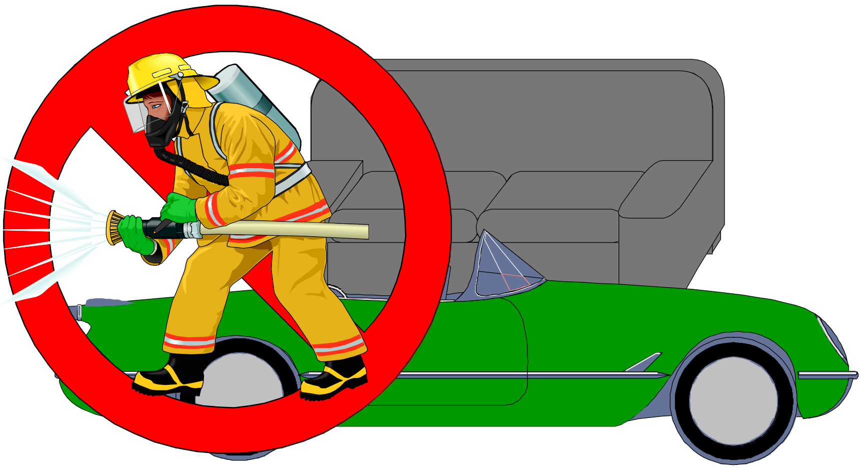
# Risk Reduction Strategy and Analysis of Advantages and Drawbacks for Pentabromodiphenyl Ether



## Stage 4 Report

Prepared for
Department of the Environment,
Transport and the Regions

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*RPA*
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# *Risk Reduction Strategy and Analysis of Advantages and Drawbacks of Pentabromodiphenyl Ether*

Stage 4 Report - March 2000

prepared for

The Department of the Environment, Transport and the Regions

by

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| **RPA REPORT - ASSURED QUALITY** | |
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# EXECUTIVE SUMMARY

Pentabromodiphenyl ether (penta-BDPE) is used as a flame retardant, almost exclusively in polyurethane (PUR) foams. It is used primarily in flexible PUR foams but also to a lesser degree in non-foamed PUR such as elastomers.

The environmental Risk Assessment for penta-BDPE concludes that releases of this substance from PUR foam production facilities results in risks from secondary poisoning effects in the fish-based (aquatic) food chain, while releases from the use of foams containing penta-BDPE result in risks from secondary poisoning effects in the earthworm-based (terrestrial) food chain. This report provides details of a study conducted for the UK Department of the Environment, Transport and the Regions (DETR) to develop a risk reduction strategy to address these environmental risks.

Consideration has been given to risk reduction measures which are already in place. These have been effective to some extent in reducing the use and environmental emissions of this substance and there is an ongoing trend towards the replacement of this penta-BDPE with alternative flame retardants. It may be the case that the use of this substance would cease in the coming years without any additional form of risk reduction. However, given the nature and severity of the risks and the uncertainty of reliance upon these, it is concluded that additional risk reduction measures are required.

Three main applications for penta-BDPE in PUR foams have been identified during this study:

1. in PUR foam-based laminated automotive applications such as headrests;

2. in the production PUR foams for domestic furniture, including cot mattresses (where penta-BDPE is used for commercial reasons by one company because it does not contain phosphorus); and

3. in the production of various small run and prototype components, such as (non-foamed) PUR instrument casings.

The manufacture of these products in the EU is estimated as being associated with <1% of PUR foam production and <0.4% of the FR market. The total value of the market for penta-BDPE is estimated as Euro 4.3 million (£2.7 million).

Suitable alternative flame retardants exist for all of the types of applications in which penta-BDPE is used. These are generally other halogenated flame retardants. A range of these alternatives can allow finished products to meet the requirements of the relevant fire safety standards and, therefore, their use would not compromise consumer safety.

An appraisal of the toxicological profile of key alternative flame retardants has been undertaken. It has been concluded that alternative flame retardants are available which, based on the available data, are less hazardous to the environment than penta-BDPE. However, some of these substances are still classified as dangerous for the environment.

Three possible risk reduction options have been assessed as means of controlling the risks arising from the use of penta-BDPE as a flame retardant in PUR foams. Conclusions from the appraisal of these options in terms of their effectiveness, practicality, economic impact and monitorability are summarised in Table 1. This table also sets out the conclusions drawn on the overall balance of the advantages versus the drawbacks of these measures.

Consideration was given to the possibility of tackling risks arising from the use of penta-BDPE-based foams by placing restrictions upon the migration of penta-BDPE from products (as an alternative to an outright ban) through changes in the production process or use of smaller quantities of flame retardant. This was not found to be technically feasible. Consideration was also given to targeting restrictions at specific uses of penta-BDPE. Data paucity makes it impossible to ensure the effectiveness of this option. In addition, there do not appear to be any specific reasons for favouring restrictions for one sector whilst omitting another.

Environmental quality standards and the use of the licensing system for Integrated Pollution Prevention and Control (IPPC) address only the risks arising from PUR foam production and not those which arise from emissions of penta-BDPE from finished products.

Only restrictions upon the marketing and use of penta-BDPE have the potential to address the risks arising from both the production and use of PUR foams.

On the basis of the data provided, marketing and use restrictions - in the form of a ban - are believed to provide an effective and practical means for controlling secondary poisoning risks arising from both the production and use of polyurethane foams containing penta-BDPE. Economic impacts are also believed to be limited given the small size of the market and the availability of alternatives. However, there may be issues associated with the monitoring of imports of finished articles from outside the EU which will need to be addressed.

It is believed that only this option has the potential to provide adequate control of the environmental risks associated with this substance. Given that the trend is away from use of this substance and that relatively few difficulties are anticipated in its replacement, it is considered that the advantages of this option outweigh the potential drawbacks.

**Table 1: Summary of Advantages and Drawbacks**

| | Marketing & Use Restrictions | EQSs and/or Limit Values | IPPC |
|---|---|---|---|
| **Effectiveness** | Total ban would eliminate all risks associated with penta-BDPE from production and use of PUR products<br>Insufficient data for implementing measures targeted at specific uses. Not feasible to reduce concentrations of penta-BDPE within products, or to better contain penta-BDPE within those products<br>Suitable alternative FRs available in technical and environmental terms (and thus no additional risks of injury from fires expected)<br>Implementation probably no earlier than 2002 | Will only address risks to aquatic environment (fish-based food chain), i.e. from PUR production.<br>Not suited to addressing risks associated with emissions from finished products (earthworm-based food chain), i.e. from PUR use | Will not address majority (90%) of risks of secondary poisoning in earthworm-based food chain which arise mainly from emissions from products<br>May not apply to companies manufacturing non-foamed polyurethane products<br>Implementation delayed til 2007 for existing installations in some Member States |
| **Practicality** | Mechanisms for national implementation already developed in Member States<br>Additional legislation required to control storage and transport (though no risks identified here) | No problems envisaged in setting measurable EQO/EQS | Relatively simple to implement since infrastructure for IPPC required in all Member States. BAT may not sufficiently reduce emissions of penta-BDPE. Also, flexibility in adoption of BAT across Member States. |
| **Monitorability** | Possible difficulty of controlling imports of penta-BDPE within PUR products | Appears technically feasible to monitor at likely level of EQO/EQS | Suitable mechanisms should be in place for monitoring emissions under IPPC at PUR production facilities (which may require some extension in order to monitor emissions of penta-BDPE and levels in the environment) |

**Table 1: Summary of Advantages and Drawbacks**

| | Marketing & Use Restrictions | EQSs and/or Limit Values | IPPC |
|---|---|---|---|
| **Economic Impact** | **FR suppliers**: limited since penta-BDPE represents <0.4% of total EU FRs use and <0.5% in terms of value. Markets already developed for some alternatives. Costs of the order of Euros ±10k to 100k.<br>**Automotive component manufacturers**: One-off costs in reformulating and testing alternatives and new process streams (Euro 1.9 million). Annual costs of Euro 1 million from increase in process scrap (annual value of PUR market for sector Euro 20,500 million).<br>**Upholstered furniture manufacturers**: One-off reformulation costs of Euro 300k estimated (annual value of PUR market for sector Euro 1,060 million).<br>**Non-foamed polyurethane manufacturers**: One-off reformulation costs of Euro £200k estimated (annual value of PUR market for sector Euro 1,000 million). | **FR suppliers**: no additional direct costs expected<br>**PUR producers**: unquantified but dependent upon existing levels of release at a site-specific level and whether monitoring costs passed on (which may be around Euro 96,000 to 160,000 (£60,000 to £100,000) per year). Producers indicate that reductions in emissions would not be necessary (although this does not consider fugitive emissions).<br>**Regulators**: administrative costs unknown. Monitoring costs passed on to PUR producers | **FR suppliers**: no additional direct costs expected<br>**PUR producers**: unquantifiable since site-specific data on additional controls required unavailable. However, producers would be expected to be covered by IPPC and only additional costs for controlling penta-BDPE emissions would be incurred, plus any additional monitoring costs (expected to be similar to EQS and/or limit value option)<br>**Regulators**: administrative costs unknown. Monitoring costs passed on to PUR producers<br>Overall costs should prove to be similar to those of banning use of penta-BDPE or of EQS/limit value approach |
| **Balance of Advantages and Drawbacks** | Only option able to address all risks associated with manufacture and use of PUR containing penta-BDPE<br>Not likely to result in greater risk from fires or greater risks to environment given availability of suitable alternative FRs<br>Costs insignificant when compared with the annual value of the effected sectors and unlikely to be significantly greater than other options | Lower benefits since will not address risks arising from emissions from finished products and may be as costly as full marketing and use restrictions | Lower benefits since will not address risks arising from emissions from finished products and may be as costly as full marketing and use restrictions |

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**ANNEX 2: LIST OF CONSULTEES**

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# GLOSSARY OF ACRONYMS

| | |
|---|---|
| BAT | Best Available Technology (or 'Techniques') |
| BCF | Bioconcentration Factor |
| BFR | Brominated Flame Retardant |
| BFRIP | Brominated Flame Retardants Industry Panel (US) |
| BRE | Building Research Establishment |
| BREF Note | BAT Reference Document for IPPC |
| BRMA | British Rubber Manufacturers Association |
| BRUFMA | British Rigid Urethane Foam Manufacturers Association |
| Deca-BDPE | Decabromodiphenyl ether |
| DETR | Department of the Environment, Transport and the Regions |
| DTI | Department of Trade and Industry |
| EBFRIP | European Brominated Flame Retardants Industry Panel |
| E&E | Electrical and Electronics (industry) |
| EQO | Environmental Quality Objective |
| EQS | Environmental Quality Standard |
| EPA | Environmental Protection Agency (e.g. US EPA, Danish EPA) |
| ESR | Existing Substances Regulation |
| EU | European Union |
| EUROPUR | European Association of Flexible Polyurethane Foam Blocks Manufacturers |
| FAA | Federal Aviation Administration (FAA) |
| FIRA | Furniture Industry Research Association |
| FPF | Flexible Polyurethane Foam |
| FMVSS 302 | Federal Motor Vehicle Safety Standard 302 |
| FR | Flame Retardant |
| HSE | Health and Safety Executive |
| IPC | Integrated Pollution Control |
| IPPC | Integrated Pollution Prevention and Control |
| ISOPA | European Isocyanate Producers Association |
| HMIP | Her Majesty's Inspectorate of Pollution (now Environment Agency) |
| HR | High Resilience (foams) |
| IFD | Induced Force Deflection |
| KEMI | National Chemicals Inspectorate, Sweden |
| $K_{OW}$ | Octanol-Water Partition Coefficient (usually as log $K_{OW}$) |
| MDI | Diphenylmethane di-isocyanate |
| MIRA | Motor Industry Research Association |
| MSDS | Material Safety Data Sheet |
| OECD | Organisation for Economic Co-operation and Development |
| Octa-BDPE | Octabromodiphenyl ether |
| OSPAR | Oslo and Paris Conventions |
| PBB | Poly Brominated Biphenyl |
| PBDD | Poly Brominated Dibenzo Dioxin |
| PBDE | Poly Brominated Diphenyl Ether (also PBDPE) |
| PBDF | Poly Brominated Dibenzo Furan |

| | |
|---|---|
| PBDPE | Poly Brominated Diphenyl Ether (also PBDE) |
| PBT | Persistent, Bioaccumulative and Toxic (substance) |
| PC | Personal Computer |
| PCB | Poly Chlorinated Biphenyl |
| PCB | Printed Circuit Board |
| PE | Polyethylene |
| Penta-BDPE | Pentabromodiphenyl ether |
| PEC | Predicted Environmental Concentration |
| PFA | Polyurethane Foam Association (US) |
| PNEC | Predicted No-Effect Concentration |
| POP | Persistent Organic Pollutant |
| PP | Polypropylene |
| PUR | Polyurethane |
| PVC | Poly Vinyl Chloride |
| RIM | Reaction Injection Moulding |
| RPE | Respiratory Protective Equipment |
| RPA | Risk & Policy Analysts Ltd |
| SIDS | Sudden Infant Death Syndrome |
| SMMT | Society of Motor Manufacturers and Traders |
| TBBPA | Tetrabromobisphenol A |
| TBBE | Tetrabromo Benzoate Ester |
| TCEP | Tri (chloroethyl) Phosphate |
| TCPP | Tri (chloropropyl) Phosphate |
| TDCP | Tri (dichloropropyl) Phosphate |
| TDI | Toluene di-isocyanate |
| TFA | Textile Finishers Association |
| TGD | Technical Guidance Document |
| tpa | Tonnes per annum |
| UNEP | United Nations Environment Programme |
| US DOT | United States Department of Transportation |
| WEEE | Waste Electrical and Electronic Equipment |

# 1. BACKGROUND

## 1.1 Introduction

Pentabromodiphenyl ether (penta-BDPE)[1] is on the second priority list of substances drawn up under Europe's Existing Substances Regulation (793/93/EEC). The UK is responsible for assessing the risks associated with the manufacture and use of penta-BDPE and for developing a risk reduction strategy for those endpoints which pose unacceptable risks to human health and/or the environment.

This report sets out the environmental component of the risk reduction strategy for penta-BDPE. The report has been prepared by Risk & Policy Analysts Limited (RPA) for the Department of the Environment, Transport and the Regions (DETR) for presentation to other Member States of the European Union and to the European Commission, who together will decide on the risk reduction measures to be implemented.

The development of this strategy has been overseen by a steering group consisting of representatives from other UK government departments, other member state governments, industry and an environmental organisation. Steering Group members are listed in Annex 1. These include the UK's Health & Safety Executive which is the body responsible for developing the human health component of the risk reduction strategy.

This report presents the findings of the fourth and final stage of study. Possible risk reduction options were identified in Stage 1, which also evaluated the effectiveness of existing risk reduction options and established a list of consultees. Stage 2 involved a systematic qualitative assessment of the advantages and drawbacks of these options. Further information was gathered for Stage 3 which took the form of a semi-quantified assessment of options.

Data gathering has taken the form of literature review and consultation. A total of 145 organisations have been contacted by telephone, letter, fax and/or e-mail. Consultation has focussed on those producing polyurethane foams but has also involved flame retardant manufacturers and other organisations (particularly those in the automotive field). Given the limited use of penta-BDPE in the EU, most information for the assessment has been provided by a small number of organisations. That said, almost half the organisations contacted have actively responded to our request for information. A full list of consultees is given in Annex 2.

Information has been provided by consultees on a confidential basis. Thus, while published reports and other publicly available data are referenced, data provided by consultees are not. Where data are not referenced, these are essentially the results of personal communications.

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[1] CAS Number: 32534-81-9, EINECS Number: 251-084-2

## 1.2 The Basic Use Pattern of the Substance

### 1.2.1 Overview

Throughout this report, the acronym penta-BDPE is used. This refers to the commercial formulations of pentabromodiphenyl ether. These commercial formulations also contain the tri-BDPE, tetra-BDPE and hexa-BDPE congeners to some extent, although the primary component is penta-BDPE.

Penta-BDPE is used as a flame retardant (FR), almost exclusively in the manufacture of flexible polyurethane (PUR) foams. Around 95% of penta-BDPE used in the EU is associated with this application and is reported to be used in the furniture, automotive and packaging industries. Small amounts of penta-BDPE are also used in solid (non-foamed) PUR applications such as casings (this use being associated with a number of prototype and small-run products). It has been reported that penta-BDPE may also be used in specialised applications such as PUR textile treatments for fire resistant work and safety wear, in flame retarded speciality PUR elastomers (for example, in industrial tyres/wheels or the conveyor belting industry, as well as some smaller applications), and PUR coatings in carpets[2].

During the first stage of this study, several sectors other than PUR foams were considered as possible users of penta-BDPE. These were textiles, electronics, plastics other than PUR and rubber. During Stage 2 these uses were investigated further and the findings are outlined below.

***Textiles***

Initial consultation indicated that a significant proportion of penta-BDPE may be used in the textiles industry. No evidence has been found to support this, however. Indeed, a major textiles association has confirmed that penta-BDPE is almost certainly *not* used in the textiles industry, although some use apparently occurred in the past. That said, some small amount of use may be associated with speciality fire-resistant clothing using PUR treatment of textiles, as indicated above. This study has found no evidence, however, indicating that this use currently exists.

***Electronics***

Early consultation indicated that penta-BDPE may be used in the electronics industry, possibly in epoxy potting compounds. It was, however, also stated to be unlikely that this was indeed a current use for the substance. Further consultation and literature review indicated that penta-BDPE is not used in the electrical and electronics industries within Europe (EBFRIP, 1999a). It may well, however, be used in laminates for some printed

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[2] However, these uses have not been confirmed and the consultee providing these data has indicated that use in some of these applications has ceased.

circuit boards (PCBs) produced outside the EU. Use is thought to be confined to PCBs made in Asia only and use in this application is thought to be decreasing.

The majority of electrical and electronics equipment containing brominated flame retardants appear to utilise mainly tetrabromobisphenol A, although some use deca-BDPE. This is part of a continuing trend towards use of flame retardants which form a part of the polymer structure (reactive as opposed to additive flame retardants), such as tetrabromobisphenol A (TBBPA). In addition, there is a further trend away from flame retardants which contain no organically-bound chlorine or bromine (a trend which has important implications for the flame retardancy of these products).

### Plastics other than Polyurethane

Use of penta-BDPE in polyolefin-type thermoplastics is thought to be non-existent. These plastics include polyethylene (PE) and polypropylene (PP). Also, use in PVC is not thought to occur since the chlorine which is part of the polymer provides some flame retardant properties and, in cases where this is insufficient, chlorinated flame retardants tend to be added (such as chlorinated paraffins).

Although some indication was given that penta-BDPE may be used in styrenic plastics employed in electronics enclosures, this was not investigated further. Since penta-BDPE is not used in the EU electronics industry (EBFRIP, 1999a), this use is not believed to be a concern.

### Rubber

Initial consultation revealed one company that had been using penta-BDPE in the manufacture of rubber conveyor belts for the mining industry. As indicated above, this was likely to have been in products based upon PUR elastomers. The company involved has since ceased using penta-BDPE for this purpose and it is believed that use of penta-BDPE no longer occurs in this sector.

### Other Possible Uses

In the past, patents have been issued for the use of penta-BDPE as a hydraulic fluid and an oil well completion fluid. It has been suggested that these disperse uses could explain the ubiquity of penta-BDPE in some biota in and near the North Sea (rather than emissions from polyurethane foam products). However, the claim that penta-BDPE was actually used in these applications has not been verified.

Given the above findings, only the use of penta-BDPE in PUR is considered in the remainder of this report. The remainder of this Section provides a summary of data on the use of penta-BDPE in this application with further information presented in Section 4.

### 1.2.2 Manufacture, Supply and Use of Penta-BDPE-Based Flame Retardants

Neither penta-BDPE nor FR formulations containing penta-BDPE are manufactured in the EU. Two FR suppliers have been identified as selling penta-BDPE-based FRs in the EU, with one being a minor player compared with the other.

The Risk Assessment (Environment Agency, 1999) estimates that in 1994 around 300 tonnes per annum (tpa) of penta-BDPE was used in the EU in the manufacture of PUR foams, with a further 800 tpa imported in finished articles. In this regard, the main supplier of penta-BDPE has stated that imports of penta-BDPE to the EU are expected to be around 125 tonnes or less in the year 2000, a figure similar to that for 1998 and 1999. Imports within products could similarly be much lower (also around 100 tpa).

Penta-BDPE is the least important of the three commercial polybrominated diphenyl ethers (PBDPEs) on the market (penta-BDPE, octa-BDPE and deca-BDPE), representing just 9% of the PBDPEs used in the EU (or imported into the EU on finished articles) each year (KEMI, 1999b). Overall, use of penta-BDPE-based FRs in the EU represents less than 0.4% of the EU FR market which stood at around 300,000 tpa in 1995.

Three applications for penta-BDPE have been identified through consultation with PUR manufacturers and their trade associations:

- in foam-based laminated automotive applications such as headrests;
- in the production of phosphorus-free penta-based foams for domestic furniture, some of which includes cot mattresses; and
- in the production of various small run and prototype components, such as rigid PUR elastomer instrument casings.

Consultation with flame retardant suppliers has also indicated that penta-BDPE is used to a small extent in the production of packaging for electronic equipment. This use occurs in the US and, to a lesser extent, in the EU.

Based on data provided by consultees, these applications are believed to account for between 85 tpa and 95 tpa of penta-BDPE used in the EU each year. This correlates reasonably well with industry estimates of current usage (100 tpa to 125 tpa).

## 1.3 Past Control of the Substance

In the early 1990s, a Directive was proposed under the framework of Directive 76/769/EEC (the Marketing and Use Directive) which would have prevented the use of both PBDPEs and polybrominated biphenyls (PBBs) as FRs. (Although it simply placed restrictions upon the amounts used in products, use of these FRs below the specified concentrations would have been made impractical since they would have had little effect upon the flame retardancy of materials at the proposed concentrations.) This Directive was withdrawn in 1995 because of the inclusion of PBDPEs on the priority lists under the Existing Substances Regulation and because of the apparent lack of substitutes.

The primary mechanism for control of PBDPEs has been the voluntary commitment made by the FR industry in 1995. This outlined measures to be taken in order to reduce environmental risks associated with PBDPEs, PBBs and TBBPA[3]. It was largely focussed upon the manufacturers of brominated flame retardants but was also intended to have an effect further down the chain of trade. Progress reports on compliance with this commitment have been submitted by industry though they have not been reviewed for the purposes of this strategy.

PBDPEs are also on a list of substances outlined by the OSPAR Convention. The aim of the convention is to reduce and eventually eliminate emissions of these substances into the marine environment. Sweden has also pushed for a ban on PBDPEs and PBBs through this forum. As a result of pressure from a number of sources, it is expected that production of the only remaining PBB - decabromobiphenyl - by those companies which are party to the voluntary commitment (referred to above) will cease in the near future.

Several ecolabel schemes have placed requirements for the exclusion or restricted use of penta-BDPE and other halogenated flame retardants. These cover products such as bed mattresses, textiles and electrical and electronic equipment. Although lacking any specific legal obligation, ecolabels are likely to have some effect in reducing the use of these substances.

Several EU Member States have attempted to invoke national measures to control the risks of brominated flame retardants, particularly PBDPEs and PBBs. In particular, these include Denmark, Sweden, the Netherlands and Germany. The measures have largely been ineffective since proposals generally have not been passed as national law. Denmark and Sweden have recently tabled recommendations that penta-BDPE (and some other brominated flame retardants) be phased out by all EU Member States. Denmark is also developing an action plan (see Section 3.6) to address brominated flame retardants.

Section 3 provides a more thorough discussion of the measures already in place to reduce the risks associated with penta-BDPE.

## 1.4 Concerns Leading to Prioritisation of Penta-BDPE for Risk Assessment

Penta-BDPE was prioritised for assessment under the Existing Substances Regulation due to the detection of high levels in the environment in the 1980s and early 1990s. These

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[3] As mentioned above, there are three commercial PBDPEs. The VIC also affected the only commercial PBB at the time which was decabromo biphenyl.

include a large number of studies conducted in Sweden[4] which have shown penta-BDPE to be persistent and bioaccumulative.

Concentrations in wildlife and in humans have also increased significantly. In relation to the latter point, one study on concentrations in human breast milk has formed part of the basis of Sweden's concerns regarding penta-BDPE. The study details how concentrations of penta-BDPE in some breast milk samples have increased exponentially since 1972, with a doubling time of around 5 years (KEMI, 1999a).

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[4] See e.g. OECD (1994).

# 2. THE RISK ASSESSMENT

This section details the stages involved in the life cycle of penta-BDPE which have been identified as being of concern by the Risk Assessment (Environment Agency, 1999). It also includes further information regarding risks as notified during this study.

No risks arise from the manufacture of penta-BDPE since it is no longer produced within the EU (although some of the high concentrations measured in the environment are believed to be associated with sites of former manufacture). Similarly, no risks arise from the formulation of penta-BDPE-based flame retardants as this step also takes place outside the EU. As indicated in Section 1, risks arising from the use of penta-BDPE in PUR foams are based on the following levels of usage: 300 tpa of penta-BDPE in the manufacture of foams in the EU and 800 tpa of penta-BDPE in the import of finished articles. All risks identified are associated with the manufacture and use of penta-BDPE in polyurethane (PUR) products.

Risks to the atmosphere and those arising from regional emissions to the aquatic environment (in both surface waters and sediments) have been found to be acceptable. There remains a need for further information and/or testing with regard to risks to the aquatic compartment from local sources.

The Risk Assessment has identified a need for risk reduction in the case of non-compartment-specific effects relevant for the food chain (secondary poisoning). In particular, for secondary poisoning in the fish and earthworm-based food chains, the estimated ratios of predicted environmental concentration to predicted no effect concentration (PEC/PNEC) are greater than one:

- the PEC/PNEC ratio for the fish-based food chain (i.e. for birds or mammals eating fish) is 2.2. Releases of penta-BDPE from PUR foam manufacture dominate the calculation, contributing 99% to the resulting concentration; and

- the PEC/PNEC ratio for the earthworm-based food chain is 1.7. Releases to air are of most importance, with releases from the use of PUR foams being the largest contributor (90% compared with 10% from PUR foam manufacture).

On this basis, the Risk Assessment identifies a need to limit the risks associated with both PUR foam manufacture and the use of these foams. For the fish-based food chain, predicted environmental concentrations are consistent with measured levels found in the environment in industrialised areas. The wide distribution of the chemical and its high measured concentrations in higher animals indicate that biaccumulation and biomagnification are of significant concern.

Industry is currently undertaking additional environmental studies on toxicity: a fish early life study has been completed and additional studies on sediment, earthworms, terrestrial plants and soil microorganisms are ongoing.

The classification of penta-BDPE as R50/53 ("very toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment") was agreed in September 1999.

This report for DETR deals only with environmental risks, human health risks being the remit of the UK Health & Safety Executive. However, it is relevant to note that the Human Health Risk Assessment has identified that risk reduction measures are required for the exposure of humans via the environment to penta-BDPE from PUR foam production facilities. This conclusion has been reached through calculation of the levels in various foodstuffs which form part of the human diet, the concentrations themselves determined by levels in agricultural soil and grassland.

There are also concerns over increasing levels of penta-BDPE found in human breast milk. Precautionary action is to be taken to address this risk to human health.

In February 2000, the European Commission's Scientific Committee on Toxicity, Ecotoxicity and the Environment issued their opinion (CSTEE, 2000) on the environmental risk assessment. The CSTEE generally agreed with the conclusions of the risk assessment although they raised a number of comments. However, these comments are not expected to affect the conclusions of the risk assessment and consequent the need for risk reduction remains.

# 3. EXISTING RISK REDUCTION MEASURES

## 3.1 Introduction

Several mechanisms are already in place, on varying scales and including various participants, either to reduce the environmental impacts associated with the use of penta-BDPE or to reduce/eliminate its use in certain sectors.

The key measures which are already in place, are in the process of being implemented, or have been attempted in the past include:

- voluntary commitments by industry to reduce the environmental impacts associated with this and other brominated flame retardants (BFRs) and to reduce use of certain types of BFRs;

- proposals to ban/restrict the use of penta-BDPE either as a whole or on a sectoral basis through both unilateral and also multilateral fora. This includes proposals for legislation on several levels; and

- ecolabelling schemes which require that certain flame retardants are not used (the categories of which include penta-BDPE).

More generally, there are also measures for the control of environmental pollution within the sector of concern (manufacture and use of polyurethane foams). These measures are discussed below along with industry responses to pressures (e.g. of potential legislation) which have led to reductions in use and in environmental impacts.

## 3.2 European Legislative Action

### 3.2.1 Proposals for Marketing and Use Restrictions

In 1991, the European Commission proposed a Directive which would restrict the use of all polybrominated diphenyl ethers (PBDPEs)[5]. These restrictions were proposed as an amendment to the Marketing and Use Directive (76/769/EEC).

The European Parliament did not give an opinion on its first reading of the proposal. Subsequently, the proposal was withdrawn in December 1995 because commercial PBDPEs were to undergo risk assessments under the ESR and also because the Commission saw the Voluntary Industry Commitment under the auspice of the OECD as a suitable alternative to the Directive (see Section 3.3). In addition, problems were anticipated due to the apparent lack of suitable alternative flame retardants at that time.

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[5] Answer given by Mrs Bjerregaard on behalf of the Commission, response to Written Question E-3004/98 by Doeke Eisma (ELDR), OJ No. C 142/66, 21 May 1999.

The proposed Directive (COM (91) 7 Final, as amended following its withdrawal[6], would have placed the following restrictions on the use of PBDPEs in plastics and textiles: on entry into force, the Directive would have immediately prohibited the placing on the market of seven members of the group - mono, di, tri, tetra, hexa, hepta and nona bromodiphenyl ether. As such, the Directive sought to prevent the use of these congeners as flame retardants. It was stated in the proposed Directive that none of these seven were used to any great extent at the time (although several were present in high concentrations in formulations based on the remaining three group members). The Directive further proposed that the three main PBDPEs (deca-BDPE, octa-BDPE and penta-BDPE) should be prohibited five years later. The proposal would have limited the concentrations of these substances in formulations and products (including plastics and textiles) to less than 0.1 per cent by mass. This concentration limit would have effectively prevented any use of these PBDPEs as FRs.

### 3.2.2 Proposed Directive on Waste from Electrical and Electronic Equipment

At present there are proposals for a Directive controlling the wastes arising from electrical and electronic equipment (the WEEE Directive). Early drafts of the proposal recommended a ban on the use of all halogenated flame retardants from electrical and electronic equipment in certain parts. This aspect was withdrawn by the third draft. However, a ban on both PBDPEs and PBBs is still proposed. This proposed ban has been criticised by the brominated flame retardants industry which contends that it preempts and somewhat contradicts the risk assessment process for PBDPEs (EBFRIP, 1999a). The industry also argues that a ban would undermine their flexibility in the choice of materials, affecting their ability to maximise recyclability without compromising fire safety.

EBFRIP (1999b) states that a phase-out of halogenated flame retardants would make it impossible for some plastic materials to meet voluntary fire safety standards[7]. Apparently, this has led in some cases to manufacturers of television sets reducing the flame retardancy of their products for the European market (and the products would not now be acceptable in North American and Japanese markets).

The proposed WEEE Directive would have no impact upon the use of concern in this risk reduction strategy (i.e. of penta-BDPE in PUR foams). However, it may have implications for the market for PBDPEs as a whole in the EU which, in turn, may have knock-on effects for penta-BDPE. It will also create additional issues associated with negative perceptions in relation to the environmental and human safety of the substance.

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[6] Proposal for a Council Directive amending Directive 76/769/EEC on the approximation of the laws, regulations and administrative provisions of the Member States relating to restrictions on the marketing and use of certain dangerous substances and preparations. COM (91) 7 (Official Journal Reference C46 of 22 February 1991).

[7] Some manufacturers specify more than the minimum fire safety level in their material specifications.

### 3.2.3 Restrictions on Other Flame Retardants

Other brominated FRs have also been banned for use in certain applications. Notably, tris (2,3-dibromopropyl) phosphate (‘TRIS’) and all ten polybrominated biphenyls were prohibited for use in textiles which come into contact with the skin (Directives 79/663 and 83/264 respectively).

### 3.2.4 Other EU Action

In addition to an assessment of the risks of penta-BDPE, risk assessments for the two other commercial polybrominated diphenyl ethers, octa-BDPE and deca-BDPE, are being carried out with the UK and France as joint rapporteurs.

Sweden are also undertaking assessment of another brominated flame retardant, hexabromocyclododecane (HBCD), which is on the 2nd priority list under Regulation 793/93/EEC.

## 3.3 Voluntary Industry Commitment

Industry has undertaken a voluntary commitment[8] to reduce the risks associated with certain brominated flame retardants. These include PBDPEs, PBBs and also TBBPA. This Commitment was formally presented to the OECD’s 23rd Joint Meeting of the Chemicals Group and Management Committee in June 1995. The industry representatives party to the 1995 commitment were the major brominated flame retardant manufacturers through their European and US trade associations (EBFRIP and BFRIP respectively). In 1996, a further commitment by Japanese producers was incorporated. The main commitments of the voluntary agreement are as follows:

- flame retardant manufacturers, through the Responsible Care Product Stewardship initiatives, are to educate their customers on how to properly handle, use, recycle and dispose of products (thus addressing the entirety of products’ life cycles);
- manufacture and import/export of polybrominated biphenyls (PBBs) is to be ceased by major manufacturers with minor exceptions. This was agreed so that PBBs would not be used as alternatives to PBDPEs;
- only the three principal polybrominated diphenyl ethers are to be manufactured (i.e. penta, deca and octa BDPE - although the commercial products do contain a mixture of congeners);

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[8] Voluntary Commitment by the Major Global Producers of Selected Brominated Fire Retardants Covered Under OECD's Risk Reduction Programme, June 30th 1995.

- to minimise levels of penta-BDPE released during manufacture using BAT and to ensure regular review of in-house environmental programmes to address the other aspects of its life cycle; and
- further commitments regarding accountability and on data provision including the undertaking of various toxicity studies.

The Commitment also requires industry to give evidence of actions taken under the Commitment at regular intervals. The following gives details of progress made as evidenced by the initial reporting phase in 1997, with particular reference to those aspects relating to penta-BDPE. This is taken mainly from a review by the UK DETR (DETR, 1999).

Regarding environmental exposure, most companies have disseminated information to customers on safe disposal and recycling. Plant operation improvements have been made widely, though information is lacking on specific progress made in reducing levels of flame retardants in process wastes. This has been highlighted as a future step to be taken, as is the need for further information from customers on the results achieved in their processes and in relation to their emissions, etc.

Commitments to undertake toxicity studies are generally seen to be well fulfilled; a number of such studies has already been conducted and plans made for further work.

The resolution to cease manufacture and import/export of PBBs has been adhered to, with the exception provided for within the Commitment. This also applies to the agreement to produce only the three commercial polybrominated diphenyl ether congeners (two in Japan). However, information is lacking on the quantities of these chemicals produced and associated trends in production.

Measures to use effluent and emissions treatment have been agreed in order to minimise environmental exposure from manufacturing processes. (The responses were generally seen not to have provided sufficient data on quantitative reductions although evidence was provided on the reduction of dust emissions during packaging of materials.) These moves may have had some impact on environmental concentrations of penta-BDPE as the chemical was manufactured in the EU until relatively recently.

These findings show that the Commitment has been effective in some respects, such as increasing awareness through the chain of trade and in placing restrictions on the manufacture and import of certain flame retardants. However, the reporting procedure was lacking in areas such as the provision of specific information on reductions of emissions of brominated flame retardants to the environment (DETR, 1999).

The Japanese commitment (Flame Retardants Conference of Japan, 1995) goes further than the initial industry commitment. They have agreed not to manufacture or import PBDPEs or PBBs except octa-BDPE and deca-BDPE. Therefore, manufacture and use of penta-BDPE in Japan should be either minimal or non-existent.

The current process (i.e. the Risk Assessment under the ESR) reveals that a concern still exists in relation to penta-BDPE. This is highlighted both by the assessment of current emissions and resultant environmental concentrations and by the levels detected in the environment on a very wide scale.

Industry was due to present its final progress report on compliance with the Voluntary Industry Commitment to the OECD's Working Party on Risk Management in January 2000 (OECD, 1999). Progress reports from industry on compliance with this commitment have been submitted by industry though they have not been reviewed for the purposes of this strategy.

## 3.4 The OSPAR Convention

This replaces the Oslo and Paris Conventions and is properly known as the OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic. The objective of the OSPAR Commission (OSPARCOM) is:

> "to prevent pollution of the maritime area by continuously reducing discharges, emissions and losses of hazardous substances ... with the ultimate aim of achieving concentrations in the marine environment near background values for naturally occurring substances and close to zero for man-made synthetic substances."

The OSPAR Commission is guided by the precautionary principle, the polluter pays principle, the use of BAT and also the principle of substitution (i.e. hazardous substances should be substituted with less hazardous ones). Emissions of new hazardous substances should be prevented except where allowed for by the substitution principle. Risk Assessment is also to be used as a tool for prioritising and developing action programmes.

Brominated flame retardants are amongst 15 groups of chemicals on the OSPAR List of Chemicals for Priority Action. The Commission's aim is to reduce discharges, emissions and losses of hazardous substances which could reach the marine environment to levels which are not harmful to humans or the environment by the year 2000. The further aim is for the cessation of such releases by the year 2020 (OSPAR, 1998).

Sweden is the lead country for PBDPEs under the OSPAR Convention and has put forward various proposals for a ban on the use of PBDPEs and PBBs for the protection of the sea. Progress to date is as follows (KEMI, 1999b):

- in 1994, a PARCOM Recommendation was proposed concerning the phase-out of penta-BDPE (and deca-BDPE);

- in 1995, Sweden proposed a PARCOM Decision concerning the phase-out of deca-BDPE only. There was insufficient support for this Decision;

- in 1997, Sweden suggested that further proposals be put on hold to take into account relevant results of on-going work in other international fora including work under the Existing Substances Regulation. This suggestion was accepted; and

- Sweden has suggested that the phase-out of brominated flame retardants be put back on the agenda at the latest in the year 2001.

In its October 1999 report (KEMI, 1999b), Sweden confirms the 2020 target for PBDPEs (i.e. the cessation of discharges, emissions and losses). An interim target is also set for the year 2005. This is to take the form of phasing-out those uses making up the majority of releases. These uses are to be identified through the ESR process (i.e. by the Risk Assessment for penta-BDPE and also those for octa-BDPE and deca-BDPE).

## 3.5 Ecolabels

Several ecolabels have been introduced in the EU which limit or prohibit various categories of brominated flame retardants (and indeed other flame retardants). These ecolabels are concerned with the use of flame retardants in products such as electrical and electronic equipment, textiles and bed mattresses. They include the Nordic Swan (covering Sweden, Norway, Denmark and Finland), the EU ‘flower’, the German ‘Blue Angel’ and the internationally recognised Swedish standard for computers TCO 95, which has since been updated to TCO 99.

Although penta-BDPE is no longer used in the European electronics industry (EBFRIP, 1999a), it has been used for this purpose in the past. It is reported to be used in some flame retarded components manufactured in Asia which include laminates for encapsulation, although this use has largely been superseded by use of tetrabromo bisphenol A (TBBPA) (Danish EPA, 1999a).

Restrictions upon use of brominated flame retardants in the various ecolabeling schemes are as follows:

- the Nordic Swan requires that no PBBs or PBDPEs are used in computer plastic parts over 25g, or in copiers, printers and faxes. Also, no PBDPEs should be used in fridges, dishwashers, windows, floorings, building materials and textiles (at over 1% w/w for latter);

- the German Blue Angel requires that no organohalogens be used in personal computers. No PBDPEs or PBBs should be used in copiers, printers, faxes, TVs, etc. or in building materials;

- the TCO 95 label/standard states that no organic bromine should be used in personal computer parts over 25g (Danish EPA, 1999a); and

In addition, under the EU ecolabelling scheme (the flower), restrictions have been placed upon the use of various categories of flame retardants. There are a number of these which are of relevance to this study[9]. They include the requirement that bed mattresses do not contain flame retardants which are classified as dangerous for the environment under Directive 67/548/EEC. The ecolabel for textile products requires that flame retardants are not used where they are classified as R45, R46, R51, R52, R53, R60 or R61 under Directive 67/548/EEC.

Furthermore, the ecolabel for personal computers requires that plastic parts heavier than 25 grams do not contain flame retardants that contain any organically bound bromine or chlorine (thus excluding all halogenated flame retardants). The ecolabel for portable computers goes even further: it requires that plastic parts heavier than 25g, and plastics for moulding of power supplies, batteries or other peripheral equipment specifically do not contain any PBDPEs[10] or decabromobiphenyl. This is in addition to a requirement that any flame retardants used are not classified using any of the risk phrases referred to in the ecolabel for textile applications.

These schemes have met with significant opposition from the industry. For example, EBFRIP issued a legal complaint which criticised the schemes in that they:

- discriminate against brominated flame retardants without scientific justification;
- are drawn up in a discriminatory manner on the basis of incomplete information;
- compromise health and safety by increasing the risk of fire hazard for users of electronic equipment;
- restrict trade in these flame retardants and the electronic products which contain them in the territories in question; and
- prevent competition and innovation in the flame retardant sector (EBFRIP, 1997).

With respect to this study, the ecolabels categorise flame retardant chemicals in varying ways, e.g. PBDPEs, brominated flame retardants as a group, organohalogens or those flame retardants with certain environmental risk phrases. Penta-BDPE falls into all of the categories considered (since its classification as R50/53 was agreed in September 1999).

Although their use is not mandatory, the ecolabelling criteria do provide an indication of the steps which are being taken to eliminate the use of brominated flame retardants from some applications. Furthermore, such action will have knock-on effects for the perception of penta-BDPE and other flame retardants in environmental terms and thus their acceptability for use.

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[9] These are bed mattresses (OJ L 302, 02/10/1998, p31), textile products (OJ L 57, 17/02/1999, p21), personal computers (OJ L 70, 26/02/1999, p46) and portable computers (OJ L 276, 13/10/1999, p7).

[10] It includes a list of nine congeners (dibromodiphenyl ether through to decabromodiphenyl ether) although only nine are marketed as commercial products and the risk assessments for octa and deca-BDPE have, at the time of writing, not identified any unacceptable risks to the environment.

## 3.6 Unilateral Actions

### 3.6.1 Germany

In Germany, provisions have been put in place to control the risks of PBDPEs and PBBs through the Chemicals Prohibition Ordinance. Prohibitions were introduced for products which contain polybrominated dibenzodioxins and dibenzofurans (PBDDs and PBDFs) under the 'Dioxin Ordinance'. Since there exists the theoretical potential for the formation of brominated dioxins and furans in the reprocessing of plastic materials containing brominated flame retardants, the prohibitions have had knock-on effects upon the use of PBDPEs (Danish EPA, 1999a).

In addition, the German Chemical Industry Association (VCI) and Association of the Plastics Producing Industry (VKI) voluntarily agreed to discontinue use of PBDPEs as long ago as 1986 (VKI, 1997).

With respect to specific applications, it is reported that the German automotive federation (VDA) has also black-listed penta-BDPE.

### 3.6.2 Sweden

The Swedish Government adopted a Bill in 1991 (Government Bill 1990/91:90 "A Living Environment") which took the view that the use of brominated flame retardants should be limited, including recommendations that the most harmful of these substances should be phased out (KEMI, 1999a). On this basis, the *Flame Retardants Project* was initiated to assess the risks to human health and the environment of these substances and, if required, to propose measures to reduce these risks. In the final report of the project (KEMI, 1996), the following was concluded:

> "In the light of existing knowledge concerning levels in the environment, bioaccumulation and persistence, it is concluded that the use of PBDE (polybrominated diphenyl ethers) and PBB (polybrominated biphenyls) must be discontinued".

It was recommended in 1999 that "Sweden should actively endeavour to bring about a ban on use at EU level as soon as possible" and that Sweden "should not await the final outcome of work now in progress under the EU programme for existing substances, considering the long time it can take for that work to be capable of resulting in an operational ban on use" (KEMI, 1999a).

At the meeting of the Environment Council in December 1999, Sweden and Denmark both proposed formally that other EU Member States phase out the use of these substances.

### 3.6.3 Denmark

In Denmark, it is reported that use of brominated flame retardants has been totally phased out of the manufacture of flexible foams (Danish EPA, 1999a). These have largely been replaced by chlorinated phosphate esters and melamine and, in some cases, with ammonium polyphosphates and reactive phosphorus polyols.

Penta-BDPE has been on the Danish list of undesirable substances for two years. The Danish authorities are in the latter stages of developing an action plan on brominated flame retardants. This plan includes the following:

- discussion and agreement with Danish industry and the retail sector on reduction of the use of brominated flame retardants;
- evaluation of useable alternatives and proposals for new projects on cleaner products;
- preparation of information material, for consumers and the retail trade;
- intensified efforts to ensure that eco-labelled products shall, where possible, not contain brominated flame retardants;
- assessment of environmentally sound disposal methods;
- analyses of sludge and soil for brominated flame retardants; and
- assessment - jointly with the Danish Working Environment Authority - of possible occupational environment problems for staff involved with the treatment of electronic waste (Danish EPA, 1999b).

In addition, the Danish Government, together with Sweden, made the recommendation to the Environment Council to phase out these substances in all Member States, as referred to above.

### 3.6.4 The Netherlands

In the Netherlands, a ban on PBBs and PBDPEs was proposed based on the findings of risk assessments in the early 1990s. This was never implemented partly because the conclusions became less certain in subsequent reports in terms of the health and environmental effects of these substances, and also because there was a general agreement on the part of industry to shift away from their use.

## 3.7 Controls Specific to Polyurethane Foam Manufacture

### 3.7.1 Health and Safety Legislation

Polyurethane foam manufacture is a process which is already highly controlled through existing health and safety legislation. This is primarily due to the highly hazardous nature of the isocyanate materials which form one of the two primary components of PUR. Isocyanates are reputedly the most significant cause of occupational asthma in the UK (HSE, 1999) and thus respiratory protective equipment (RPE) is widely used to protect workers. Consultation has indicated that one of the reasons behind the small number of manufacturers of flexible polyurethane foams is the stringent health and safety requirements in place for the use of isocyanates.

### 3.7.2 Integrated Pollution Control

The framework for control of polyurethane manufacturing processes is well established. Under the system of Integrated Pollution Control (IPC) in the UK, the process falls under ‘organic chemicals’ under the ‘chemical industry’ heading. Di-isocyanate processes are also specified for control under the section on miscellaneous industry (Bell, 1997).

The UK Environment Agency (Her Majesty’s Inspectorate of Pollution at the time) has published a guidance note for IPC processes using di-isocyanates (and in particular toluene di-isocyanate, TDI), including processes for the manufacture of flexible polyurethane foams and polyurethane elastomers (HMIP, 1995). The note provides information on techniques and standards for the control of environmental impacts from both new and existing processes. It considers the substances thought to cause most harm and provides guidance on techniques for pollution abatement, compliance monitoring, recording and reporting. The document provides useful information as to how emissions can be controlled, but its scope is insufficient to provide specific controls for the emissions of penta-BDPE from polyurethane foam manufacture: emissions of organic compounds are considered as total emissions rather than specific emissions for the various substances (and indeed penta-BDPE is not volatile, although it might be included as such due to the nature of the process in which it is heated).

### 3.7.3 Integrated Pollution Prevention and Control

The UK’s IPC regime has been superseded by the European Integrated Pollution Prevention and Control (IPPC) regime which is provided for by Directive 96/61/EC. The deadline for implementation of IPPC within Member States was October 1999. In the list of processes falling under the scope of the Directive (Annex I), the process most applicable to polyurethane foam production facilities is Section 4.1 (h) for chemical installations for the production of basic plastic materials, including polymers. Relevant emission standards could thus be set under this framework since organohalogen compounds are included in the indicative list of substances to be taken into account if relevant for fixing emission limit values (Annex III).

IPPC is discussed in more detail in Sections 5 and 6 of this report. Respectively, these sections relate to a discussion of potential risk reduction measures and to an assessment of those measures.

### 3.7.4 UK Code of Practice for Flexible Polyurethane Manufacture

The British Rubber Manufacturers Association (BRMA) has, in conjunction with the UK Health and Safety Executive (HSE) and various other experts, prepared a Code of Practice for flexible polyurethane foam manufacture (BRMA, 1990). This document is intended to address human health hazards in the main and is focussed upon di-isocyanates (which are the most acutely toxic substances involved in this process). The Code does, however, provide information on other chemicals used in flexible polyurethane foam manufacture, including penta-BDPE. The Code provides extensive guidance on the handling and storage of the substances in question including information on the toxicity of chemicals used and guidance on risk assessments for polyurethane foam manufacturers. Due to the nature of the document, however, no information is provided on how the environmental effects of the individual substances should be controlled, aside from issues which also relate to human health, such as storage and waste disposal.

## 3.8 The POPs Convention

The POPs Convention is overseen by the United Nations Environment Programme (UNEP). Under the Convention, a list of 12 substances which are persistent, bioaccumulative and toxic (PBT) and which also have the potential for long range transport has been drawn up. This has been supplemented with a further six chemicals including hexabromobiphenyl.

It is intended that further chemicals be added to the list of substances covered by the Convention. In this respect, a *Criteria Expert Group* (CEG) has been established to set out the inclusion of further substances in the future. Draft criteria have been developed by the CEG (UNEP, 1999) and, on the basis of the Risk Assessment for penta-BDPE, it would appear a proposal could be made for inclusion of this substance under the Convention. This proposal would then be screened against criteria relating to its risk profile and a risk management evaluation would be carried out based upon various socio-economic considerations. The Conference of the Parties would then decide whether or not the substance should be included under the Convention.

Inclusion under the POPs Convention would appear to provide a means by which any EU risk reduction measures could be promulgated internationally.

## 3.9 Conclusions on Existing Risk Reduction Measures

The risks arising from the manufacture and use of penta-BDPE and other brominated flame retardants are being currently addressed using a variety of instruments and through a number of fora. Measures such as the Voluntary Industry Commitment have restricted the use of this substance and will have led to some reductions in environmental risks associated with its use. However, the Risk Assessment has indicated that releases to the environment need to be limited at the current time (on the basis of secondary poisoning via the fish and earthworm-based food chains) and that there is a need to consider additional measures for further risk reduction.

A feature of certain existing measures, such as process guidance under IPC (and potentially under IPPC) is that these are not currently specific enough to control emissions of penta-BDPE from polyurethane manufacture.

It is, therefore, evident that further risk reduction measures are required in order to address the risks associated with the use of penta-BDPE in its various applications.

# 4. MARKET FOR AND USAGE OF PENTA-BDPE

## 4.1 The Flame Retardant Market

### 4.1.1 The European Flame Retardant Market

Data on the size of the European FR market and its associated value are presented in Table 4.1. In 1995, the European FR market was estimated to be between 200,000 and 300,000 tpa and worth over £500 million (Euro 800 million) annually (Stevens and Mann, 1999). In terms of tonnages consumed, alumina trihydrate is the most important FR. In terms of value, the most important FRs are brominated compounds (although some minor FRs command a slightly higher price per tonne). In 1995, brominated compounds represented just over 20% of the EU FR market in terms of tonnages used and just over 34% in terms of value.

**Table 4.1: Estimated EU Flame Retardant Consumption***

| Flame Retardant Type | Consumption (k tpa) | Value mEUR pa | Unit Value mEUR/kt |
|---|---|---|---|
| Alumina trihydrate | 120 | 96.0 | 0.8 |
| Ammonium phosphates | 7.5 | 36.0 | 4.8 |
| Antimony oxides | 18 | 91.2 | 5.1 |
| Brominated compounds | 64 | 278.6 | 4.4 |
| Chlorinated organophosphorus compounds | 22 | 60.5 | 2.7 |
| Magnesium compounds | 2.5 | 6.9 | 2.8 |
| Melamine | 11 | 35.2 | 3.2 |
| Other chlorinated compounds | 35 | 48.0 | 1.4 |
| Other organophosphorus compounds | 27.5 | 115.2 | 4.2 |
| Red phosphorus | 4 | 32.0 | 8.0 |
| Zinc compounds | 3 | 9.6 | 3.2 |
| Other compounds | 1.5 | 2.4 | 1.6 |
| All Types | 316 | 811.5 | 2.6 |

Source: Stevens and Mann (1999)

* Values converted from UK Sterling assuming £1 million equivalent to 1.6 million Euro (1.6 mEUR)

Table 4.2 presents data on the value of FRs and organobromines in particular in various EU Member States. The market for FRs in Germany is by far the largest in the EU, representing 29% of all FR value. In addition, the markets in France, Great Britain and Belgium make up a further 42% of EU value.

**Table 4.2: Flame Retardant Use in European Member States in 1995***

| Member State | Organobromines | | | All Flame Retardants | |
|---|---|---|---|---|---|
| | Value mEUR | % of Organo-bromine Value | % of Total National Value of FR | Total Value mEUR | % of Total Value |
| Belgium | 43.4 | 16% | 64% | 67.7 | 8% |
| France | 59.7 | 21% | 45% | 132.5 | 16% |
| Germany | 61.9 | 22% | 26% | 235.0 | 29% |
| Great Britain | 41.3 | 15% | 30% | 137.3 | 17% |
| Italy | 32.8 | 12% | 31% | 104.3 | 13% |
| Netherlands | 17.1 | 6% | 34% | 50.6 | 6% |
| Scandinavia | 3.0 | 1% | 11% | 27.5 | 3% |
| Spain | 10.1 | 4% | 36% | 27.7 | 3% |
| Other Europe | 9.3 | 3% | 32% | 29.0 | 4% |
| **Total** | **278.6** | **100%** | **34%** | **811.5** | **100%** |

Source: IAL Consultants (1997)

* Values converted from UK Sterling assuming £1 million equivalent to 1.6 million Euro (1.6 mEUR)

In terms of organobromines (BFRs), the most valuable markets are in France and Germany, which together make up around 43% of total EU FR value. The markets in Belgium, Great Britain and Italy are the next largest also having a combined total of 43% of the EU BFR market. Compared with total sales of FR's, organobromines appear to be of most importance with regard to Belgium and France. Indeed, they appear to be important FR's to all Member States.

### 4.1.2 The Use of Flame Retardants in Consumer Products

Of the 300,000 tpa of FRs used in Europe in 1995, only around 17,000 tpa were used in consumer products (i.e. products which consumers can purchase) with the vast majority of FRs used in the construction industry or in other non-consumer products. In terms of consumer products, over half (58%) of all European FR usage is associated with upholstered furniture. This figure is much higher for the UK (90%) due to flammability regulations (see Section 4.1.3). Indeed, owing to the high levels of FR use in furniture for the UK market, the UK accounts for almost 65% of all EU FR usage. Data on the market for FRs for use in consumer products are summarised in Table 4.3.

These data should at best be seen as indicative: use of flame retardants in upholstered furniture in European countries other than the UK is certainly not zero. In addition, consultation has indicated that flame retardants (and in particular penta-BDPE) are indeed used in automotive products in the UK.

**Table 4.3: Use of Flame Retardants by Consumer Product Type**

| Product | Description | UK (tpa) | Rest of Europe (tpa) | Total Europe (tpa) |
|---|---|---|---|---|
| Upholstered furniture | Textiles | 2,400 | 0 | 2,400 |
| | Fillings (foam) | 7,500 | 0 | 7,500 |
| Televisions | Backcasings | 500 | 3,500 | 4,000 |
| | Printed Circuit Boards | 65 | 435 | 500 |
| Business machines in the home | PC monitor casings, internal components, PCs, printers, fax machines, copiers | 150 | 650 | 800 |
| Other consumer electrical/ electronic products | Vacuum cleaners, coffee machines, printed circuit boards, plugs, sockets | 115 | 625 | 740 |
| DIY products | PU foam sealants (some used in insulation and DIY electrical products) | 65 | 335 | 400 |
| Automotive | Seating, headrests, door panels | 0 | 500 | 500 |
| Children’s nightwear and toy nursery | Girls nightdresses and wendy houses | 150 | 0 | 150 |
| **Total** | **All Uses** | **10,945** | **6,045** | **16,990** |

Source: Stevens and Mann (1999)

### 4.1.3 Fire Safety Standards

As indicated above, the use of FRs in some products has been driven by fire safety standards. This is particularly true of domestic furniture and transport applications.

Some standards originate outside the EU or exist within only a few EU Member States. In many cases, however, companies will manufacture goods to meet these standards because products may be exported to areas where the standards apply.

***Domestic Furniture***

Standards for the fire safety of domestic furniture differ somewhat between EU Member States and also with other countries around the world. These differences are often relatively minor but, in the case of the UK in particular, may be significant. There is, at present, no harmonised set of standards for fire safety testing of furniture in the EU. As a result, consideration is given mainly to those standards which are most stringent since these will generally be adopted by foam manufacturers where products are exported.

Cigarettes have been the most frequent cause of home fires (Stone, 1998) and this is reflected in the fact that smouldering ignition sources are used in many test protocols. However, flexible polyurethane foam is generally resistant to smouldering ignition sources, being more readily ignitable through open flame sources. As a result, fire safety standards for furniture generally include both smouldering ignition sources and open flame sources. This is the case in what are regarded as the two most stringent standards:

1. California Test TB 117 is used for the individual components of furniture (PFA, 1994).

2. British Standard BS 5852 is used for composite furniture articles. BS 5852: Part 1 (1979) and BS 5852: Part 2 (1982) are specified in the Furniture and Furnishings (Fire) (Safety) Regulations 1988 (S.I. No. 1324).

In relation to the second standard, composite tests may reveal fire hazards not reflected in testing of individual components due to the complex interactions between, for example, filling materials and fabric coverings. Several tests are set out in the Regulations and Standards. These include tests upon filling material, cover fabric and ‘upholstery’ (the combination of the cover fabric and the filling material). The ignition sources used to simulate both smouldering and open flame sources include a cigarette test, a match test (using a small gas flame), a large gas flame and a wooden crib.

In addition, further tests exist for furniture used in public buildings, as the potential risks may be greater, for example, where there is mass occupancy. The relevant standards reflect greater requirements for fire resistance; these are California Technical Bulletin 133 and two more stringent tests under BS 5852.

Flame retardancy of upholstered furniture has brought about considerable benefits in terms of lives saved through prevention of fires. For example, Stevens and Mann (1999) estimate that, over the ten year period to 1997 since the introduction of the 1988 regulations, a total of 710 lives may have been saved in the UK purely through reduction in the number of fire deaths where upholstered furniture is the first material to ignite. This is set against a background of an overall saving in lives which may be as high as 1860 people over the same period.

Use of flame retardants has become more widespread since the introduction of these regulations (and similar strengthening of requirements in other countries). They are a relatively simple means by which the requirements of the regulations can be met. Thus, their use in flexible polyurethane foam for upholstered furniture has been of considerable benefit.

***Transportation***

In the US, the accepted standard for the interiors of motor vehicles is Motor Vehicle Safety Standard 302 (FMVSS 302). This states that, for individual components, the rate of flame spread must not exceed 101.6 mm/min (4 in/min)[11]. This is a small-scale test which is regulated by the US Department of Transportation. This is also the standard recommended in the UK Society of Motor Manufacturers and Traders' (SMMT) TEC 811/1989 guideline. However, there is a UN standard which requires only 254 mm/min (10 in/min).

Flexible polyurethane foam is also used for seat cushioning in the aircraft industry where it is the principal fire load in aircraft interiors (US DOT, 1997). Strict standards for flame retardancy are required which are specified by the US Federal Aviation Administration (FAA) in the Federal Aviation Regulations, Part 25, Appendix F, Part II (Flammability of Seat Cushions). This involves composite testing of seats with the requirement that flames must not spread to an adjacent seat and that weight loss must not exceed 10%.

## 4.2 The Polyurethane Market

### 4.2.1 Overview

There is a range of polyurethane (PUR) materials which have significantly different properties (as illustrated in Figure 4.1). Both blown (i.e. foamed) and non-cellular PUR types are of concern to this study.

Polyurethanes are formed from two primary components: polyols and isocyanates. The former are produced through the reaction of ethylene oxide and/or propylene oxide to form oligomeric[12] molecules. They are generally polyethers which are terminated by hydroxy (OH) groups. However, some polyurethanes are based upon *polyesters* which also contain OH groups. Indeed, some of the foams in which penta-BDPE is used are based upon polyesters.

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[11] More specifically, it states that "Material shall not burn, nor transmit a flame front across its surface, at a rate of more than 4 inches per minute. However, the requirement concerning transmission of a flame front shall not apply to a surface created by the cutting of a test specimen for purposes of testing. If a material stops burning before it has burned for 1 minute from the start of timing, and has not burned more than 2 inches from the point where timing was started, it shall be considered to meet the burn-rate requirement of the standard".

[12] Oligomer is the term for molecules produced through the partial polymerisation of chemical units (monomers). They are of intermediate molecular weight between monomers and polymers.

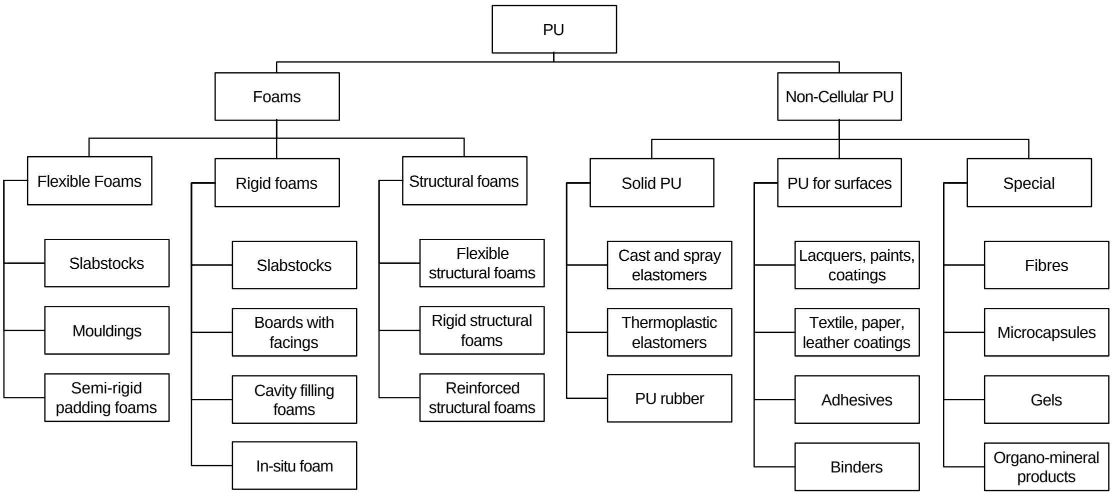

**Figure 4.1: Forms of Polyurethane (after Uhlig, 1999)**

The two primary isocyanate compounds used in the manufacture of polyurethanes are TDI and MDI[13]. TDI has historically been more widely used than MDI, though use of the latter is currently becoming more important. Reaction of the polyol with the isocyanate is the process which actually leads to the formation of the urethane group - this group is not actually part of the polymer backbone (Nicholson, 1997).

The primary polyurethane production processes which are applicable to the use of penta-BDPE are outlined below. These are based largely on an HMIP Guidance Note (HMIP, 1995).

### *Slabstock Polyurethane Foam*

This type of foam is generally employed in the manufacture of products for domestic furnishing/cushioning. The polyol and isocyanate components are transferred by metering pumps to a mixing head. Additives such as flame retardants are also included at this stage.

In order to achieve a foamed effect, water can be used as a blowing agent. This reacts with the isocyanate to create bubbles of carbon dioxide. Alternatively, a blowing agent such as methylene chloride may be used which volatilises, thence creating bubbles.

As the components react to form the foam, they are transferred onto a conveyor (vertical or horizontal) which is contained, often by paper walls. Once the foam has formed, the paper walls are removed and the product is cut into blocks. The foam is then transferred to a separate area where the curing process is completed and the product is allowed to cool.

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[13] Toluene di-isocyanate and diphenylmethane di-isocyanate respectively.

### Moulded Polyurethane Foams

In the production of moulded foams, the ready-mixed components (polyol, di-isocyanate, flame retardant, catalyst, etc.) are dispensed into moulds which may be temperature conditioned prior to filling.

Generally, the moulds are closed and then heated in order to generate the necessary rates of reaction. In 'cold cure moulding' the reaction occurs at ambient temperature although this process is not thought to be used for the products employing penta-BDPE (which are generally heated to around 170°C). Once cured, the moulded foam products are trimmed and finished.

### Non-foamed Moulded Polyurethanes

In the production of non-foamed products, no blowing agent (such as water or methylene chloride) is added to the mixture of reactants. The products which can be produced by this method are varied but, in relation to use of penta-BDPE, they include rigid and elastomeric products.

In production of the non-foamed PUR products which have been identified in this study (generally prototypes and small runs), the flame retardant is supplied predispersed in one of the two primary polyurethane components (the polyol). The polyol and isocyanate are then fed from separate tanks into a mould. The processes employed for the various products vary somewhat but include rotational moulding and reaction injection moulding (RIM). The latter process has been identified as one in which polyurethanes using penta-BDPE are produced.

### Use of Penta-BDPE

Greatest use of penta-BDPE (95%) is in flexible PUR foams which are generally produced in densities of 7.5 to 56 kg/m$^3$ (Stone, 1998). Foam rigidity is determined primarily by the degree of crosslinking which is present in the foam. This in turn is determined by the degree of chain branching in the parent polyol: highly branched polyols yield rigid PUR foams; a small degree of branching will yield a flexible foam.

The remaining use of penta-BDPE (5%) is in other types of PUR which are not foamed but are solid, in the form of elastomers or rigid products (not thought to include rigid polyurethane *foams*). Elastomers are formed by the reaction of a linear polyol with the isocyanate.

## 4.2.2 The Polyurethane Market

### Overview

Most of the PUR manufactured in Europe is used in furniture and bedding (23%). Other key uses include in construction (22%) and the automotive sector (16% ). Use of PURs across all sectors is illustrated in Figure 4.2.

Data on the PUR industry has been collated by ISOPA (the European Isocyanate Producers Association) for a report entitled "Socio-economic data on the European Polyurethane Industry (ISOPA, 1999). Around 2.3 million tonnes of PUR is produced in Europe annually. This equates to one third of global consumption which stood at 6.9 million tonnes in 1999 (Uhlig, 1999). With respect to the chain of trade:

- 25 companies, employing over 7,000 people, are involved in the manufacture of PUR chemicals and systems;
- over 6,000 companies, with a workforce of 72,000, are involved in direct production of PUR (e.g. foamers, moulders and board makers); and
- it is estimated that a further 31,900 companies, employing over 670,000 people are involved in downstream activities (such as end producers, retailers and wholesalers).

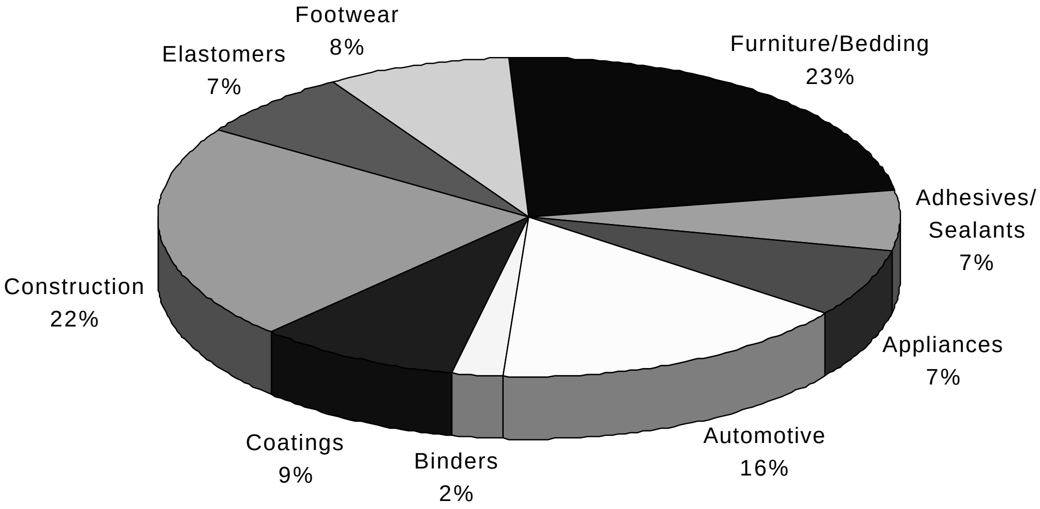

**Figure 4.2: Sectors of Polyurethane Use in Europe (ISOPA, 1999)**

In terms of value, the market for chemicals/systems for PUR manufacture is worth Euro 5,305 million (£3,316 million) annually. The value added by companies involved, for example, in foam production is around Euro 40,235 million (£25,200), giving a total value of Euro 45,540 million (£28,460 million) for the downstream market in PUR products.

*The Market for Flexible Polyurethane Foams*

EU production of flexible slabstock foam is reported to be 390,000 tpa (1998 data). The UK produces just over 15% of this flexible foam with a production rate of 60,000 tpa. Flexible slabstock foam production accounts for around 17% of total European PUR production (2.3 million tpa). At the global level, flexible PUR foam represents over 40% of production (3 million tpa), however it is not clear whether these two sets of data are directly comparable. For example, in addition to slabstock foams, which are used mainly for upholstery, flexible PUR is also associated with moulded products.

As a result of rationalisation, the manufacture of flexible PUR slabstock foam in the UK is reported to be dominated by five UK companies, with a couple of additional minor players. UK industry is represented by the British Rubber Manufacturers Association (BRMA) which in turn is a member of EUROPUR, the European trade association for the manufacturers of flexible PUR foam blocks. Details of EUROPUR membership are presented in Table 4.4.

**Table 4.4: EUROPUR Membership**[14]

| Country | Number of Companies | Country | Number of Companies |
|---|---|---|---|
| Austria | 1 | Italy | 15 |
| Belgium | 4 | Netherlands | 5 |
| Denmark | 4 | Portugal | 2 |
| Finland | 2 | Spain | 12 |
| France | 5 | Sweden | 4 |
| Germany | 11 | United Kingdom | 6 |
| Ireland | 2 | **Total for Table** | **73** |

Source: EUROPUR Directory, 27th May 1999

Based on membership of EUROPUR, it appears that the structure of the industry in the rest of Europe mirrors that in the UK. In particular, Austria, Belgium, Denmark, Finland, France, Ireland, the Netherlands, Portugal and Sweden all have six or fewer member companies. In contrast, Germany, Italy and Spain have between 11 and 15 companies reported as EUROPUR members.

Data in Table 4.4 suggests that there are roughly 73 companies producing flexible PUR slabstock foams in the EU. However, these data are associated with a number of uncertainties[15].

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[14] This refers to the number of individual companies. Companies with more than one site in a Member State are counted only once.

[15] Only members of EUROPUR are reported in Table 4.4, there are likely to be other companies operating in the EU. These 73 companies operate at 81 different sites in the EU based on EUROPUR (1999). In addition, a number of companies operate in more than one country and a number are owned by larger groups. For example, one company operates in four countries under the same group name and three of the major UK manufacturers are owned by the same group.

### 4.2.4 The Use of Flame Retardants in PUR Foams

Polyurethane foams are, when used alone, highly flammable materials. This is because they are organic materials and have a high surface area for combustion (because they are foamed). This latter property (i.e. having an open structure) also allows for easy flow of oxygen. Some of the key factors affecting the flammability of polyurethane foams include the density of the foam, its composition, porosity, cell size and the presence or absence of additives (Stone, 1998).

In order to meet the stringent fire safety standards required by law and/or by end users, the addition of flame retardants is, therefore, often necessary. There exists a huge number of flame retardant chemicals which are based upon differing mechanisms of action and different chemical elements.

***Mechanism of Action***

The following information is focussed primarily upon those flame retardants which are suitable for use in polyurethane foams and, in particular, halogenated flame retardants, of which penta-BDPE is one. Other substances and their modes of action are also considered in order to provide a background to the use of these chemicals.

Combustion occurs through a chemical reaction which is sustained by free radicals[16]. It is characterised by two principal stages:

1. A heat source initiates degradation of the polymer to yield volatile products of low mass which migrate to the polymer surface and enter the gas phase.

2. The volatile products are oxidised by free radical reactions (burning), which evolves further heat to produce more volatile components from the polymer (Nicholson, 1997).

Flame retardants can act by limiting the efficiency of either of these processes. Some flame retardants act by increasing the transfer of heat through the polymer. This reduces localised high temperatures in the foam and thus limits the production of the combustible volatile components. These chemicals are generally inorganic substances.

Other flame retardants serve to limit the flow of volatiles into the combustion zone. For example, metal borates such as zinc borate react in a fire to form a glassy layer which prevents such migration. Others, such as melamine, react to form an impervious melt which serves the same purpose. Some (e.g. hydrated alumina) not only form an impermeable char layer but also evolve water which helps to extinguish the fire (BFRIP, 1992).

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[16] Free radicals are chemical species (atoms or molecules) which have an unpaired electron, making them very reactive. They are often involved in chain branching reactions since their reaction with other chemical species frequently leads to formation of another free radical.

Halogenated flame retardants (based upon bromine or chlorine) break down when heated. This leads to the evolution of chlorine and bromine free radicals. These free radicals act to terminate the otherwise self-sustaining combustion reactions through reaction with the free radicals involved in the combustion process to yield stable products. These flame retardants are sometimes used in conjunction with antimony trioxide ($Sb_2O_3$), a substance which does not itself have flame retardant properties but acts synergistically with halogenated flame retardants through the production of an antimony halide which scavenges free radicals and also prevents access to oxygen (Nicholson, 1997).

Some flame retardants combine a number of the above properties. In particular, this is true of halogenated alkyl phosphates such as tri (chloropropyl) phosphate (TCPP). These substances contain a halogen (chlorine) and can thus act by scavenging gas phase free radicals. They also contain phosphorus which acts through formation of an impervious char layer.

### *Flame Retardant Requirements for Polyurethane Foams*

Detailed below are some of the primary concerns which are taken into account when selecting an appropriate flame retardant for a particular application:

1. **Thermal stability and degradation temperature**: these are primary requirements as concerns a flame retardant's efficacy (e.g. in meeting standards such as BS 5852 or FMVSS 302). The flame retardant must have sufficient thermal stability to withstand polyurethane foam production temperatures which tend to be of the order of 170°C[17]. This will help to ensure that the 'scorch' effects encountered with some flame retardants are avoided. Also, in the case of halogenated flame retardants, degradation should occur very close to the flame front such that the halogen free radicals are released at the correct time to retard the combustion mechanism when exposed to heat. Similarly, with other flame retardants, it must be ensured that the flame retarding mechanism (such as char formation) becomes operative at a suitable temperature.

2. **Physical State**: in order for the flame retardant to become dispersed within the polyurethane during manufacture, it is preferential that the flame retardant is a liquid of relatively low viscosity. Viscous liquids generally require either heating or mixing with a liquid of lower viscosity (such as the polyol component of the polyurethane) in order to ensure even distribution within the product.

3. **Volatility**: a flame retardant should be of relatively low volatility if an additive type is chosen. This helps to ensure that it remains within the polyurethane matrix in order to ensure that flame retardancy is retained throughout the product's lifetime. Also, in the case of foams used in automobile interiors, this will help to ensure that the flame retardant will not contribute significantly to

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[17] Penta-BDPE undergoes thermal decomposition at around 235°C (MSDS from Bromine Compounds Ltd internet website http://bromine.esi.be - note this product is not on sale in the EU).

‘fogging’ problems which are encountered with some volatile additives[18]. If the flame retardant is also hydrophobic, it will tend to be resistant to leaching when washed.

4. **Final Product Properties**: the flame retardant should have minimal effects upon the properties of the final polyurethane product (though the effects of a flame retardant will tend to be taken into account during formulation). These properties include, for example, indentation force deflection (IFD[19]), density, tensile strength, fatigue and, of course, flame retardancy. It is also essential that these properties are retained throughout a product’s lifetime and a number of accelerated aging tests[20] exist to ensure that physical properties are retained in the long term (this retention of properties will be dependent upon the various components of a product, including the flame retardant).

### 4.2.5 The Market for Flame Retardants in PUR Foam

Table 4.5 overleaf sets out the consumption of various types of FRs in PUR in the EU. Organobromines and chlorinated organophosphorus compounds are most widely used (making up 68% of FR usage in PUR). It should be noted that these data include all forms of PUR (not just flexible foams).

On a global scale, the two groups of flame retardants used most widely in flexible PUR foams for upholstered furniture are penta-BDPE (sometimes mixed with phosphate esters) and various chlorinated alkyl phosphates (particularly tri (2-chloropropyl) phosphate, TCPP), frequently mixed with melamine and also with non-halogenated phosphate esters (Stone, 1998). In the EU, however, the latter type is far more widely applied.

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[18] Note that such fogging problems are generally not primarily associated with flame retardants but with other plastics additives, such as plasticisers. Reactive flame retardants will not tend to contribute to this phenomenon and there will be varying degrees of this type of loss amongst the additive type flame retardants.

[19] IFD provides a measure of the load bearing capacity of polyurethane foams. It can be specified in terms of the force required to yield a specific deflection or of the foam’s deflection under a specified force (e.g. representing a person’s weight in a car). Specifically, it is “a measure of the load bearing capacity of flexible polyurethane foam. IFD is generally measured as the force (in pounds) required to compress a 50 square inch circular indentor foot into a four inch thick sample no smaller than 24 inches square, to a stated percentage of the sample's initial height” (PFA, 1994).

[20] Tests for accelerated aging (under both dry and humid conditions) and also the other physical properties mentioned are specified in ASTM D3574 (ASTM, 1995).

**Table 4.5: Use of Flame Retardants in PUR in the EU in 1995[*]**

| Flame Retardant | Value mEUR | % of Use by Value |
|---|---|---|
| Organobromines | 50.4 | 36% |
| Organochlorines | ✓ | |
| Chlorinated organophosphorus | 44.8 | 32% |
| Other organophosphorus | 14.2 | 10% |
| Antimony oxide | - | |
| Alumina trihydrate | 3.2 | 2% |
| Other flame retardants | 25.6 | 19% |
| **Total** | **138.2** | **100%** |

Key: ✓ in the original report is believed to mean that this FR is used but associated quantities are not known; - is believed to mean no data available

Source: IAL Consultants (1997)

* Values converted from UK Sterling assuming £1 million equivalent to 1.6 million Euro (1.6 mEUR)

## 4.3 Use of Penta-BDPE

### 4.3.1 The Market for Penta-BDPE

As noted earlier, neither penta-BDPE nor FR formulations containing penta-BDPE are manufactured in the EU. There are two companies involved in the supply of penta-BDPE to the EU market, with one being a minor player compared with the other.

The Risk Assessment (Environment Agency, 1999) estimates that in 1994 around 300 tpa of penta-BDPE were used in the EU, with a further 800 tpa imported in finished articles. In this regard, the main supplier of penta-BDPE has indicated that for the year 2000, a figure of 125 tonnes is more appropriate for use and 100 to 125 tonnes for imports in other products. Taking into account the other minor supplier, the overall figure for use, including within imported products, may be around 250 tpa.

Penta-BDPE was the least important of the three polybrominated diphenyl ethers (PBDPEs) on the market (penta-BDPE, octa-BDPE and deca-BDPE) in 1994, representing just 9% of the PBDPEs used in the EU or imported on finished articles (KEMI, 1999a). That year, the market for polybrominated diphenyl ethers (PBDPEs) was estimated to be around 11,860 tpa in the EU (as shown in Table 4.6), representing just over 17% of the total usage of brominated FRs in 1995 (at 64,000 tpa). Overall, use of penta-BDPE-based FRs in the EU represents less than 0.4% of EU FR usage which stood at around 300,000 tpa in 1995[21]. The main markets for penta-BDPE are the US and elsewhere outside the EU.

**Table 4.6: Use of Polybrominated Diphenyl Ethers in Europe in 1994**

| **Type** | **Use in the EU tpa** | **Imported on Products tpa** | **Total Usage (tpa)** | **% of EU PBDPE market** |
|---|---|---|---|---|
| penta-BDPE | 300 | 800 | 1100 | 9.3% |
| octa-BDPE | - | - | 2550 | 21.5% |
| deca-BDPE | - | - | 8210 | 69.2% |
| **Total** | - | - | **11860** | **100%** |

Source: KEMI (1999b) and Environment Agency (1999)

Table 4.7 presents further data on the consumption of brominated ethers (PBDPEs) in various EU Member States in 1995. The largest consumer of brominated ethers was France (31.3% of EU consumption) followed by Belgium (20%), Italy (18.8%), Great Britain and Germany (both at 12.5%). Note that there are significant differences between the total consumption figures given in this table and that presented in Table 4.6. The reasons for this difference are not clear from the data provided. However, the total "usage" figures given in Table 4.6 refer to both use in production and presence in imported articles while the consumption data in Table 4.7 refer just to use in the EU.

Table 4.8 provides more detailed data relating specifically to penta-BDPE. This has been based upon the data underlying Tables 4.6 and 4.7, supplemented with further data from IAL (1997).

As shown in Table 4.8, the calculated value for the use of penta-BDPE in the EU is estimated to be around Euro 4.3 million (£2.7m) per year. The market for penta-BDPE used in polyurethanes is also assumed to be Euro 4.3 million (£2.7m) per year since this is believed to be the only current use for the substance (some in flexible foam and some in solid products such as elastomers).

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[21] Note that the total figure of 1,100 tpa for use of penta-BDPE has been used here. If recent industry estimates of around 250 tpa (around 125 tpa imported as the flame retardant and a similar amount imported in products) were used, the usage of penta-BDPE would account for only 0.08% of total FR use.

**Table 4.7: Consumption of Brominated Ethers in Europe in 1995**

| Member State | Consumption tpa | % of Total Consumption |
|---|---|---|
| Belgium | 1600 | 20.0% |
| France | 2500 | 31.3% |
| Germany | 1000 | 12.5% |
| Great Britain | 1000 | 12.5% |
| Italy | 1500 | 18.8% |
| Netherlands | - | |
| Scandinavia | - | |
| Spain/Portugal | 300 | 3.8% |
| Other Europe | 100 | 1.3% |
| **Total** | **8000** | **100%** |

**Source: IAL Consultants (1997)**

**Table 4.8: Use of Flame Retardants in the EU**

| | All Flame Retardant Use | | Flame Retardant Use in PUR | | Source |
|---|---|---|---|---|---|
| | Use (k tpa) | Value (mEUR) | Use (k tpa) | Value (mEUR) | |
| All FR | | 811.5 | | 138.2 | IAL (1997) |
| BFRs | 64 | 278.6 | 10.5 | 50.4 | IAL (1997) |
| PBDPEs | 8 | 31.4 | | | IAL (1997) |
| PBDPEs | 11.89 | 46.6 | | | KEMI (1999b) |
| Penta-BDPE | 1.1 | 4.3 | 1.1 | 4.3 | RAR |

The values for PBDPEs (use data from KEMI, 1999b) and penta-BDPE (use data from the Risk Assessment) were calculated using the value data for PBDPEs from IAL (1997) (i.e. 31.4 mEUR ÷ 8,000 tpa = 3.95 mEUR per kt). It is assumed that the price per tonne of penta-BDPE is equivalent to that of combined PBDPEs

Based upon the above, the EU market for penta-BDPE, is 8.6% of the value of BFRs used in PUR and 3.1% of all FR value in PUR. In terms of total uses (including those other than PUR), penta-BDPE market value is 1.5% of all BFR value and 0.5% of total FR value[22]. This can be compared directly with the figure of just under 0.4% for the usage of penta-BDPE as compared to total EU FR usage. That the former figure is higher is due to the fact that BFRs tend to command a higher than average price per tonne.

In terms of quantities, based upon the 1,100 tpa use of penta-BDPE (assumed in the Risk Assessment), this is 10.5% of all BFR use in PUR and 1.7% of total BFR use. As mentioned above, it represents just under 0.4% of total EU FR use for all applications.

Three applications for penta-BDPE have been identified through consultation with PUR manufacturers and their trade associations:

- in foam-based laminated automotive applications such as headrests;
- in the production of phosphorus-free penta-based foams for domestic furniture, some of which includes cot mattresses; and
- in the production of various small run and prototype components, such as rigid PUR elastomer instrument casings.

As indicated, the first two uses are associated with flexible foams and the last with solid PUR such as elastomers. Consultation with the UK and German trade associations for rigid PUR foams (British Rigid Urethane Foam Manufacturers Association (BRUFMA) and IVPU) indicates that penta-BDPE is not used in the rigid PUR foams in these countries.

Consultation with flame retardant suppliers has indicated that penta-BDPE is also used in small amounts in the production of packaging for electronic equipment within the EU (and to a greater extent in the US). In addition, scrap foam from PUR production is exported to the US to make carpet padding. This will contain penta-BDPE as well as all other FR.

### 4.3.2 Use of Penta-BDPE in Laminated Materials for Automotive Applications

#### *The Use of PUR in the Automotive Sector*

PUR foams have many applications in car interiors including seating, steering wheels, acoustic management systems, dashboards and door panels[23]. Indeed, it has been suggested that the bulk of a car interior is foam.

Data on the market for automotive PUR products is presented in Table 4.9 (with supporting data on the PUR industry as a whole in Section 4.2.2). There are 100

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[22] Note that, as with the percentage by weight of total FR use, this value of 0.5% of total EU FR market value would be reduced to around 0.1% if the figure for total use of penta-BDPE is 250 tpa (as suggested recently by the industry), rather than 1,100 tpa.

[23] Urethanes Technology, December 1999/January 2000, page 7.

companies involved in the production of foams and moulded PUR for the automotive market, consuming around 16% of total PUR production. These companies add considerable value to the PUR, increasing its market value from Euro 815 million (£509m) to Euro 20,500 million (£12,800m) (or from 15.4% to 45% of the total for PUR as a whole).

**Table 4.9: The Automotive Polyurethane Market**

| **Link in the Chain of Trade** | **Volume** | | **Market Value** | | **Companies** | | **People** | |
|---|---|---|---|---|---|---|---|---|
| | **kt** | **% of PUR total** | **mEUR** | **% of PUR total** | **No.** | **% of PUR total** | **No.** | **% of PUR total** |
| PUR Chemical Manufacturers | 365 | 16% | 815 | 15.4% | | | 1100 | 15.5% |
| Foamers/ Moulders | | | 20500 | 45.0% | 100 | 1.6% | 3900 | 5.42% |
| Retailers/ Wholesalers/ Tier 1 Suppliers | | | | | 150 | 0.5% | 160000 | 23.9% |

Source: ISOPA, 1999

### *Use of Penta-BDPE*

Penta-BDPE is used in the UK in the production of foams for applications such as car ceilings and headrests. With respect to the rest of the EU, this use of penta-BDPE recently ceased in Italy and the chemical is not used in Spain, Germany (where use ceased some time ago), France and the Netherlands (which have also moved away from penta-BDPE). Globally, one car manufacturer has reported that penta-BDPE is still used in the automotive industry to quite a large extent in applications such as head-liners, carpeting and dashboards. However, this is not the case for seating where other flame retardants such as deca-BDPE are generally used.

Overall, use of penta-BDPE in automobile interiors is indicated to be decreasing and it has been suggested that all use in this application will disappear soon. This is due in part to pressure from car manufacturers. The German Automotive Federation (VDA) is reported to have black-listed penta-BDPE and thus German manufacturers have replaced this product. With respect to specific manufacturers, Volvo has placed penta-BDPE on its black list and does not use it in seat foam where it has been replaced with a phosphorus-based product. Another manufacturer has also stated that penta-BDPE is prohibited for use in any of its vehicle components through its inclusion upon that company's list of 'substances of concern'.

### Levels of Use

Penta-BDPE is associated with the production of 350 tpa of foams for automotive applications in the UK. Compared with 60,000 tpa of flexible PUR foams produced each year, this application represents 0.6% of UK production. It is associated with between 14 tpa and 35 tpa of penta-BDPE usage[24].

Levels of use in other Member States are not known, although trends in use suggest that it is likely to be small.

### Reasons for Use

Foams for automotive applications are associated with speciality end-products which have a high technical specification. Penta-BDPE is particularly effective in reducing the risk of ignition and the rate of burn and at meeting emission levels for volatiles set by the automotive industry. Penta-BDPE also gives minimal interference with critical physical property performance requirements and is not associated with the discoloration of foam which some components manufacturers find unacceptable.

With respect to specific properties, penta-BDPE is used because it provides good thermal and hydrolytic stability compared with alternative flame retardants. Non-thermally stable flame retardants would be unable to pass automotive flammability standards, while flame retardants with poor hydrolytic stability are associated with the interior fogging of automobile windows. The hydrolytic stability of halogenated flame retardants such as penta-BDPE means that these also perform well in the acidic conditions encountered in automobile interiors especially with polyester-based PUR foams. The concern is that the acidic environment will rapidly degrade the final products leading to parts failure (i.e. delamination of fabric from backing).

As a result of its properties, penta-BDPE performs well with respect to the following automotive industry tests:

- flammability standards, where the US standard FMVSS 302 is the industry standard used across the board;
- fogging standards where these are generally defined at the company level. These were initiated by the German automotive industry to address the issue of the strong odours associated with new cars. While the initial targets of fogging standards were plasticisers, there are now standards across the whole spectrum of products used including polyurethane foams; and
- aging tests which ensure the durability of car components. Foams are artificially aged to examine the potential impact of real-time aging on FR and mechanical

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[24] This range arises from differing assumptions concerning the concentration of penta-BDPE in automotive foams. The Risk Assessment assumes foams contain 10% penta-BDPE. Information supplied by the producer of automotive foams suggests that such foams may contain only 4% penta-BDPE.

properties. Certain FR are not amenable to meeting certain heat and humidity aging requirements.

In some applications, penta-BDPE-based foam is used to assist the performance of other polymeric materials which are combined with it in the composite. This results in the use of higher penta-BDPE concentrations than are necessary to flame retard the foam itself.

### 4.3.3 Use of Penta-BDPE in Upholstery Products

#### *The Use of Flame Retardants and PUR in the Furniture/Bedding Sector*

Flame retardants are widely used in upholstered furniture. As reported in Section 4.1.2, over half (58%) of all European FR usage on consumer products is associated with upholstered furniture and in the UK this figure is much higher (90%) due to its flammability regulations (BS 5852 and the Furniture and Furnishings (Fire Safety) Regulations 1988). FRs used in upholstery foams alone account for over 68% of the UK's FR usage in consumer products.

Data on the market for PUR in furniture and bedding is presented in Table 4.10. There are 400 companies involved in the production of foams and moulded PUR for use in furniture and bedding, consuming around 23% of total PUR production. Around 5,500 people are involved in this production and the value of their output is Euro 12,100 million (£7,500m) per annum.

**Table 4.10: The Market for Polyurethane in Furniture/Bedding**

| **Link in the Chain of Trade** | **Volume** | | **Market Value** | | **Companies** | | **People** | |
|---|---|---|---|---|---|---|---|---|
| | **kt** | **% of PUR total** | **mEUR** | **% of PUR total** | **No.** | **% of PUR total** | **No.** | **% of PUR total** |
| PUR Chemical Manufacturers | 530 | 23% | 1060 | 20% | | | 1500 | 21.1% |
| Foamers/ Moulders | | | 12100 | 26.6% | 400 | 6.6% | 5500 | 7.6% |
| Retailers/ Wholesalers/ Furniture Professionals | | | | | 6500 | 20.4% | 210000 | 31.3% |

Source: ISOPA, 1999

#### *Use of Penta-BDPE*

A UK producer of foam has indicated that it uses penta-BDPE in the production of polyurethane foams for domestic furniture, some of which include cot mattresses. That producer has a requirement for the avoidance of foams containing phosphorus FRs. Italian producers of slabstock foams have indicated that they do not use penta-BDPE.

It is known that the EU market for penta-BDPE-based foam has decreased significantly in recent years. Thus, whilst it may have been significant in the past, it is now relatively small. In comparison, use of penta-BDPE for this application is reportedly far higher in the US, with penta-BDPE and TCPP being the two most commonly used flame retardants.

In terms of variations in use across Member States, it has been argued that most penta-BDPE will be used in the UK where the fire legislation for private furniture is the more stringent compared with other EU Member States.

### *Levels of Use*

Consultation with UK foam producers and their trade association indicates that at least 5 tpa of penta-BDPE is used in the UK in the production of 50 tpa of foam. Polyurethane foam for use in upholstered furniture is predominantly of the slabstock form. Compared with 60,000 tpa of flexible slabstock PUR foams produced each year, the quantities identified represent under 0.1% of UK production. However, this application is one of the two largest uses for penta-BDPE in the EU and overall use across the EU is expected to be greater than 5 tpa.

EUROPUR has provided an approach for estimating European levels of penta-BDPE usage in upholstery applications based on data provided by the UK trade association for flexible foams[25]. A key assumption in the approach is that UK usage of penta-BDPE is higher than elsewhere in Europe given the UK's stringent fire safety standards. Taking levels of UK usage for penta-BDPE in upholstery applications and grossing this up to the European level (using the same assumptions as before) indicates that around 11 tpa of penta-BDPE is used in the production of around 110 tpa of foam for upholstery uses[26]. This equates to around 0.03% of the EU's production of flexible slabstock foams (at 390,000 tpa) and 0.02% of total PUR usage in furniture and bedding (at 530,000 tpa).

Penta-BDPE will also be present in upholstered goods imported into the EU. Data provided by a supplier of penta-BDPE confirms that this chemical can be found in the PUR foams of some imported furniture into the UK. In terms of imports from outside the EU, this company assumes that these will account for around 100 tpa to 125 tpa of penta-BDPE (compared with the 800 tpa assumed in the Risk Assessment).

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[25] EUROPUR estimated that of the 390,000 tpa of flexible PUR foams produced in the EU each year (1998 data), only around 0.02% (i.e. 80 tpa) contained penta-BDPE. This was based on data from the UK which reported that 35 tpa of UK-produced foams contained penta-BDPE. Based on the contention that this use arose from fire safety requirements in domestic furniture, all of this use was assumed to be associated with upholstery applications such as domestic cushioning (in fact, all of this use was associated with automotive applications). Assuming that this foam contained 10% penta-BDPE, this use accounted for around 8 tpa of penta-BDPE across Europe.

[26] 35 tpa of foam produced in the UK equated to production of 80 tpa at the European level. Using the same ratio, 50 tpa of UK production equates to 110 tpa EU production.

### *Reasons for Use*

The one company identified as using penta-BDPE for this application does so because this was the first flame retardant tested which both allowed the foam to pass the relevant requirements (in the standards and regulations) and because it was not based upon phosphorus.

The company chooses to use a phosphorus-free FR because of concerns in the past over a possible link between phosphorus-based flame retardants and ‘cot-death’ (sudden infant death syndrome, SIDS). This issue was brought to prominence in the media in the early 1990s. The theory suggested that toxic by-products (such as phosphine) could arise from fungal metabolism of phosphorus-based flame retardants, hence contributing to SIDS. Such concerns led a number of companies to seek alternative substances. Despite the fact that this theory has now been discredited (DOH, 1998), it remains a reason for the continued use of phosphorus-free flame retardants by some companies. This is a function of a requirement by the company’s customers to use phosphorus-free flame retardants.

## 4.3.4 Use of Penta-BDPE in Elastomers

### *The Use of PUR in Elastomers*

Data on the market for PUR in elastomers is presented in Table 4.11. This is a relatively small sector of the total PUR market representing around 7% of PUR consumption and involving a total of 1,100 companies. 350 companies formulate elastomers or produce speciality systems, with an output valued at Euro 1,000 million per annum.

**Table 4.11: The Market for Polyurethane in Elastomers**

| **Link in the Chain of Trade** | **Volume** | | **Market Value** | | **Companies** | | **People** | |
|---|---|---|---|---|---|---|---|---|
| | **kt** | **% of PUR total** | **mEUR** | **% of PUR total** | **No.** | **% of PUR total** | **No.** | **% of PUR total** |
| PUR Chemical Manufacturers | 160 | 7% | 500 | 9.4% | | | 500 | 7.0% |
| Formulators/ Speciality System Houses | | | 1000 | 2.2% | 350 | 5.7% | 2500 | 3.5% |
| Retailers/ Wholesalers/ Elastomer Goods Fabricators | | | | | 750 | 2.4% | 15000 | 2.2% |

Source: ISOPA, 1999

### *Use of Penta-BDPE*

One UK-based company has been identified which produces small quantities of flame retarded PUR systems employing penta-BDPE for use in solid (non-foamed) applications, generally as elastomers. These PUR systems are liquids at room temperature and some of them are castable. They are used in production of various small run and prototype components, such as PUR elastomer instrument casings.

Contact with one of the company's customers indicates that the PUR systems are processed by machine dispensing into a mould. Castability of these systems allows for the production of large parts or parts with thick cross-sections. Other processes for which these systems may be used are rotational moulding, spin cast and reaction injection moulding (RIM). It is thought that some elastomers containing penta-BDPE are produced by the latter method.

### *Levels of Use*

Around 1.2 tpa of penta-BDPE are used in the production of rigid PUR elastomers in the UK each year. The levels of use in other Member States is not known. However, the main supplier of penta-BDPE indicates that uses other than in flexible PUR foam constitute less that 5% of total usage. This would equate to 5 tpa to 6 tpa based on 1999 and 2000 sales figures (of 100 tpa to 125 tpa of penta) and 15 tpa based on the assumptions used in the Risk Assessment. Like other uses of penta-BDPE, it is likely that use in such applications is decreasing.

### *Reasons for Use*

Penta-BDPE is used in these applications because of the need to achieve good fire ratings for products. It is apparently used sometimes in combination with other flame retardants such as aluminium trihydrate and ammonium polyphosphate.

Since the products made from these PUR systems appear to be relatively diverse, it is likely that penta-BDPE is used in order that customers can be sure of meeting any fire regulations by using materials which are tried and trusted. In this context, penta-BDPE is used for its high bromine content (and thus its good flame retardancy) and also its consistent ability to meet specifications.

## 4.3.5 Other Uses of Penta-BDPE

### *Packaging*

Consultation with a flame retardant supplier has indicated that penta-BDPE is also used in the production of packaging. In particular, a polyester/PUR foam complying with UL94-HF1[27]. However, consultation as part of this study failed to identify any PUR producers using penta-BDPE in this application.

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[27] UL 94 is the US Underwriters Laboratory test for materials in contact with electrical equipment. A flame is used for 60 seconds and various requirements for the flammability of the material must be met (Stone, 1998). Under UL 94, specific requirements are made for foamed products, such as the length of time which the 1/2 inch thick sample burns or glows. Furthermore, HF-1 under UL 94 requires that no drops from foamed products ignite an underlying surface (Danish EPA, 1999).

The flame retardant supplier suggests that use in this application in Europe is small, accounting for less than 5 tpa of penta-BDPE with most use being in the US. While it is “very likely” that some penta-BDPE-based flexible foam is imported into, as well as exported from, Europe with the shipping of electronic equipment, actual amounts are unknown.

***Carpet Padding***

A supplier of penta-BDPE has reported that scrap foam from PUR production facilities is shipped to the US to make ‘rebond’, a carpet padding used between carpet and hard flooring surfaces such as concrete and wood. The rebond is not attached to the carpet, thus the padding (rebond) is a separate material from the carpet itself. Carpet is laid over the rebond to provide a cushion effect and helps in minimizing carpet wear.

Scrap foam exported to the US will include foam which contains penta-BDPE. The supplier of penta-BDPE has indicated that, to the best of its knowledge, rebond is not imported into Europe and thus this will not affect exposure to penta-BDPE in the EU.

### 4.3.6 Variations in the Use of Penta-BDPE by Member State

All three of the above uses of penta-BDPE take place in the UK. With respect to flexible PUR foams, two of the five major UK-based companies use penta-BDPE. In the Netherlands, penta-BDPE is not used by members of the Dutch Plastics Federation which covers 95% of the national market (and all major producers and multinationals). None of the four main Dutch producers of flexible PUR foams use penta-BDPE. In Denmark, the Danish EPA reports that there are only four producers of flexible PUR, none of which use penta. While there are "rumours" of some small producer(s) using penta-BDPE for automobile seats, this use could not be verified. There is reported to be no use of penta-BDPE in Italy.

As discussed in Section 4.3.2, penta-BDPE is not believed to be used in the production of automotive products in Italy, Spain, Germany, France and the Netherlands.

Customs and Excise import data suggest that, in the period 1996 to 1998, penta-BDPE may have been imported into EU Member States from elsewhere in the EU (specifically Belgium-Luxembourg, France, Italy, the Netherlands, Sweden and the UK) and from other countries (specifically Israel and the USA)[28]. It is not possible to say whether these imports actually took place or to quantify the amounts of penta-BDPE involved because penta-BDPE shares a customs code with another chemical (1,2,4,5 tetrabromo-3,6-bis (pentabromophenoxy) benzene) and data for the two chemicals cannot be distinguished.

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[28] These data were provided by the main supplier of penta-BDPE to the EU. It is assumed that these data relate to supply of penta-BDPE in formulations and not as a neat product.

### 4.3.7 Summary

Data on the use of penta-BDPE is summarised in Table 4.12. This shows the continuing trend away from the use of penta-BDPE in recent years.

**Table 4.12: Use of Penta-BDPE in the EU**

| Type of Penta-BDPE Usage | Tonnes Per Annum | |
|---|---|---|
| | UK | EU |
| Total use | 20 to 41[c] | 100 to 125[b]<br>(300[a] in 1994) |
| Imports on finished articles | - | 100 to 125[b]<br>(800[a] in 1994) |
| Use in flexible foams | 19 to 40[c] | 91[c] to 119[b] |
| Use in automobile applications | 14 to 35[c] | - |
| Use in upholstery applications | 5[c] | 11[c] |
| Use in rigid elastomers | 1.2[c] | 6[b, c] |
| Use in packaging | - | 6[b] |

Key: a Risk Assessment (1994 data)
b flame retardant suppliers (1999/2000 data)
c PUR industry (1999/2000 data)

Data for the UK suggest the biggest use of penta-BDPE to be in automotive applications. This is associated with between 14 tpa and 35 tpa of penta-BDPE depending on whether the foam is assumed to contain 4% or 10% of the chemical. The second most important use of penta-BDPE is in upholstery applications. In this regard, data provided by the PUR industry correspond well with those reported by the two suppliers of penta-BDPE. As reported above, the main supplier indicates that (to the best of its knowledge), penta-BDPE-based PUR foam is used in Europe by the automotive, furniture and packaging industries. The first two of these are reported to be the main applications and in both uses the foam is covered with another material, such as a cloth fabric or leather.

However, there are also uncertainties in data provided by the PUR industry, in particular concerning levels of penta-BDPE use at the EU level. In Section 4.3.3, it is estimated that 11 tpa of penta-BDPE are used in upholstery applications across the EU using EUROPUR assumptions provided at the second stage of the study. Using these same assumptions, it can be estimated that total use of penta-BDPE in flexible foams is 91 tpa[29]. However,

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[29] At Stage 2, 35 tpa of penta-containing foam produced in the UK equated to production of 80 tpa at the European level. Using the same ratio, 400 tpa of UK production equates to 914 tpa of EU production. This equates to 91tpa of penta-BDPE assuming a 10% concentration in PUR foams.

there are difficulties in translating these assumptions to the data collated in the third stage of the study[30] which suggest that usage may be much lower.

## 4.4 The Benefits of Penta-BDPE

In general terms, penta-BDPE is chosen for use in its specific applications for reasons which include the following (see *Flame Retardant Requirements for Polyurethane Foams* in Section 4.2.4):

- penta-BDPE is a liquid both at room temperature and also at the temperatures involved in PUR foam manufacture (during mixing of polyols and isocyanates, etc.). This is in contrast to the majority of other brominated flame retardants which tend to be solids. Being a liquid phase flame retardant means that it is more easily mixed within the starting materials and thus more evenly distributed (although it is still relatively viscous and requires either heating to around 60°C or mixing with a less viscous component such as the polyol);

- it has a high bromine content. Bromine is the most efficient halogen compound in terms of flame retardancy, making penta-BDPE very effective in various applications;

- related to the previous point, the degradation temperature of penta-BDPE is such that it can withstand the processing temperatures of around 170°C (avoiding the scorching and discolouration effects which occur with some other flame retardants) but will decompose at higher temperatures, releasing bromine free radicals to help terminate the combustion mechanism[31];

- penta-BDPE is a relatively involatile substance and, therefore, will not contribute significantly to fogging effects in automobiles. The good containment within the polymer matrix also helps to contribute in this respect. A related property is that it will not be lost from a product over its lifetime to the extent of some other flame retardants (aided also by the fact that penta-BDPE is relatively hydrophobic); and

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[30] Based on the contention that the UK's use of penta-BDPE arose from fire safety requirements in domestic furniture, all of the UK's use was assumed to be associated with upholstery applications such as domestic cushioning. This fact was used to estimate the relative use of penta-BDPE in the EU as a whole compared with the UK. However, most of the UK's use of penta-BDPE is associated with automotive applications. Furthermore, the concentration of penta-BDPE in automotive applications is thought to be lower than in foams for upholstery uses.

[31] In some applications, if another flame retardant such as deca-BDPE were used, it would not degrade at the correct temperature and would thus provide insufficient flame retardancy (deca-BDPE is used in other types of products in which a different degradation temperature is required).

- in the polyurethane foams in which it is used, the physical properties can be maintained under dry and humid accelerated aging tests. It also does not have such deleterious effects upon these properties as some other flame retardants[32].

Cost is generally not an issue which would favour the use of penta-BDPE since non-brominated FRs tend to be cheaper (although this is not always the case).

## 4.5 Alternatives to Penta-BDPE

### 4.5.1 Background

This section provides details of the availability of alternatives to penta-BDPE for the applications in question. These applications are certain flexible PUR foams used in the automotive sector and in upholstered furniture and also small quantities of non-foamed PUR products (such as prototypes). The discussion reflects the consultants' understanding of the alternatives in terms of their technical suitability and their suitability from an environmental perspective. Information is based upon consultation with industry and a review of relevant literature (including data provided by the relevant competent authorities for notification of new substances[33]).

It should be noted that the data provided are those available from secondary literature sources at the time of writing and are not comprehensive. The data may also be of variable/unknown quality and the information has not been independently evaluated nor critically assessed for the purposes of this report.

The Technical Guidance Document for Development of Risk Reduction Strategies states, with respect to the assessment of substitutes where marketing and use restrictions are considered, that (paragraph 6.26 in the TGD):

> "In all cases, the available information of the hazard profile of the substitutes should be assessed and described. To what extent the exposure to (and consequently risks of) the substitutes should be evaluated, is a matter of case-by-case judgement. The upper limit of the substitute evaluation is the prioritisation under Regulation 793/93, but since it is both time-consuming and resource-intensive, it should only be done after careful consideration and consultations."

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[32] For example, some flame retardants such as TCPP can impart unwanted plasticising effects upon certain foam products. This may lead to lowered tensile strength and reduced IFD.

[33] Directive 67/548/EEC on the classification, packaging and labelling of dangerous substances was ameneded for the sixth time in 1979 by Directive 79/831/EEC. This required that substances brought onto the market after 1981 be notified to a competent authority in one of the member states. This notification is then valid for the whole community. Upon notification, substances are placed upon the ELINCS list (as opposed to existing substances, such as penta-BDPE, which are on the EINECS list) and a risk assessment must be carried out according to Directive 93/67/EEC and the relevant technical guidance.

In this case, it has been decided that the assessment of alternatives should comprise an appraisal of the hazard profile of those substances identified as suitable for the applications in question (automotive, furniture and non-foamed small runs/prototypes). This, combined with information on the physical properties of the key alternatives has formed the basis of the appraisal of hazard and of potential risk to the environment. Therefore, this review does not constitute a full assessment of "risk". Rather, it provides an appraisal of their toxicology and some indications as to *possible* risk to the environment[34].

Appraisal of the suitability of alternatives has been made on the basis of the following criteria:

- technical issues associated with the production process where an alternative flame retardant is used;
- whether the finished product will be able to achieve performance in fire safety terms which is at least equivalent to that of the substance being replaced;
- the effects of using an alternative flame retardant upon other aspects of the properties of the finished article, such as product lifetime and performance in use; and
- whether the potential risks to the environment of the alternative are less than (and certainly not more than) those of penta-BDPE.

With regard to the second of these points, it is considered an essential requirement that any alternative flame retardant is able to meet the relevant fire safety standards (discussed in Section 4.1.3). This is important not only in the context of consumer safety but also in light of the fact that the use of flame retardants in consumer products may actually confer an overall environmental benefit. For example, recent work conducted in Sweden (Simonson and Stripple, 2000) indicates that over a product's life-cycle, emissions of PAHs and dibenzodioxins and furans may be markedly higher for non flame retarded articles (television sets) than those which contain flame retardants.

### 4.5.2 TBBE

#### *Background to Use and Applications*

The discussion in this section is based on information provided for one specific flame retardant, the precise nature of which is proprietary. It is a mixed ester but is comprised mainly of a tetrabromobenzoate ester (referred to herein as TBBE). As with penta-BDPE, it is used as an additive (as opposed to reactive) flame retardant.

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[34] Furthermore, risk assessments are due to be carried out for a number of the substances considered in the future.

Use of this substance as a flame retardant has been notified under the procedure set out in the 1979 amendment to Directive 67/548/EEC and basic information has been provided by the manufacturer as to the physical properties, use category and (eco)toxicological profile. This information, along with its MSDS and a review article on its performance have been used to inform the following discussion.

At the time of notification, use of this substance was between 100 and 1000 tpa. It is thought that use has been increasing in recent years but that, overall, usage remains relatively low due to the early nature of its market development. Like penta-BDPE, it is thought to be used exclusively as a flame retardant in flexible polyurethane foams. Indeed, it is marketed specifically as a non-diphenyl ether suitable for the flexible urethane market.

### *Technical Suitability*

TBBE is reported to be suitable for use in both furniture and automotive applications (Jacobs *et al*, 1997). In automotive applications, it allows the product to meet the FMVSS 302 fire safety standard and does not contribute significantly to fogging effects within the car. It also allows furniture to meet the relevant fire safety standards.

Its processing and physical properties are similar to those of penta-BDPE and it can be used in both polyether and polyester polyol based PUR foams (penta-BDPE is used in both types).

When used in low density flexible PUR foams it reduces the unwanted scorch effects which can occur as a result of high water content.

As with penta-BDPE, but unlike some other flame retardants which have good thermal and hydrolytic stability, it can be used in high resilience (HR) foams without incurring softening (plasticisation) of the centre of the foam.

In technical terms, therefore, TBBE presents a suitable alternative to penta-BDPE for the applications in question. Given its recent entry into the marketplace, its widespread applicability has yet to be proven. Also, it is reported that it is not a complete ‘drop-in’ substitute since some reprocessing would be required (though this would be the case for any alternative flame retardant - or indeed any other additive - which is incorporated into an existing product).

### *Potential Risks to the Environmen Associated with Replacement of Penta-BDPE*

A comparison of TBBE and penta-BDPE is provided in Annex 3. This is based generally upon the information required for substances under Article 3 of Regulation 793/93/EEC and set out in Annex III thereof.

The information available is relatively sparse as compared with that for penta-BDPE. However, it is sufficient to draw some conclusions as to the relative toxicity of TBBE and indications as to the *potential* risks to the environment:

- in terms of acute aquatic toxicity testing, the data reported indicate that it is of generally lower toxicity than penta-BDPE (though they both have some values below the 1 mg/l threshold for labelling as R50);

- it is not readily biodegradable;

- due to the two points above, it is classified as R50/53[35]. It is also classified as R48/R22[36];

- it is likely to partition strongly to organic carbon in soil, sediment and biota. However, it will do so to a slightly lesser extent than penta-BDPE due to its (marginally) higher water solubility and higher vapour pressure.

The MSDS for this substance indicates that the US EPA have raised concerns that its lower brominated degradation products may be harmful to the environment.

No data have been made available as to the chronic toxicity of this substance. This is an important issue since the chronic toxicity of penta-BDPE is a source of major concern in terms of the Risk Assessment.

Overall, this substance has slightly lower acute toxicity than penta-BDPE and is unlikely to bioaccumulate to quite the same extent (though bioaccumulation could still be significant). It will biodegrade to a slightly greater extent than penta-BDPE although it is still classified as 'not readily biodegradable'. In terms of labelling, the same risk phrase for the environment would apply as for penta-BDPE.

Based upon the available information (acute hazards only), this substance is marginally less hazardous to the environment than penta-BDPE. Thus, if used to replace all current use of penta-BDPE it would be likely to present a slightly lower risk to the environment. However, chronic effects are unknown at present so the comparison has not been made using the same level of information.

### 4.5.3 Chlorinated Alkyl Phosphate Esters

#### *Background to Use and Applications*

A number of chlorinated alkyl phosphate esters are used commercially as flame retardants in flexible polyurethane foams, as indicated in Table 4.13. The particular application to which they are suited depends upon the substance under consideration.

Consultation and literature review has indicated that the most commonly used substance for the specific applications under consideration is tri (2-chloropropyl) phosphate, TCPP, the chemical structure of which is illustrated in Figure 4.4. Other members of this group

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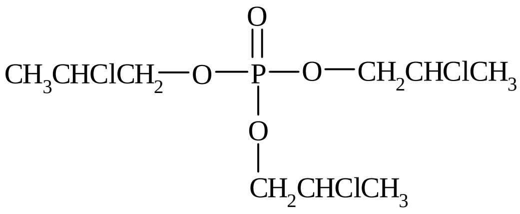
[35] Very toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment.

[36] Harmful: danger of serious damage to health by prolonged exposure if swallowed.

are based upon a similar structure, having varying degrees of chlorine substitution and, in some cases, different alkyl chain lengths.



$$\mathrm{CH_3CHClCH_2{-}O{-}\underset{\underset{\underset{CH_2CHClCH_3}{|}}{O}}{\underset{|}{\overset{\overset{O}{\|}}{P}}}{-}O{-}CH_2CHClCH_3}$$

**Figure 4.4: Tri (2-chloropropyl) phosphate**

**Table 4.13: Summary of Various Chlorinated Alkyl Phosphates**

| **Substance** | **Properties** |
|---|---|
| Tri (1,3-dichloroisopropyl) phosphate (TDCP) | Suitable for rigid and flexible polyurethane foams and uses where hydrolytic stability is crucial. Low volatility. Low fogging. Little effect upon foam processing. Lower viscosity version better suited to flexible polyurethane foams. |
| Oligomeric chloroalkyl phosphate | Suitable for flexible polyurethane foam. Good permanency, efficiency and thermal stability (avoids scorching). Suitable for furniture and automotive applications. |
| Oligomeric chloroalkyl phosphate/phosphonate | High efficiency in flexible PUR foam to meet most stringent domestic furniture and automotive standards. Low fogging so suitable for automotive foams. |
| Tri (2-chloroisopropyl) phosphate (TCPP) | Flexible and rigid PUR foams. Good hydrolytic stability and reduced scorching. Not recommended for direct application to or use in formulations intended for apparel uses. |
| Chlorinated Phosphorus Ester | Liquid flame retardant of low viscosity. Suitable for bonded flexible urethane foams to meet CPSC FF1-70 and FMVSS 302. Aids lamination. |
| Chlorinated aliphatic aromatic ester of phosphoric acid | Suitable for flexible polyurethane foams where lack of discolouration is of crucial importance. |

Source: MSDSs and product descriptions for several companies' products.

In addition to being sold as the pure commercial product, some of these substances are also marketed as a mixture with aromatic phosphate esters, as is the case with some commercial formulations of penta-BDPE.

These substances are marketed by several companies throughout the EU and are used as flame retardants in a variety of polyurethane formulations. TCPP, along with penta-BDPE, is one of the two most widely used flame retardants for the US flexible polyurethane foam market (Stone, 1998). In the UK and Europe, TCPP is used more in relative terms than is penta-BDPE with annual consumption estimated to be 20,000 tpa (compared with 300 tpa for penta-BDPE), the majority of which relates to use in flexible polyurethane foams.

Although consultation with industry has indicated that some companies are reducing use of TCPP in favour of newer flame retardants more suitable for their specific applications, there have been no significant reductions in the quantities of this flame retardant used across the EU as a whole. Indeed, the major suppliers of TCPP indicate that usage is actually increasing owing to new technologies in both rigid and flexible PUR foam systems.

### *Technical Suitability*

TCPP is deemed to be a technically viable flame retardant for use in the domestic furniture application. Evidence for this has been provided during consultation with industry which indicates that it is far more widely used for this application than is penta-BDPE.

Several potential issues arise, however, in the use of this group of substances as alternatives to penta-BDPE:

- flame retardants such as these, which contain halogenated alkyl (straight chain) groups, tend to display greater scorch effects than those with halogenated aromatic (ring structure) flame retardants such as penta-BDPE and TBBE;

- TCPP can display unwanted plasticising effects, reducing the tensile strength and load bearing capacity (measured as IFD) of the finished product;

- in some applications, the properties of foams based upon these substances tend to be diminished to a greater extent under accelerated aging tests than for foams using penta-BDPE. This relates both to product decomposition and to volatile loss from the polyurethane material, which also tends to be greater than for penta-BDPE;

- in the applications under question, there is a commercial requirement for the use of flame retardants which do not contain phosphorus (although based on a mis-perception, as discussed in Section 4.3.3) ; and

- in a number of specific applications, it is difficult to achieve a low degree of fogging and also the desired combination of other properties in a finished product, when using these FRs.

Such issues would need to be addressed if one of these substances (and indeed any other flame retardant) were to be used instead of penta-BDPE. However, it is thought that these difficulties could be overcome by using the most appropriate flame retardant from this group of substances in any given application. For example, scorch effects can be overcome by choosing types with greater thermal stability or by blending with other components. With respect to plasticising effects, all flame retardant additives could have an unwanted effect in a foam system. There are, however, technologies available to control the degree of plasticisation.

In addition, several of these substances are stated to have low fogging characteristics (see Table 4.13) and indeed tri (1,3-dichloroisopropyl) phosphate (TDCP) is used in some automobile interior applications (KEMI, 1996). There are in fact a large number of substances currently on the market which allow the fogging requirements for automobiles to be met. Furthermore, consultation with industry indicates that a number of automobile manufacturers do not use penta-BDPE and use these substances instead.

With respect to the requirement for use of flame retardants which do not contain phosphorus, this is not widespread throughout the industry and should not be seen as a reason to disfavour these substances in general. However, the company in question markets its product as phosphorus-free and thus TCCP would not be a suitable replacement even though it is acceptable from a technical perspective.

In technical terms, these substances provide suitable alternatives to penta-BDPE for a majority of applications. While the most widely used (TCPP) is not suitable for certain automotive applications, this is not true of other substances in this group.

### *Potential Risks to the Environmen Associated with Replacement of Penta-BDPE*

Assessment of one of this group[37], tri (chloroethyl) phosphate (TCEP), is already underway with Germany as rapporteur (BAUA, 1998). TCEP is on the 2nd list of priority substances under Regulation 793/93/EEC. The first draft of the assessment for TCEP indicates the following key points about the use of this substance:

- TCEP is used primarily as a plasticiser and viscosity regulator with flame-retarding properties for polyurethane, polyesters, polyvinyl chloride and other polymers;
- it is labelled as N (Dangerous for the environment), R51 (Toxic to aquatic organisms) and R53 (May cause long-term adverse effect in the aquatic environment) under Annex I of Directive 67/548/EEC;
- there are two producers and one importer of TCEP in the EU;
- consumption is considered to be 2,040 tpa for the purposes of the risk assessment, though use is reported to be declining; and
- it is considered non-biodegradable.

Overall, the initial conclusions of the risk assessment indicate no need for limiting the risks to the environment. There is a requirement for further information/testing although

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[37] Member States have proposed that a further three of these substances undergo risk assessment by inclusion on the fourth priority list under Regulation 793/93/EEC (though the list has yet to be agreed).

this applies to formulation of paints and varnishes and not to use in polyurethane foams. However, there are two primary considerations with respect to the use of this substance as a replacement for penta-BDPE:

1. Whilst TCEP is used in some polyurethane applications, it may not be technically suitable for the applications associated with penta-BDPE.

2. Due to the nature of the environmental hazard posed by this substance (as illustrated by the labelling requirements), if it were used as a replacement for penta-BDPE, there would still be a potential for risks to the environment, though it is considered less dangerous for the environment than penta-BDPE based upon its classification.

The most suitable replacement of this group in technical terms is likely to be TCPP. Therefore, the toxicological profile of this substance has been examined in detail. Table A3-1 in Annex 3 provides a summary of the available (eco)toxicological data for TCPP as compared to penta-BDPE (and also TBBE).

This information indicates the following for the potential risks to the environment of TCPP:

- although significantly lower than for penta-BDPE the log $K_{OW}$ value is still relatively high, indicating a tendency to partition to organic carbon in soils, sediments and biota. However, TCPP has much higher values for water solubility and vapour pressure which would tend to reverse this tendency. In addition, TCPP has a lower bioconcentration factor (BCF), indicating that it may be better metabolised in animals (and humans) than is penta-BDPE. TCPP is not, therefore, considered bioaccumulative;

- based upon toxicity to fish, daphnia (acute and chronic) and algae, TCPP is less toxic than either penta-BDPE or TBBE. TCPP is also more biodegradable than penta-BDPE, based upon tests in activated sludge inocula. However, TCPP is not considered readily biodegradable in OECD type 301 (‘ready biodegradability’) studies[38];

- in terms of environmental monitoring, TCPP has been measured at slightly higher levels than penta-BDPE in sediment and has also been measured in water (at low concentrations). These data appear to corroborate the opinions expressed above with regard to the environmental partitioning of these substances; and

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[38] At present TCPP is not classified with respect to its biodegradability. If it were to be classified as ‘not readily biodegradable’ based on the result of an OECD type 301 test, it would then be classified as either R51/53 or R52/53 depending upon which IUCLID data were used for algal growth inhibition. In fact, TCPP is not currently included in Annex I to Directive 67/548/EEC nor is it labelled under the voluntary classification scheme of EU manufacturers.

- it is expected that, if TCPP were to be used as a replacement, the associated PNEC value would be greater than for penta-BDPE and, in this respect, it could be considered less harmful to the environment.

Also, if TCPP were chosen as an alternative to penta-BDPE, the relative increase in environmental emissions of the substance would be small due to the higher existing levels of use of TCPP (an increase of a few hundred tpa compared with an existing use of 20,000 tpa). Thus, the additional risks imposed are unlikely to be significant compared with existing usage.

It should be noted that, through inclusion on the fourth priority list under Regulation 793/93/EEC, a detailed risk assessment for TCPP will be carried out in the future.

### 4.5.4 Melamine

Melamine is often used in flexible polyurethane foams, frequently in combination with chlorinated alkyl phosphate esters. In particular, consultation has indicated that it is used widely in combination with TCPP by the UK flexible polyurethane foam industry. Often, a derivative of melamine is used, particularly melamine phosphate or cyuranate.

For a majority of flame retarded PUR articles, melamine is not really suitable as a flame retardant when used alone: in the quantities required for the foam to meet relevant fire safety standards, the foam tends to suffer significant loss of material properties. Melamine is suitable for use in some flexible polyurethane foams, however, since it can withstand processing temperatures of up to 250°C. This may make it particularly suited to low density foams in which temperatures are reportedly higher. Use of melamine phosphate sometimes allows a reduction in levels of smoke produced as compared with halogenated flame retardants.

In terms of toxicity, little data are available on environmental exposure and effects. The rodent acute $LD_{50}$ values reported in the IUCLID database range from 3.2 to 7.0 g/kg bw. Melamine derivatives (such as melamine cyuranate) tend to have lower acute toxicity than melamine alone as evidenced by values ranging between 4.5 and 20 g/kg.

In terms of chronic toxicity, the IUCLID database reports no differences in the general health of dogs fed 30,000 ppm melamine for a year although crystalluria was observed from 60 to 90 days. Chronic toxicity tests on rats and mice also indicate that melamine is of low toxicity.

### 4.5.5 Graphite Impregnated Foams

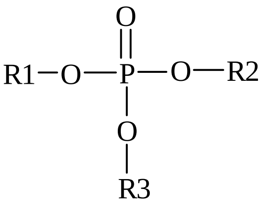
In recent years, foams have been developed which are impregnated with an intumescent form of graphite. These foams are apparently sometimes used in combination with TCPP although the graphite would provide most of the flame retardancy.

Use of these foams has apparently increased, particularly in aircraft seating where it enables seats to pass the US Department of Transport's Federal Aviation Regulation

(FAR) 25.853 – Annex 1, Part 2. Foam seats are the primary load of flammable material in aircraft interiors (US DOT, 1997) and this method would appear to be preferable to the use of halogenated flame retardants, although the some of the latter types are still reportedly used.

### 4.5.6 Non-Halogenated Phosphate Esters

These substances have the general chemical formula indicated in Figure 4.5. The groups marked R1, R2 and R3 represent, in most cases, identical groups.



$$\mathrm{R1{-}O{-}\overset{\displaystyle O}{\overset{\|}{P}}{-}O{-}R2}\quad \text{with } \mathrm{P{-}O{-}R3}$$

**Figure 4.5: Non-Halogenated Phosphate Esters**

Three flame retardants which may have the potential to replace penta-BDPE include:

- trioctyl phosphate (all groups replaced with $C_8H_{19}$);
- tricresyl phosphate (all groups replaced with $CH_3$-$C_6H_4$); and
- triphenyl phosphate (all groups replaced with $C_6H_5$).

Recent research has indicated that some substances from this group of flame retardants have been developed which can attain the relevant fire safety standards for upholstered furniture (Stone, 1998). They are usually, however, used in conjunction with halogenated flame retardants such as penta-BDPE or TCPP. Apparently, tri-alkyl phosphate esters (such as trioctyl phosphate) are used more widely in rigid polyurethane foam applications. However, trioctyl phosphate is (or has been in the past) used in some flexible polyurethane foams since it is included in the BRMA’s Code of Practice referred to in Section 3 (BRMA, 1990). Tricresyl phosphate may also be used in some polyurethane elastomers but no detailed evidence of this has been obtained during the consultation exercise.

More generally, the Danish EPA (1999a) state that “phosphorus compounds – often in combination with nitrogen compounds [e.g. melamine] – incorporated into the polymer structure are some of the main candidates for substituting brominated flame retardants for thermosets.”

Phosphorus compounds such as these act in the solid phase through formation of a carbonaceous char layer, as compared to halogenated flame retardants which act by providing halogen free radicals to terminate the combustion process (which is based upon chain branching free radical reactions).

These compounds vary widely in terms of their toxicity and, since there is little indication available as to which types would be used in the applications concerned, this is not considered in detail here. Triphenyl phosphate (TPP) which is widely used, apparently has no significant toxic effects such as mutagenicity or neurotoxicity, although it is found relatively widely in the environment (Danish EPA, 1999a)[39]. However, consultation has indicated that neurotoxicity may be a problem for other flame retardants in this group.

### 4.5.7 Hydrated Alumina

Hydrated Alumina ($Al_2O_3.3H_2O$) is the most widely used aluminium-based flame retardant. It is used in some flexible polyurethane foams where it acts through formation of a char layer and through the evolution of water (Stone, 1998). This reaction is also endothermic which serves to further inhibit combustion.

A review by Stevens and Mann (1999) concludes for this substance that “in view of the lack of reported adverse effects from the very extensive environmental exposure to aluminium compounds, including alumina, it is extremely unlikely that any adverse effects would ensue from the levels of exposure ... in the use of consumer products”.

Since it is a solid and is required in particularly high concentrations in order to meet the desired fire safety standards, hydrated alumina is unlikely to provide a suitable substitute for penta-BDPE in the applications concerned. Therefore, no further consideration is given herein to this substance.

### 4.5.8 Conclusions on Alternative Flame Retardants

Based upon the above discussion (which in turn is based upon literature review and consultation with industry), only two types of substances are considered here as suitable alternatives to penta-BDPE in technical terms. These substances are chlorinated alkyl phosphate esters (particularly TCPP) and TBBE. This is not to say that they are the only viable alternatives to penta-BDPE since in other applications (other PUR products and also non-PUR products), replacement has already taken place with other flame retardants[40].

Table 4.14 provides a summary of the suitability of TCPP and TBBE as compared with penta-BDPE. It contains information on the technical suitability based upon the above discussions and on the environmental hazard profile based upon the information in Annex 3.

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[39] The IUCLID database reports several mammalian studies for neurotoxicity of TPP but that “the neurotoxic effects observed in early studies in the cat were due to an impurity in the test substance and not to TPP itself.”

[40] For example, penta-BDPE has historically been used in the electronics industry to some extent. This is no longer the case since other flame retardants such as tetrabromobisphenol A (a reactive flame retardant) and deca-BDPE are more widely used.

Of these alternative substances, TBBE can generally be considered the most suitable in technical terms for the full range of applications under consideration. However, both TBBE and TCPP are deemed to be unsuitable for some (but by no means all) automotive applications. Nonetheless both can be used in automotive applications and also for upholstered furniture in general (although TCPP is not used by the company requiring a phosphorus-free product). Indeed, almost all of the 20,000 tpa of TCPP used in the EU is in flexible PUR foams. Also, other chlorinated alkyl phosphates are used in automotive applications, allowing foams to meet the relevant standards for fire retardancy and for material properties, including low fogging.

In terms of the available information on the hazard profiles of the two key substitutes, TCPP appears of lower toxicity for the environment than both penta-BDPE and TBBE

TBBE is of slightly lower toxicity for the environment than penta-BDPE but is still labelled as being ‘very toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment’. It is likely that, if TCPP is used as a replacement for penta-BDPE, the overall risk to the environment would be less due to its lower toxicity and bioaccumulation and its greater biodegradation.

If TBBE is used, the hazard profile indicates that risks to the environment would be reduced to some extent but that they might still be significant. However, use would prevent further accumulation of penta-BDPE in the environment - although this is true of any replacement.

Overall, it is concluded that there exist suitable alternatives in technical terms for all of the applications in which penta-BDPE is used. This has been confirmed by a statement from EUROPUR. Suitable substitutes include TCPP and TBBE, but there will be additional flame retardants which are suitable but which have not been considered here.

It is also concluded that alternatives are available that are of lower toxicity than penta-BDPE and that would be expected to pose lower risks to the environment.

**Table 4.14: Suitability of TCPP and TBBE as Compared to Penta-BDPE**

| | **Penta-BDPE** | **TCPP** | **TBBE** |
|---|---|---|---|
| ***Technical Suitability*** | | | |
| For Automotive Applications | Suitable since already in use | Suitable for most applications but not all. Other members of this group are suitable. | Suitable |
| For Upholstered Furniture | | Suitable (but not for those requiring phosphorus-free foam) | Suitable |
| For Non-Foamed PUR (e.g. prototypes) | | Unknown | Suitable |
| ***Environmental Hazards*** | | | |
| Environmental Partitioning | Partitions strongly to organic carbon in soil, sediment and biota | Will partition to organic carbon in soil, sediment and biota but to much lesser extent than penta-BDPE | Likely to partition strongly to organic carbon in soil, sediment and biota but to slightly lesser extent than penta-BDPE |
| Acute Toxicity | Very toxic to aquatic organisms | Either ‘toxic’ or ‘harmful’ to aquatic organisms | Very toxic to aquatic organisms (but less so than penta-BDPE based upon limited data) |
| Reproductive Toxicity | Very toxic | Harmful | Unknown |
| Biodegradation | Not readily biodegradable | Not readily biodegradable in the findings of one study but not classified as such | Not readily biodegradable |
| Bioaccumulation | Yes, very significant | Not bioaccumulative | Unknown but likely to be more bioaccumulative than TCPP but less than penta-BDPE |
| Classification for the Environment | None at present. Proposed classification is<br>N; R50/53 (environment)<br>Xn; R48/21/22 (human health) | Not classified (even under manufacturers voluntary scheme). However, would be either R51/53 or R52/53 if considered not readily biodegradable | R50/53 |

# 5. FURTHER RISK REDUCTION OPTIONS

## 5.1 Introduction

The following text sets out possible risk reduction measures for controlling the risks associated with penta-BDPE. These are based upon those set out in the *Technical Guidance Document for Development of Risk Reduction Strategies* (TGD)[42]. The TGD identifies four categories of risk management measure. These relate to:

- manufacture, industrial and professional use;
- packaging, distribution and storage;
- domestic and consumer use; and
- waste management.

Only the first of these are relevant here. Within this category of measure, various possible controls are listed. These are reproduced in Table 5.1.

**Table 5.1: Possible Control Options**

| | |
|---|---|
| Controls on manufacture | Better hazard information |
| Restrictions on marketing and/or use | Biological exposure indices/monitoring |
| Redesigning the process itself | Medical surveys |
| Safe systems of work | Training |
| Good manufacturing practice | Use of personal protective equipment |
| Classification and labelling | Licensing of operators or operations |
| Separation of personnel | End-of-pipe controls |
| Monitoring/maintenance of equipment | Emission limit values and monitoring |
| Dust suppression methods | Environmental quality standards |
| Occupational Exposure Limits and/or air monitoring | Environmental agreements |
| Integrated Pollution Prevention and Control | |

The options initially deemed to be suitable for controlling the risks arising from the use of penta-BDPE in PUR foams were:

- restrictions on marketing and use;
- environmental quality standards and/or limit values;

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[42] European Commission, January 1998, Office for Official Publications of the European Communities.

- environmental agreements; and
- integrated pollution prevention and control.

All four of these options were assessed qualitatively at Stage 2 of the study. While an environmental agreement has the potential to be as effective as marketing and use restrictions, its performance is dependent on the co-operation and voluntary actions of industry. While the main supplier of penta-BDPE indicated that it would be willing (in principle) to enter into an environmental agreement, neither PUR foam producers nor their trade associations commented on their possible involvement. For this reason, the environmental agreement option was dropped from further consideration.

The three remaining options are discussed below.

## 5.2 Restrictions on the Marketing and Use of Penta-BDPE

These restrictions can be imposed via Directive 76/769/EEC relating to restrictions on the marketing and use of certain dangerous substances and preparations. Previous proposals for legislation on polybrominated diphenyl ethers aimed to utilise this Directive and were to be included in the 12th Amendment to the Directive (i.e. adding further chemicals to the list originally provided for in Annex I of the Directive).

Measures adopted in accordance with the Directive may include:

- outright bans upon the use of certain substances and preparations;
- bans upon the use of certain substances and preparations in certain products; or
- restrictions on the concentrations of dangerous substances in products.

Restrictions upon marketing and use are particularly suited to risks arising from the use of PUR foams. In particular, an outright ban would ensure that no further penta-BDPE would be released from within the EU. Alternatively, it may be possible to tackle risks associated with the use of penta-BDPE-containing products by placing restrictions upon the migration of penta-BDPE from these products. It may also be possible to target restrictions at specific uses of penta-BDPE, perhaps using this approach in combination with other risk reduction options.

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## 5.3 Environmental Quality Standards and/or Limit Values

Emission Limit Values (or emission standards) can be placed upon discharges to specify the maximum allowable concentration of a particular pollutant in effluent and/or the maximum amount to be discharged over time. They are a ‘source-based’ approach in that they focus upon levels of pollutants being discharged from an installation. By contrast, Environmental Quality Standards (EQSs) constitute a ‘target-based’ approach. They are used to specify a level of pollutant in the receiving environment at which no adverse effects are expected to occur (e.g. biological effects). An EQS can be set in order to achieve an overall Environmental Quality Objective (EQO) for a target environment which can apply on a local, regional, national or international (e.g. EU) basis. Also, limit values may be imposed in order to meet a specified EQS/EQO.

These measures are provided for in Directive 76/464/EEC on pollution caused by dangerous substances discharged into the aquatic environment. A provision appears to exist for the possible inclusion of penta-BDPE in this Directive since the category "organohalogen compounds" is given in List I which is set out in the Directive. Pollution by List I chemicals should be eliminated through measures whose extent can be set out in daughter Directives to 76/464/EEC. Both EQSs and Limit Values can be used to achieve the desired effects. In implementing Directive 76/464/EEC across Europe, the Limit Value approach is used by all Member States except the UK which uses EQSs.

It is envisaged that Directive 76/464/EEC will be repealed as of the end of 2007 when the proposed Water Framework Directive[43] is introduced. This would, for certain priority substances, [44]establish *both* EQSs *and* Limit Values. Best Available Technology (BAT) is intended to be used in the process of setting the Limit Values.

The effect of the introduction of this Directive would require that both EQSs and Limit Values be adopted for substances under its control (the 'combined approach'). However, the arguments regarding advantages and drawbacks will mostly be applicable under either system.

However, EQSs and Limit Values concentrate only upon the aquatic environment and thus this measure could not be used alone to address the wider secondary poisoning risks of concern. A separate measure would be required to limit risks associated with releases to the terrestrial environment. In addition, this measure is better suited to point source releases (i.e. releases from PUR production) than to diffuse releases (i.e. from the use of foams).

## 5.4 Integrated Pollution Prevention and Control (IPPC)

The IPPC Directive[45] was adopted in accordance with the following principles (amongst others):

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[43] European Commission (1997): Proposal for a Council Directive establishing a framework for action in the field of water policy, COM (97) 49 Final, as amended by COM (97) 614 Final and COM (1998) 76 Final.

[44] In February 2000, the European Commission published a proposal for a European Parliament and Council Decision establishing the list of priority substances in the field of water policy (CEC, 2000). Substances have been prioritised on the basis of a combined monitoring and modelling based approach. This proposed list includes "brominated diphenylether" and would, as it currently stands, provide for control of penta-BDPE.

[45] Council Directive 96/61/EC of 24 September 1996 concerning integrated pollution prevention and control.

- pollution prevention at source and the 'polluter pays' principle, with minimisation of pollution where prevention is not possible;

- use of an integrated approach to pollution control as a means to achieving sustainable development, as set out by the EC's Fifth Environmental Action Programme; and

- that different approaches to pollution control to different media may encourage shifting of pollution between media.

It also takes into account the principles of various other legislative requirements as set out under Directives such as those concerning Environmental Impact Assessment (85/337/EEC) and Dangerous Substances (76/464/EEC).

IPPC provides the legislative framework for controlling emissions from industrial facilities. Sites are to be operated on the principle of Best Available Techniques which will be defined on a pan-European basis. The EC is to provide guidance on what constitutes BAT within each industry sector in the form of BAT Reference Documents (BREF notes). National authorities will then establish emissions values and conditions for individual sites.

Since the approach concentrates upon all environmental media, it would appear to be better suited to the risks associated with penta-BDPE than, for example, emission limit values. However, since IPPC is process based, it will not address the risks arising from the *use* of (EU manufactured and imported) products containing penta-BDPE. It is the use of these products, rather than their manufacture, which is primarily responsible for the risks identified for the earthworm-based (terrestrial) food chain.

# 6. ASSESSMENT OF POSSIBLE RISK REDUCTION MEASURES

## 6.1 Introduction

The TGD requires that possible further risk reduction options be examined against the following criteria:

- effectiveness: the measure must be targeted at the significant hazardous effects and routes of exposure identified by the risk assessment. The measure must be capable of reducing the risks that need to be limited within and over a reasonable period of time;

- practicality: the measure should be implementable, enforceable and as simple as possible to manage. Priority should be given to commonly used measures that could be carried out within the existing infrastructure (though not to the exclusion of novel measures);

- economic impact: the impact of the measure on producers, processors, users and other parties should be estimated; and

- monitorability: monitoring should be possible to allow the success of risk reduction to be assessed.

With respect to assessments of economic impact, qualitative assessments are acceptable. For marketing and use restrictions, a more detailed analysis of advantages and drawbacks, including an assessment of alternative substances, is required. The following analysis provides a semi-quantified assessment of possible options.

## 6.2 Marketing and Use Restrictions

### 6.2.1 Effectiveness

***Effectiveness of a Total Ban***

Marketing and use restrictions could be used to prevent the use of penta-BDPE in the manufacture of PUR foams in the EU. If implemented, these restrictions would also prevent the import of such products into the EU for sale in the EU. A total ban on the use of penta-BDPE, therefore, would eliminate risks arising from both the manufacture and use of penta-BDPE-containing PUR foams. This would apply to all end-points and not just those identified as being of concern by the Risk Assessment (i.e. not just for secondary poisoning via the fish and earthworm-based food chains).

### *Targeted Measures*

Releases of penta-BDPE from the use of PUR products are of concern for the earthworm-based food chain (see Section 2). The PEC/PNEC ratio of 1.7 for this end-point indicates that risks could be reduced to acceptable levels with a 50% reduction in releases. Consideration was given to the possibility of targeting risk reduction measures at specific uses of penta-BDPE in order to achieve this reduction. In general, this was not possible with the available usage data as uncertainties still exist concerning the levels of use in particular applications.

The general consensus across the industry as a whole is that UK usage of penta-BDPE is associated with upholstery products (owing to the UK's stringent fire safety standards) and for this reason is higher than elsewhere in Europe. However, actual UK usage data indicates that most penta-BDPE is used in foams for the automotive industry and levels of use at the EU level in this application are not known. Thus, it is not possible to judge the impact of restricting penta-BDPE use in the automotive sector or upholstery sectors individually as usage data are lacking.

With respect to the use of penta-BDPE in packaging, a supplier of penta-BDPE has indicated that this is associated with less than 6 tpa of the penta-BDPE used in the EU. However, most penta-BDPE emissions from this application are likely to arise from packaging material imported into the EU with electronic equipment and the associated tonnages are unknown.

The other application identified during the study is in non-foamed polyurethanes for prototypes and small runs (e.g. instrument casings). Flame retardant suppliers indicate that these account for less than 6 tpa of penta-BDPE used in the EU. Thus this application represents 5% of total penta-BDPE usage and (all other things being equal) contributes 5% to risk levels. Banning this application alone would not achieve the necessary level of risk reduction. Conversely, it may be possible to allow penta-BDPE use to continue in this application and still achieve the necessary level of risk reduction. However, as levels associated with imported articles are not known, strong arguments for continued usage would need to presented for this to be considered (see Section 6.2.3).

### *Reducing Concentrations of Penta-BDPE*

As an alternative to banning the use of penta-BDPE, it would be theoretically possible to restrict its use to below a specified concentration. This would allow releases to be limited to acceptable levels (i.e. to reduce the PEC/PNEC ratio to below one). Reduction in emissions from finished articles could theoretically be accomplished by:

- reducing the concentration of penta-BDPE within the foam; or
- reformulating so as to achieve this effect (e.g. use of an additional additive).

Consultation with PUR manufacturers has indicated that reductions in concentrations of penta-BDPE would not be achievable as usage has already been minimised to the degree possible (as a result of the need to minimise costs). Concentrations of penta-BDPE are generally optimal and it is not thought that reformulation using existing quantities of penta-BDPE could reduce emissions. For example, the producer of foams for automotive applications does not know of any technology that could be used to encapsulate more efficiently the penta-BDPE materials in the foamed product.

Thus, whilst in theory the concentration of penta-BDPE could be further reduced, compensatory action would be required to achieve the necessary flame retardancy, possibly leading to a reduction in material properties. For example, the producer of non-foamed polyurethanes has indicated that it is not possible to reduce concentrations of penta-BDPE in products since this would sacrifice some of the flame retardant properties.

This issue has also been considered by a supplier of penta-BDPE. The supplier is not aware of any existing technology to eliminate emissions of penta-BDPE from produced goods. It is reported that enclosing the foam in an impermeable membrane would require significant research and commercial investigation, for which the projected costs are incomprehensible. It is also reported that penta-BDPE can only be broken down by exposure to direct UV light. Given that upholstery and automotive foams are covered or enclosed this is not expected to be an issue.

#### *Risks from Alternatives*

Any form of marketing and use restriction would also introduce risks arising from the use of alternatives to penta-BDPE.

Firstly, it should be noted that EUROPUR has confirmed that in technical terms, there are suitable alternative flame retardants for all of the applications in which penta-BDPE is used (although some reformulation will generally be required in order for them to be used). These alternatives can be used to produce the desired end-product and, at the same time, meet the relevant standards for fire safety.

A discussion of the hazards of and *potential* risks to the environment of the alternative flame retardants was given in Section 4.5. The only types which have been identified as being suitable in technical terms are other halogenated flame retardants (based upon chlorine or bromine). In particular, these are the TBBE substance and TCPP. However, these two substances may not be suitable for all applications (e.g. some automotive applications) and other halogenated flame retardants, such as other chlorinated alkyl phosphates, may be suitable for some applications.

The primary reason why non-halogenated flame retardants appear to be unsuitable for some of the applications in question is that they cannot provide the required degree of protection against fire. This is partially due to the efficacy of the free radical scavenging mechanism through which halogenated flame retardants act.

Consideration was given in Section 4.5 as to the toxicological profile of alternative flame retardants, with particular emphasis on TBBE and TCPP. Suggestions were also provided as to the likely risk to the environment of using these alternatives. It was concluded that:

- TCPP is less hazardous for the environment and, if used to replace penta-BDPE, the overall increase in risk to the environment would be low due to the existing high levels of use of this substance; and

- TBBE is marginally less dangerous for the environment than penta-BDPE, based upon acute toxicity data alone. However, data is lacking as to chronic toxicity and TBBE has the same classification for the environment (R50/53) as does penta-BDPE.

Aside from these compounds, phosphate esters would appear to be the next most suitable substitute. However, these compounds are very diverse - both in terms of their suitability for use and also in terms of their relative risks compared with penta-BDPE. A detailed discussion of the potential risks of these substances has not been provided since no clear indications have been given that any particular substance would provide a suitable alternative for the applications in which penta-BDPE is currently used.

It is concluded that alternatives are available that are of lower toxicity than penta-BDPE and that would be expected to pose lower risks to the environment.

#### *Timing*

In terms of timing, the introduction of restrictions under Directive 76/769/EEC could only take place following an assessment of the advantages and disadvantages of this measure by the European Commission. This would increase the time taken to implement restrictions such that they would be unlikely to be in place until the year 2002.

### 6.2.2 Practicality

#### *Overview*

Directive 76/769/EEC has been used on a number of occasions to restrict the use of hazardous substances in the EU. It is a standard and effective approach for controlling risks and it is expected that practical methods for implementation of the Directive have been devised by Member States.

The issue of whether a ban upon the marketing and use of penta-BDPE could be extended to the production, storage and transport of this substance was raised by the Netherlands (these other categories are referred to in Regulation 1488/94 laying down the principles for risk assessment of existing substances). In this regard, the European Commission has stated that “the provisions of the [Marketing and Use] Directive are not applicable to the transport of dangerous substances and preparations, for exports to non-EU countries, to transports in transit regime...” (CEC, 1998). Thus, additional legislation would be required if these processes also require control (although no unacceptable risks have been identified for transport or storage).

### *Issues Associated with Imports of Finished Goods*

While it may be relatively simple to control imports of flame retardants based on penta-BDPE into the EU, the same cannot be said of articles containing penta-BDPE. For this reason, it is envisaged that the Directive would be easier to enforce with respect to the production of penta-BDPE-containing PUR foams within the EU than for the import of penta-BDPE-containing articles.

According to the Risk Assessment, of the 1,100 tpa of penta-BDPE "used" in the EU in 1994, 300 tpa was used in the production of PUR foams and 800 tpa was imported in finished articles. Based on these data, imports of finished articles contribute almost 75% of penta-BDPE releases from use of such goods. Even using revised data provided by the flame retardant manufacturers for 1999, (100 tpa to 125 tpa of penta-BDPE used in the EU and similar levels imported on finished goods), imports are associated with 50% of the releases from the use of PUR products. Thus, monitoring of penta-containing PUR-based imports is a key concern with respect to the effectiveness of any marketing and use restrictions.

A supplier of penta-BDPE has indicated that it is extremely difficult to quantify the chemical in finished products. While it is possible, it is technically difficult and also very expensive. In this regard, the UK Department of Trade and Industry’s Consumer Affairs and Competition Policy Directorate has commissioned the development of a more appropriate methodology for determining the chemical species present in flame-retarded consumer goods.

Given the difficulties with the availability of test methods, effective implementation of a marketing and use restriction may require a certification system for imported goods.

## 6.2.3 Economic Impact

### *Impacts on Flame Retardant Suppliers*

A ban on the use of penta-BDPE would impact the suppliers and users of penta-BDPE. Of the two EU-based suppliers, one has indicated that penta-BDPE is only a minor product in its range. Even for the major EU supplier, penta-BDPE represents only 5% of brominated FR sales. Thus, a ban on the use of penta-BDPE is likely to have limited direct impacts to its suppliers.

A ban could, however, affect the perception of other PBDPEs such as deca-BDPE and octa-BDPE which could lead to reductions in the use of these FR in the EU. In addition, penta-BDPE is used more in the US and a European ban could have a knock-on impact to this market. That said, loss of penta-BDPE (or other PBDPEs) from the market will create a greater market for alternatives if, as is the case here, these alternatives are effective. Thus, some FR suppliers could incur losses from a ban while others may benefit.

With respect to extending a ban to production, storage and transport, one of the two companies supplying penta-BDPE to the EU market has indicated that it does indeed store and then export some of their penta-BDPE (which is initially imported) to outside the EU. There would, therefore, be additional burdens upon this company in the event that a ban were extended to these other activities. However, this company has indicated that penta-BDPE will probably not be supplied in the near future (owing to a desire to move out of this market), so that any such effects would not be incurred.

In terms of overall costs to suppliers, penta-BDPE sales are valued at Euro 4.3 million (£2.7 million) per annum (or 0.5% of the total FR market in the EU[46] which has an annual value of Euro 810 million (£507 million)). Given that there are effective alternatives to penta-BDPE in all applications, this market will not be lost. The impacts of marketing and use restrictions will therefore be the difference in profit from sales of penta-BDPE compared with that for the alternatives. Data on the profit margins associated with different types of FR are not known. However, margins for alternatives may be higher than for penta-BDPE (in which case there will be benefits to the FR suppliers) or lower (in which case there will be costs).

Overall, the value of direct impacts to the FR industry arising from a ban on the use of penta-BDPE are likely to be in the range Euro 10,000's to 100,000's, where these could be either costs or benefits.

### *Overview of Impacts to PUR Producers*

For any user of penta-BDPE, the scale of economic impacts will depend on the cost and effectiveness of the alternatives. In addition, there will be one-off costs associated with testing alternatives and there could be costs arising from changes in production processes or from reductions in product quality, for example.

Concerning the costs of alternatives, consultation indicates that, in general, these are similar to penta-BDPE or significantly lower. This ties in with data presented in Section 4.1 indicating that penta-BDPE is associated with the higher-cost end of the FR market. The exceptions are new FRs on the market such as TBBE. These are more expensive than penta-BDPE owing, in part, to the need for FR suppliers to recoup the costs associated with the development of these FRs and the costs of notifying them as new chemicals. One would expect the costs of such new FR to reduce over time as their share of the market increases.

In terms of effectiveness, for some alternatives there may be an increase in costs associated with the need for higher loadings. For example, chlorinated alkyl phosphate esters are marketed as an alternative to penta-BDPE in automotive applications. Cost-wise these are similar to penta-BDPE on a per unit basis, but using these FR worsens the properties of the foam and, in particular, the physical properties. The foams become

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[46] Value of penta-BDPE includes imports of products containing penta-BDPE, as detailed in Section 4.3.1.

softer and around 10% to 20% more FR is required (thus increasing FR costs by 10% to 20%).

An indication of the relative importance of FR costs (and in particular penta-BDPE) compared with costs of PUR raw materials has been derived from data presented in Section 4. Table 6.1 shows that FR costs vary from between 7% to 18% of raw material costs depending on the penta-BDPE loading and sector.

**Table 6.1: Importance of Penta-BDPE Costs Compared with PUR Raw Materials**

| Sector | PUR Chemicals (kt) | Cost of Chemicals[a] (mEUR) | Cost of PUR Chemicals Euro/tonne | % Penta-BDPE Loading in Foam | Raw Material Cost for 1t PUR foam[b] (Euro) | % Raw Material Cost for Penta-BDPE |
|---|---|---|---|---|---|---|
| Automotive | 365 | 815 | 2233 | 4% | 2301 | 7% |
| | | | | 10% | 2403 | 16% |
| Furniture/ Bedding | 530 | 1060 | 2000 | 10% | 2193 | 18% |
| Elastomers | 160 | 500 | 3125 | 10% | 3206 | 12% |

Key: a = taken as the market value of the output of PUR chemicals manufacturers
b = where penta is Euro 3,930 per tonne
Note: These data do not include other raw materials, which may constitute a significant proportion of total raw material costs. However, the percent raw material costs of the FR are considered to be accurate.

Source: ISOPA, 1999 (see section 4.3.1); IAL, 1997 (see Section 4.3.2)

### *Impacts on Producers of Automotive Components*

Consultation with the EU PUR production industry has identified one company using between 14 tpa to 35 tpa of penta-BDPE in the production of laminated flexible PUR components for the automotive industry (see Section 4.3.2). Most companies producing these types of products are not using penta-BDPE (partly due to the black-listing of these substances by car manufacturers), thus substitution with alternatives FRs is possible.

The most appropriate flame retardants in technical terms are TBBEs and some chlorinated alkyl phosphates. Use of the TBBEs would allow the desired product requirements to be met in terms of the following:

- flame retardancy is at least equivalent to that of penta-BDPE (and allows the fire safety standard FMVSS 302 and its equivalents to be met);

- their impact on fogging within automobile interiors is similar (low) to that of penta-BDPE; and

- they would not add any significant deleterious effects to other physical properties of the polyurethane foams, including following accelerated aging tests (although some reformulation of products would likely be required in order to incorporate their use).

For the chlorinated alkyl phosphates, more significant reformulation may be required in order for these to be used as alternatives to penta-BDPE and, in some cases, there may also be adverse effects upon the properties of a finished product. However, use of the most appropriate member of this group for the application in question and proper reformulation can generally allow the relevant requirements for physical properties and flame retardancy to be met.

The UK user of penta-BDPE has tested a number of alternatives but cannot disclose them for reasons of commercial confidentiality. That said, they have indicated that neither TBBE nor TCCP is suitable for the majority of foam produced[47]. Alternative products have been seen to influence a variety of the properties of the end product:

- flammability;
- emission behaviour;
- melt characteristics;
- processing efficiency;
- limited product range;
- discolouration; and
- reduced accelerated humidity aging properties.

Alternatives are reported to have limited possibilities due to performance problems - some alternatives are more volatile and result in higher releases during emission tests (e.g. for fogging). Also alternatives have an effect on the appearance of the foam.

The main concern for the UK company is loss of business - and it is reported that business may already have been eroded in Europe. Current levels of penta-BDPE-based business are estimated to be Euro 1.6 million (£1 million) per annum compared with a turnover of just over Euro 56 million (£35 million) in 1996. Losing this business could impact up to 5% of the workforce of 300 (i.e. 15 people).

The following additional costs are also estimated for introducing alternative products:

- new streams required: £50,000 (Euro 80,000)
- potential increase in process scrap: £50,000 (Euro 80,000) per annum, and
- customer trials and approvals: £150,000 (Euro 240,000).

The £50,000 (Euro 80,000) for new streams is a one-off cost associated with new pumping systems (typically comprising pressure vessel, pipes, flow meters, temperature control, pumps and valves) designed specifically for the use of alternative flame retardants. Production is computer controlled and systems have to be integrated and

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[47] There do exist flame retardants which are technically suitable, albeit with some requirement for reformulation, for all of the applications in which penta-BDPE is currently used. This has been verified by EUROPUR.

designed specifically for the throughput, viscosity and specific gravity of the materials in use. At present it is not known how many new systems will be required. The cost of one system is Euro 40,000 (£25,000) and the company has tentatively assumed that two such systems will be required (i.e. that two alternatives FRs will be required) to make the range of products currently produced.

The Euro 80,000 (£50,000) per annum costs arising from increased scrap are associated with flammability failures from specific areas of product and having to use less efficient flame retardants. As an alternative to incurring these failures, foam density could be increased. Overall the company conservatively estimates an increase in scrap of 5% which is valued at Euro 80,000 (£50,000) per annum for a production rate of 350 tpa.

To put these costs in context for the UK, there are 7,000 suppliers of automotive components with 330,000 jobs in the manufacture of vehicles and components. Annual UK production of vehicle components is valued in excess of Euro 16 billion (£10 billion) (1997 data) and motor vehicle seats and parts totaling Euro 55.5 million (£34.7 million)[48] were exported from the UK to other EU countries in 1992.

With respect to the rest of Europe (as reported in Section 4), penta-BDPE is not believed to be used in the production of automotive products in Italy, Spain, Germany, France and the Netherlands. Consideration of Table 4.7 in Section 4 reveals that these five countries consumed nearly 70% of the brominated ethers used in the EU in 1995. If the UK is added to this list, then consumption increases to around 80%. This suggests that there is likely to be little use of penta-BDPE in automotive applications elsewhere in the EU.

To derive costs for the European automotive sector arising from the introduction of marketing and use restrictions for penta-BDPE, it is necessary to make assumptions concerning levels of penta usage at the European level (as these data do not exist as shown in Table 4.12). In the absence of additional information, it is assumed that the ratio of penta-BDPE use in the automotive and upholstery sectors in the UK holds true across Europe as a whole and that these applications account for the majority penta-BDPE usage. In addition it is assumed that the UK company is representative of others in the EU.

Thus, there are assumed to be a total of six companies using 84 tpa of penta-BDPE in the production of automotive components across the EU[49]. This equates to 2,100 tpa of PUR valued at Euro 9.6 million (£6 million) per annum. If marketing and use restrictions were to result in loss of this business, these companies would therefore incur costs of £6

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[48] Converted from 1992 sterling to November 1999 sterling using Retail Price Index.

[49] A minimum of 14 tpa of penta-BDPE is used in the automotive sector in the UK and 5 tpa in upholstery. Assuming the same rate of usage, a total of six European companies would consume 84tpa of penta-BDPE in automotive applications and a further six would consume 30 tpa in upholstery. On this basis, total European usage of penta-BDPE in these two applications would be 114 tpa which equates well with industry estimates of current usage (100 tpa to 125 tpa). The 14 tpa chosen to represent consumption in the automotive sector in the UK is the low end of the range 14 tpa to 35 tpa. This figure has been chosen to ensure costs are not underestimated.

million per annum. However, there would also be benefits to other companies able to take advantage of this gap in the market. If business were retained, there would be one-off costs of Euro 1.9 million (£1.2 million) and on-going costs of Euro 1 million (£0.6 million) per annum (based on the figures for the UK company given above). Whilst it is possible to challenge these assumptions upon which these estimates are based, they do serve to provide indicative order of magnitude estimates of the costs of marketing and use restrictions.

To put these costs in context for the EU, there are 100 companies involved in the production of foamed and/or moulded components for the automotive industry with an output valued at Euro 20,500 million per annum (as detailed in Section 4.3.2). Thus, costs to the automotive industry associated with a ban on the use of penta-BDPE are small (at the very most 0.05% of the annual value of outputs from this sector of the PUR industry[50]) .

### *Impacts on Producers of Upholstered Furniture*

One UK company has been identified as using 5 tpa of penta-BDPE in the production of 50 tpa of PUR foams for domestic furniture, some of which include cot mattresses. Grossing this data up to the EU level using industry assumptions indicates that use of penta-BDPE in furniture and bedding is associated with just 0.02% of PUR usage in this sector (see Section 4.3.3). Thus there are many flame retardants which, in technical terms, could be used to replace penta-BDPE in this application. These are used widely by other companies manufacturing foams for the same purpose and meet flammability requirements. The user of penta-BDPE has indicated that, in the event of a ban on penta-BDPE, the technology is available to allow use of such alternatives with relatively little in the way of increased costs.

One of the principle flame retardants used by other companies for this application is TCPP (often used in combination with melamine). TCPP is based upon phosphorus (the flame retardancy coming from the presence of both this and chlorine within the substance). TCPP is not deemed to be a suitable alternative by the identified company because of concerns in the past over a possible link between phosphorus-based flame retardants and ‘cot-death’ (sudden infant death syndrome, SIDS - see discussion in 4.3.3). The company in question states that it might be willing to use a phosphorus-based flame retardant if it became widely accepted that these are no longer implicated in SIDS. However, it would be more likely to use one which is not based upon phosphorus (and it indicates that these are available). The user of penta-BDPE has indicated that little in the way of technical difficulties would be expected in using an alternative flame retardant.

The company has not indicated that any custom would be lost through the use of an alternative flame retardant in these products. (Even if this market were to be lost, penta-based foams represent only 1% of the company’s total production of PUR foam). The

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[50] Euro 9.6 million pa compared with Euro 20,500 million pa.

only costs would appear to be in reformulating their products to use that substance. Although these have not been quantified by the company, it has indicated that these do not appear to be prohibitive, given the relatively small use of the substance as compared to production of other foams and also the limited technical difficulties which are expected.

These reformulation costs can be valued using similar assumptions to those used for the automotive industry. The producer of automotive PURs provided three sets of costs estimates, one of which related to the one-off costs associated with changes in the production systems and another relate to customer trials and approvals (assumed to equate to reformulation costs). These one-off costs were valued at Euro 320,000 (£200,000) for a PUR production rate of 350 tpa (i.e. around Euro 900/£570 per tonne) and two process streams. Thus, reformulation costs for the UK user producing 50 tpa of penta-based PUR foams each year can be valued at around Euro 52,000 (£32,500) (taking reformulation costs of Euro 1,040 (£650) per tonne to be conservative and to allow for economies of scale). Assuming there are six such producers in the EU[51] gives reformulation costs of Euro 312,000 (£195,000).

### *Impacts on Producers of Non-foamed Polyurethanes*

One UK company has been identified as using 1.2 tpa of penta-BDPE in the production of solid (non-foamed) applications, generally elastomers. These are used downstream by a company producing various small run and prototype components, such as rigid PUR elastomer instrument casings. The company has indicated that there are several possible options for substituting penta-BDPE in these products and that it would probably be possible to reformulate products using alternative flame retardants. However, this might be at the cost of either reduced product performance or poorer fire performance.

It is reported that phosphorus and/or chlorine based flame retardants cannot provide the required degree of flame retardancy for all of the applications in question. In order to achieve the same degree of flame retardancy, greater quantities of the alternatives would have to be used. No information was provided on other brominated flame retardants but it is likely that some could be used (such as TBBE) in a similar manner, although - as indicated by a FR supplier - this would require some reformulation of products.

The company has not been able to put a figure to the costs of using an alternative flame retardant. However, it would appear that the production of PUR systems for the same customers and applications would continue. (No loss of revenue is anticipated provided that customer requirements can be met).

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[51] As for the derivation of costs for the automotive sector this assumes that: the ratio of penta-BDPE use in the automotive and upholstery sectors in the UK holds true across Europe as a whole; that these applications account for the majority penta-BDPE usage; and that the UK company is representative of others in the EU. These six users have a penta-BDPE consumption of 30 tpa. This is higher than the 11 tpa derived from industry data (see Section 4.3.3). However, adoption of this higher figure ensures costs are not underestimated.

With respect to the EU as a whole, use of penta-BDPE in non-foamed PUR is a minor application associated with only 5% or less of total penta-BDPE use (i.e. six tpa for a total use of 125 tpa). If it is assumed that penta-BDPE forms 10% of the PUR, this equates to 60 tpa of penta-containing PUR. If one-off reformulation costs of Euro 1,040 (£600) per tonne are assumed (as for the upholstery industry), these can be valued at Euro 62,400 (£39,000)

***Impacts on Producers of Other Products***

Small quantities of penta-BDPE (< 5 tpa across the EU) are also used in the production of foam for the packaging of electrical and electronic equipment (see Section 4.3.5). This use was reported by a flame retardant supplier towards the end of the study. No information has been provided by the PUR industry concerning this use. Neither has detailed consideration been given to the issue of alternatives to penta-BDPE for this application. The reason for use of penta-BDPE in this application is to meet the requirements of the relevant fire safety test, UL 94-HF1 (see Section 4.3.5).

With no data, it is not believed to be appropriate to attempt to value the impacts of marketing and use restrictions on this sector. That said, given the small quantities of penta-BDPE used (and thus PUR produced) and the nature of this application, it would be difficult to see how these costs would be significant compared with those for other sectors.

Finally, penta-BDPE finds its way into carpet padding produced in the US (see Section 4.3.5). As this product is not produced in the EU, no further consideration is given to this application.

***Other Costs Relating to Alternatives***

There would be additional costs arising from the use of alternatives in all sectors if these alternatives resulted in poorer fire safety performance than penta-BDPE (e.g. associated with additional losses of property and/or life). In this regard, fire safety standards provide the benchmark against which such performance can be measured. It is believed that there is at least one alternative for each of the applications under consideration[52] which allows the relevant fire safety standards to be met. Given that meeting the relevant standard would be a criterion for the selection of an alternative flame retardant, such additional costs are not considered further.

### 6.2.4 Monitorability

It should be relatively simple to monitor whether a ban on the use of penta-BDPE is being implemented by the producers of PUR foams. Monitoring the use of penta-BDPE in imports of finished articles would be more difficult, but would be necessary given that these are believed to be the source of between 50% and 75% of penta-BDPE emissions in the EU (see Section 6.2.2)

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[52] Bar packaging which has not been given detailed consideration.

In the UK in 1996, the ratio of furniture imports to demand was 36% and the ratio of exports to sales was 39% (ONS, 1999). Therefore, it seems likely that there are significant imports and exports of furniture into and out of the UK (although what percentage of these are from outside the EU is not known).

The costs of such monitoring will depend on the body undertaking the monitoring and the additional requirements imposed by that monitoring. In the UK, imports could be monitored through Trading Standards bodies. They are responsible for enforcing the UK Fire and Furniture (Fire Safety) Regulations concerning the ignitability of foam fillings and coverings. They check that imported furniture has the required permanent label and identify non-compliant items. Importers must be able to prove that the furniture they import complies with the regulations, have the results of any tests and keep all paperwork for five years. Use of such an organisation with an existing monitoring system would seek to reduce costs from those associated with any new system.

Additional costs will arise from the requirement for testing and, perhaps, certification. No data have been forthcoming which allow these costs to be quantified.

## 6.3 Environmental Quality Standards and/or Limit Values

### 6.3.1 Effectiveness

Environmental Quality Standards (EQSs) and Limit Values can be set under Directive 76/464/EEC on pollution caused by dangerous substances discharged into the aquatic environment (as noted in Section 5). This system is due to be replaced by the proposed Water Framework Directive. These are both focussed upon the aquatic environment and this option, therefore, does not address releases to other media. In addition, this measure is better suited to point source releases (i.e. releases from PUR production) than to diffuse releases (i.e. from the use of foams). Thus, this option would only be effective for secondary poisoning via the fish-based food chain where releases to the aquatic environment from PUR foam production constitute around 99% of the total PEC for this end-point. This option would not be effective in addressing releases of penta-BDPE from the use of foams which give rise to secondary poisoning risks via the earthworm-based food chain.

### 6.3.2 Practicality

For this option to be practicable, it must be possible to specify an EQS/EQO for receiving waters (i.e. to specify a level of penta-BDPE in the aquatic environment at which no adverse effects are expected to occur).

The PNEC for secondary poisoning via the fish-based food chain is 1 mg/kg. For this PNEC not to be exceeded, the annual average PEC in the aquatic environment would need to be less than 0.14 µg/l. This implies that the EQO for penta-BDPE would be 0.14 µg/l or lower. In this regard, it is common to apply a safety factor of 10 to derive an

EQO[53]. Thus, the EQO could be as low as 0.014 µg/l. Any limit value would be expected to be set above the EQO, once defined, in order to reflect dilution of effluent. In setting an EQS/EQO, however, aquatic toxicity data would also need to be taken into account. Current available data suggest a PNEC for the aquatic compartment of 0.11 µg/l, although this could be as low as 0.01 µg/l based on data relating to sediments.

A key issue is whether it is possible to detect penta-BDPE at these levels. The UK Environment Agency has indicated that it does not foresee any difficulties monitoring down to around 0.01 µg/l in river water (assuming penta-BDPE is soluble and can be extracted from river water). While there is no routine monitoring for penta-BDPE, brominated compounds of this type are reported to be generally amenable to measurement. As commercial penta-BDPE is a mixture of isomers, any standard would have to take this into account - it could be set for the combination of the isomers, or for specific components. Individual isomers could be specified, but this would probably push the required concentrations even lower.

It has been suggested that, as a major concern is that penta-BDPE is bioaccumulative in the aquatic environment, any monitoring proposal would need to include sampling biota. The UK Environment Agency has indicated that while they can undertake bioaccumulation standstill studies (e.g. a background study on mussels to ensure that levels do not accumulate), usually for freshwater an annual sediment sample is taken.

### 6.3.3 Economic Impact

#### *Costs to PUR Producers*

Once any EQS and/or Limit Value was implemented, impacts would fall directly on PUR foam manufacturers discharging direct to surface waters and sewage treatment operators for effluent discharged to sewer. Where foam producers need to reduce penta-BDPE emissions, they may choose to:

1. improve the storage, handling and use of penta-BDPEs and associated products;
2. make process changes;
3. install treatment systems and/or alter disposal routes; and/or
4. seek alternative FR products.

The option chosen by companies would vary by site and depend on a number of factors including the nature of the production process. In all cases, companies could be expected to choose the least costly means of compliance, with some companies (e.g. those which do not release to the water environment) potentially incurring no costs (depending on the response of sewage treatment operators). In this regard, this option may be favoured by industry as it is flexible and minimises costs. However, this will not be the case if monitoring is difficult or costly.

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[53] This safety factor is normally applied to a PNEC and not a PEC.

With respect to releases from facilities, consultation with industry has indicated that releases from foam production facilities are already low due to existing actions and the intrinsic nature of the foams. In particular, storage of penta-BDPE is in bunded areas, with transfer to holding tanks by self-contained pumping systems. With respect to losses from foams, it is reported that due to the method by which the flame retardant blend is added during the foam forming process, any releases of penta-BDPE (including vaporization) are expected to be extremely small.

It has been indicated by all the companies using penta-BDPE that there are no direct emissions to water (either to sewer or controlled waters), aside from spillages, which are not considered under ESR Risk Assessment. For example, one company has indicated that liquid effluent is generated by processes which do not relate to the use of penta-BDPE-based products, therefore there is no penta-BDPE in the effluent[54].

The IPC Guidance Note does not identify specific potential release routes to water through any of the processes involved in the manufacture of PUR. However, it states that contamination of process waters, site drainage waters and emergency fire waters may occur (and should be treated in accordance with any discharge consent for controlled waters or sewers). The document generally relates this to areas in which spillages occur.

Where a blowing agent other than water is used (e.g. one of the penta-BDPE users uses methylene chloride in many of their foams), this can be recovered by scrubbing and subsequent steam stripping. The IPC Guidance Note states that the resultant aqueous condensate should be recovered for re-use. This condensate may contain some penta-BDPE, although it should not be released to the environment if it is recycled.

### *Monitoring Costs*

There will be costs to the authorities associated with developing an EQS/EQO and monitoring the receiving water courses. It may be necessary to develop a method and to check that there are no artificial artefacts (e.g. there are many phenolic compounds in river water which can sometimes cause problems with measurement). As indicated above, since penta-BDPE is a mix of isomers, there would be a need to calibrate against good quality standards. In this regard there may be no standard test material, or one may exist as a result of monitoring for occupational health purposes. If there is sufficient demand, the standards bodies will supply quality standards at costs upward of Euro 1,600 (£1,000).

For authorised discharges to water courses, the maximum frequency for monitoring discharges would be once a week in the UK. The additional costs associated with these visits would be very small if sampling is already taking place as a result of existing

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[54] The assumption in the risk assessment is that within the factory most penta-BDPE is released to air. Half of this is assumed to find its way into the waste water stream of the plant (perhaps after being condensed by the extraction equipment). Thus, of the 0.6 kg/tonne of penta-BDPE released to water, 0.5kg comes from releases to air within the factory, while 0.1kg comes from the handling of raw materials.

legislative requirements - just the cost of an extra sampling bottle and a few extra minutes of the sampler's time.

Assuming the analysis would require just a gas chromatograph or a mass spectrometer, the costs of this plus the extraction procedure would probably be Euro 48 (£30) per sample (Euro 64-80 (£40-£50)) per sample including profits for commercial laboratories). Costs could be as high as Euro 160 (£100) per sample for a small number of samples for which a laboratory was required to set up specially. Added to this would be the costs of monitoring receiving waters on a monthly basis. It has been suggested by the UK Environment Agency that a figure of Euro 16,000 (£10,000) in annual costs per site for monitoring would not be an underestimate.

If the above figure was extrapolated assuming monitoring was required at six to ten sites across the EU, total per annum costs would be amount to Euro 96,000 to 100,000 (£60,000 to £100,000). Additional costs would be incurred in terms of techniques employed to control emissions and also in terms of administration by the regulators. Thus, the total costs could be of an equivalent magnitude to the estimated value of the EU market for penta-BDPE (£2.7 million (Euro 4.3 million) as discussed in Section 4.3.1).

In the UK, these monitoring costs are passed onto industry (or water companies) but in a fixed way according to a charging scheme. The charging scheme is factored according to the size of the discharge, its content (there is a higher charge for more dangerous materials) and the quality of the receiving waters (the higher the quality, the higher the charge).

For discharges to sewer, water companies would be responsible for monitoring discharges to their facilities. Discharges from the sewage treatment works would be monitored by the Environment Agency in the UK.

### 6.3.4 Monitorability

To demonstrate the effectiveness of this option, discharges to sewers and those direct to the aquatic environment would need to be monitored. This will be dependent upon the availability of instruments with sufficiently low limits of detection. As indicated above, it would appear that monitoring can take place at the required levels.

## 6.4 Integrated Pollution Prevention and Control

### 6.4.1 Effectiveness

The IPPC framework can only be used to reduce emissions from PUR foam production facilities. It cannot address risks arising from the use of PUR foams. Thus, this option would only be effective for secondary poisoning via the fish-based food chain where PUR foam production constitutes around 99% of the total PEC for this end-point. (For secondary poisoning via the earthworm-based food chain, around 90% of the PEC is associated with releases from use of foams).

Manufacture of PUR foams is "almost certainly" covered by IPPC, although it is not clear exactly under which category. It may be "basic plastic materials (polymers, synthetic fibres and cellulose-based fibres)" or "synthetic rubbers". (In this regard, the IPPC Directive is not as specific as the UK's regulations which implement it. These include specific reference to isocyanates which are translated across from the old system of Integrated Pollution Control which already controlled PUR production). However, IPPC covers only the manufacture of chemicals and not their use. Thus, the implication is that those buying in ready-mixed packages of chemicals (e.g. for the manufacture of elastomers) which are simply mixed on site will not be covered by IPPC.

Under the IPPC Directive, releases of penta-BDPEs would be controlled though emission limits and the use of BAT for pollution prevention. Thus, there is overlap with the 'EQS and Limit Value' option. However, the IPPC directive requires that emissions to air, water and land are prevented or, where this is not practicable, reduced. Thus, this option has the potential to reduce emissions across all media and not just water as is the case with the 'EQS and Limit Value' option. That said, with the EQS option it is possible to set an EQS that would reduce emissions further than required under BAT (and it is emissions to water which lead to the requirement for risk reduction from PUR facilities).

One further factor is that emissions of penta-BDPE will not necessarily be reduced under IPPC. Flame retardants may be given some consideration but other releases from PUR production may be considered more important. If releases of penta-BDPE were raised as an issue by the EU, they would be considered in the development of the BREF (BAT reference document). However, even then the candidate BAT may or may not reduce releases of penta-BDPE to below the level required for this assessment under ESR (i.e. to reduce the PEC/PNEC ratio to below one). It may be that the BAT has releases which are high for penta-BDPE but low for all other releases (unlikely but possible). The chosen BAT will be that which on balance is thought to be best. Even if the BAT were to reduce emissions of penta-BDPE, Member States may not choose to adopt it. BREFs offer only guidance, with their purpose being to facilitate the exchange of information. Given that the BREF is not prescriptive, it allows for a specific approach to be taken; therefore, Member States can deviate from the candidate BAT.

With respect to timing, the general provisions of the IPPC Directive came into force in 1999. However, it is to be implemented by industry sector over the forthcoming years up to 2007. The implementing Pollution Prevention and Control Act has been passed within the UK and the relevant Regulations are undergoing final consultation. Coverage of the polymers sector is not likely to occur in the very near future: work on the relevant BREF note is not scheduled until 2001 and, at least in the UK, the sector is not expected to be brought under control until 2003 (although this date may change).

### 6.4.2 Practicality

Although the IPPC Directive is now in force, it does not need to be implemented for existing installations until 2007. While some Member States will implement the Directive prior to this time, others do not intend to do so. Thus, existing PUR production facilities in some Member States may not be controlled under IPPC until 2007.

By 2007 all Member States should have a system in place which ensures that IPPC requirements are enforced. The existence of such an infrastructure would make this option relatively simple to implement.

### 6.4.3 Economic Impact

In assessing the economic impacts of the IPPC option, only additional costs should be considered. In other words, the costs of this option will be associated with expenditure over and above that which will be incurred from implementing other aspects of the IPPC Directive. More details on the IPPC Directive, its associated costs and the required reductions in the levels of penta-BDPE releases would be required in order to make an estimate of what these costs may be.

With respect to reductions in emissions, as indicated in Section 6.3, all the companies using penta-BDPE have indicated that there are no direct emissions of penta-BDPE to water (either to sewer or controlled waters), with the only foreseeable emissions thought to be from any spillage which might occur. However, this information does not take into account the fugitive emissions which are considered by the Risk Assessment.

### 6.4.4 Monitorability

For this option to be effective, releases from IPPC facilities would need to be monitored. It is assumed here that there is a mechanism for such monitoring within the proposals for IPPC. As with the EQS and Limit Value approach, monitoring will be dependent upon the availability of suitable instrumentation.

# 7. CONCLUSIONS AND RECOMMENDATIONS

## 7.1 Conclusions

Three possible risk reduction options have been assessed as means of controlling the risks arising from the use of penta-BDPE as a flame retardant in PUR foams. The conclusions from the assessment of these in terms of effectiveness, practicality, economic impact and monitorability are summarised in Table 7.1 This table also sets out our view on the overall balance of advantages versus drawbacks of these measures.

Only marketing and use restrictions have the potential to address the risks arising from both the production and use of PUR foams. Environmental quality standards and the use of the licensing system for Integrated Pollution Prevention and Control (IPPC) address only the risks arising from PUR foam production.

Three applications for penta-BDPE in PUR foams have been considered in detail in this study:

1. in PUR foam-based laminated automotive applications such as headrests;

2. in the production PUR foams for domestic furniture, including cot mattresses (where penta-BDPE is used for commercial reasons by one company because it does not contain phosphorus); and

3. in the production of various small run and prototype components, such as (non-foamed) PUR instrument casings.

A fourth (minor) application, use in foams for the packaging of electrical and electronic equipment, was identified only in the latter stages of this study and has thus been considered in less depth.

Manufacture of all the above products in the EU is estimated as being associated with <0.1% of total PUR production, <1% of PUR foam production and <0.4% of the FR market. The total value of the market for penta-BDPE is estimated as Euro 4.3 million (£2.7 million).

Suitable alternative flame retardants exist for all of the applications in which penta-BDPE is currently used. These can allow the desired products to be made which meet the relevant fire safety standards. The ecotoxicity of the alternatives considered is generally lower than that of penta-BDPE and, therefore, these substances could be expected to pose a lesser risk to the environment. The degree to which toxicity is lower, however, is dependent upon the specific alternative flame retardant under consideration.

EU suppliers of penta-BDPE have indicated that there is a general trend towards the replacement of this substance with alternative flame retardants. It may be the case that the use of this substance would cease in the coming years. However, the existing risk reduction measures are deemed to be insufficient to guarantee that the desired level of risk reduction is achieved.

Consideration was given to the possibility of tackling risks arising from the use of penta-BDPE-based foams by placing restrictions upon the migration of penta-BDPE from products (as an alternative to an outright ban) through changes in the production process or use of smaller quantities of flame retardant. This was not found to be technically feasible. Consideration was also given to targeting restrictions at specific uses of penta-BDPE. Data paucity makes it impossible to ensure the effectiveness of this option. In addition, there do not appear to be any particular reasons for favouring restrictions for one sector whilst omitting another.

On the basis of the data provided, marketing and use restrictions - in the form of a ban - are believed to provide the most effective and practical means for controlling secondary poisoning risks arising from both the production and use of polyurethane foams containing penta-BDPE. However, there may be issues associated with the monitoring of imports of finished articles from outside the EU.

The estimated costs to flame retardant suppliers and manufacturers of PUR products arising from a ban on the use of penta-BDPE are summarised in Table 7.2. Due to a paucity of data in many areas it has been necessary to make a number of assumptions in deriving these estimates.

**Table 7.2: Summary of Estimated Costs to European Industry from Marketing and Use Restrictions**

| **Sector** | **One-off Reformulation Costs (mEUR)** | **Annual Costs (mEUR pa)** |
|---|---|---|
| Flame retardant suppliers | - | ±0.01 to 0.1 |
| Producers of automotive PURs | 1.9 | 1 |
| Producers of PUR for upholstery | 0.3 | - |
| Producers of rigid PUR | 0.2 | - |
| Producers of packaging foam | <0.2 | - |
| **Total** | **2.4** | **~ 1.1** |

Within these estimates, all PUR producers are assumed to incur reformulation costs in proportion to their annual rate of production. No estimate of reformulation costs is given for flame retardant suppliers. This is because there are believed to be effective alternatives already on the market for all applications of penta-BDPE[55], thus reformulation of flame retardant packages is not necessary. While some FR suppliers may choose to develop new products the associated costs are considered to form part of their on-going research and development costs.

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[55] Except packaging which has not been given detailed consideration.

Annual costs have been estimated for flame retardant suppliers and producers of automotive components. Those for the former are estimated to be of the order Euros ±10,000 to 100,000 and are associated with differences in profit margin between penta-BDPE and alternatives. Because the profit margin for alternative FRs may be higher than for penta-BDPE suppliers may actually benefit from a ban. Annual costs to the automotive sector are associated with increases in process scrap.

## 7.2 Recommendations

It is believed that only marketing and use restrictions have the potential to provide adequate control of the environmental risks associated with penta-BDPE. Given that the trend is away from use of this substance and that relatively few difficulties are anticipated in its replacement, it is considered that the advantages of this option outweigh the potential drawbacks.

Therefore, it is recommended that the marketing and use of penta-BDPE be prohibited through an amendment to Directive 76/769/EEC.

However, it is also recommended that research be undertaken to confirm that the alternatives do confer lower environmental and health risks.

It is further recommended that the issues surrounding the monitoring of imports of finished products from outside the EU should be examined.

**Table 7.1: Summary of Advantages and Drawbacks**

| | Marketing & Use Restrictions | EQSs and/or Limit Values | IPPC |
|---|---|---|---|
| **Effectiveness** | Total ban would eliminate all risks associated with penta-BDPE from production and use of PUR products<br>Insufficient data for implementing measures targeted at specific uses. Not feasible to reduce concentrations of penta-BDPE within products, or to better contain penta-BDPE within those products<br>Suitable alternative FRs available in technical and environmental terms (and thus no additional risks of injury from fires expected)<br>Implementation probably no earlier than 2002 | Will only address risks to aquatic environment (fish-based food chain), i.e. from PUR production.<br>Not suited to addressing risks associated with emissions from finished products (earthworm-based food chain), i.e. from PUR use | Will not address majority (90%) of risks of secondary poisoning in earthworm-based food chain which arise mainly from emissions from products<br>May not apply to companies manufacturing non-foamed polyurethane products<br>Implementation delayed til 2007 for existing installations in some Member States |
| **Practicality** | Mechanisms for national implementation already developed in Member States<br>Additional legislation required to control storage and transport (though no risks identified here) | No problems envisaged in setting measurable EQO/EQS | Relatively simple to implement since infrastructure for IPPC required in all Member States. BAT may not sufficiently reduce emissions of penta-BDPE. Also, flexibility in adoption of BAT across Member States. |
| **Monitorability** | Possible difficulty of controlling imports of penta-BDPE within PUR products | Appears technically feasible to monitor at likely level of EQO/EQS | Suitable mechanisms should be in place for monitoring emissions under IPPC at PUR production facilities (which may require some extension in order to monitor emissions of penta-BDPE and levels in the environment) |

**Table 7.1: Summary of Advantages and Drawbacks**

| | Marketing & Use Restrictions | EQSs and/or Limit Values | IPPC |
|---|---|---|---|
| **Economic Impact** | **FR suppliers**: limited since penta-BDPE represents <0.4% of total EU FRs use and <0.5% in terms of value. Markets already developed for some alternatives. Costs of the order of Euros ±10k to 100k.<br>**Automotive component manufacturers**: One-off costs in reformulating and testing alternatives and new process streams (Euro 1.9 million). Annual costs of Euro 1 million from increase in process scrap (annual value of PUR market for sector Euro 20,500 million).<br>**Upholstered furniture manufacturers**: One-off reformulation costs of Euro 300k estimated (annual value of PUR market for sector Euro 1,060 million).<br>**Non-foamed polyurethane manufacturers**: One-off reformulation costs of Euro £200k estimated (annual value of PUR market for sector Euro 1,000 million). | **FR suppliers**: no additional direct costs expected<br>**PUR producers**: unquantified but dependent upon existing levels of release at a site-specific level and whether monitoring costs passed on (which may be around Euro 96,000 to 160,000 (£60,000 to £100,000) per year). Producers indicate that reductions in emissions would not be necessary (although this does not consider fugitive emissions).<br>**Regulators**: administrative costs unknown. Monitoring costs passed on to PUR producers | **FR suppliers**: no additional direct costs expected<br>**PUR producers**: unquantifiable since site-specific data on additional controls required unavailable. However, producers would be expected to be covered by IPPC and only additional costs for controlling penta-BDPE emissions would be incurred, plus any additional monitoring costs (expected to be similar to EQS and/or limit value option)<br>**Regulators**: administrative costs unknown. Monitoring costs passed on to PUR producers<br>Overall costs should prove to be similar to those of banning use of penta-BDPE or of EQS/limit value approach |
| **Balance of Advantages and Drawbacks** | Only option able to address all risks associated with manufacture and use of PUR containing penta-BDPE<br>Not likely to result in greater risk from fires or greater risks to environment given availability of suitable alternative FRs<br>Costs insignificant when compared with the annual value of the effected sectors and unlikely to be significantly greater than other options | Lower benefits since will not address risks arising from emissions from finished products and may be as costly as full marketing and use restrictions | Lower benefits since will not address risks arising from emissions from finished products and may be as costly as full marketing and use restrictions |

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# ANNEX 1

# LIST OF PROJECT STEERING GROUP MEMBERS

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Department of the Environment, Transport and the Regions (client)

Building Research Establishment

Danish Environmental Protection Agency

Department of Trade and Industry

Environment Agency for England and Wales

Great Lakes Chemical Corporation

Health and Safety Executive

Ministere de l'environnement, France

National Institute of Public Health and the Environment, The Netherlands (on behalf of the Competent Authority)

World Wildlife Fund

# ANNEX 2

# LIST OF ORGANISATIONS CONTACTED

# ANNEX 2: LIST OF ORGANISATIONS CONTACTED

The following list does not include organisations which have been contacted via standard letters and which have not provided any response. Furthermore, it does include some companies which were contacted and provided no response.

**Flame Retardants**

Akzo Chemicals
Albright & Wilson
Bromine and Chemicals Ltd.
CIA (Chemical Industries Association), Flame Retardants Sector Group
Contract Chemicals
EBFRIP (European Brominated Flame Retardants Association)
Great Lakes Chemical Corporation

**Polyurethane Foams**

AIPEF (Italian PUR Trade association)
ALVEO AG
ASEPUR (Spanish PUR Trade association)
Barkston Plc
BING (European Rigid PUR Foam Trade Association)
Breasley Foam
BRUFMA (British Rigid Urethane Foam Manufacturers Association)
BRMA (British Rubber Manufacturer's Association)
Bayer plc
BLIC (Liaison Office of the Rubber Industries of the European Union)
Caligen Foam
Carpenter PLC
Carpenter PUR S.A. (France)
Copely Developments Ltd
Drury Adams Ltd
Duflex
Elastogran (UK) Ltd
European Association of Flexible Polyurethane Blocks Manufacturers (EUROPUR)
FECHIPLAST (Belgian PUR Trade Association)
Foam Engineers Ltd
Freeman Distribution
FR Warren & Co Ltd
Heaven Dowsett & Co Ltd
Hubron Sales Ltd
Huntsman Polyurethanes
Hyperlast Ltd
Industrial Latex Compounds Ltd
ISOPA (European Isocyanate Producers Association)
IVPU (German Rigid PUR Foam Trade Association)

K2 Polymers
Kay Metzler
Lyondell Chemical Europe Limited
NE Plastics Ltd
NVR (Dutch PUR Trade Association)
Plastindustrien I Danmark (Danish PUR Trade association)
Polyurethane Foam Association (US)
PU Components Ltd
Ramer Ltd
Ramfoam Ltd
Resina
Reticel Ltd
RIM-CAST
Scapa Polymerics
Siber Hegner Ltd
SNPA (French PUR Trade association)
Swedish Plastics and Chemicals Association
Technical Foam Services Ltd
Thyssen Garfield
TJ Morgan (Barry) Ltd
TKT Cosyfoam
Tufnol Ltd
Urethane Solutions
Urethanes Technology Magazine (Crane Communications)
Venturefoam
Vermasson Ltd
Vitafoam
Vitec
Vulcascot
VWI (German PUR Trade association)
Whitchem Ltd
Zotefoams

### Automotive and Furniture Industries

British Furniture Association
British Plastics Federation
Dunlopillo
Dunlop Enerka Belting
Ford Motor Company
FIRA (Furniture Industry Research Association)
Gates Rubber Company
MIRA (Motor Industry Research Association)
SMMT (Society of Motor Manufacturers and Traders)
Textile Finishers Association
Toyota (GB) PLC
Volvo

**Others**

Building Research Establishment
Customs and Excise
Danish Environmental Protection Agency
DETR (Department of the Environment, Transport and the Regions), (Chemicals & Biotechnology, Vehicle Standards)
DTI (Department of Trade and Industry), (Chemicals Directorate, Consumer Safety Unit)
Environment Agency
European Vinyls Corporation
Federation of the Electronics Industry
Health & Safety Executive
KEMI (Swedish National Chemicals Inspectorate)
Martin Baker Aircraft Co. Ltd
Ministere de l'environnement, France
OSPARCOM (Oslo and Paris Commissions)
PCIF (Printed Circuit Interconnection Federation)
RAPRA Technology
RIVM (National Institute of Public Health and the Environment, The Netherlands)
SP Swedish National Testing and Research Institute
Swedish Environmental Protection Agency
Trading Standards
University of Surrey, Polymer Research Centre
World Wildlife Fund

# ANNEX 3

# COMPARISON OF PENTA-BDPE, TCPP AND TBBE

**Table A3.1: Comparison of Penta-BDPE with TCPP and TBBE**

| **Criteria** | **Penta-BDPE** | **TCPP** | **TBBE** |
|---|---|---|---|
| *Basic Information* | | | |
| CAS Number | 32534-81-9 | 13674-84-5 | NA (Trade Secret) |
| EINECS Number | 251-084-2 | 237-158-7 | NA |
| Molecular Weight | 564.72 | 322 | 549.9 to 706.1 |
| Chemical Formula | $C_{12}H_5Br_5O$ | $C_9H_{18}Cl_3O_4P$ | Blend of brominated aromatic esters |
| Method of Use | Additive FR | Additive FR | Additive FR (use up to 10% w/w) |
| Quantities Used (tpa) | 300 | 10,000 to 50,000 (IUCLID)<br>IPCS (1998b) gives 20,000 tpa global consumption for 1997 | 100 to 1000 tpa |
| *Physico-Chemical Properties* | | | |
| Physical State | Amber Liquid | Liquid | Viscous Amber Liquid |
| Melting Point | -7 to -3°C | -42°C (IUCLID) | (freezing point < -25°C) |
| Boiling Point | Decomposes > 200°C | 194.5°C at 1333 Pa<br>341.5°C at 101325 Pa<br>(IUCLID) | 317 to 331°C |
| Vapour Pressure (Pa) | $4.69 \times 10^{-5}$ at 21°C | 266 at 25°C (DTI) | $1.3 \times 10^{-4}$ at 25°C |
| Water Solubility (mg/l) | 0.0133 (Commercial Product) (25°C)<br>0.024 (penta-BDPE) | 1,600 at 20°C (IUCLID) | 2.01 at 20°C |
| Log $K_{OW}$ | 6.57 | 3.33 at 20°C (IUCLID - dependent upon the volume/ratio of octanol saturated with water) | log P > 6.2 |
| Viscosity (cps) | $> 2 \times 10^6$ at 25°C | 68.5 at 20°C (IUCLID) | 500 at 25°C |
| Density (Relative to water) | 2.25 to 2.28 | 1.29 at 20°C (IUCLID) | 1.7 |

**Table A3.1: Comparison of Penta-BDPE with TCPP and TBBE**

| **Criteria** | **Penta-BDPE** | **TCPP** | **TBBE** |
|---|---|---|---|
| Decomposition Temperature | > 200°C | Decomposition observed in one boiling point test at 235 to 248°C (IUCLID - however, see boiling point also) | NA |
| *Environmental Fate and Pathways* | | | |
| Photodegradation | Possible to some extent | NA | NA |
| Stability in Soil | NA | NA | $t_{1/2}$ > 1 year at 25°C (at pH 4, 7 and 9) |
| Stability in Water | Thought to be hydrolytically stable although some photodegradation will likely occur | NA | |
| Monitoring Data | Not reported in water or soil<br>Sediment: up to 0.54 mg/kg wet wt. (Sweden) | Water: up to 0.00009 mg/l but 0.013 mg/l in Japan<br>Sediment: up to 1mg/kg (IUCLID)<br>Traces of TCPP have been detected in industrial and domestic effluents but not in surface waters. It has not been detected in surveys of sediments. Traces of TCPP have been detected in raw peaches, raw pears and fish (IPCS (1998b)) | NA |
| Transport | Widely distributed and also physical properties indicate adsorbs to particles | NA | NA |
| Environmental Partitioning | $K_{OC}$ = 264058<br>(calculated using log $K_{OC}$ = 0.81 x log $K_{OW}$ + 0.10 in the RAR)<br>Likely to partition strongly to soil and sediment | $K_{OC}$ = 627 (using equation from RAR)<br>Much more likely to partition to water than penta-BDPE or TBPE but will still partition relatively strongly to soil and sediment | $K_{OC}$ > 28840 at 20°C<br>(however, calculated as 132434 from $K_{OW}$ using equation from RAR)<br>Likely to partition strongly to soil and sediment |

**Table A3.1: Comparison of Penta-BDPE with TCPP and TBBE**

| **Criteria** | **Penta-BDPE** | **TCPP** | **TBBE** |
|---|---|---|---|
| Biodegradation | No degradation (as $CO_2$) evolution after 29 days in an OECD 301B ready biodegradation test in activated sludge inoculum carried out to GLP. 2.4% theoretical $CO_2$ evolution after 93 days.<br>Not readily biodegradable | 14% of 20 mg/l after 28 days under OECD Test 301 E (to GLP) (IUCLID) which indicates not readily biodegradable. However, not classified as such. | 6% after 28 days. Not readily biodegradable |
| Bioaccumulation | BCF = 14,350 l/kg | BCF = 0.8 to 4.6 from two studies (42 day freshwater fish, OECD 305C) (IUCLID) | NA |
| *Environmental Effects* | | | |
| Acute Fish | Greater than water solubility<br>96H LC50 > 0.021 mg/l | GLP values reported in IUCLID range from 56 mg/l (*Brachydanio rerio*, 96H LC50) to 180 mg/l (*Lepomis macrochirus*, 120H LC50, based upon linear regression and nominal dose levels) | 96H LC50 > 2 mg/l<br>(greater than water solubility) |
| Acute Daphnia | 48H EC50 = 0.014 mg/l<br>NOEC = 0.0049 mg/l | 48H EC50 = 65 to 335 mg/l<br>48H LC50 = 131 mg/l (IUCLID) | 48H EC50 = 0.37 mg/l |
| Algal Growth Inhibition | 24H EC10 = 0.0027 to 0.0031 mg/l<br>(no difference between groups at over 24H)<br>*Selenastrum capricornutum* 96H EC50 > 0.026 mg/l | *Selenastrum capricornutum* 96H EC50 = 4 mg/l also 96H EC50 = 47 mg/l (IUCLID) | *Selenastrum capricornutum* 96H EC50 > 2 mg/l<br>Also EbC50 (72H) and ErC50 (72H) both > 2 mg/l |
| Fish Early Life Study | To be undertaken | NA | NA |
| 21 Day Daphnia Reproduction | NOEC = 0.0053 mg/l; LOEC = 0.0098 mg/l. | No effects at 1 mg/l and NOEC = 32 mg/l (industry communication) | NA |
| Sediment Toxicity | (RAR used eqbm. partitioning) | NA | NA |
| Terrestrial Toxicity | (RAR used eqbm. partitioning) | NA | NA |
| *Mammalian Toxicity* | | | |
| Acute Oral | Rat LD50 = 2640 to 6200 mg/kg | Values from 1017 (female) to 4200 mg/kg (male) in IUCLID | LD50 > 5,000 mg/kg (rat) |

**Table A3.1: Comparison of Penta-BDPE with TCPP and TBBE**

| **Criteria** | **Penta-BDPE** | **TCPP** | **TBBE** |
|---|---|---|---|
| Acute Inhalation | Single inhalation exposures not adequately investigated in animals although no deaths from one hour exposure to 200 mg/l aerosol. Suggests penta-BDPE is of low acute toxicity following inhalation exposure | Best values from IUCLID appear to be 4 to 7.2 mg/l in rat 4H LC50 | NA |
| Acute Dermal | LD50 > 2000 mg/kg (rabbit - i.e. no deaths at 2000 mg/kg)<br>Effects after 3 days in rats: weight loss, piloerection, lethargy, tremors, chromodacryorrhea, and diuresis | LD50 > 2000 mg/l in rats and rabbits for most studies in IUCLID | LD50 > 2000 mg/kg (rabbit - i.e. no deaths at 2000 mg/kg) |
| Corrosiveness and Irritation (Skin, Eye) | Erythema and oedema in rabbits<br>Slight eye irritant in rabbits | Non-irritant in most studies but slight in some rabbit eye and skin tests (IUCLID) | Slight eye irritant in rabbits |
| Sensitisation | No | No (IUCLID) | Yes (in M&K Assay) |
| Repeated Dose Toxicity | Liver and thyroid changes within 4 weeks of repeated oral dosing (2 mg/kg/day liver, 10 mg/kg/day thyroid)<br>'Chloracne type' response in rabbit ear study | Rat oral 14d: reduced weight gain and food consumption in males at 10600 mg/kg to OECD 407<br>Rat oral 90d: reduced weight and thyroid follicular hyperplasia at 20000 mg/kg (both sexes) and also mild cortical tubular degenerative changes at 7500 mg/kg in males to OECD 408<br>Rat oral 28d: increased female mortality at 1000 mg/kg (NOAEL = 100 mg/kg) (IUCLID) | Rat oral 28d: no neurotoxicity; kidney effects at 1000 mg/kg/day; NOAEL for systemic toxicity of 160 mg/kg/day |
| Mutagenicity (*in vivo*, *in vitro*) | Negative in *in vitro* tests and probably also *in vivo* due to limited metabolism | *In vitro*: negative in Ames test, bacterial gene mutation assay, DNA damage & repair assay, mouse lymphoma assay and yeast gene mutation assay<br>*In vivo*: negative in cytogenic assay (IUCLID) | No evidence of mutagenic activity in *Salmonella typhimurium* and *Escherichia coli* when tested in dimethyl sulphoxide |
| Carcinogenicity | NA | NA | NA |

**Table A3.1: Comparison of Penta-BDPE with TCPP and TBBE**

| **Criteria** | **Penta-BDPE** | **TCPP** | **TBBE** |
|---|---|---|---|
| Reproductive Toxicity | No evidence of damage to gonads in 90 day study with up to 100 mg/kg/day. Also, no foetal effects at at least 200 mg/kg/day | NA (only test mentioned in IUCLID was for substance of different CAS No.) | NA |
| Experience With Human Exposure | Toxicokinetic evidence suggests is absorbed from environmental sources of exposure and is distributed to adipose tissue and breast milk | NA | NA |
| Risk/Safety Phrases | None at present. Proposed classification is N; R50/53 (environment)<br>Xn; R48/21/22 (human health) | None | R50/53 (environment)<br>R48/R22 (human health) |

Note: NA = Information not available
The sources for the above information are as follows:
Penta-BDPE: October 1998 Draft RAR
TCPP: IUCLID database, DTI (1999) and IPCS (1998b)
TBPE: MSDS, review article (physical properties) and NONS information