and intestinal cells (15). (d) DNA repair: this is effective against DNA adducts formed from both synthetic and natural chemicals, and is inducible in response to DNA damage (16). (e) Animals' olfactory and gustatory perception of bitter, acrid, astringent, and pungent chemicals: these defenses warn against a wide range of toxins and could possibly be more effective in warning against some natural toxins that have been important in food toxicity during evolution, than against some synthetic toxins. However, it seems likely that these stimuli are also general defenses and are monitoring particular structures correlated with toxicity; some synthetic toxic compounds are also pungent, acrid, or astringent. Even though mustard, pepper, garlic, onions, etc., have some of these attributes, humans often ignore the warnings.

The fact that defenses are usually general, rather than specific for each chemical, makes good evolutionary sense. The reason that predators of plants evolved general defenses against toxins is presumably to be prepared to counter a diverse and ever-changing array of plant toxins in an evolving world; if a herbivore had defenses only against a set of specific toxins it would be at a great disadvantage in obtaining new foods when favored foods became scarce or evolved new toxins.

Various natural toxins, some of which have been present throughout vertebrate evolutionary history, nevertheless cause cancer in vertebrates. Mold aflatoxins, for example, have been shown to cause cancer in trout, rats, mice, monkeys and possibly in humans (2,17). Eleven mold toxins have been reported to be carcinogenic (6) and nineteen mold toxins have been shown to be clastogenic (18). Many of the common elements are carcinogenic (e.g., salts of lead, cadmium, beryllium, nickel, chromium, selenium and arsenic), or clastogenic (18) at high doses, despite their presence throughout evolution. Selenium and chromium are essential trace elements in animal nutrition.

Furthermore, epidemiological studies from various parts of the world show that certain natural chemicals in food may be carcinogenic risks to humans: the chewing of betel nuts with tobacco around the world has been correlated with oral cancer (17,19). The phorbol esters present in the Euphorbiaceae, some of which are used as folk remedies or herb teas, are potent mitogens and are thought to be a cause of nasopharyngeal cancer in China and esophageal cancer in Curacao (20,21). Pyrrolizidine toxins are mutagens that are found in comfrey tea, various herbal medicines, and some foods; they are hepatocarcinogens in rats, and may cause liver cirrhosis and other pathologies in humans (19).

Plants have been evolving and refining their chemical weapons for at least 500 million years and incur large fitness costs in producing these chemicals. If these chemicals were not effective in deterring predators, plants would not have been naturally selected to produce them.

Humans have not had time to evolve into a "toxic harmony" with all of the plants in their diet. Indeed, very few of the plants that humans eat would have been present in an African hunter-gatherer's diet. The human diet has changed drastically in the last few thousand years, and most humans are eating many recently introduced plants that their ancestors did not, e.g. coffee, cocoa, tea, potatoes, tomatoes, corn, avocados, mangoes, olives, and kiwi fruit. In addition, cruciferous vegetables such as

cabbage, broccoli, kale, cauliflower, and mustard were used in ancient times "primarily for medicinal purposes" and were spread as foods across Europe only in the middle ages (22,23). Natural selection works far too slowly for humans to have evolved specific resistance to the food toxins in these newly introduced plants.

Poisoning from plant toxins in the milk of foraging animals was quite common in previous centuries. Cow or goat milk and other ingested dairy products were contaminated by the natural toxins from plants that were eaten by foraging animals in non-industrial, agricultural societies, because toxins that are absorbed through the animal's gut are often secreted in the milk. Since the plants foraged by cows vary from place to place and are usually inedible for human consumption, the plant toxins that are secreted in the milk are, in general, not toxins to which humans could have easily adapted. Abraham Lincoln's mother, for example, died from drinking cow's milk that had been contaminated with toxins from the snakeroot plant (24). Foraging cows can eat bracken fern, which contains a known carcinogen; the milk from cows eating bracken fern is carcinogenic to rats (19). When cows and goats forage on lupine, their offspring may have teratogenic abnormalities, such as "crooked calf" syndrome caused by the anagyrene in lupine (25-27). Such significant amounts of these teratogens can be transferred to the animals' milk that drinking the milk during pregnancy is teratogenic for humans (25-27): in one rural California family, a baby boy, a litter of puppies, and goat kids all had a "crooked" bone birth-defect. The pregnant woman and the pregnant dog had both been drinking milk obtained from the family goats that had been foraging on lupine, the main forage in winter (25-27).

Anticarcinogenic chemicals in the diet may help to protect humans equally well against synthetic and natural carcinogens. Although plants contain anticarcinogenic chemicals that may protect against carcinogens (28,29) these anticarcinogens e.g., plant antioxidants, do not distinguish whether carcinogens are synthetic or natural in origin.

It has been argued that synergism between synthetic carcinogens could multiply hazards; however, this is also true of natural chemicals, which are by far the major source of chemicals in the diet.

DDT bioconcentrates in the food chain due to its unusual lipophilicity; however natural toxins can also bioconcentrate. DDT is often viewed as the typically dangerous synthetic pesticide because it persists for years; it was representative of a class of chlorinated pesticides. Natural pesticides, however, also bioconcentrate if lipophilic: the teratogens solanine (and its aglycone solanidine) and chaconine, for example, are found in the tissues of potato eaters (30-32). Although DDT was unusual with respect to bioconcentration, it was remarkably non-toxic to mammals, saved millions of lives, and has not been shown to cause harm to humans (33). To a large extent DDT, the first major synthetic insecticide, replaced lead arsenate, a major carcinogenic pesticide used before the modern era; lead arsenate is even more persistent than DDT. When the undesirable bioconcentration and persistence of DDT and its lethal effects on some birds were recognized it was prudently phased out, and less persistent chemicals were developed to replace it. Examples are the synthetic pyrethroids that disrupt the same sodium-channel in insects as DDT (34), are degraded rapidly in the environment, and can often be used at a concentration as low as a few grams per acre.

Natural toxins can have the same mechanisms of toxicity as synthetic toxins: the case of dioxin. Cabbage and broccoli contain a chemical whose breakdown products bind to the body's Ah receptor, induce the defense enzymes under the control of the receptor, and possibly cause mitogenesis - just as does dioxin (TCDD), one of the most feared industrial contaminants. TCDD is of great public concern because it is carcinogenic and teratogenic in rodents at extremely low doses. The doses humans ingest are, however, far lower than the lowest doses that have been shown to cause cancer and reproductive damage in rodents.

TCDD exerts many or all of its harmful effects in mammalian cells through binding to the Ah receptor (35). A wide variety of natural substances also bind to the Ah receptor, e.g. tryptophan oxidation products (36), and insofar as they have been examined, they have similar properties to TCDD. A cooked steak, for example, contains polycyclic hydrocarbons that bind to the Ah receptor and mimic TCDD. In addition, a variety of flavones and other plant substances in the diet, such as indole carbinol (IC) also bind to the Ah receptor. IC is the main breakdown compound of glucobrassicin, a glucosinolate that is present in large amounts in vegetables of the Brassica genus, including broccoli (about 25 mg per 100 g portion) (36a) Brussels sprouts (125 mg per 100 g) (36a), and cabbage (25 mg. per 100 g) (23). When tissues of these vegetables are lacerated, as occurs during chewing, they release an enzyme that breaks down the glucobrassicin. The enzyme is quite heat stable, and cooked vegetables yield most of the indole compounds that raw vegetables do (37). Therefore, we assume for the following calculation that 20% of glucobrassicin is converted to IC on eating. At the pH of the stomach, IC makes dimers and trimers that induce the same set of detoxifying enzymes as TCDD (37-39). IC, like TCDD, protects against carcinogenesis when given before aflatoxin or other carcinogens (39-41). However, when given after aflatoxin or other carcinogens, IC, like TCDD, stimulates carcinogenesis (38). This stimulation of carcinogenesis has also been shown for cabbage itself (42). These IC derivatives appear to be much more of a potential hazard than TCDD if binding to the Ah receptor is critical for toxic effects. The Environmental Protection Agency's human "reference dose" (formerly "acceptable dose limit") of TCDD is 6 femtograms (fg) per kilogram per day. This should be compared with 5 mg of IC per 100 g of broccoli or cabbage (6). Although the affinity of one major indole dimer in binding to Ah receptors is less than that of TCDD by a factor of about 8,000 (L. Bjeldanes and C. A. Bradfield, personal communication), the effective dose to the Ah receptor from a helping of broccoli would be about 1,500 times higher than that of TCDD, taking into account an extra factor of 1,000 for the very long lifetime of TCDD in the body (several years) and assuming that the lifetime of the hydrophobic indole dimers is as short as one day. Another IC dimer has recently been shown to bind to the Ah receptor with about the same affinity as TCDD (L. Bjeldanes and C. A. Bradfield, personal communication). However, it is not clear whether at the low doses of human exposure either is hazardous; they may even be protective. It seems likely that many more of these natural "dioxin simulators" will be discovered in the future.

If TCDD is compared with alcohol it seems of minor interest as a teratogen or carcinogen. Alcoholic beverages are the most important known human chemical teratogen (43). In contrast, there is no persuasive evidence that TCDD is either carcinogenic or teratogenic in humans, although it is both at near-toxic doses in rodents. If one compares the teratogenic potential of TCDD to that of alcohol for causing birth defects (after adjusting for their respective potency as determined in

rodent tests), then a daily consumption of the EPA reference dose of TCDD (6 fg) would be equivalent in teratogenic potential to a daily consumption of alcohol from 1/3,000,000 of a beer. That is equivalent to drinking a single beer (15 g ethyl alcohol) over a period of 8,000 years.

Alcoholic beverages in humans are a risk factor for cancer (17) as well as birth defects. A comparison of the carcinogenic potential for rodents of TCDD with that of alcohol (adjusting for the potency in rodents) (2) shows that ingesting the TCDD reference dose of 6 fg per kilogram per day is equivalent to ingesting one beer every 345 years. Since the average consumption of alcohol in the United States is equivalent to more than one beer per person per day, and since 5 drinks a day are a carcinogenic risk in humans, the experimental evidence does not of itself seem to justify the great concern over TCDD at levels in the range of the reference dose.

TRADEOFFS BETWEEN NATURAL AND SYNTHETIC PESTICIDES

Since no plot of land is immune to attack by insects, plants need chemical defenses—either natural or synthetic—in order to survive pest attack. "It has been suggested that one consequence of crop plant domestication is the deliberate or inadvertent selection for reduced levels of secondary compounds that are distasteful or toxic. Insofar as many of these chemicals are involved in the defense of plants against their enemies, the reduction due to artificial selection in these defenses may account at least in part for the increased susceptibility of crop plants to herbivores and pathogens. . . ." (44). Therefore, there is a tradeoff between nature's pesticides and synthetic pesticides.

Cultivated plant foods commonly contain on average fewer natural toxins than do their wild counterparts. For example, the wild potato *Solanum Acaule*, the progenitor of cultivated strains of potato, has a glycoalkaloid content about 3 times that of cultivated strains and is more toxic (45,46). The leaves of the wild cabbage *Brassica oleracea* (the progenitor of cabbage, broccoli, and cauliflower) contain about twice as many glucosinolates as cultivated cabbage (47). The wild bean *Phaseolus lunatus* contains about 3 times as many cyanogenic glucosides as does the cultivated bean (48). Similar reductions in toxicity through agriculture have been reported in lettuce, lima bean, mango, and cassava (49).

One consequence of disproportionate concern about synthetic pesticide residues is that plant breeders are developing plants that are more insect-resistant, but that are also higher in natural toxins. Two recent cases illustrate the potential hazards of this approach to pest control. 1) When a major grower introduced a new variety of highly insect-resistant celery into commerce, a flurry of complaints were made to the Centers for Disease Control from all over the country because people who handled the celery developed rashes and burns when they were subsequently exposed to sunlight. Some detective work found that the pest-resistant celery contained 6,200 ppb of carcinogenic (and mutagenic) psoralens instead of the 800 ppb present in normal celery (6,50-52). It is not known whether other natural pesticides in the celery were increased as well. The celery is still on the market. 2) A new potato, developed at a cost of millions of dollars, had to be withdrawn from the market because of its acute toxicity to humans—a consequence of higher levels of two natural toxins, solanine and chaconine. Solanine and chaconine inhibit cholinesterase, thereby blocking nerve transmission, and are known rodent teratogens. They were widely introduced into the world diet about 400 years ago with the dissemination of the

potato from the Andes. Total toxins are present in normal potatoes at a level of 15 mg per 200-g potato (75 ppm), which is less than a ten-fold safety margin from the measurably toxic, daily dose level for humans (45). Neither solanine nor chaconine has been tested for carcinogenicity. In contrast, the cholinesterase inhibitor malathion, the main synthetic organophosphate pesticide residue in our diet (0.006 mg per day), has been tested and is not a carcinogen in rats or mice. Common cultivars of plants differ widely in the level of particular natural toxins (6), and other factors in the plant also play a part in pest resistance. Breeding or genetic engineering can be used to increase or decrease specific chemicals or other factors.

Certain cultivated crops have become popular in developing countries because they thrive without costly synthetic pesticides. However, the tradeoffs of cultivating some of these naturally pest-resistant crops are that they are highly toxic and require extensive processing to detoxify them. For example, cassava root, a major food crop in Africa and South America, is quite resistant to pests and disease; however, it contains cyanide at such high levels that only a laborious process of washing, grinding, fermenting, and heating can make it edible; ataxia due to chronic cyanide poisoning is endemic in many of the cassava-eating areas of Africa (53). In one part of India, the pest-resistant grain *Lathyrus sativus* is cultivated to make some types of dahl. Its seeds contain the neurotoxin beta-N-oxalyl aminoalanine, which causes a crippling nervous system disorder, neurolathyrism (54).

There is a tendency for non-scientists to think of chemicals as being only synthetic, and to characterize synthetic chemicals as toxic, as if every natural chemical were not also toxic at some dose. Even a recent National Research Council report (55) states: "Advances in classical plant breeding. . . offer some promise for nonchemical pest control in the future. Nonchemical approaches will be encouraged by tolerance revocations. . . ." The report was concerned with pesticide residues, but ignored natural pesticides. Tomatine, one of the natural toxins in tomatoes, is a recent chemical too, since it was introduced to the world diet from Peru 400 years ago. Neither tomatine nor its aglycone, tomatidine, an antifungal steroid-like molecule, has been tested in rodent cancer bioassays. Tomatine is present at 36 mg per 100-g tomato (360 ppm), a concentration that is much closer to the acutely toxic level in humans than are manmade pesticide residues (45).

As an alternative to synthetic pesticides, it is legal for "organic farmers" to use the natural pesticides from one plant species against pests that attack a different plant species, e.g. rotenone (which Indians used to poison fish), or the pyrethrins from chrysanthemum plants. These naturally-derived pesticides have not been tested as extensively for carcinogenicity (rotenone is negative, however), mutagenicity or teratogenicity as have synthetic pesticides; therefore, their safety compared to synthetically-derived pesticides should not be prematurely assumed.

Synthetic pesticides have markedly lowered the cost of plant food, thus increasing consumption. Eating more fruits and vegetables and less fat may be the best way to lower risks of cancer and heart disease, other than giving up smoking (35,56,57).

"TOXIC CHEMICALS" AND HUMAN RISK

Positive results are remarkably common in high-dose screening tests for carcinogens, clastogens (agents breaking chromosomes), teratogens and mutagens. About half of the chemicals tested, whether natural or synthetic, are carcinogens in

chronic, high-dose rodent tests (5,6) and about half are clastogens in tissue culture tests (18). A high proportion of positives is also reported for rodent teratogenicity tests: 38% of the 2,800 chemicals tested in laboratory animals "have been teratogenic" in the standard, high-dose protocol (58). It is therefore reasonable to assume that a sizeable percentage of both synthetic and natural chemicals will be reproductive toxins at high doses. Mutagens may also be common: of the 340 chemicals tested for carcinogenicity in both rats and mice and mutagenicity in Salmonella (59; L.S. Gold, unpublished) 46% were mutagens, and mutagens were nearly twice as likely to be carcinogenic than were non-mutagens. Of these 340 chemicals, 70% were either mutagens or carcinogens or both. How much this high frequency of positive results is due to bias in selecting chemicals is not known (5). Even if selection bias doubled the percentage of positives, which we think is unlikely (5), the high proportion of positives would still mean that almost everything natural we eat contains carcinogens, mutagens, teratogens, and clastogens (6). Thus, testing a random group of natural pesticides and pyrolysis products from cooking should be a high priority for these various tests so an adequate comparison can be made to synthetic toxins.

Dozens of mammalian metabolites are commonly produced from any reasonably complex molecule. Therefore, even non-mutagenic, non-clastogenic, non-carcinogenic, and non-teratogenic chemicals, whether synthetic or natural, are likely to produce some carcinogenic, clastogenic, teratogenic and mutagenic mammalian metabolites.

Several chemicals that have been shown to be carcinogens at high doses in rodents have also been shown to be anticarcinogens in other animal models at lower doses, e.g., limonene, caffeic acid, dioxin, indole carbinol (28,29). Therefore, the dose and context of a chemical exposure may be critical.

The first rule of toxicology is that all chemicals are "toxic chemicals"; it is the dose that makes the poison. High-dose tests are relevant for some occupational or medicinal exposures that can be at high doses (2,60). With mutagens there is some theoretical justification for thinking that low doses may have an effect, although the complexities of inducible protection systems may well produce a dose-response threshold, or even protective effects at very low doses. The high endogenous DNA damage rate is also relevant (5). In any case, there should be a threshold of attention for hypothetical risks that are low compared to background risks, otherwise resources are diverted from more important risks. The arguments in these papers undermine many assumptions of current regulatory policy and necessitate a rethinking of policy designed to reduce human cancer. Minimizing pollution is a separate issue, and is clearly desirable for reasons other than effects on public health.

It is by no means clear that many significant risk factors for human cancer will be single chemicals that will be discovered by screening assays. Dietary imbalances are likely to be a major contributor to human cancer (43,56,57) and understanding these should be, but is not, a major priority of research. Understanding why caloric restriction dramatically lowers cancer and mitogenesis rates, and extends life span in experimental animals (61,62) should also be a major research priority. More studies on mechanisms of carcinogenesis are also a high priority.

ACKNOWLEDGMENT

We are indebted to R. Peto, N. B. Manley, T. H. Slone, C. Wehr, R. Beier, L. W. Wattenberg, R. Hall, T. Jukes, G. R. Fenwick, J. Caldwell, J. Duke, C. VanEtten, D. Freedman, R. Prokopy, and N. Ito for criticisms. This work was supported by National Cancer Institute Outstanding Investigator Grant CA39910, by National Institute of Environmental Health Sciences Center Grant ES01896; Contract No. DE-AC03-76SF00098: Director, Office of Energy Research, Office of Health and Environmental Research, Division of the U.S. Department of Energy. We dedicate this paper to the memory of William Havender.

REFERENCES

1. Ames, B. N., Magaw, R. & Gold, L. S. (1987) *Science* 236, 271-280.
2. Gold, L. S., Bernstein, L., Magaw, R. & Slone, T. H. (1989) *Environ. Health Perspect.* 81, 211-219.
3. Gold, L. S., Sawyer, C. B., Magaw, R., Backman, G. M., de Veciana, M., Levinson, R., Hooper, N. K., Havender, W. R., Bernstein, L., Peto, R., Pike, M. C. & Ames, B. N. (1984) *Environ. Health Perspect.* 58, 9-319.
4. Gold, L. S., de Veciana, M., Backman, G. M., Magaw, R., Lopipero, P., Smith, M., Blumenthal, M., Levinson, R., Gerson, J., Bernstein, L. & Ames, B. N. (1986) *Environ. Health Perspect.* 67, 161-200.
5. Gold, L. S., Slone, T. H., Backman, G. M., Magaw, R., Da Costa, M., Lopipero, P., Blumenthal, M. & Ames, B. N. (1987) *Environ. Health Perspect.* 74, 237-329.
6. Gold, L. S., Slone, T. H., Backman, G. M., Eisenberg, S., Da Costa, M., Wong, M., Manley, N. B., Rohrbach, L. & Ames, B. N. (1990) *Environ. Health Perspect.* 84, 215-285.
7. Gold, L. S., Slone, T. H. & Bernstein, L. (1989) *Environ. Health Perspect.* 79, 259-272.
8. Ames, B. N., Profet, M. & Gold, L. S. *Proc. Natl. Acad. Sci. USA*, in press.
9. Haseman, J. K. (1985) *Fundam. Appl. Toxicol.* 5, 66-78.
10. McConnell, E. E. (1989) *J. Am. Coll. Toxicol.* 8, 1115-1120.
11. Kociba, R. J. (1987) *Environ. Health Perspect.* 76, 169-174.
12. Peto, R., Parish, S. E. & Gray, R. G. (1985) in *Age-Related Factors in Carcinogenesis*, eds. Likhachev, A., Anisimov, V. & Montesano, R. (International Agency for Research on Cancer, France), pp. 43-53.
13. Doll, R. & Peto, R. (1981) *J. Natl. Cancer Inst.* 66, 1191-1308.
14. Ames, B. N. (1989) *Environ. Mol. Mutagen* 14, 66-77.

15. Ames, B. N. (1989) *Free Rad. Res. Commun.* 7, 121-128.
16. Pitot, H. C., Goldsworthy, T. L., Moran, S., Kennan, W., Glauert, H. P., Maronpot, R. R. & Campbell, H. A. (1987) *Carcinogenesis* 8, 1491-1499.
17. Farber, E. (1987) *Environ. Health Perspect.* 75, 65-70.
18. Butterworth, B. E. & Slaga, T. (1990) eds. *Chemically Induced Cell Proliferation: Implications for Risk Assessment* (Wiley-Liss, Inc., New York).
19. Butterworth, B. E. & Goldsworthy, T. L.,
20. Cohen, S. M. & Ellwein, L. B. (1990) *Science*.
21. Dunsford, H. A., Sell, S. & Chisari, F. V. (1990) *Cancer Res.* 50, 3400-3407.
22. Fraga, C. G., Shigenaga, M. K., Park, J.-W., Degan, P. & Ames, B. N. (1990) *Proc. Natl. Acad. Sci. USA* 87, 4533-4537.
23. Shigenaga, M. K., Gimeno, C. J. & Ames, B. N. (1989) *Proc. Natl. Acad. Sci. USA* 86, 9697-9701.
24. Richter, C., Park, J.-W. & Ames, B. N. (1988) *Proc. Natl. Acad. Sci. USA* 85, 6465-6467.
25. Weinberg, R. A. (1990) in *Oncogenes and the Molecular Origins of Cancer* (Cold Spring Harbor Laboratory Press, New York).
26. Weinberg, R. A. (1989) *Cancer Res.* 49, 3713.
27. Tong, C., Fazio, M. & Williams, G. M. (1980) *Proc. Natl. Acad. Sci. USA* 77, 7377-7389.
28. Schiestl, R. H., Gietz, R. D., Mehta, R. D. & Hastings, P. J. (1989) *Carcinogenesis* 10, 1445-1455.
29. Liskay, R. M. & Stachelek, J. L. (1983) *Cell* 35, 157-165.
30. Fahrig, R. (1976) *Mol. & Gen. Genet.* 144, 131-140.
31. Ramel, C. (1988) *Mutat. Res.* 205, 13-24.
32. Grodon, J., Nakamura, Y. & German, J. (1990) *Proc. Natl. Acad. Sci. USA* 87, 4315-4319.
33. Cavenee, W. K., Dryja, T. P., Phillips, R. A., Benedict, W. F., Godbout, R., Gallie, B. L., Murphree, A. L., Strong, L. C. & White, R. L. (1983) *Nature* 305, 779-784.
34. Cavenee, W. K., Hansen, M. F., Nordenskjold, M., Kock, R., Maumenee, I., Squire, J. A., Phillips, R. A. & Gallie, B. L. (1985) *Science* 228, 501-503.
35. Hansen, M. F. & Cavenee, W. K. (1987) *Cancer Res.* 47, 5518-5527.
36. Sasaki, M., Okamoto, M., Sato, C., Sugio, K., Soejima, J., Iwama, T., Ikeuchi, T., Tonomura, A., Miyaki, M. & Sasazuki, T. (1989) *Cancer Res.* 49, 4402-4406.

37. Erisman, M. D., Scott, J. K. & Astrin, S. M. (1989) *Proc. Natl. Acad. Sci. USA* 86, 4264-4268.
38. Vogelstein, B., Fearon, E. R., Hamilton, S. R., Kern, S.E., Preisinger, A. C., Leppert, M., Nakamura, Y., White, R., Smits, A. M. M. & Bos, J. L. (1988) *N. Engl. J. Med.* 319, 525-532.
39. Vogelstein, B., Fearon, E. R., Kern, S. E., Hamilton, S. R., Preisinger, A. C., Nakamura, Y. & White, R. (1989) *Science* 244, 207-211.
40. Turner, D. R., Grist, S. A., Janatipour, M. & Morley, A. A. (1988) *Proc. Natl. Acad. Sci. USA* 85, 3189-3192.
41. Orr-Weaver, T. L. & Spradling, A. C. (1986) *Mol. Cell. Biol.* 6, 4624-4633.
42. Coni, P., Pichiri-Coni, G., Ledda-Columbano, Rao, P. M., Rajalakshmi, S., Sarma, D. S. R. & Columbano, A. (1990) *Carcinogenesis* 11, 835-839.
43. Wilson, V. L., Smith, R. A., Ma, S. & Cutler, R. G. (1987) *J. Biol. Chem.* 262, 9948-9951.
44. Lu, L.-J. W., Liehr, J. G., Sirbasku, D. A., Randerath, E., Randerath, K. (1988) *Carcinogenesis* 9, 925-929.
45. Nicklas, J. A., O'Neill, J. P., Sullivan, L. M., Hunter, T. C., Allegretta, M., Chastenay, B. V., Libbus, B. L. & Albertini, R. J. (1988) *Environ. and Mol. Mutagen* 12, 271-284.
46. Nicklas, J. A., Hunter, T. C., O'Neill, J. P. & Albertini, R. J. (1989) *Mutat. Res.* 215, 147-160.
47. Albertini, R. J., O'Neill, J. P., Nicklas, J. A., Allegretta, M., Recio, L. & Skopek, T. R. (1990) in *Proceedings of the 5th International Conference on Environmental Mutagens* (Alan R. Liss, Inc., New York).
48. Allegretta, M., Nicklas, J. A., Sriram, S. & Albertini, R. J. (1990) *Science* 247, 718-721.
49. Trosko, J. E. (1989) *J. Am. Coll. Toxicol.* 89, 1121-1132.
50. Trosko, J. E., Chang, C. C., Madhukar, B. V. & Oh, S. Y. (1990) *In Vitro Toxicol.* 3, 9-26.
51. Yamasaki, H., Enomoto, K., Fitzgerald, D. J., Mesnil, M., Katoh, F. & Hollstein, M. (1988) in *Cell Differentiation, Genes and Cancer*, IARC Scientific Publication No. 92, eds. Kakunaga, T., Sugimura, T., Tomatis, L. & Yamasaki, H. (International Agency for Research on Cancer, France), pp. 57-75.
52. Farber, E. (1990) *Biochem. Pharmacol.* 39, 1837-1846.
53. Farber, E., Parker, S. & Gruenstein, M. (1976) *Cancer Res.* 36, 3879-3887.
54. Farber, E. (1984) *Cancer Res.* 44, 5463-5474.

55. Mirsalis, J. C. & Steinmetz, K. L. (1990) in *Mouse Liver Carcinogenesis: Mechanisms and Species Comparisons*, eds. Stevenson, D., McClain, M., Popp, J., Slaga, T., Ward, J. & Pitot, H. (Wiley-Liss, New York).
56. Mirsalis, J. C., Tyson, C. K., Steinmetz, K. L., Loh, E. K., Hamilton, C. M., Bakke, J. P. & Spalding, J. W. (1989) *Environ. Mol. Mutagenesis* 14, 155-164.
57. Joossens, J. V. & Geboers, J. (1981) *Nutr. Cancer* 2, 250-261.
58. Furihata, C., Sato, Y., Hosaka, M., Matsushima, T., Furukawa, F. & Takahashi, M. (1984) *Biochem. Biophys. Res. Commun.* 121, 1027-1032.
59. Tuyns, A. J. (1988) *Nutr. Cancer* 11, 229-232.
60. Lu, J.-B. & Qin, Y.-M. (1987) *Int. J. Epidemiol.* 16, 171-176.
61. Furihata, C., Sudo, K. & Matsushima, T. (1990) *Carcinogenesis* 10, 2135-2137.
62. Coggon, D., Barker, D. J. P., Cole, R. B. & Nelson, M. (1989) *J. Natl. Cancer Inst.* 81, 1178-1182.
63. Charnley, G. & Tannenbaum, S. R. (1985) *Cancer Res.* 45, 5608-5616.
64. Karube, T., Katayama, H., Takemoto, K. & Watanabe, S. (1989) *Jpn. J. Cancer Res.* 80, 698-701.
65. Ward, J. F., Limoli, C. L., Calabro-Jones, P. & Evans, J. W. (1987) in *Anticarcinogenesis and Radiation Protection*, eds. Cerutti, P. A., Nygaard, O. F. & Simic, M. G. (Plenum, New York).
66. Crawford, D. & Cerutti, P. (1988) in *Anticarcinogenesis and Radiation Protection*, eds. Nygaard, O., Simic, M. & Cerutti, P. (Plenum, New York), pp. 183-190.
67. Chan, T. M., Chen, E., Tatoyan, A., Shargill, N. S., Pleta, M. & Hochstein, P. (1986) *Biochem. Biophys. Res. Commun.* 139, 439-445.
68. Craven, P. A., Pfanstiel, J. & DeRubertis, F. R. (1987) *J. Clin. Invest.* 79, 532-541.
69. Sieweke, M. H., Stoker, A. W. & Bissell, M. J. (1989) *Cancer Res.* 49, 6419-6424. 69a. Madsen, C. (1989) *Lab. Animals* 23, 241-247.
70. Demopoulos, H. B., Pietronigro, D. D., Flamm, E. S. & Seligman, M. L. (1980) *J. Environ. Pathol. Toxicol.* 3, 273-303.
71. Templeton, A. (1980) *J. Environ. Pathol. Toxicol.* 3, 387-397.
72. Lewis, J. G. & Adams, D. O. (1987) *Environ. Health Perspect.* 76, 19-27.

73. Petruska, J., Marsh, J. P., Kagan, E. & Mossman, B. T. (1988) *Am. Rev. Respir. Dis.* 137, 403.
74. Yeh, F.-S., Mo, C.-C., Luo, S., Henderson, B. E., Tong, M. J. & Yu, M. C. (1985) *Cancer Res.* 45, 872-873.
75. Wu, T. C., Tong, M. J., Hwang, B., Lee, S.-D. & Hu, M. M. (1987) *Hepatology* 7, 46-48.
76. Peto, R. & zur Hausen, H. (1986) eds. *Banbury Report 21. Viral Etiology of Cervical Cancer* (Cold Spring Harbor Laboratory, New York).
77. Inoue, J., Seiki, M., Taniguchi, T., Tsuru, S. & Yoshida, M. (1986) *EMBO J.* 5, 2883-2888.
78. Taniguchi, T., Yamada, G., Shibuya, H., Maruyama, M., Haradu, H., Hatakeyama, M. & Fujita, T. (1988) in *Cell Differentiation, Genes and Cancer*, eds. Kakunaga, T., Sugimura, T., Tomatis, L. & Yamasaki, H. (International Agency for Research on Cancer, France), vol. 92, pp. 181-184.
79. Rathbone, B. J. & Heatley, R. V. (1989) eds. *Campylobacter pylori and gastroduodenal disease* (Blackwell, Oxford).
80. Blaser, M. J. (1989) ed. *Campylobacter pylori in gastritis and peptic ulcer disease* (Igaku-Shoin, New York).
81. Preston-Martin, S., Pike, M. C., Ross, R. K., Jones, P. A. & Henderson, B. E. (1990) in *Chemically Induced Cell Proliferation: Implications for Risk Assessment*, eds. Butterworth, B. & Slaga, T. (Alan R. Liss, Inc., New York), in press.
82. Henderson, B. E., Ross, R. & Bernstein, L. (1988) *Cancer Res.* 48, 246-253.
83. Iversen, O. H., (1988) ed. *Theories of Carcinogenesis* (Hemisphere Publishing, Washington, D.C.).
84. Columbano, A., Ledda-Columbano, G. M., Ennas, M. G., Curto, M., Chelo, A. & Pani, P. (1990) *Carcinogenesis* 11, 771-776.
85. Zeiger, E. (1987) *Cancer Res.* 27, 1287-1296.
86. Ashby, J. & Tennant, R. W. (1988) *Mutat. Res.* 204, 17-115.
87. Hoel, D. G., Haseman, J. K., Hogan, M. D., Huff, J. & McConnell, E. E. (1988) *Carcinogenesis* 9, 2045-2052.
88. Hoel, D. G. & Portier, C. J. (1990), submitted for publication.
89. Swenberg, J. A., Richardson, F. C., Boucheron, J. A., Deal, F. H., Belinsky, S. A., Charbonneau, M. & Short, B. G. (1987) *Environ. Health Perspect.* 76, 57-63. 89a. Deal, F. H., richardson, F. C., & Swenberg, J. A. (1989) *Cancer Res.* 49, 6985-6988.
90. Peto, R., Gray, R., Brantom, P. & Grasso, P. (1990) *Cancer Res.*,.

91. Peto, R., Gray, R., Brantom, P. & Grasso, P. (1990) *Cancer Res.*
92. Gray, R., Peto, R., Brantom, P. & Grasso, P. (1990) *Cancer Res.*,
93. Bernstein, L., Gold, L. S., Ames, B. N., Pike, M. C. & Hoel, D. G. (1985) *Fundam. Appl. Toxicol.* 5, 79-86.
94. Jones, T. D. (1984) *Health Phys.* 4, 533-558.
95. Little, J. B., Kennedy, A. R. & McGandy, R. B. (1985) *Radiat. Res.* 103, 293-299.
96. Wolff, S., Afzal, V. Wiencke, J. K., Olivieri, G. & Michaeli, A. (1988) *Int. J. Radiat. Biol.* 53, 39-48.
97. Yalow, R. S. (1988) in *Biological effects of low-level radiation in Low-Level Radioactive Waste Regulation: Science, Politics, and Fear*, ed. Burns, M. E. (Lewis Publishers, Inc., Michigan), pp. 239-259.
98. Wolff, S., Olivieri, G. & Afzal, V. (1990) in *Chromosomal Aberrations: Basic and Applied Aspects*, eds. Natarajan, A. T. & Obe, G. (Springer-Verlag, New York).
99. Cai, L. & Liu, S.-Z. (1990) *Int. J. of Radiat. Biol.* 58, 187-194.
100. Wolff, S., Wiencke, J. K., Afzal, V., Youngblom, J. & Cortes, F. R. (1989) in *Low Dose Radiation: Biological Bases of Risk Assessment*, eds. Baverstock, K. F. & Stather, J. W. (Taylor & Francis, England).
101. Zeise, L., Crouch, E. A. C. & Wilson, R. (1986) *J. Am. Coll. Toxicol.* 5, 137-151.
102. National Research Council (1989) *Diet and Health* (National Academy Press, Washington, D.C.).
103. National Research Council (1982) *Diet, Nutrition, and Cancer* (National Academy Press, Washington, D.C.).
104. Joosens, J. V., Hill, M. J. & Geboers, J. (1986) eds. *Diet and Human Carcinogenesis* (Elsevier Science Publishers B. V., Amsterdam).
105. Lipkin, M. (1988) *Cancer Res.* 48, 235-245.
106. Yang, C. S. & Newmark, H. L. (1987) *CRC Crit. Rev. Oncol. Hematol.* 7, 267-287.
107. Pence, B. C. & Buddingh, F. (1988) *Carcinogenesis* 9, 187-190.
108. Reddy, B. S. & Cohen, L. A. (1986) eds. *Diet, Nutrition, and Cancer: A Critical Evaluation*, Vols. I and II (CRC Press, Florida).
International Agency for Research on Cancer (1989) *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: Overall Evaluations of Carcinogenicity: An Updating of*

IARC Monographs Volumes 1-46, Supplement 7 (International Agency for Research on Cancer, France).

Gold, L. S. Backman, G. M., Hooper, N. K. & Peto, R. (1987) Environ. Health Perspect. 76, 211-219.

ANNEXE 5

Lead consumption in Sweden in 1992 was:

All figures expressed in tonnes/year.

Lead consumption in Sweden	
Application:	Consumption
Accumulators, batteries:	22,000
Lead cable sheathing less than:	3,000
Crystal glass:	1,300
Electronics:	1,300
Ammunition:	1,200
Weights:	1,000
Metal alloys:	900
Fishing weight, nets:	600
Chimney plates:	500
Plastic additives, excl. PVC pipes:	400
Leaded petrol:	340
PVC pipes:	225
Other usages:	150
Rust protection, paint:	90

If lead in PVC pipes is a problem, why should the use of lead in crystal glass be allowed, just for enjoying the art of glass blowing, with no environmental benefit?

ANNEXE 6

Lead emissions in Sweden.

The annual emission of lead to the environment was calculated to be:
All figures expressed in tonnes/year.

Lead emissions in Sweden	
product	emission
Accumulators:	3,000
Ammunition:	1,200
Fishing weights, nets:	600
Leaded petrol:	340
Rust protection paint:	90
PVC pipes:	0.08

ANNEXE 7

Energy and crude oil use for different materials.

All figures as GJ/ton for energy use and ton/ton for crude oil.

Energy and crude oil use for different materials		
Material	energy use	crude oil use
<u>PVC</u>	53	0.63
<u>LD/HDPE</u>	70	1.10
<u>PP</u>	73	1.17
<u>PS</u>	80	1.26
<u>PET</u>	84	1.65
<u>PC</u>	107	1.68
Steel	30	0.00
Aluminium	200	0.00

Source: Milieuvriendelijk verpakken in de toekomst
(Dutch: Environmentally friendly packaging in the future)
Stichting Milieudefensie (NI), 1991.

ANNEXE 8

Critical volumes for the production of different materials.

All figures in m³ air/kg and dm³ water/kg.

Critical volumes for the production of different materials.		
Material	c.v. air	c.v. water
<u>PVC</u>	700	3,000
<u>LDPE</u>	265	1,650
<u>PP/HDPE</u>	325	3,685
<u>PS</u>	255	6,335
<u>PET</u>	180	8,000
<u>PC</u>	180	5,050
Steel	3,400	4,600
Aluminium	9,320	27,700

Source: Milieuvriendelijk verpakken in de toekomst
(Dutch: Environmentally friendly packaging in the future)
Stichting Milieudefensie (NI), 1991.

ANNEXE 9

An LCA by van den Berg *et al.* (1996) compared iron, polyethylene and PVC piping for low pressure gas distribution systems in Holland. The following environmental themes were considered:

- Photochemical oxidant formation potential: reactions of NO_x with volatile organic substances leads, under the influence of UV light, to photochemical oxidant creation, which causes smog.
- Nutrification potential: the addition of nutrients to water or soil will increase production of biomass and may threaten biodiversity.
- Global warming potential: an increasing amount of carbon dioxide, for example, in the earth's atmosphere leads to an increasing absorption of heat radiation and consequently to an increase in temperature.
- Human toxicity potential: exposure of humans to toxic substances causes health problems. Exposure can take place through air, water or soil and especially through the food chain.
- Abiotic depletion potential: abiotic depletion refers to the extraction of raw materials such as ores and energy sources faster than they are created.
- Odour threshold limit: exposure to odorous compounds is measured as the volume of air polluted to the odour threshold.
- Ozone depletion potential: depletion of the ozone layer leads to an increase in the UV light reaching the earth's surface. This may lead to human diseases and may influence ecosystems.

Using a cradle-to-grave approach, their conclusions were that in terms of all of these environmental themes, PVC was better than or equal to the other materials considered.