Environment Agency

using science to create a better place

Environmental risk evaluation report: Tetraphenyl resorcinol diphosphate (CAS no. 57583-54-7)

ea/br/e/sci/v1

The Environment Agency is the leading public body protecting and improving the environment in England and Wales.

It's our job to make sure that air, land and water are looked after by everyone in today's society, so that tomorrow's generations inherit a cleaner, healthier world.

Our work includes tackling flooding and pollution incidents, reducing industry's impacts on the environment, cleaning up rivers, coastal waters and contaminated land, and improving wildlife habitats.

This report is the result of research commissioned and funded by the Environment Agency's Science Programme.

Published by:
Environment Agency, Rio House, Waterside Drive, Aztec West, Almondsbury, Bristol, BS32 4UD
Tel: 01454 624400 Fax: 01454 624409
www.environment-agency.gov.uk

Further copies of this report are available from:
The Environment Agency's National Customer Contact Centre by emailing:
enquiries@environment-agency.gov.uk
or by telephoning 08708 506506.

Author(s):
Brooke D N, Crookes M J, Quarterman P and Burns J

Dissemination Status:
Publicly available

Keywords:
Aryl phosphate, flame retardant, UKCCRMP

Research Contractor:
Building Research Establishment Ltd, Bucknalls Lane, Garston, Watford WD25 9XX

Environment Agency's Project Manager:
I Doyle, Chemicals Assessment Unit, Red Kite House, Howbery Park, Wallingford OX10 8BD
Tel. +44 (0)1491 828557

Collaborator(s):
Institute of Environment and Health, Cranfield University, Cranfield MK43 0AL

Environment Agency's Project Executive:
S Robertson, CAU

Product Code:
SCHO0809BQUL-E-P

Science at the Environment Agency

Science underpins the work of the Environment Agency. It provides an up-to-date understanding of the world about us and helps us to develop monitoring tools and techniques to manage our environment as efficiently and effectively as possible.

The work of the Environment Agency's Science Department is a key ingredient in the partnership between research, policy and operations that enables the Environment Agency to protect and restore our environment.

The science programme focuses on five main areas of activity:

- **Setting the agenda**, by identifying where strategic science can inform our evidence-based policies, advisory and regulatory roles;
- **Funding science**, by supporting programmes, projects and people in response to long-term strategic needs, medium-term policy priorities and shorter-term operational requirements;
- **Managing science**, by ensuring that our programmes and projects are fit for purpose and executed according to international scientific standards;
- **Carrying out science**, by undertaking research – either by contracting it out to research organisations and consultancies or by doing it ourselves;
- **Delivering information, advice, tools and techniques**, by making appropriate products available to our policy and operations staff.

Steve Killeen

Head of Science

Executive summary

An environmental risk assessment has been carried out for tetraphenyl resorcinol diphosphate (CAS no. 57583-54-7) on the basis of available information and using the methods of a European Technical Guidance Document. In Europe, this substance is mainly used as a flame retardant in thermoplastics/styrenic polymers, with other use in PVC, polyurethanes, paints and coatings and pigment dispersions.

Potential risks are identified for use in thermoplastics, PVC, polyurethane, paints and coatings and pigment dispersions for some or all of surface water (fresh and marine), sediment (fresh and marine) and soil compartments.

Emission estimates are based on information from a number of generic sources, including emission scenario documents and other risk assessments, so they could be refined with more specific information for the substance itself.

The assessment could also be refined by performing further toxicity tests. It is unlikely that further data on freshwater organisms would lead to significant changes in the findings. Studies on sediment and terrestrial organisms would allow the assessments for these compartments to be refined. In each case, it is likely that three long-term studies would be required. The actual need for testing is closely linked with that for the other triaryl and alkyl/aryl phosphates considered as part of this project. A suggested testing strategy for the group as a whole is outlined in a separate overview document.

The risks to waste water treatment plant, the air compartment, secondary poisoning (freshwater and marine food chains and terrestrial food chains) and to humans exposed through the environment from production and all uses of tetraphenyl resorcinol diphosphate are considered to be low.

Tetraphenyl resorcinol diphosphate does not meet the criteria for a persistent, bioaccumulative and toxic (PBT) or very persistent and very bioaccumulative (vPvB) substance.

Introduction

This report is one of a series of evaluations covering a group of related substances that represent the major aryl phosphate ester products used in Europe:

Triphenyl phosphate
Trixylenyl phosphate
Tricresyl phosphate
Cresyl diphenyl phosphate
Tris(isopropylphenyl) phosphate
Isopropylphenyl diphenyl phosphate
Tertbutylphenyl diphenyl phosphate
2-Ethylhexyl diphenyl phosphate
Isodecyl diphenyl phosphate
Tetraphenyl resorcinol diphosphate

A further substance is known to be commercially available, but it has already been assessed under the Notification of New Substances (NONS) Regulations. Information is also available on some (possibly obsolete) triaryl phosphates that are not thought to be supplied in the EU. This information is summarised in Annex A, but the risks from these products have not been assessed. Information for the group as a whole has also been used in this assessment, where appropriate, to fill any gaps in the database for this particular substance. Annex B discusses the read-across of data between the various phosphate esters considered.

This group was highlighted for assessment during preliminary work for a review of flame retardants (eventually published as Environment Agency 2003), particularly because they are potential replacements for other flame retardants that have already been identified as a risk to health or the environment. Regulators need to understand the potential consequences of such market switches before substantial replacement takes place. These assessments are not intended to provide a basis for comparison between the different aryl phosphates themselves; such a comparison would require consideration of a wider range of factors than are included here (such as human health risks, efficacy, recycling potential and costs). The assessments have been produced as part of the UK Coordinated Chemical Risk Management Programme (UKCCRMP) (http://www.defra.gov.uk/environment/chemicals/ukrisk.htm).

The methodology used in the report follows that given in an EU Technical Guidance Document (TGD)[1] for risk assessment of existing substances. The scientific work was mainly carried out by the Building Research Establishment Ltd (BRE), under contract to the Environment Agency. The review of mammalian toxicity data for the assessment of non-compartment specific effects was carried out by the Institute of Environment and Health, under contract to the Department for Environment, Food and Rural Affairs (Defra).

[1] This document has recently been replaced by similar guidance for the REACH Regulation.

Contents

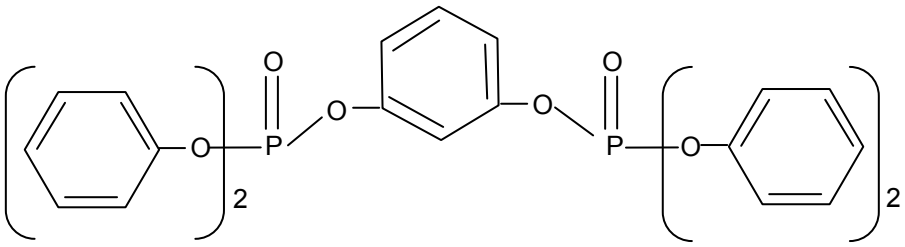
List of tables

1 General substance information

1.1 Identification of the substance

This assessment considers the following commercial substance.

CAS No:	57583-54-7
EINECS No:	260-830-6
IUPAC Name:	Tetraphenyl resorcinol diphosphate
Molecular formula:	$C_{30}H_{24}O_8P_2$
Molecular weight:	574.47 g/mol
Structural formula:	



The following CAS number is also used for this substance by some EU suppliers.

CAS No:	125997-21-9
EINECS No:	Not on EINECS
Name:	Phosphoryl chloride, polymer with resorcinol phenyl ester

Other names, abbreviations, tradenames and registered trademarks for this substance include the following:

Fyrolflex RDP®

Phosphoryl chloride, polymer with 1,3-benzenediol, phenyl ester

RDP

Reofos RDP®

Resorcinol bis(diphenyl) phosphate

Some of the tradenames and trademarks may refer to older products no longer supplied to the EU, or products produced outside the EU, but these are included in the report as they are sometimes referred to in the open literature.

The name tetraphenyl resorcinol diphosphate is used in this assessment.

1.2 Purity/impurity, additives

1.2.1 Purity/impurities

The main component of the commercial substance is as the structure in Section 1.1. Production of the substance also leads to the production of oligomers which contain additional resorcinol phenylphosphate groups in the chain. Hence triphosphate, tetraphosphate and higher oligomers may be present, as well as triphenyl phosphate. One commercial substance had the composition: 68 per cent tetraphenyl resorcinol diphosphate (as in Section 1.1); 19 per cent triphosphate; 6 per cent tetraphosphate; three per cent higher oligomers; 4 per cent triphenyl phosphate.

Great Lakes Chemical Corporation (2002) report a commercial tetraphenyl resorcinol diphosphate that contains a maximum of five per cent triphenyl phosphate (typically one to two per cent) and a maximum of 500 mg/kg (0.05 per cent) free phenol.

1.2.2 Additives

Additives are not thought to be present in commercially supplied products, although some aryl phosphate ester products are sometimes supplied as blends with other (halogenated) flame retardants.

1.3 Physico-chemical properties

Detailed test reports were not available for review, and so the validity of many of the reported values for physico-chemical properties is not always clear.

1.3.1 Physical state (at normal temperature and pressure)

Commercial tetraphenyl resorcinol diphosphate is a clear liquid at room temperature (Great Lakes Chemical Corporation 2002).

1.3.2 Melting point

No data are available on the melting point of tetraphenyl resorcinol diphosphate. As the commercial product is a liquid at room temperature, the melting point will be taken to be below 20°C in the assessment.

1.3.3 Boiling point

The boiling point of a commercial tetraphenyl resorcinol diphosphate is reported to be above 300°C at atmospheric pressure. The decomposition temperature of the same product is also above 300°C (Great Lakes Chemical Corporation 2002).The boiling point is assumed to be above 300°C in this assessment[2].

[2] Further data on the boiling point of this substance are being generated under the US High Production Volume program. Preliminary results indicate that the boiling point is above 400°C using the OECD 103 method. This is consistent with the data already available.

1.3.4 Density

The relative density of a commercial tetraphenyl resorcinol diphosphate is given as 1.31 at 20°C (Great Lakes Chemical Corporation 2002).

The relative density is assumed to be 1.31 at 20°C in the assessment.

1.3.5 Vapour pressure

The vapour pressure at ambient temperature is an important physico-chemical property for environmental risk assessment because it is used to estimate both the distribution of a substance in the environment and the volatile releases from products.

IUCLID (2001) reports the vapour pressure of tetraphenyl resorcinol diphosphate to be below 0.1 hPa (below 10 Pa) at 38°C. A vapour pressure of 17 Pa at 20°C has been quoted for this substance (Akzo Nobel 2003), but this value appears to be rather high compared with the data available for other aryl phosphates (see Annex B) and so is not considered further.

A vapour pressure (at 25°C) of 2.06×10^{-8} mmHg (2.7×10^{-6} Pa) can be estimated for tetraphenyl resorcinol diphosphate from its structure using the Syracuse Research Corporation MPBPWIN (version 1.28) software (modified Grain method).

No reliable vapour pressure data are available for tetraphenyl resorcinol diphosphate at temperatures around 20-25°C. Annex B considers the vapour pressure data available for other aryl and aryl/alkyl phosphates and suggests that a vapour pressure of around 8.7×10^{-6} Pa at 20°C would be appropriate for tetraphenyl resorcinol diphosphate. Although there are some uncertainties in this estimate, this value is used in the risk assessment in the absence of other data[3].

1.3.6 Water solubility

The commercial tetraphenyl resorcinol diphosphate Reofos RDP is reported to be immiscible with water (Great Lakes Chemical Corporation 2002). IUCLID (2001) reports the water solubility of tetraphenyl resorcinol diphosphate to be below 10 mg/l at 25°C. A water solubility of 0.69 mg/l has been determined for another commercial tetraphenyl resorcinol diphosphate product using the OECD 105 method (Akzo Nobel 2003).

A water solubility of around 1.1×10^{-4} mg/l at 25°C can be estimated for tetraphenyl resorcinol diphosphate using the Syracuse Research Corporation WSKOW version 1.30 software (the estimate is based on an estimated log K_{ow} of 7.41).

The experimentally derived water solubility of tetraphenyl resorcinol diphosphate is 0.69 mg/l and this is used in the assessment[4].

[3] Further data on the vapour pressure of this substance are being generated under the US HPV program. Preliminary results indicate that the vapour pressure is 2.59×10^{-3} Pa at 20°C using the OECD 104 method. This value is considerably higher than assumed in the assessment, and appears to be out of line with the data available for aryl phosphates as a whole (see Annex B).

[4] Further data on water solubility are being generated for this substance under the US HPV program. Preliminary results indicate that the solubility is 1.05 mg/l at 20°C by the OECD 105 method. This is similar to, but slightly higher than, the value used in this assessment.

1.3.7 Octanol-water partition coefficient (log K_{ow})

No reliable measured octanol-water partition coefficient data are available for tetraphenyl resorcinol diphosphate. A log K_{ow} of 7.41 can be estimated for tetraphenyl resorcinol diphosphate from its structure using the Syracuse Research Corporation Log K_{ow} (version 1.60) software.

Annex B considers the data available for other aryl and aryl/alkyl phosphates and suggests that a log K_{ow} of around 5.5 would be appropriate for tetraphenyl resorcinol diphosphate. Although there are some uncertainties in this estimate, this value is used in the risk assessment in the absence of other data[5].

1.3.8 Hazardous physico-chemical properties

A flash point of above 250°C has been determined for a commercial tetraphenyl resorcinol (Great Lakes Chemical Corporation 2002).

The autoignition temperature of a commercial tetraphenyl resorcinol diphosphate is reported as 585°C.

No information could be located for explosivity or oxidising properties of this substance.

1.3.9 Henry's law constant

A Henry's law constant of 2.94×10^{-13} atm m^3/mol (2.98×10^{-8} Pa m^3/mol) at 25°C can be estimated for tetraphenyl resorcinol diphosphate from chemical structure (bond contribution method) using the Syracuse Research Corporation HENRYWIN (version 3.00) software.

A further value for Henry's law constant can be estimated from the vapour pressure at 20°C (8.7×10^{-6} Pa) and water solubility (0.69 mg/l). These data give a Henry's law constant of 0.0072 Pa m^3/mol at 20°C for tetraphenyl resorcinol diphosphate. Although there are large uncertainties in this value (being based on an estimated vapour pressure value), it is used in this assessment as it is consistent with the water solubility and vapour pressure data assumed for the substance.

1.3.10 Summary of physico-chemical properties

The physico-chemical properties of tetraphenyl resorcinol diphosphate are summarised in Table 1.1.

[5] A log K_{ow} for this substance is being determined as part of the US HPV program. Preliminary results indicate that the log K_{ow} is 4.93 determined by the OECD 107 method. This value is similar to, but slightly lower than, the value assumed in this assessment.

Table 1.1 Summary of environmentally relevant physico-chemical properties for tetraphenyl resorcinol diphosphate

Property	Value
Melting point	<20°C
Boiling point (at atmospheric pressure)	>300°C
Relative density	1.31 at 20°C
Vapour pressure	8.7×10^{-6} Pa at 20°C
Water solubility	0.69 mg/l at room temperature
Octanol-water partition coefficient (log value)	5.5
Henry's law constant	0.0072 Pa m^3/mol at 20°C

2 General information on exposure

2.1 Production

There are two known European production sites (including Chemtura (formerly Great Lakes), UK). Information on production volume and market size is therefore confidential. It is possible that other companies may supply this substance, but no further information is available for this report.

2.2 Use

2.2.1 General introduction

Aryl phosphate flame retardants were first commercialised in the early twentieth century for use in flammable plastics such as cellulose nitrate and later for cellulose acetate (Weil 1993). Use in cellulose products is still significant, but the largest application is now in plasticized vinyl polymers. The main applications of these products are in wire and cable insulation, connectors, automotive interiors, vinyl moisture barriers, furniture upholstery, conveyor belts (for mining) and vinyl foams.

In addition to their use as flame retardants in polymer systems, triaryl phosphates are also used as fire-resistant hydraulic fluids, lubricants and lubricant additives (Weil 1993). Small amounts are also reported to be used as non-flammable dispersing media for peroxide catalysts.

2.2.2 Uses of tetraphenyl resorcinol diphosphate

Tetraphenyl resorcinol diphosphate is reported to be used as a flame retardant in engineering thermoplastics such as phenylene oxide blends, thermoplastic polyesters, polyamides, vinyls and polycarbonates (Weil 1993). It is a colourless to light yellow liquid (pour point -12°C) and is reported to be less volatile than the triaryl phosphates. Other similar diphosphates are also available. Levchik *et al.* (2000) indicated that aromatic phosphates, including tetraphenyl resorcinol diphosphate, are the primary flame retardants for polycarbonate and acrylonitrile-butadiene-styrene (ABS) copolymers.

Information on the sales of tetraphenyl resorcinol diphosphate into the EU has been provided by the relevant supplier companies for the year 2005. The specific figures are confidential, however, the major current area of use of tetraphenyl resorcinol diphosphate in the EU is in thermoplastics/styrenic polymers, with other uses in PVC, polyurethanes, paints and coatings and pigment dispersions.

3 Environmental exposure

This assessment has been prepared in accordance with the principles of Council Regulation (EEC) 793/93 (the Existing Substances Regulation or ESR)[6] and the methods laid down in Commission Regulation (EC) 1488/94[7] , which is supported by a technical guidance document or 'TGD' (EC 2003). The European Union System for the Evaluation of Substances (EUSES) computer program[8] (v2.0.3) implements the TGD models. The EUSES output file for this assessment is confidential because of the information it contains on tonnage and use pattern.

The assessment is generic, representing a *realistic worst case approach* for a hypothetical environment that broadly reflects average European conditions. It uses a number of assumptions (such as a fixed river dilution level), and further details can be found in the TGD. The assessment is based on estimated sales figures for Europe and some site-specific information. Since these are confidential, the calculations are presented in the Confidential Annex, but they are discussed qualitatively in the report as appropriate.

3.1 Environmental fate and distribution

3.1.1 Degradation

Abiotic degradation

Atmospheric photooxidation

A rate constant for reaction of tetraphenyl resorcinol diphosphate with atmospheric hydroxyl radicals of 2.1×10^{-11} cm^3/molecule s can be estimated from its structure using the Syracuse Research Corporation AOP (version 1.86) software. This program implements the method recommended in the TGD for estimating the rate constant.

Using an atmospheric hydroxyl radical concentration of 5×10^5 molecules/cm^3, a half-life for the reaction in air is estimated to be 18 hours.

Hydrolysis

An OECD 111 study on hydrolysis as a function of pH was carried out using a commercial tetraphenyl resorcinol diphosphate product (Wildlife International 2000). The test was carried out at pH 4, 7 and 9 at two temperatures (10°C and 20°C). The concentration of the tetraphenyl resorcinol diphosphate tested was 1 mg/l at pH 7 and 9 (reported to be around half of the water solubility limit in water) and 0.5 mg/l at pH 4. The test substance was added to the sterile buffer solutions (buffer concentration was 0.05 M) as a solution in acetonitrile (concentration of acetonitrile in the final solution was 1 µl/ml) and the disappearance of the test substance was monitored over 30 days using HPLC analysis (one replicate at each temperature/pH was run but triplicate samples from each replicate were analysed at each sampling point). The half-lives determined were 32, 20 and 55 days at 10°C and pH 9, 7 and 4 respectively, and 21,

[6] O.J. No L 084, 05/04/1993 p. 0001–0075.
[7] O.J. No L 161, 29/06/1994 p. 0003–0011.
[8] Available from the European Chemicals Bureau, http://ecb.jrc.ec.europa.eu/.

17 and 11 days at 20°C and pH 9, 7 and 4 respectively. The report also indicated that the shape of the degradation curves (which appeared to move towards a plateau) suggested that the hydrolysis was an equilibrium process between the parent compound and its degradation products.

Photolysis

No information on the direct photolysis of tetraphenyl resorcinol diphosphate under environmentally relevant conditions is available[9].

Biodegradation

Van Ginkel and Stroo (1996) found 66 per cent degradation of tetraphenyl resorcinol diphosphate after 56 days in an OECD 301D closed bottle test. The concentration of the test substance used was 2.7 mg/l. The test substance was first dissolved in dichloromethane and then a small volume of this solution was added to two grams of silica gel (100-200 mesh). After the solvent had evaporated, the silica gel/test substance mixture was added directly to the BOD bottles and it was assumed that the test substance would be slowly released from the gel into the water. The inoculum was derived from activated sludge treating predominantly domestic waste water and the activated sludge was preconditioned to reduce the endogenous respiration rate. The final inoculum concentration used in the test was 2 mg dry weight/litre (the OECD 301D test would normally use either 0.05 to 5 ml of secondary effluent or river water, but the concentration of activated sludge used here is consistent with under 30 mg dry weight/litre requirements for other ready biodegradation tests). The degradation after 28 days was 37 per cent.

Based on the above result tetraphenyl resorcinol diphosphate can be considered to be inherently biodegradable (but not meeting the specific criteria as defined in the TGD).

Summary of degradation

Abiotic degradation

The available information shows that tetraphenyl resorcinol diphosphate can undergo hydrolysis under acid, neutral and alkaline conditions. No information is available on the products from this hydrolysis but, by comparison with other trialkyl and trialkyl/aryl phosphates, products are likely to be diphenyl phosphate or other diaryl phosphates, which will be more stable to hydrolysis than the parent compound. However, unlike the other triaryl and trialkyl/aryl phosphates studied, the rate of hydrolysis appears to still be significant around pH 7 (the rate for most other trialkyl/aryl phosphates appears to be slow at pH 7 and only becomes significant at high or low pH).

A hydrolysis half-life of around 21 days is assumed here as a realistic worst case (although the rate appears to be higher than this at lower pH, the temperature of the experimental data (20°C) is higher than that routinely found in the environment).

No information is available on the direct photolysis reactions of tetraphenyl resorcinol diphosphate under environmentally relevant conditions. Atmospheric photo-oxidation is predicted to occur with a half-life of around 18 hours.

[9] A study to determine the absorption coefficients under acidic, neutral and basic pH using ultraviolet-visible light (OECD 101 method) is being carried out under the US HPV program. Results from the study are not yet available.

In summary, the abiotic degradation rate constants and half-lives assumed in the assessment are as follows:

Hydrolysis	$khydr_{water}$ = 0.033 d^{-1}	half-life = 21 d
Photolysis	$kphoto_{water}$ = 0 d^{-1}	half-life = infinite
Atmospheric photooxidation	k_{OH} = 2.1×10^{-11} cm^3/molecule s	half-life = 18.3 h

Biodegradation

The most likely pathway for biodegradation of triaryl phosphates is the initial hydrolysis of the phosphate ester to form orthophosphate and corresponding phenolic compounds or alcohols, which themselves undergo further biodegradation (Saeger *et al.* 1979).

The only degradation study available for tetraphenyl resorcinol diphosphate is a standard ready biodegradation test that showed 37 per cent degradation after 28 days and 66 per cent degradation after 56 days. Thus, although this test shows that the substance is not readily biodegradable, it does provide some indication that the substance is potentially inherently biodegradable. Therefore, it is assumed that the substance is inherently biodegradable for the purposes of this assessment.

The recommended biodegradation half-lives for surface water, soil and sediment from the TGD are summarised below (inherently biodegradable (not clear if the specific criteria are fulfilled), Kp_{soil} = 147 l/kg).

Sewage treatment plant	k = 0 h^{-1}	half-life = infinite
Surface water	k = 0 h^{-1}	half-life = infinite
Sediment	k = 2.3×10^{-4} d^{-1}	half-life = 3,000 days
Soil	k = 2.3×10^{-4} d^{-1}	half-life = 3,000 days

However, based on the biodegradation data, an infinite half-life in surface water may be overly conservative for this substance. The recommended biodegradation half-life for surface water from the TGD for an inherently biodegradable substance meeting specific criteria is 150 days and it is proposed to use this value here instead.

For sediment, the TGD recommends that the default rate constant should be ten times lower than that for soil to reflect the fact that the deeper sediment layers are anaerobic (this calculation assumes that degradation under anaerobic conditions does not occur). However, the available information for other triaryl phosphates (for example, see the risk evaluation report for triphenyl phosphate in this series) suggests that these substances may also be degraded under anaerobic conditions at a similar rate to aerobic conditions. Therefore, for this assessment, it is assumed that the degradation rate constant (and hence half-life) in sediment is the same as in soil.

Although the phenolic part of the triaryl phosphate will undergo mineralisation, orthophosphate/phosphoric acid will also be produced as a result of the degradation. The fate, behaviour and effects of this substance are beyond the scope of this assessment.

In summary, the following biodegradation rate constants and half-lives are assumed in the assessment:

Sewage treatment plant	$k = 0\ h^{-1}$	half-life = infinite
Surface water	$k = 4.7\times10^{-3}\ h^{-1}$	half-life = 150 days
Sediment	$k = 2.3\times10^{-4}\ d^{-1}$	half-life = 3,000 days
Soil	$k = 2.3\times10^{-4}\ d^{-1}$	half-life = 3,000 days

3.1.2 Environmental partitioning

Adsorption

No experimental data on the adsorption of tetraphenyl resorcinol diphosphate to soil or sediment are available.

A K_{oc} of 1.25×10^{8} l/kg can be estimated for tetraphenyl resorcinol diphosphate from its structure using the Syracuse Research Corporation PCKOC version 1.63 software, which employs a molecular connectivity index method.

Chapter 4 of the TGD recommends the following equation for estimating K_{oc} from log K_{ow} for phosphates:

$$\log K_{oc} = 0.49 \log K_{ow} + 1.17$$

Using this equation for tetraphenyl resorcinol diphosphate (log K_{ow} of 5.5) results in an estimated K_{oc} of 7,328 l/kg. Since this is obtained using the method recommended in the TGD, it is used in the risk assessment. The resulting partition coefficients for soils and sediments calculated using the methods given in the TGD are shown below.

K_{oc}	7,328 l/kg		
Kp_{susp}	733 l/kg	$K_{susp\text{-}water}$	184 m^3/m^3
Kp_{sed}	366 l/kg	$K_{sed\text{-}water}$	184 m^3/m^3
Kp_{soil}	147 l/kg	$K_{soil\text{-}water}$	220 m^3/m^3

These values are used in the risk assessment.

Volatilisation

No studies are available on the volatilisation of tetraphenyl resorcinol diphosphate. The Henry's law constant estimated for the substance is 0.0072 Pa m^3/mol at 20°C. This indicates that volatilisation from water is likely to be limited.

Fugacity modelling

The potential environmental distribution of tetraphenyl resorcinol diphosphate has been studied using a generic level III fugacity model. The model used was a four-compartment model (EQC version 1.01, May 1997) that has been circulated for use within the Organisation for Economic Cooperation and Development (OECD) High Production Volume (HPV) programme. The model was run four times with a nominal release rate of 1,000 kg/hour initially entering the air, soil or water compartments in different proportions. The physico-chemical properties used and the results of the modelling exercise are shown in

Table 3.1.

Table 3.1 Results of generic level III fugacity model for tetraphenyl resorcinol diphosphate

Input data	Value				
Vapour pressure	8.7×10^{-6} Pa at 20°C				
Water solubility	0.69 mg/l				
Henry's law constant	0.0072 at 20°C				
Log Kow	5.5				
Atmospheric half-life	18.3 hours				
Half-life in water	21 days				
Half-life in soil and sediment	3,000 days				
Emission rate	**Model results at steady state**				
	Amount in air	**Amount in soil**	**Amount in water**	**Amount in sediment**	**Overall residence time/persist-ence**
1,000 kg/hour to air 1,000 kg/hour to soil 1,000 kg/hour to water	8.9×10^{-3}%	95.6%	0.26%	4.15%	1,999 days
1,000 kg/hour to air 0 kg/hour to soil 0 kg/hour to water	0.036%	99.2%	0.044%	0.71%	1,497 days
0 kg/hour to air 1,000 kg/hour to soil 0 kg/hour to water	1.2×10^{-5}%	99.9%	6.3×10^{-3}%	0.10%	4,251 days
0 kg/hour to air 0 kg/hour to soil 1,000 kg/hour to water	4.5×10^{-5}%	0.13%	5.87%	94.0%	249 days

The results of the model show that only a small amount of the tetraphenyl resorcinol diphosphate released to the environment will be in the air compartment at steady state. When the substance is released to air it distributes mainly to the soil compartment, presumably by atmospheric deposition. When it is released to soil, the substance generally remains in the soil, with only a small fraction distributing to the water and sediment compartment. When released to water, the substance is likely to distribute mainly to the sediment phase at steady state, but a small fraction is also predicted to remain in the water phase.

The behaviour of tetraphenyl resorcinol diphosphate during waste water treatment was estimated using the EUSES model. Using the degradation rate of 0 h^{-1} (see Section 3.1.1), a K_{oc} of 7,328 l/kg (see above) and a vapour pressure of 8.7×10^{-6} Pa at 20°C (see Section 1.3.5), the following behaviour is predicted:

Degraded	0%
Adsorbed to sludge	46.0%
Volatilised to air	0.01%
To effluent	54.0%

These values are used in predicted environmental concentration (PEC) calculations.

3.1.3 Bioaccumulation and metabolism

No experimental data on accumulation of tetraphenyl resorcinol diphosphate in aquatic organisms are available.

A bioconcentration factor (BCF) for fish can be estimated based on the log K_{ow} of 5.5. Using the methods recommended in the TGD, a BCF for fish of 9,440 l/kg can be estimated. However, it has been noted for other triaryl phosphates that this method appears to overestimate the actual BCF for this group of compounds.

A further BCF of 363 l/kg has been estimated for this substance (Akzo Nobel 2003). The value was estimated with the BCFWIN program using the average values of the log K_{ow} of the various components present in the commercial product.

Annex B considers the available data for all triaryl phosphate esters and based on a read-across of these data, the BCF for tetraphenyl resorcinol diphosphate (the main component of the commercial products) is expected to be around 969 l/kg. This value is used in the risk assessment.

In addition to a BCF, the revised TGD also requires a biomagnification factor (BMF) to be taken into account. For tetraphenyl resorcinol diphosphate, the default BMF would be one (BCF 969).

For the terrestrial food chain, the TGD requires a BCF for earthworms. No experimental data are available for this endpoint and so an earthworm BCF is estimated using the following equation given in the TGD:

$$BCF_{earthworm} = 0.84 + 0.012\ K_{ow}/RHO_{earthworm}$$

where $RHO_{earthworm}$ = density of the earthworm = 1 kg/l

K_{ow} = octanol-water partition coefficient

Using a log K_{ow} of 5.5, the $BCF_{earthworm}$ is estimated to be 3,796 l/kg. This value is used in the assessment, though its reliability is unknown.

3.2 Environmental releases

3.2.1 General discussion

The releases from production and use of tetraphenyl resorcinol diphosphate were estimated using a number of sources such as the default methods from the TGD, the Emission Scenario Document (ESD) on plastics additives (OECD 2004), and scenarios developed under the Existing Substances Regulation for other substances with similar uses. In the absence of specific information on the substance, the ESD and scenarios for other substances are considered to be a reasonable basis for emission estimation; the TGD default values are intended for use as realistic worst case values in the absence of other data. Hence, estimates from these sources will have a degree of uncertainty. Actual calculations are considered confidential, as they are based on confidential production and use figures.

The producers of tetraphenyl resorcinol diphosphate provided information on the amounts used by representative large customers, and this was used in the local estimates of emissions from use.

3.2.2 Releases from production

Releases from production sites were estimated from specific information provided by the producing companies. The results are included in Table 3.2. For one of the sites, further qualitative information on the processes used has been provided which indicates that the actual emissions will be much lower than those in Table 3.2. This is considered in the risk characterisation.

3.2.3 Releases from use (processing)

Thermoplastics, PVC and polyurethanes

Emissions from the use in thermoplastics and styrenics were estimated using the methods outlined in the ESD on plastics additives (OECD 2004). The ESD provides methods for estimating the releases from three stages:

- handling of raw materials;
- compounding – the blending into the polymer of additives;
- conversion – the forming of the polymer into finished articles.

The first two stages are assumed to always take place together. There are companies which compound the plastics and then sell them on to converters, so separate calculations are carried out for the two as well as for the case where compounding and conversion take place together. The emission factors in the ESD are derived from information on a model substance, di(2-ethylhexyl)phthalate (DEHP), and are modified according to the relative properties of this substance and the substance of interest. The main property affecting the emissions is the vapour pressure of the substance. Tetraphenyl resorcinol diphosphate has a lower vapour pressure than DEHP, and is classed as of 'low volatility' according to the criteria in the ESD[10]. The ESD also uses the particle size or form of the substance in estimating the possible releases from raw materials handling. Tetraphenyl resorcinol diphosphate is a liquid (Section 1.3.1).

The emission factors derived using the ESD methods are:

- Compounding (including raw materials handling): 0.001 per cent to air, 0.011 per cent to waste water.
- Conversion: 0.001 per cent to air, 0.001 per cent to waste water.

Pigment dispersions

Emissions from this use were estimated using the plastics additives ESD (OECD 2004), considering a compounding step only. Emission factors are the same as those for thermoplastics above.

Paints

Emissions from the blending (formulation) of paints and their application were estimated using the TGD default values, which are 0.1 per cent to air and 0.3 per cent

[10] 'Low volatility' is used in comparison to DEHP which is of 'medium volatility'. All phosphates assessed in this series have vapour pressures considered low for organic substances.

to water for formulation, and 0.1 per cent to water for application. This assumes that paints containing the substance are used in industry rather than by the general public.

3.2.4 Releases over lifetime of products

Tetraphenyl resorcinol diphosphate is used in products which are expected to have extended service lives (more than one year). These are therefore potentially important sources of emission.

Possible losses through leaching and volatilisation are considered in this section. Limited information on the release of tetraphenyl resorcinol diphosphate is available, and has been included here, but estimates are based on the methods outlined in the Emission Scenario Document (OECD 2004) and also take into account approaches used in the risk assessment of other substances (for example, the risk assessment on medium-chain chlorinated paraffins carried out under the Existing Substances Regulation (ECB 2005)). The approach taken also considers the release of polymer particulates (waste remaining in the environment) over the lifetime of products and at disposal as appropriate; this is based on the treatment of this area in other risk assessments such as that on medium-chain chlorinated paraffins.

In the absence of information on the types of polymeric materials in which the pigment dispersions are used, a release of five per cent to cover the service life and losses on disposal (see below) is assumed.

Leaching loss

No information on the potential for leaching of tetraphenyl resorcinol diphosphate from products was located.

For thermoplastics, polyurethane and one PVC use, use in products indoors is assumed and losses through leaching are expected to be negligible. For the other PVC use, factors from the ESD on plastics additives are used in the assessment for emissions. Compared to the model substance di-(2-diethylhexyl)phthalate (DEHP) in the ESD, tetraphenyl resorcinol diphosphate is classed as a medium solubility substance, and the factor is increased accordingly from that for DEHP (which is low solubility). The factor also depends on the nature of the products and how they are used. A factor of 7.25 per cent over the lifetime of the product is used.

Emission factors for paints are also based on the ESD, with leaching of 0.75 per cent per year (based on external use of the paints).

Volatile loss

Great Lakes Chemical Corporation (2002) report a thermogravimetric weight loss of five per cent at 307°C, ten per cent at 337°C and 50 per cent at 403°C for a commercial tetraphenyl resorcinol diphosphate. The data refer to a 10 mg sample heated at a rate of 10°C per minute under a nitrogen atmosphere. The weight loss observed is probably due to both volatilisation and degradation of the substance.

These data do not allow emission factors for the service life to be estimated. For thermoplastics, the assessment for triphenyl phosphate in this series includes the derivation of an emission factor of 0.012 per cent over the lifetime of the article. This is used here, but adjusted to account for the difference in vapour pressure (triphenyl

phosphate is considered a high volatility substance, tetraphenyl resorcinol diphosphate a low volatility one). The emission factor used is 0.00048 per cent over the lifetime.

For use in PVC and polyurethane, factors from the ESD on plastics additives are used, as applied in the risk assessment of medium-chain chlorinated paraffins as appropriate. Volatile losses from products occur at ambient temperatures, where tetraphenyl resorcinol diphosphate is considered to have a low vapour pressure in relation to DEHP, the reference compound. The appropriate factor from the ESD is therefore that for low volatility substances or 0.01 per cent over the lifetime of the product.

For paints, the approach for thin films from the plastics ESD was used. This gave an emission factor of 0.51 per cent over a seven-year lifetime.

Waste in the environment

This considers the loss of substance in particles of plastic material from articles in use. The approach is the same as that used in the risk assessment for medium-chain chlorinated paraffins. For PVC uses, a loss of two per cent of the material over the lifetime of the products or articles is assumed; for thermoplastics and polyurethanes no waste generation over the lifetime; and for paints a five per cent loss. There are also further losses on disposal, two per cent loss for PVC, thermoplastics and polyurethane and five per cent loss for paints. As noted above, losses of pigment dispersions are taken as five per cent across the whole of service life and disposal. In the calculations, the substance in these particles is assumed to be available in the environment; this is likely to be an overestimate, but there are no actual data to indicate how much may be available.

3.2.5 Summary of environmental releases

The estimated environmental releases of tetraphenyl resorcinol diphosphate are summarised in Table 3.2.

Table 3.2 Summary of environmental releases of tetraphenyl resorcinol diphosphate

Life cycle stage		Local(kg/day)		Regional (kg/year)			Continental (kg/year)		
		Air	**Water**	**Air**	**Water[a]**	**Soil**	**Air**	**Water[a]**	**Soil**
Production sites			0.043 11		1,540 to surface water[c]			7 to surface water[c]	
Pigment dispersion	Raw materials handling and compounding	0.005	0.055						
	In service losses/waste in the environment			0.06	14.9 to surface water	45	0.54	135 to surface water	405
PVC – 1	Raw materials handling and compounding	0.001	0.011						
	Conversion	0.001	0.001						
	Raw materials handling, compounding and conversion	0.002	0.012	e	e		e	e	
	In service losses			0.02			0.18		
	Waste in the environment			8.0×10^{-4}	0.2 to surface water[d]	0.6	7.2×10^{-3}	1.79 to surface water[d]	5.4
PVC – 2	Raw materials handling and compounding	0.001	0.011						
	Conversion	0.001	0.001						
	Raw materials handling, compounding and conversion	0.002	0.012	e	e		e	e	
	In service losses			0.1	14.5		0.9	131	
	Waste in the environment			7.63×10^{-3}	1.9 to surface water[d]	5.72	0.07	17.1 to surface water[d]	51.5

Table 3.2 continued.

Life cycle stage		Local (kg/day)		Regional (kg/year)			Continental (kg/year)		
		Air	**Water**	**Air**	**Water[a]**	**Soil**	**Air**	**Water[a]**	**Soil**
Paints and coatings	Formulation	0.003	0.01	e	e		e	e	
	Processing		0.015						
	Losses during service life			0.51	5.25 to surface water		5.5	47.3 to surface water	
	Waste remaining in the environment			9.73×10^{-3}	2.4 to surface water	7.3	0.09	21.8 to surface water	65.6
Thermo-plastics/ styrenics	Raw materials handling and compounding	0.057	0.625						
	Conversion	0.057	0.057						
	Raw materials handling, compounding and conversion	0.12	0.68	e	e		e	e	
	In service losses			1.7			15.3		
	Waste in the environment			7.1	1,775 to surface water[d]	5,347	64	15,976 to surface water[d]	48,121
Poly-urethane	Raw materials handling and compounding	0.005	0.055						
	Conversion	0.005	0.005						
	Raw materials handling, compounding and conversion	0.01	0.06	e	e		e	e	
	In service losses			2			18		
	Waste in the environment			0.4	100 to surface water[d]	300	3.6	896 to surface water[d]	2,700

Table 3.2 continued.

Life cycle stage		Local (kg/day)		Regional (kg/year)			Continental (kg/year)		
		Air	Water	Air	Water[a]	Soil	Air	Water[a]	Soil
Miscellan-eous	Unallocated tonnage			0.04	0.11 plus 3.5 to surface water	10.6	0.33	1 plus 31.6 to surface water	95
Total				48	3,674	5,731	148	17,495	51,465

Notes:
a) Regional and continental emissions to water are split 80:20 between waste water treatment and direct discharge to surface water, expect where noted.
b) Local releases thought to be small.
c) Emissions calculated from site-specific data, after waste water treatment (sludges from production sites are not applied to land, calculating the values after treatment allows this to be reflected in the emission estimates).
d) Releases from waste in the environment are assumed to go directly to surface water.
e) Values for individual steps are confidential, but are included in the total figure.

3.3 Environmental concentrations

3.3.1 Aquatic environment (surface water, sediment and wastewater treatment plant)

Calculation of PECs

PECs for surface water and sediment were estimated with the EUSES 2.0.3 program using the data summarised in the previous sections as input. The concentrations predicted for water and sediment are shown in Table 3.3.

Table 3.3 Summary of predicted local concentrations for the aquatic compartment

Scenario		PEC_{local}			
		Microorganisms in sewage treatment plant (mg/l)	**Surface water - emission episode (μg/l)**	**Surface water - annual average (μg/l)**	**Sediment (mg/kg wet wt.)**
Production of tetraphenyl resorcinol diphosphate		0.14 and 1.16×10^{-3}	3.55 and 0.07	3.41 and 0.07	0.57 and 0.01
Pigment dispersions	Production of dispersions	0.01	1.52	1.26	0.24
PVC – 1	Compounding	2.97×10^{-3}	0.35	0.05	0.06
	Conversion	2.7×10^{-4}	0.08	0.08	0.01
	Combined compounding and conversion	3.24×10^{-3}	0.37	0.32	0.06
PVC – 2	Compounding	2.97×10^{-3}	0.35	0.05	0.06
	Conversion	2.7×10^{-4}	0.08	0.08	0.01
	Combined compounding and conversion	3.24×10^{-3}	0.37	0.32	0.06
Paints and coatings	Formulation	2.7×10^{-3}	0.32	0.27	0.05
	Application	4.05×10^{-3}	0.45	0.05	0.07
Thermo-plastics/ styrenics	Compounding	0.17	16.7	13.8	2.68
	Conversion	0.02	1.58	1.3	0.25
	Combined compounding and conversion	0.18	18.2	15	2.91
Poly-urethane	Compounding	0.01	1.52	0.06	0.24
	Conversion	1.35×10^{-3}	0.19	0.19	0.03
	Combined compounding and conversion	0.02	1.66	1.37	0.27

The predicted regional concentrations are 0.054 μg/l for surface water and 0.015 mg/kg wet weight for sediment.

Predicted concentrations were also calculated for the marine environment using the EUSES program. These are included in Table 3.4. Note that production is not included in the table as the production sites do not discharge to the marine environment.

Table 3.4 Summary of predicted concentrations for the marine environment

Scenario		PEC_{local}		
		Marine water - emission episode (μg/l)	**Marine water - annual average (μg/l)**	**Marine sediment (mg/kg wet wt.)**
Pigment dispersions	Production of dispersions	0.28	0.23	0.04
PVC – 1	Compounding	0.06	4.67×10^{-3}	9.43×10^{-3}
	Conversion	9.46×10^{-3}	9.46×10^{-3}	1.51×10^{-3}
	Combined compounding and conversion	0.06	0.05	0.01
PVC – 2	Compounding	0.06	4.67×10^{-3}	9.43×10^{-3}
	Conversion	9.46×10^{-3}	9.46×10^{-3}	1.51×10^{-3}
	Combined compounding and conversion	0.06	0.05	0.01
Paints and coatings	Formulation	0.05	0.04	8.64×10^{-3}
	Application	0.08	4.72×10^{-3}	0.01
Thermo-plastics/ styrenics	Compounding	3.1	2.55	0.5
	Conversion	0.29	0.24	0.05
	Combined compounding and conversion	3.37	2.77	0.54
Poly-urethane	Compounding	0.28	5.26×10^{-3}	0.04
	Conversion	0.03	0.03	4.68×10^{-3}
	Combined compounding and conversion	0.30	0.25	0.05

As no measured data are available on the levels of tetraphenyl resorcinol diphosphate in water or sediment, the calculated PECs are used in the risk characterisation.

3.3.2 Terrestrial compartment

Calculation of PECs

PECs for the soil compartment were estimated using EUSES 2.0.3 and are summarised in Table 3.5.

Table 3.5 Summary of predicted local concentrations for the terrestrial and air compartments

Scenario		PEC_{local}			
		Annual average conc. in air (mg/m^3)	**Agricultural soil – 30 day average (mg/kg wet wt.)**	**Agricultural soil – 180 day average (mg/kg wet wt.)**	**Groundwater under agricultural soil (μg/l)**
Production of tetraphenyl resorcinol diphosphate		3.06×10^{-7} 9.38×10^{-9}	2.14×10^{-4} 1.47×10^{-4}	2.14×10^{-4} 1.47×10^{-4}	1.66×10^{-3} 1.14×10^{-3}
Pigment dispersions	Production of dispersions	1.15×10^{-6}	0.33	0.32	2.47
PVC – 1	Compounding Conversion Combined compounding and conversion	9.14×10^{-9} 2.86×10^{-7} 4.65×10^{-7}	0.07 6.12×10^{-3} 0.07	0.06 6.02×10^{-3} 0.07	0.5 0.05 0.54
PVC – 2	Compounding Conversion Combined compounding and conversion	9.14×10^{-9} 2.86×10^{-7} 4.65×10^{-7}	0.07 6.12×10^{-3} 0.07	0.06 6.02×10^{-3} 0.07	0.5 0.05 0.54
Paints and coatings	Formulation Application	6.94×10^{-7} 8.38×10^{-9}	0.06 0.09	0.06 0.09	0.45 0.67
Thermo-plastics/ styrenics	Compounding Conversion Combined compounding and conversion	1.3×10^{-5} 1.3×10^{-5} 2.74×10^{-5}	3.7 0.34 4.03	3.63 0.33 3.95	28.1 2.58 30.6
Poly-urethane	Compounding Conversion Combined compounding and conversion	1.22×10^{-8} 1.4×10^{-6} 2.29×10^{-6}	0.33 0.03 0.36	0.32 0.03 0.35	2.47 0.23 2.7

Notes: a) Sludge from the production sites is not applied to agricultural land.

Estimated regional concentrations for the soil compartment are summarised below.

$PEC_{regional}$ = 1.59×10^{-4} mg/kg wet weight for agricultural soil
= 1.23×10^{-3} μg/l for pore water of agricultural soil
= 1.47×10^{-4} mg/kg wet weight for natural soil
= 0.14 mg/kg wet weight for industrial soil

As no measured data are available on the actual levels of tetraphenyl resorcinol diphosphate in soil, the calculated PECs are used in the risk characterisation.

3.3.3 Air compartment

Calculation of PECs

Concentrations of tetraphenyl resorcinol diphosphate in air were estimated using EUSES 2.0.3. The PECs calculated are summarised in Table 3.5.

The predicted regional concentration in air is 8.37×10^{-9} mg/m^3.

As no measured data are available on the actual levels of tetraphenyl resorcinol diphosphate in air, the calculated PECs are used in the risk characterisation.

3.3.4 Non-compartment specific exposure relevant for the food chain

Predicted concentrations in biota and food

Predicted concentrations of tetraphenyl resorcinol diphosphate in fish and earthworms are shown in Table 3.6 and predicted concentrations in food for human consumption are shown in Table 3.7. Concentrations were calculated using EUSES 2.0.3.

Table 3.6 Summary of predicted local concentrations for secondary poisoning

Scenario		Predicted concentration			
		Fish (mg/kg)	Earthworms (mg/kg)	Marine fish (mg/kg)	Marine top predators (mg/kg)
Production of tetraphenyl resorcinol diphosphate		1.68 and 0.06	4.94×10^{-3} and 4.04×10^{-3}	n/a	n/a
Pigment dispersions	Production of dispersions	0.64	4.23	0.11	0.03
PVC – 1	Compounding	0.05	0.85	4.45×10^{-3}	4.39×10^{-3}
	Conversion	0.06	0.08	6.77×10^{-3}	4.86×10^{-3}
	Combined compounding and conversion	0.18	0.93	0.03	9.1×10^{-3}
PVC – 2	Compounding	0.05	0.85	4.45×10^{-3}	4.39×10^{-3}
	Conversion	0.06	0.08	6.77×10^{-3}	4.86×10^{-3}
	Combined compounding and conversion	0.18	0.93	0.03	9.1×10^{-3}
Paints and coatings	Formulation	0.16	0.77	0.02	8.32×10^{-3}
	Application	0.05	1.16	4.48×10^{-3}	4.4×10^{-3}

Table 3.6 continued.

Scenario		Predicted concentration			
		Fish (mg/kg)	**Earthworms (mg/kg)**	**Marine fish (mg/kg)**	**Marine top predators (mg/kg)**
Thermo-plastics/ styrenics	Compounding	6.7	48	1.24	0.25
	Conversion	0.66	4.42	0.12	0.03
	Combined compounding and conversion	7.28	52.3	1.34	0.27
Poly-urethane	Compounding	0.05	4.23	4.74×10^{-3}	4.45×10^{-3}
	Conversion	0.12	0.39	0.02	6.77×10^{-3}
	Combined compounding and conversion	0.69	4.62	0.12	0.03

Notes: a) Sludge from the production site is not applied to agricultural land.

As no measured data are available on the actual levels of tetraphenyl resorcinol diphosphate in biota, calculated PECs are used in the risk characterisation.

Table 3.7 Summary of predicted local concentrations in food for human consumption

Scenario		Concentration							
		Fish (mg/kg)	Root crops (mg/kg)	Leaf crops (mg/kg)	Drinking water (mg/l)	Meat (mg/kg)	Milk (mg/kg)	Air (mg/m^3)	Total daily human intake (mg/kg bw/day)
Production of tetraphenyl resorcinol diphosphate		3.3 and 0.06	4.0×10^{-3} and 2.7×10^{-3}	3.5×10^{-4} and 1.1×10^{-5}	8.5×10^{-4} and 1.6×10^{-5}	5.6×10^{-4} and 1.4×10^{-5}	1.8×10^{-4} and 4.4×10^{-6}	3.0×10^{-7} and 1.0×10^{-9}	5.5×10^{-3} and 1.2×10^{-4}
Pigment dispersions	Production of dispersions	1.22	5.93	3.2×10^{-3}	2.5×10^{-3}	2.6×10^{-3}	8.3×10^{-4}	1.1×10^{-6}	0.03
PVC – 1	Compounding	0.05	1.19	3.9×10^{-4}	5.0×10^{-4}	3.9×10^{-4}	1.3×10^{-4}	7.6×10^{-10}	6.6×10^{-3}
	Conversion	0.08	0.11	3.6×10^{-4}	4.7×10^{-5}	2.1×10^{-4}	6.7×10^{-5}	2.8×10^{-7}	7.5×10^{-4}
	Combined compounding and conversion	0.31	1.3	9.3×10^{-4}	5.4×10^{-4}	7.1×10^{-4}	2.2×10^{-4}	4.6×10^{-7}	7.7×10^{-3}
PVC – 2	Compounding	0.05	1.19	3.9×10^{-4}	5.0×10^{-4}	3.9×10^{-4}	1.3×10^{-4}	7.6×10^{-10}	6.6×10^{-3}
	Conversion	0.08	0.11	3.6×10^{-4}	4.7×10^{-5}	2.1×10^{-4}	6.7×10^{-5}	2.8×10^{-7}	7.5×10^{-4}
	Combined compounding and conversion	0.31	1.3	9.3×10^{-4}	5.4×10^{-4}	7.1×10^{-4}	2.2×10^{-4}	4.6×10^{-7}	7.7×10^{-3}
Paints and coatings	Formulation	0.26	1.08	1.1×10^{-3}	4.5×10^{-4}	7.8×10^{-4}	2.5×10^{-4}	6.9×10^{-7}	6.4×10^{-3}
	Application	0.05	1.62	5.2×10^{-4}	6.7×10^{-4}	5.4×10^{-4}	1.7×10^{-4}	1.2×10^{-12}	9.0×10^{-3}
Thermo-plastics/ styrenics	Compounding	13.3	67.3	0.04	0.03	0.03	9.5×10^{-3}	1.3×10^{-5}	0.39
	Conversion	1.26	6.19	0.02	2.6×10^{-3}	9.9×10^{-3}	3.1×10^{-4}	1.3×10^{-5}	0.04
	Combined compounding and conversion	14.5	73.3	0.05	0.03	0.04	0.01	2.7×10^{-5}	0.43
Polyurethane	Compounding	0.06	5.92	1.9×10^{-3}	2.5×10^{-3}	1.9×10^{-3}	6.2×10^{-4}	3.8×10^{-9}	0.03
	Conversion	0.18	0.55	1.7×10^{-3}	2.3×10^{-4}	1.0×10^{-3}	3.3×10^{-4}	1.4×10^{-6}	3.3×10^{-3}
	Combined compounding and conversion	1.33	6.47	4.6×10^{-3}	2.7×10^{-3}	3.5×10^{-3}	1.1×10^{-3}	2.3×10^{-6}	0.04
Regional sources		0.05	2.9×10^{-3}	1.0×10^{-5}	1.3×10^{-5}	1.2×10^{-5}	3.8×10^{-6}	8.4×10^{-9}	1.0×10^{-4}

4 Effects assessment: Hazard identification and dose (concentration) – response (effect) assessment

4.1 Aquatic compartment

The following sections review the available toxicity data for tetraphenyl resorcinol diphosphate with aquatic organisms. Where possible, a validity marking is given for each study (this appears in the summary tables within each section). The following validity markings have been used:

1 **Valid without restriction.** The test is carried out to internationally recognised protocols (or equivalent protocols) and all or most of the important experimental details are available.

2 **Use with care.** The test is carried out to internationally recognised protocols (or equivalent protocols) but some important experimental details are missing, or the method used, or endpoint studied, in the test means that interpretation of the results is not straight forward.

3 **Not valid.** There is a clear deficiency in the test that means the results cannot be considered valid.

4 **Not assignable.** Insufficient detail is available on the method used to allow a decision to be made on the validity of the study.

In terms of the risk assessment, toxicity data assigned a validity marking of one or two are considered of acceptable quality when deriving the predicted no effect concentration (PNEC).

A few of the tests are unpublished studies carried out by industry. It has not been possible to validate all of these tests within the scope of this report and these are assigned a validity marking of four unless it is clear that some aspects of the test invalidate the results (for these a validity marking of three is given). The studies given a validity marking of four are considered along with studies assigned a validity marking of one or two when deriving the PNEC.

One important property when considering the aquatic toxicity data is water solubility. However, there are no reliable water solubility data for tetraphenyl resorcinol diphosphate. As explained in Section **Error! Reference source not found.**, the best estimate for the water solubility of this substance is 0.69 mg/l. Several studies have been carried out at concentrations greater than this solubility and, although this in itself does not necessarily invalidate the test (for example, co-solvents or solubility aids could have been used to aid dispersion of the substance in the test media), it does introduce some uncertainty over the concentrations to which the organisms were actually exposed in the test. In cases where it is clear that undissolved test substance was present in the test media, the tests have been marked as not valid.

4.1.1 Toxicity to fish

Short-term studies

The short-term toxicity of tetraphenyl resorcinol diphosphate to freshwater fish is summarised in Table 4.1.

Kroon *et al.* (1996) determined a 96-hour LC_{50} of 12.37 mg/l for tetraphenyl resorcinol diphosphate with zebra fish (*Brachydanio rerio*) in a semi-static test (48-hour renewal). In addition to mortality, sublethal behavioural effects (reduced activity and loss of equilibrium) were also visually monitored in the study. The no observed effect concentration (NOEC) for these effects was 3.04 mg/l. An emulsifier was used in this test (Tween 80 was used at 100 mg/l). Analysis of water concentrations at the start of the test showed the measured concentration to be around 56-76 per cent of the nominal. This low recovery was due primarily to the presence of undissolved test substance (undissolved substance was also reported to be visible in solution four hours into the test at concentrations of 14.7 mg/l and above) and the concentration remained fairly constant during the test (analyses carried out at 48 and 96 hours showed the concentration to be in the range 84-112 per cent and 87-108 per cent of the measured concentration at time zero and after renewal respectively). The results are based on nominal concentrations of the main component of the commercial product tested. The fact that undissolved test substance was present makes the results uncertain and although no adverse effects were seen at the lowest concentration tested, actual exposure at this dosing level (in terms of the dissolved concentration) is not clear. Concentrations used in this test were all well in excess of the reported water solubility of the substance.

The toxicity of tetraphenyl resorcinol diphosphate to zebra fish (*Danio rerio*) was tested with a water-accommodated fraction (WAF) following the OECD 203 test procedure (Geurts *et al*. 2006a). The WAF was prepared by adding 0.3 g of a commercial substance to three litres of Dutch Standard Water. The solution was stirred for 24 hours, and centrifuged twice for seven minutes at 4,000 rpm, then filtered to remove non-dissolved particles. The resulting solution was used as prepared, with no further dilution. The composition of the test substance was as described in Section 1.2. No effects were seen over the 96-hour exposure. The concentration of tetraphenyl resorcinol diphosphate in the exposure solution was reported as 0.144 mg/l at the start of the exposure, and 0.073 mg/l at the end. Quantification was based on the combined areas of two peaks on the high performance liquid chromatography (HPLC) chromatogram, the two peaks being those showing an increase with concentration of the test substance in standards prepared in the mobile phase used, which was 70 per cent acetonitrile and 30 per cent water (with 0.1 per cent phosphoric acid). One of these two peaks was found to correspond to triphenyl phosphate. This peak accounts for all of the area used to quantify the substance, so it is not clear what was actually measured in the exposure solutions. The study can be interpreted as showing no effects at the solubility of the commercial product.

Great Lakes Chemical Corporation (2002) reports an unpublished 96-hour LC_{50} of 12.4 mg/l for fish (unspecified species) for a commercial tetraphenyl resorcinol diphosphate. This concentration is above the expected water solubility of the test substance and the test could be the same as that reported above for *Brachydanio rerio*.

A fish 96-hour LC_{50} and a 14-day LC_{50} of 1.2 and 0.69 mg/l respectively were estimated for tetraphenyl resorcinol diphosphate from the log K_{ow} value of 5.5 using the USEPA ECOSAR (version 0.99h) software. Using the methods given in the TGD, a 96-hour LC_{50} of 0.39 mg/l can be estimated using the equation for polar narcosis (recommended for esters) and a log K_{ow} of 5.5.

Table 4.1 Short-term toxicity of tetraphenyl resorcinol diphosphate to freshwater fish

Species	Test guide--line	Number of animals/ treatment	Age/ size	Cosolvent	Concs. tested	N or M	Test conditions						End-point	Control resp.	Effect conc.	Ref.	Val.
							Media	Temp.	Hard.	pH	Static/ flow	D.O.					
?													Mortality		96h-LC_{50} = 12.4 mg/l	Great Lakes Chemical Corp. 2002	3/4
Brachydanio rerio	OECD 203	7, loading 0.28 g/l	0.12 g	Tween 80 at 100 mg/l	3.04, 6.69, 14.71, 32.34 and 71.20 plus control (nominal concs.)	N	Dutch Stand. Water	23°C	12°	7.7-8.2	Semi-static	7.9-8.9	Mortality Behave.	0% Mortality No effects.	96h-LC_{50} = 12.37 mg/l 96h-NOEC = 3.04 mg/l	IUCLID 2001	3
Danio rerio	OECD 203	7		None	WAF from 0.3g in 3 l water; used as made	N	Dutch Stand. Water	23°C		7.2-8.2	Static	8.0-8.9	Mortality	0% mortality	No effect seen	Geurts *et al.* 2006a	2

Notes: N = Nominal concentration.
M = Measured concentration.
WAF = water accommodated fraction (see text).
Temp. = Temperature.
Hard. = Water hardness as degrees hardness.
D.O. = Dissolved oxygen (given as mg O_2/l or per cent saturation).
Val. = Validity rating (see Section 4.1): 1) Valid without restriction; 2) Use with care; 3) Not valid; 4) Not assignable.

The reliability of these estimation methods is uncertain here, but estimates obtained using the method given in the TGD were found to be in reasonable agreement (within a factor of two to three) with the experimentally determined toxicity for a number of aryl phosphate esters.

No short-term toxicity data are available for tetraphenyl resorcinol diphosphate with marine fish.

Long-term studies

No long-term toxicity data are available for tetraphenyl resorcinol diphosphate with freshwater or marine fish. The USEPA ECOSAR program (v0.99h) predicts a long-term no effect concentration of 0.042 mg/l for fish.

4.1.2 Toxicity to aquatic invertebrates

Short-term studies

The short-term toxicity of tetraphenyl resorcinol diphosphate to freshwater aquatic invertebrates is summarised in Table 4.2.

IUCLID (2001) reports the results of an unpublished acute toxicity test using tetraphenyl resorcinol diphosphate with *Daphnia magna*. The 48-hour LC_{50} was determined to be 0.76 mg/l based on measured concentrations. The study was a flow-through test using nominal concentrations of 0.65, 1.1, 1.8, 3.0 and 5.0 mg/l. The respective measured concentrations over the test period were 0.43, 0.64, 1.5, 2.2 and 3.2 mg/l. The EC_{50} determined in this test is similar to (but slightly higher than) the water solubility of the test substance but, as the results are based on measured concentrations, the result is considered to be reliable.

The toxicity of tetraphenyl resorcinol diphosphate to *Daphnia magna* was tested with water-accommodated fractions (WAFs) following the OECD 202 test procedure (Geurts *et al.* 2006b). The WAFs were prepared by adding 0.05 g or 0.005 g of a commercial substance to 500 ml of reconstituted M4 test water. The solution was stirred for 24 hours, and centrifuged twice for seven minutes at 4,000 rpm to separate the undissolved fraction from the water layer. The resulting supernatants were used as prepared, with no further dilution, as 100 mg/l and 10 mg/l solutions respectively. The composition of the test substance was as described in Section 1.2. No effects were seen over the 48-hour exposure. Concentrations of tetraphenyl resorcinol diphosphate in the exposure solutions were reported as 0.018 mg/l at the start and end of the 10 mg/l exposure, and as 0.069 mg/l at the start and 0.074 mg/l at the end of the 100 mg/l exposure. Quantification was based on the combined areas of two peaks on the HPLC chromatogram, the two peaks being those showing an increase with concentration of the test substance in standards prepared in the mobile phase used, which was 70 per cent acetonitrile and 30 per cent water (with 0.1 per cent phosphoric acid). One of these two peaks was found to correspond to triphenyl phosphate. This peak accounts for all of the area used to quantify the substance in both exposures, hence it is not clear what was actually measured in the exposure solutions. The study can be interpreted as showing no effects at the solubility of the commercial product.

Table 4.2 Short-term toxicity of tetraphenyl resorcinol diphosphate to freshwater invertebrates

Species	Test guide-line	Number of animals/ treatment	Age/ size	Cosolvent	Concs. tested	N or M	Test conditions						End-point	Control resp.	Effect conc.	Ref.	Val.
							Media	Temp.	Hard.	pH	Static/ flow	D.O.					
Daphnia magna	USEPA OPPTS 850.1010	Ten per replicate, two replicates per treatment		Dimethyl formamide	0.43, 0.64, 1.5, 2.2 and 3.2, plus control and solvent control	M		20°C	132 mg/l	8.3		8.5 mg/l	Immobil. mortality		48h-EC_{50} = 0.76 mg/l	IUCLID 2001	2
	OECD 202	Five per replicate, four replicates per treatment	<24 h		WAFs from 10 mg/l and 100 mg/l	N	M4	21°C		7.5-8.0	Static	8.2-9.1	Immobil. mortality	No effect	No effects	Geurts *et al*. 2006b	2

Notes: N = Nominal concentration.
M = Measured concentration.
WAF = water accommodated fraction (see text).
Hard. = Water hardness (given as mg $CaCO_3$/l).
Temp. = Temperature.
Val. = Validity rating (see Section 4.1): 1) Valid without restriction; 2) Use with care; 3) Not valid; 4) Not assignable.

Using the methods given in the TGD, a 48-hour EC_{50} of 0.78 mg/l can be estimated for *Daphnia magna* using the equation for polar narcosis (recommended for esters) and a log K_{ow} of 5.5. This value is in excellent agreement with the experimental value determined above. The USEPA ECOSAR program (v0.99h) predicts a lower value of 0.3 mg/l for the same endpoint.

No short-term toxicity are available data for tetraphenyl resorcinol with marine invertebrates.

Long-term studies

The long-term toxicity of tetraphenyl resorcinol diphosphate to freshwater invertebrates is summarised in Table 4.3.

An unpublished 21-day reproduction study with *Daphnia magna* was carried out using tetraphenyl resorcinol diphosphate (Wetton and Mullee 2001). Stock solutions of the test substance were prepared in dimethylformamide (the concentration of dimethylformamide in the final test solution was 100 µl/l) and the nominal concentrations tested were 0.0020, 0.0064, 0.020, 0.064 and 0.20 mg/l. The test method used was a semi-static method (test solutions renewed on days 2, 4, 7, 9, 11, 14, 16 and 18) and samples of both the freshly prepared solution and old solution were analysed for the concentration of the test substance on days 0, 2, 4, 7, 9, 11, 14, 16, 18 and 21. Both centrifuged and uncentrifuged samples were analysed to determine the actual dissolved concentration of the test substance.

Mortality (immobilisation) was found to occur only at the highest concentration tested (nominal 0.20 mg/l). No mortality was seen at nominal concentrations of 0.064 mg/l or below. The 21-day EC_{50} for mortality was estimated to be 0.11 mg/l (nominal) and the 21-day NOEC for this end point was 0.064 mg/l (nominal).

For reproduction, no statistically significant (p=0.05) differences were seen in the number of live young produced per adult between the solvent control group or the control group and the nominal 0.002, 0.0064, 0.020 and 0.064 mg/l treatment groups. In addition, no statistically significant effects were seen on the lengths of the animals at 21 days between the solvent control group and the nominal 0.002, 0.0064, 0.020 and 0.064 mg/l treatments. The EC_{50} for reproduction was estimated to be above 0.064 mg/l but below 0.20 mg/l based on the nominal concentrations tested. The NOEC for reproduction was determined to be 0.064 mg/l based on nominal concentrations.

Results of the analysis of test concentrations generally showed a reduction in the concentration with time. Results from uncentrifuged water samples (taken to represent the total (dissolved plus undissolved) concentration) were generally around 84 to 119 per cent of nominal in fresh solutions (although more variable results in the range 64 to 161 per cent of nominal were found at the two lowest test concentrations) and these fell to 49-128 per cent of nominal in the old solutions (again the lowest test concentrations showed the highest variability; the majority of values were above 80 per cent of nominal). Results from centrifuged samples (taken to represent the dissolved phase) showed generally lower concentrations, ranging from not detected to 74 per cent of nominal in the freshly prepared solutions to not detected to 46 per cent of nominal in the old solutions. The decline in concentration during the test was thought to indicate the presence of undissolved test substance, although no visual signs of undissolved substance were evident. Time-weighted mean measured concentrations in the centrifuged solutions were 7.2×10^{-4}, 0.003, 0.007, 0.021 and 0.065 mg/l for the 0.002, 0.0064, 0.020, 0.064 and 0.20 mg/l nominal treatments, respectively.

Table 4.3 Long-term toxicity of tetraphenyl resorcinol diphosphate to freshwater invertebrates

Species	Test guide-line	Number of animals/ treatment	Age/ size	Cosolvent	Concs. tested	N or M	Test conditions						End-point	Control resp.	Effect conc.	Ref.	Val.
							Media	Temp.	Hard.	pH	Static/ flow	D.O.					
Daphnia magna	OECD 211	10	<24 h	Dimethyl formamide (100 µl/l)	Nominal concs. 0.0020, 0.0064, 0.020, 0.064 and 0.20 mg/l plus control and solvent control. Mean measured concentrations 7.2×10^{-4}, 0.003, 0.007, 0.021 and 0.065 mg/l	M	Recon water	21°C	249-268	7.8	Semi-static	≥8.2 mg/l	Mortality	0% mortality	21d-NOEC = 0.021 mg/l 21d-EC_{50} = 0.037 mg/l	Wetton and Mullee 2001	2
													Repro.	Mean number of young/ adult = 102	21d-NOEC = 0.021 mg/l		

Notes: N = Nominal concentration.
M = Measured concentration.
Temp. = Temperature.
Hard. = Water hardness (given as mg $CaCO_3$/l).
D.O. = Dissolved oxygen (given as mg O_2/l or per cent saturation).
Val. = Validity rating (see Section 4.1): 1) Valid without restriction; 2) Use with care; 3) Not valid; 4) Not assignable.

Based on the above mean measured concentrations, the NOEC of 0.064 mg/l based on nominal concentrations is equivalent to a mean measured dissolved concentration of 0.021 mg/l. The 21-day EC_{50} for mortality was estimated to be 0.037 mg/l based on the mean measured dissolved concentrations. The report also indicated that the toxicity seen could have been caused by the presence of undissolved test substance during the test, although it was not possible to discount toxicity by the dissolved fraction alone.

No long-term toxicity data are available for tetraphenyl resorcinol diphosphate with marine invertebrates.

4.1.3 Toxicity to algae

Short-term studies

The toxicity of tetraphenyl resorcinol diphosphate to fresh water algae is summarised in Table 4.4.

Great Lakes Chemical Corporation (2002) give an unpublished 96-hour EC_{50} for algae (unspecified species) of above 48.6 mg/l for a commercial tetraphenyl resorcinol diphosphate. This concentration is well in excess of the expected water solubility of the test substance and so the results of this test are best interpreted in terms of no effects at water solubility of the test substance. It is also possible that this is the same study reported below.

Kroon *et al.* (1995) report the results of an acute toxicity test using tetraphenyl resorcinol diphosphate with *Selenastrum capricornutum*[11]. The 96-hour NOEC and LOEC was determined to be 24.3 and 48.6 mg/l respectively based on nominal concentrations of the main component of the commercial product (due to the low level of effects seen, it was not possible to estimate an EC_{10} or EC_{50} from the data). The report indicates that actual exposure concentrations of the main component of the commercial product were determined analytically at the start and end of the study using duplicate exposure vessels without alga for the lowest, middle and highest concentrations tested. The concentration at the start of the test was close to the nominal value (101-106 per cent of nominal) but had fallen slightly to 76-88 per cent of the nominal by 96 hours. These analyses were carried out by analysing the entire contents of the exposure vessels (as well as the growth media, the analysis included acetonitrile washings (the vessels were washed out twice prior to analysis of the contents)) and so the analytical results would not distinguish between dissolved and undissolved test substance. The test also used a relatively high concentration of an emulsifier (Tween 80 at a concentration of 80 mg/l).

Concentrations used in this study are well in excess of the water solubility of the test substance and so the results of this test are best interpreted in terms of no effects at water solubility of the test substance. Although not discussed in the test report, there is indirect evidence for the presence of undissolved test substance from the absorbance measurements taken at time zero from various solutions (cell concentrations were determined by UV/visible spectrophotometer readings at 436 nm), which were found to increase with increasing exposure concentration; at time zero, cell numbers in each exposure vessel should be the same and so an increasing absorbance reading with concentration implies that the chemical itself adsorbed light at 436 nm (unlikely) or that significant scattering of the light occurred owing to undissolved test substance.

[11] Now *Pseudokirchneriella subcapitata.*

Table 4.4 Toxicity of tetraphenyl resorcinol diphosphate to freshwater algae

Species	Test guide-line	Initial inoculum conc.	Co-solvent	Concs. tested	N or M	Test conditions				End-point	Control resp.	Effect conc.	Reference	Val.
						Media	Temp.	Hard.	pH					
?												96h-EC_{50} >48.6 mg/l	Great Lakes Chemical Corp. 2002	4
Pseudo-kirchneriella subcapitata	OECD 201	1×10^4 cells/ml	Tween 80 at 20 mg/l	3.04, 6.08, 12.16, 24.32 and 48.64 mg/l plus control and solvent control	N	Algal growth medium	23.5-24.5°C		7.7-9.1	Biomass and growth rate	57-fold increase in cell numbers in 72 hours	96h-NOEC = 24.3 mg/l 96h-LOEC = 48.6 mg/l	Kroon *et al.* 1995	2/3
	OECD 201	1×10^4 cells/ml		WAFs from 10mg/l and 100 mg/l	N	Algal growth medium	22.1-22.6		8.0-9.1	Biomass and growth rate	124-fold increase in cell numbers in 72 hours	72h-NOEC = 10 mg/l (WAF) 72h-LOEC = 100 mg/l (WAF)	Kluskens *et al.* 2006	2

Notes: N = Nominal concentration.
M = Measured concentration.
Temp. = Temperature.
Hard. = Water hardness (given as mg $CaCO_3$/l).
D.O. = Dissolved oxygen (given as mg O_2/l or per cent saturation).
Val. = Validity rating (see Section 4.1): 1) Valid without restriction; 2) Use with care; 3) Not valid; 4) Not assignable.

In spite of these factors, the test can be used in the assessment as an indication that no effect would be expected at solubility. It is unlikely that further tests of the same type would produce a clearer outcome. The validity marking of two to three reflects this.

The toxicity of tetraphenyl resorcinol diphosphate to *Pseudokirchneriella subcapitata* was tested with water-accommodated fractions (WAFs) following the OECD 201 test procedure (Kluskens *et al.* 2006). The WAFs were prepared by adding 0.0499 g or 0.0052 g of a commercial substance to 500 ml of test medium. The solution was stirred for 24 hours, and centrifuged twice for seven minutes at 4,000 rpm to separate the undissolved fraction from the water layer. The resulting supernatants were used as prepared, with no further dilution, as 100 mg/l and 10 mg/l solutions respectively. The composition of the test substance was as described in Section 1.2. Growth rate in the 100 mg/l exposure was reduced slightly (by three per cent compared to control), hence a NOEC of 10 mg/l (WAF) was derived from the study. Concentrations of tetraphenyl resorcinol diphosphate in the exposure solutions were reported as 0.018 mg/l at the start of the 10 mg/l exposure with no substance detected at the end, and as 0.064 mg/l at the start and 0.016 mg/l at the end of the 100 mg/l exposure. Quantification was based on the combined areas of two peaks on the HPLC chromatogram, the two peaks being those showing an increase with concentration of the test substance in standards prepared in the mobile phase used, which was 70 per cent acetonitrile and 30 per cent water (with 0.1 per cent phosphoric acid). One of these two peaks was found to correspond to triphenyl phosphate. This peak accounts for all of the area used to quantify the substance in both exposures at time zero, with the second peak being larger at 72 hours in the 100 mg/l exposure. It is therefore not clear what was actually measured in the exposure solutions. The study can be interpreted as showing a slight effect at the solubility of the commercial product.

The USEPA ECOSAR program (V0.99h) predicts a 96-hour EC_{50} value of 0.11 mg/l and a long-term no effect concentration of 0.088 mg/l for green algae.

No toxicity data are available for tetraphenyl resorcinol diphosphate with marine algae.

4.1.4 Toxicity to microorganisms

An EC_{10} of above 121.6 mg/l has been reported for bacteria in an unpublished test (a Robra test) using a commercial tetraphenyl resorcinol diphosphate (Great Lakes Chemical Corporation 2002). This concentration is in excess of the water solubility of the test substance and is best interpreted as showing no effects at the solubility limit in the test medium.

4.1.5 Toxicity to sediment organisms

No data are available on the toxicity of tetraphenyl resorcinol diphosphate to sediment organisms.

4.1.6 Predicted no effect concentration (PNEC) for the aquatic compartment

Surface water

Limited amounts of acute aquatic toxicity data are available. The tests on fish with the substance itself are not considered reliable; the test with a water-accommodated

fraction showed no effects. The lowest result for invertebrates is a 48-hour EC_{50} of 0.76 mg/l for *Daphnia magna*, which is slightly above the solubility. Again, a test with water-accommodated fractions showed no effects.

A long-term NOEC value of 0.021 mg/l was determined for tetraphenyl resorcinol diphosphate in a 21-day reproduction study with *Daphnia magna*. However, there is some uncertainty over the actual exposure (possible presence of undissolved test substance) in this study. An algal study on the substance itself can be considered to show no effects at solubility. A test using the water-accommodated fraction from a 100 mg/l solution showed a slight effect on growth, but although the concentration of the substance was reported, it is not clear what was actually measured.

Annex B considers the available toxicity data for all triaryl phosphates and based on a read-across of these data, the expected toxicity of tetraphenyl resorcinol diphosphate is outlined below:

- Long-term NOEC for fish is around 0.024 mg/l.
- Long-term NOEC for invertebrates is around 0.014 mg/l.
- Long-term NOEC for algae is expected to be greater than those for fish and invertebrates.

The estimated long-term NOEC for invertebrates is similar to the result from the *Daphnia* study, and gives some support to the use of the experimental result. The estimates from Annex B indicate that invertebrates are expected to be the most sensitive group. Although the available algal data are not fully reliable, they appear to indicate that no or only limited effects would be observed at the solubility. Hence the NOEC for algae could be taken to be around 0.69 mg/l.

On this basis, an assessment factor of 10 was used to derive an indicative PNEC value of 2.1 µg/l. This value is used in the risk characterisation. As there are effectively two experimental NOEC values, a PNEC based on test data alone could be derived using an assessment factor of 50, giving a value of 0.42 µg/l. This value is also considered in the risk characterisation for comparative purposes. Analyses in the WAF tests suggest that the solutions may contain very little tetraphenyl resorcinol diphosphate, so there is a high degree of uncertainty in these PNECs.

No data are available on marine species. A PNEC of 0.21 µg/l can be calculated using the long-term freshwater data as above and an assessment factor of 100.

Microorganisms

There is one toxicity result for tetraphenyl resorcinol diphosphate for microorganisms. This is an EC_{10} of above 121.6 mg/l bacteria (Robra test). The solubility of the test substance was exceeded in this test and so the results are best interpreted in terms of no effects at solubility. According to the TGD, the NOEC/EC_{10} from such a study can be used directly as the $PNEC_{microorganisms}$, and so the $PNEC_{microorganisms}$ could be taken as 0.69 mg/l (the water solubility of the substance). However, this approach may overestimate the actual toxicity of the substance to sewage treatment processes since actual solubility in pure water may not be relevant to exposure of microorganisms during waste water treatment. In this respect, no significant effects would be seen at 122 mg/l and this is used as the $PNEC_{microorganisms}$ in this case.

Sediment

No sediment toxicity data are available for tetraphenyl resorcinol diphosphate. In the absence of data, the equilibrium partitioning method can be used to estimate PNEC:

$$PNEC_{sed} = \frac{K_{susp-water}}{RHO_{susp}} \times PNEC_{water} \times 1000$$

where $K_{susp\text{-}water}$ = suspended sediment-water partition coefficient = 184 m^3/m^3 (see Section 3.1.2).
RHO_{susp} = bulk density of suspended sediment = 1,150 kg/m^3.

Using the indicative value of 2.1 μg/l derived for surface water, the provisional $PNEC_{sed}$ is estimated to be 0.336 mg/kg wet weight. This value is used in the provisional risk characterisation.

As the log K_{ow} of this substance is above five, according to the TGD, the resulting PEC/PNEC ratios should be increased by a factor of ten when using this PNEC to take into account the possibility of direct ingestion of sediment-bound substance.

The PNEC for marine sediments is derived in the same way from the marine water PNEC, and is 0.034 mg/kg wet weight. An additional factor of ten is applied to the PEC/PNEC ratios.

4.2 Terrestrial compartment

No terrestrial toxicity data are suitable for determining a PNEC for tetraphenyl resorcinol diphosphate. In the absence of data, the equilibrium partitioning method can be used to estimate the PNEC:

$$PNEC_{soil} = \frac{K_{soil-water}}{RHO_{soil}} \times PNEC_{water} \times 1000$$

where $K_{soil\text{-}water}$ = soil-water partition coefficient = 220 m^3/m^3 (see Section 3.1.2).
RHO_{soil} = bulk density of wet soil = 1,700 kg/m^3.

Using the indicative value of 2.1 μg/l derived for surface water, the provisional $PNEC_{soil}$ is estimated to be 0.272 mg/kg wet weight.

As the log K_{ow} of this substance is above five, according to the TGD, the resulting PEC/PNEC ratios should be increased by a factor of ten when using this PNEC to take into account the possibility of direct ingestion of sediment-bound substance.

4.3 Atmosphere

No information is available on the toxicity of tetraphenyl resorcinol diphosphate to plants and other organisms exposed via air. The low vapour pressure of the substance means that volatilisation to the atmosphere is likely to be limited and the resulting concentrations are likely to be low. The possibility of tetraphenyl resorcinol diphosphate contributing to atmospheric effects such as global warming and acid rain is likely to be small. In addition, as the substance does not contain halogen atoms, it will not contribute to ozone depletion.

4.4 Mammalian toxicity

An IUCLID dossier published in 2001 under the US Environmental Protection Agency's (EPA) High Production Volume (HPV) Challenge Programme is available on tetraphenyl resorcinol diphosphate. Many of the data used in this assessment were taken from the Robust Summary Dossier prepared under this programme. However, in many cases the studies are only briefly reported in the IUCLID documents, which makes it difficult to assess the quality and importance of some of the results, although Klimisch codes are assigned to each study providing an indication of study reliability. Several other primary studies cited in the IUCLID were also used.

4.4.1 Toxicokinetics, metabolism and distribution

A good quality study conducted by ITT Research Institute in 1997 investigated the metabolism and toxicokinetics of tetraphenyl resorcinol diphosphate in rats, mice and monkeys (Freudenthal *et al*. 2000). Groups of animals were given a single dose of 100 g/kg (purity not described) spiked with radiolabelled ^{14}C-tetraphenyl resorcinol diphosphate (99 per cent pure) by intravenous injection, nose-only inhalation, oral gavage or dermal exposure (Table 4.5); the latter route involved application to skin (20 per cent of body surface area) after shaving, followed by covering with a non-occlusive nylon mesh.

Table 4.5 Summary of design of metabolism and toxicokinetics study

Species and strain	No. of animals per sex	Exposure route	Exposure period	Target dose radioactivity (µCi/animal)
B6C3F1 mice	8	Intravenous	–	50
Sprague-Dawley rats	5	Intravenous	–	50
Cynomolgus monkeys	3	Intravenous	–	150
Sprague-Dawley rats	4	Inhalation	6 hours	50
Sprague-Dawley rats	5	Dermal	6 hours	100
Cynomolgus monkeys	3	Dermal	6 hours	150
Sprague-Dawley rats	6	Oral	–	100

Samples of blood, urine and faeces were collected for the quantification of ^{14}C levels. Expired air was also collected from rats for approximately seven days (exact period not given). Metabolite profiles were generated from urine and faecal samples for each animal by HPLC and the major metabolites were isolated, purified, and characterized by HPLC and mass spectrometry. The brain, mesenteric fat, kidneys, liver, lungs, testes/ovaries and spleen were collected from rats at necropsy for measurement of radioactivity.

Analysis of urine and faeces showed that tetraphenyl resorcinol diphosphate was metabolised extensively and that there was little variation in metabolism between individual animals and sexes and no apparent differences between species. The primary route of elimination was via the faeces, followed by excretion in the urine. Tetraphenyl resorcinol diphosphate was found un-metabolised in the faeces only after oral exposure, suggesting that some of the tetraphenyl resorcinol diphosphate administered by this route had passed through the gut unabsorbed. Four major metabolites were found in the faeces: hydroxy-tetraphenyl resorcinol diphosphate,

dihydroxy-tetraphenyl resorcinol diphosphate, resorcinol diphenylphosphate half-ester and hydroxyl-resorcinol diphenylphosphate half-ester. Three metabolites were identified in the urine: resorcinol, resorcinyl glucuronide, and resorcinyl sulfate.

Within seven days of exposure, rats given tetraphenyl resorcinol diphosphate by intravenous injection had excreted 13 per cent, 45 per cent and seven per cent (total of 65 per cent) of the administered dose in the urine, faeces and expired air (as CO_2), respectively, while monkeys had excreted 24 per cent and 26 per cent in the urine and faeces, respectively (total of 50 per cent, but expired air was not measured). At day 14, the total body burden of radioactivity in rats was less than four per cent of the administered dose, of which approximately two per cent was present in the lungs. No data relating to the intravenous administration of tetraphenyl resorcinol diphosphate to mice were reported.

Dermal absorption of tetraphenyl resorcinol diphosphate into the systemic circulation in rats was approximately 20 per cent of the administered test substance after the six-hour exposure period while, in monkeys, the amount absorbed was less than ten per cent. By seven days after dosing, in rats, seven per cent, 32 per cent and one per cent of the administered dose were eliminated in the urine, faeces and expired air, respectively. In monkeys, one per cent of the administered dose was eliminated in urine and one per cent in the faeces by seven days after dosing and by day 28 the remaining dose had been excreted.

In rats, around 83 per cent of the tetraphenyl resorcinol diphosphate administered by oral gavage was absorbed. Approximately 80 per cent of the administered dose was excreted in the faeces, a significant fraction of which reflected unabsorbed material, and seven per cent of the administered dose excreted in urine by the end of day one; approximately five per cent of the administered dose was excreted as CO_2 in expired air. In rats, following inhalation, the majority of tetraphenyl resorcinol diphosphate was excreted in the faeces (60 per cent in males; 52 per cent in females), with a lesser amount excreted in the urine (ten per cent in males, seven per cent in females).

Table 4.6 summarises the derived toxicokinetic parameters for rats and primates in this study. In both rats and monkeys, the highest peak plasma concentration (C_{max}) and greatest area under the curve (AUC) resulted from intravenous administration, while the lowest values resulted from dermal exposure. Toxicokinetic parameters were not determined for mice since adequate plasma volumes could not be collected during the treatment period due to the small size of the animals. Overall, it was concluded that there were no apparent differences between species or sexes in the metabolism of tetraphenyl resorcinol diphosphate, and tissue accumulation and retention of tetraphenyl resorcinol diphosphate among rats and primates was minimal indicating complete clearance of the administered dose.

Table 4.6 Summary of toxicokinetic parameters calculated from experiments carried out in rats and monkeys using various exposure routes

Exposure route	Animal species	% dose absorbed	C_{max} (mg equiv/ml plasma)	AUC (mg equiv/hr/ml)	T ½ (days)	MRT	V (l/kg)	Clearance (l/h/kg)	V_{ss} (l/kg)
Intravenous	Rat	–	29.2 at 0.1 hours	453 ± 119	2.38 ± 0.39	3.35 ± 0.55	4.95 ± 3.65	0.23 ± 0.05	17.95 ± 4.66
Intravenous	Monkey	–	81.9 ± 22.1 at 0.08 hours	1895 ± 213	5.15 ± 1.11	5.74 ± 1.57	1.64 ± 1.2	0.06 ± 0.04	9.25 ± 6.54
Dermal	Rat	20	0.43 ± 0.15 at 2.3 days	51 ± 18 (m) 95 ± 15 (f)	3.43 ± 0.21 (m) 4.05 ± 0.36 (f)	4.69 ± 0.33 (m) 6.9 ± 1.11 (f)	31.24 ± 12.73	0.25 ± 0.11	30.81 ± 8.35
Dermal	Monkey	10*	–	–	–	–	–	–	–
Oral	Rat	83	3.03 ± 0.67 at 53 minutes	263 ± 108	2.73 ± 0.28	3.93 ± 1.04	32.08 ± 12.61	0.34 ± 0.14	30.01 ± 7.8
Inhalation	Rat		12.13 ± 8.11 at 13.16 hours	273 ± 242	2.51 ± 0.95	2.16 ± 1.42	43.76 ± 52.29**	0.45 ± 0.36**	34.88**

Notes: C_{max} maximum plasma concentration; AUC, area under curve;
T ½ half-life of elimination; MRT mean resident time;
V volume of distribution; V_{ss} volume of distribution at steady state;
*Total absorption too low to enable calculations of toxicokinetic parameters.
**represents V/F, Clearance/F and V_{ss}/F, respectively, where F = bioavailability of tetraphenyl resorcinol diphosphate, which cannot be accurately determined in inhalation studies (Freudenthal *et al.* 2000).

4.4.2 Acute toxicity

Only data on experimental animals are available.

Oral

One acute oral lethality study is available, conducted to Good Laboratory Practice (GLP) and EPA OTS 798.1175 test guidelines (IIT 1994a, cited in IUCLID 2001). In this study, Sprague-Dawley rats (ten per sex) were given a single dose of tetraphenyl resorcinol diphosphate (Fyrolflex RDP, purity not described, 5,000 mg/kg bw) by oral gavage and observed for 14 days. Monocyte nonspecific esterase (MNSE) activity was measured in blood taken from each animal seven days prior to dosing, 24 hours after dosing and at the end of the 14 day observation period. All animals were necropsied and examined for gross lesions at the end of the observation period. No rats died during the study and no treatment-related clinical signs were observed in any of the animals. Necropsy findings were also normal. However, MNSE activity was significantly decreased in both male and female animals 14 days after dosing (no further results or details were given). Based on the lack of mortality, the acute oral LD_{50} in male and female rats is greater than 5,000 mg/kg bodyweight.

Inhalation

One valid acute inhalation study is available, conducted to GLP and EPA OPPTS 870.1300 test guidelines (IIT 1994b, cited in IUCLID 2001). In the study, Sprague-Dawley rats (ten per sex) were exposed by a nose-only inhalation system to aerosols of tetraphenyl resorcinol diphosphate (Fyrolflex RDP of unknown purity at 4.14 mg/l (determined by sample analysis)) for four hours, and then observed for 14 days. The mass median aerodynamic diameter of the aerosol was measured as 1.63 µm (standard deviation 2.84), which is within the respirable size range (IUCLID 2001). No rats died during the study. Clinical signs such as ptosis, salivation and discharge around the eyes and nose, were observed in eight out of 20 animals (no further details). All of the rats gained weight and all were symptom-free at the end of the 14-day observation period. No further results or details were given in the study summary. Based on the lack of mortality, the acute inhalation LC_{50} is greater than the highest attainable concentration of 4.14 mg/l for four hours.

Dermal

In an acute dermal study conducted by IIT (IIT 1994c, cited in IUCLID 2001) to GLP and EPA OPPTS 870.1200 test guidelines, tetraphenyl resorcinol diphosphate (Fyrolflex RDP, purity not described) was applied undiluted at a dose of 2,000 mg/kg to the shaved backs of Sprague-Dawley rats (ten per sex). The test sites were covered and the animals were collared to prevent oral ingestion of the test substance. After 24 hours, the test substance was removed and animals were observed daily for 14 days. No mortality or treatment-related clinical signs were observed during the observation period and all animals gained weight during the study. Necropsy findings for all rats were normal. No further details were reported in the study summary. Based on these findings, the acute dermal LD_{50} for Fyrolflex RDP is greater than 2,000 mg/kg.

Other

A study that investigated the metabolism and toxicokinetics of tetraphenyl resorcinol diphosphate in rats, mice and monkeys following a single dose of 100 mg radiolabelled tetraphenyl resorcinol diphosphate per kg administered via various routes of exposure is described in Section 4.4.1 (Freudenthal *et al*. 2000). No toxicological effects were reported in this study.

Summary of acute toxicity

No information is available from human studies.

Three good quality, though briefly reported, rat studies investigated acute toxicity following oral, inhalation or dermal administration of Fyrolflex RDP. No mortality was observed in any of the studies. However, transitory clinical signs such as salivation, ptosis and discharge around the eyes and nose were observed in eight out of 20 animals following inhalation of 4.14 mg Fyrolflex RDP/l, although all rats were symptom-free at the end of the 14-day observation period.

Based on the absence of mortality, oral and dermal LD_{50}s were above 5,000 mg/kg bodyweight and above 2,000 mg/kg, respectively, which are above the limit doses applied in modern studies, indicating a low level of toxicity via these exposure routes. The LC_{50} for inhalation was greater than highest attainable concentration of 4.14 mg/l (IUCLID 2001).

4.4.3 Irritation

Only experimental animal data are available.

Skin

RCC NOTOX conducted a GLP study to EU Directive 84/449/EEC guidelines which investigated the potential of tetraphenyl resorcinol diphosphate (purity not described) to irritate the skin (RCC NOTOX 1989a, cited in IUCLID 2001). The study is not well described in the secondary source and so it is not possible to independently assess its quality. In the study, 0.5 ml of undiluted tetraphenyl resorcinol diphosphate was applied on a semi-occlusive patch to the right flank of three adult female albino rabbits (strain not specified) for four hours. Control skin (location not clear) was also covered with a semi-occlusive patch. At the end of the exposure period, the test substance was removed using tissues and tap water. Skin was observed after 45 minutes and again at 24, 48, and 96 hours after removal of the patches for signs of oedema and erythema, and any irritation was graded according to the Draize scoring system. There were no signs of dermal irritation at the application site of any of the three animals, thus the primary skin irritation index was zero.

Eye

One GLP study, conducted to Directive 84/449/EEC guidelines, investigated the potential of tetraphenyl resorcinol diphosphate (purity not described) to irritate the eye (RCC NOTOX 1989b, cited in IUCLID 2001). In this study, 0.1 ml of undiluted tetraphenyl resorcinol diphosphate was applied to the left eye of each of three albino rabbits (strain and sex not specified). The eye lids were then held together for two

seconds. The non-treated right eye of each animal served as a control. Eyes were observed immediately after treatment and at 1, 24, 48 and 72 hours for effects on the cornea, iris, and conjunctiva. One hour after treatment, the treated eye of one rabbit showed slight conjunctival redness and chemosis; the slight irritation was no longer present at the 24-hour observation time. The treated eyes of the other rabbits showed no irritation. At 24 hours after treatment, a solution of two per cent fluorescein was applied to control and treated eyes of all rabbits, which were then examined for corneal damage. No adverse effects to the cornea or iris were observed in any of the three rabbits. The Draize score was 3.3 at one hour after treatment, indicating that tetraphenyl resorcinol diphosphate is minimally irritating.

Summary of irritation

No information is available from human studies.

In two EC guideline studies, tetraphenyl resorcinol diphosphate was not irritating to the skin but was found to cause mild reversible irritation to the eye of one of three rabbits tested.

4.4.4 Corrosivity

Studies that have investigated the potential of tetraphenyl resorcinol diphosphate to irritate the skin and eyes do not suggest that tetraphenyl resorcinol diphosphate has corrosive properties.

4.4.5 Sensitisation

A Material Safety Data Sheet (Great Lakes Chemical Corporation 2003) states that the compound is ‘not a skin sensitiser’ but no supporting reference is provided and no other information on the sensitisation potential of tetraphenyl resorcinol diphosphate has been identified. Thus, it is not possible to assess the sensitizing potential tetraphenyl resorcinol diphosphate.

4.4.6 Repeated-dose toxicity

Animal data

No studies have investigated the general toxicity of tetraphenyl resorcinol diphosphate following repeated oral administration. However, a 28-day oral study in mice conducted to investigate the effects of repeated exposure on the immune system and a repeat inhalation exposure study in rats are relevant to the assessment of the toxicity of tetraphenyl resorcinol diphosphate.

A well-reported 28-day GLP study conducted in 1996 to EPA OTS 798.2450 guidelines investigated the potential adverse effects of repeated inhalation exposure of rats to Fyrolflex RDP (Henrich *et al*. 2000). The composition of the test substance was 65 to 80 per cent tetraphenyl resorcinol diphosphate, under five per cent triphenyl phosphate and 15 to 30 per cent higher oligomers. In the study, rats (20/sex/group in the control and high-dose group and ten/sex/group in the low-dose group) were exposed by nose-only inhalation to Fyrolflex RDP aerosols generated using a Laskin

nebulizer at target concentrations of 0, 0.1, 0.5 and 2.0 mg/l, for six hours per day, five days per week, for four weeks. Chamber aerosols, measured two to three times during each exposure period, were within ten per cent of target concentrations and particle size ranged from 1.39 to 1.70 µm. Animals were sacrificed within 24 hours of the last exposure, with the exception of ten rats per sex from each of the control and high-dose groups which were held for a 60-day recovery period.

During the study, animals were observed daily for mortality and clinical signs of toxicity, and further clinical observations and measurements of food consumption and body weight were measured weekly. Haematology and clinical chemistry parameters were measured at the end of the 28-day exposure. In addition, MNSE and plasma and erythrocyte cholinesterase (ChE) activities were measured seven days prior to the first exposure, on day 29 (after the last exposure), and on days 33 (during recovery period, MNSE only) and day 89 (at end of recovery period; results discussed below). At termination, gross necropsies were conducted on all animals. The adrenal glands, brain, buccal mucosa, epididymides, oesophagus, eyes, heart, kidneys, larynx, liver, lungs, nasal turbinates, ovaries, pancreas, spleen, pituitary, thymus, thyroid glands, spinal cord, testes and trachea were examined microscopically in those control and high-dose animals killed at day 28. Any organs/tissues identified with treatment-related lesions were examined microscopically in animals from the low-, mid-dose and recovery groups. No deaths or treatment-related clinical signs were observed during the exposure and recovery periods.

The mean bodyweight and food consumption of the high-dose males was significantly decreased, with the mean bodyweight gain reduced by approximately 20 per cent in high-dose males compared with controls on day 28. No effects on bodyweight or weight gain were observed in females. Some significant differences were observed between exposed groups and controls for several parameters (such as decreased glucose in high-dose rats, increased globulin in mid-dose females, decreased bilirubin in mid- and high-dose males and haematological changes in low-dose females) but details of the magnitude of the effects were not given. However, these changes were not considered by the authors to be treatment-related on the basis of the levels recorded being within the range of historical controls, effects seen in one sex only or lack of dose-relationship.

At the end of the exposure period, a dose-related increase in absolute and relative lung weights was observed in treated animals; the increase was statistically significant in the mid- and high-dose groups. This effect persisted and remained statistically significant in high-dose animals at the end of the recovery period. Gross pathology revealed confluent white foci in the lungs of all high-dose rats after 28 days, and in six of 10 and all ten high-dose males and females respectively, after the recovery period. Lung histopathology showed alveolar histiocytosis in all mid- and high-dose group animals at the end of the exposure period and chronic foreign body inflammation was observed in high-dose animals at the end of the recovery period. The authors considered this to be a typical response to non-cytotoxic, water insoluble, foreign material that reaches the alveolar region of the lung, and this was not considered to reflect a specific toxic response to Fyrolflex RDP per se. Mean absolute liver weights were significantly increased in high-dose females (7.82 ± 0.59 g compared with controls: 6.87 ± 0.5 g) and mean relative liver weights were significantly increased in mid- and high-dose females (3.18 ± 0.39 per cent and 3.29 ± 0.18 per cent, respectively) and high-dose males (3.10 ± 0.19 per cent) after 28 days of exposure. No associated blood chemistry changes were noted and, although no histopathological changes normally associated with liver enzyme induction were noted, neither were any changes associated with liver toxicity. The authors considered the liver weight effect to be an adaptive response, associated with metabolism of the test substance. Based on the bodyweight changes in high-dose males and the apparently non-chemical specific changes noted in the lungs of mid- and high-dose animals, the NOEL for general toxicity endpoints is 0.1 mg/l.

A 28-day GLP study conducted in 1992 by IIT Research Institute investigated the potential adverse effects of repeated exposure of mice to a commercial preparation of tetraphenyl resorcinol diphosphate, with a particular focus on effects on the immune system (Sherwood *et al*. 2000). The study is of good quality; the elements of the study addressing immunotoxicity and neurotoxicity are reported below. With regard to general toxic potential, in this study groups of 50 female B6C3F1 mice were given 500, 1,500 or 5,000 mg/kg bw/day of the test substance (Fyrolflex RDP Lot No. 3185S-23-1, composition not given) by oral gavage, for 28 days. Negative control animals were sham-dosed and did not receive any test or control material. Positive control animals were dosed with either cyclophosphamide or diethylstilbestrol. Half of the animals were killed after the 28-day exposure period while the remaining ones were held untreated for an additional 60-day recovery period. Bod weights were determined weekly. Gross necropsies, histopathology of the thymus, spleen, representative lymph nodes and all gross lesions, thymus and spleen wet weights, were conducted on ten animals per group at the end of the exposure and recovery periods. No treatment-related clinical signs were seen in any of the animals and none died during the exposure or recovery periods. There were no adverse necropsy findings. A significant increase in bodyweight of high-dose mice was observed at week four, and other small changes in bodyweight were noted in other groups at different time points though these are not considered to be treatment-related. Based on these findings, the no observed adverse effect level (NOAEL) in mice for general toxic endpoints (excluding neurotoxic and immunotoxic endpoints) was 5,000 mg/kg bw/day.

Neurotoxicity

In the 28-day rat GLP study conducted to test guidelines by Henrich *et al* (2000, discussed in detail above), effects on MNSE and plasma and erythrocyte ChE were assessed in animals exposed to Fyrolflex RDP aerosols at target concentrations of 0, 0.1, 0.5 and 2.0 mg/l. Plasma ChE was significantly inhibited in high-dose males (15 per cent) and mid- and high-dose females (38 and 64 per cent, respectively) at the end of the 28-day exposure period, and was still affected in the high-dose females at the end of the 60-day recovery period. However, erythrocyte ChE activity was unaffected after exposure (day 29) and recovery (day 89) and no clinical signs suggestive of a neurotoxic effect were observed. Intergroup differences in MNSE activity did not display any evidence of dose-relationship; activity in low- and mid-dose animals was higher than controls, but that for high-dose animals was similar to controls. The authors considered these findings not to be of toxicological significance, and the NOEL for neurotoxic endpoints was therefore considered to be 2.0 mg/l.

In the 28-day study in mice conducted by IIT Research Institute (Sherwood *et al*. 2000), described in detail above, animals received 0, 500, 1,500 or 5,000 mg/kg bw/day of Fyrolflex RDP by oral gavage, for 28 days. Measurement of erythrocyte ChE activity and plasma ChE was conducted on ten animals per group at the end of the exposure and recovery periods. Values reported in both treated and control animals were noted to be very variable. After both 28 days' exposure and a 60-day recovery period, erythrocyte and plasma ChE activity levels in sham control and Fyrolflex RDP-treated animals were significantly lower than those of baseline control animals. There was, however, a dose-related decrease in plasma ChE compared with the sham controls on day 29 but this difference was not apparent after the 60-day recovery period. The significance of this isolated finding in terms of the neurotoxic potential of this compound is questionable.

Immunotoxicity

In the 28-day immunotoxicity study conducted by IIT Research Institute (Sherwood *et al*. 2000, described in detail above), the test battery was selected from those recommended by the National Toxicology Programme for immunotoxicity evaluation of

xenobiotics. Measured immune system endpoints included: thymus and spleen cellularity and cell viability; splenic natural killer cell activity; splenic T-lymphocyte blastogenesis; macrophage numbers and phagocytic activity; antibody forming cell response; and host susceptibility to infectious challenge with *Listeria monocytogenes*. No significant differences were observed in spleen or thymus weights or cellularity, and no histopathologic changes in thymus, spleen or lymph nodes were found. There were no treatment-related changes in peritoneal cell numbers or cell types, peritoneal macrophage phagocytic activity or host susceptibility to infection. Splenic natural killer cell activity, lymphocyte blastogenesis, and antibody forming cell function were also unaffected by treatment. In this 28-day study Fyrolflex RDP, treatment did not result in immunotoxicity and therefore the NOAEL for immunotoxicity is greater than 5,000 mg/kg bw/day.

Human data

No human data are available.

Summary and discussion of repeated- dose toxicity

Two well-conducted studies inform on the general toxicity potential of tetraphenyl resorcinol diphosphate following repeated administration by oral gavage or inhalation; good quality information is also available from a mouse study on immunotoxic potential, and there are limited but relevant data on neurotoxic potential in rats and mice.

In a well-reported 28-day rat inhalation study conducted to GLP and test guidelines, significantly lower bodyweight and food consumption values were noted in males given Fyrolflex RDP at 2.0 mg/l, and evidence of liver enlargement was noted in rats of both sexes exposed at 0.5 or 2.0 mg/l. Pathological changes considered typical of the response of rodent lungs to high-level exposure to non-cytotoxic, water insoluble, foreign material were also noted in these treated groups, but this effect was not considered to reflect a specific toxic response to Fyrolflex RDP per se. The NOEL for general toxicity endpoints in this study was 0.1 mg/l. In a 28-day mouse oral study conducted to GLP and test guidelines, treatment with tetraphenyl resorcinol diphosphate at up to 5,000 mg/kg bw/day did not elicit any treatment-related changes suggestive of general toxicity or immunotoxicity, and this level was therefore considered to be the oral NOAEL in mice. Furthermore, although the extent of investigations of neurotoxicity endpoints was limited in these studies, neither study provided clear evidence of neurotoxic effects for tetraphenyl resorcinol diphosphate.

4.4.7 Mutagenicity

Studies in vitro

Genetic mutations

A reverse mutation assay conducted in 1998 by Covance Laboratories for Akzo Nobel Chemicals Inc. (cited in IUCLID 2001) found that TBRDP (at 5,000, 2,500, 1,000, 333, 100, and 33.3 µg/plate) was not mutagenic to strains of *Salmonella typimurium* and *Escherichia coli,* with or without metabolic activation. The study was carried out to GLP and OECD test 471 guidelines, although no further details on the test methodology or

results were reported. A Klimisch code of (1) valid without restriction was assigned to this study in the secondary source, providing an indication of study reliability.

Chromosomal effects

A mammalian chromosomal aberration test was undertaken in cultured human lymphocytes in 1989 by RCC NOTOX for GE Plastic Europe (cited IUCLID 2001). The study was carried out to OECD test guideline 473 and GLP, but full study details were not available. A Klimisch code of (1) valid without restriction was assigned to this study in the secondary source, providing an indication of study reliability. In the study, human peripheral lymphocytes were incubated with tetraphenyl resorcinol diphosphate, with and without metabolic activation, for up to 96 hours. Cells were arrested in the metaphase stage by the addition of colchicine, and then chromosomes were examined microscopically for the presence of aberrations (breaks, gaps, fragments, dicentrics and exchange figures). Positive controls (mytomycin C without activation, and cyclophosphamide with metabolic activation) produced statistically significant increases in the frequency of aberrant cells, while tetraphenyl resorcinol diphosphate exposure did not induce chromosomal aberrations with or without metabolic activation.

Studies in vivo

One *in vivo* genotoxicity study was conducted to GLP and OECD guideline 474 (RCC NOTOX 1988, cited IUCLID 2001) which assessed the potential of tetraphenyl resorcinol diphosphate to induce microneuclei in the bone marrow cells of mice; full study details were not available. In the study, three groups of mice (five/sex/group) were given a single dose of tetraphenyl resorcinol diphosphate (500 mg/kg bw) by oral gavage and bone marrow was extracted from the mice at 24, 48 or 96 hours after dosing. Postive control animals were given the chemical cyclophosphamide, and bone marrow extracted 48 hours later. Slides were prepared containing bone marrow smears and the numbers of micronuclei per 1,000 polychromatic erythrocytes counted for each animal. There was no increase in the frequency of micronuclei in bone marrow cells from tetraphenyl resorcinol diphosphate-treated mice. In contrast, positive control animals showed a significant increase in the number of micronuclei in bone marrow cells.

Summary of mutagenicity

Three OECD guideline studies assessed the mutagenicity and genotoxic potential of tetraphenyl resorcinol diphosphate *in vitro* and *in vivo*. The level of reporting of these studies in the secondary literature is not sufficient to determine the quality of the studies and results. Nonetheless, all three studies gave negative results, which indicate, on a weight-of-evidence basis, that tetraphenyl resorcinol diphosphate is unlikely to be an *in vivo* mutagen.

4.4.8 Carcinogenicity

No data are available on the carcinogenic potential of tetraphenyl resorcinol diphosphate.

4.4.9 Toxicity to reproduction

Fertility and reproductive toxicity

A two-generation study conducted by IIT Research Institute in 1996, to GLP and EPA OPPTS 870.3800 guidelines, investigated the possible effects of tetraphenyl resorcinol diphosphate exposure on reproduction and fertility in rats (Henrich *et al.* 2000). In the study, male and female Sprague-Dawley rats (30/sex/group) were given untreated diet or diet containing Fyrolflex RDP (composition not given) at a concentration of 1,000, 10,000 or 20,000 ppm (equivalent to achieved doses of 0, 49, 520 or 995 mg/kg bw/day for males and 0, 59, 602 or 1,199 mg/kg bw/day for females, respectively). Animals of the parental generation (F_0) were dosed for ten weeks prior to mating, during a two-week mating period, and through gestation and lactation until sacrifice. First generation (F_1) pups (culled to four/sex/litter on postnatal day four) were weaned on postnatal day 25, and selected pups (at least one/sex/litter) were housed and fed the same dose levels as the parent animals for 11 weeks prior to mating, through mating, gestation, lactation and weaning, until sacrifice (equivalent to achieved doses of 0, 55, 602 or 1,260 mg/kg bw/day for F_1 males and 0, 63, 683 or 1,411 mg/kg bw/day for F_1 females, respectively). Second generation (F_2) pups were culled to four/sex/litter on postnatal day four. All F_2 pups and their F_1 sires and dams were sacrificed after weaning of the F_2 generation.

Animals were examined at least once a day for morbidity and mortality, and during gestation dams were examined twice a day for signs of parturition. Each animal was given a weekly clinical examination involving handling, and on the day of birth the gross external appearance of each pup was evaluated. Anogenital distance was measured in F_1 control and high-dose pups (one/sex/litter) at birth (postnatal day zero). Food consumption and bodyweights were measured on a weekly basis in all rats prior to mating, then weekly in male rats after mating and on gestation days 0, 6, 12, 18 and 20 and postnatal days 0, 4, 7, 14 and 21 in pregnant females. Pups were weighed on postnatal days 0, 4, 7, 14 and 21. Vaginal smears were taken from all females for three weeks prior to mating to evaluate cyclicity. F_0 and F_1 rats (at least 20/sex/group) were subjected to gross necropsy whereas F_2 rats and culled pups were euthanized and discarded without necropsy. The uterus, ovaries with oviducts, testes, left total and caudal epididymides, prostate, brain, liver, kidneys, adrenal, spleen, thymus and seminal vesicles were weighed at necropsy; these organs were then examined for any gross lesions as were the vagina, cervix, stomach and pituitary. Sperm count, morphology and motility (total and progressive) were assessed in control and high-dose F_0 and F_1 male rats (at least 25 per group). The following tissues (as appropriate) were examined microscopically in control and high-dose F_0 rats (20 per group): vagina, uterus, ovaries with oviducts, cervix, testes, epididymides, prostate and seminal vesicles. The ovaries, testes and any gross lesions were examined in control and high-dose F_1 animals (20 per group). The livers from control and high-dose F_0 and F_1 rats were also examined microscopically (ten/sex/group).

The only clinical observation in F_0 and F_1 animals was the appearance of red material around the eyes and nose. This sign was slightly more frequent among treated animals (1-6/sex/group) when compared with controls (one or two per sex) and was considered to be related to general stress. No treatment-related mortality was observed during the study; one F_0 dam in the high-dose group died spontaneously at postnatal day seven and two F_1 dams (one mid-, one high-dose) died during parturition. Some initial decreases (during week one) in food consumption, bodyweight and bodyweight gain were noted in mid- and high-dose F_0 animals, particularly males, which was attributed to taste aversion. By the end of the first week, the rats appeared to have acclimatised to the diet. No effects were observed on F_0 maternal bodyweight, bodyweight gain and

food consumption during gestation, although a dose-related reduction in food consumption, mean bodyweight and bodyweight gain was noted in treated F_1 pups (significant at mid- and high-doses) during lactation and after weaning, and a significant reduction in the mean litter bodyweight in F_2 pups was observed at all doses. These effects were also attributed to a taste aversion. The effects on bodyweight persisted throughout the duration of the study.

Sexual maturation (assessed as time of vaginal patency and preputial separation) was significantly delayed in mid- and high-dose F_1 rats, which the authors attributed to the decreased food consumption and bodyweights. No differences in the reproductive performance or litter size and litter survival were observed between groups in the F_0 and F_1 generations, and no differences were observed on the average frequency of the oestrus cycle. No effects on sperm count, motility and morphology were noted, and there were no differences in the mean anogentital distance between groups of F_1 rats. No treatment-related gross lesions were observed. However, adrenal and liver weights were significantly increased in mid- and high-dose F_0 and F_1 males and F_1 females (adrenal – high dose only), and at all doses in F_0 females. Microscopic examination of the livers of ten male and female rats from the high-dose and control group revealed hepatic periportal hypertrophy, characterised by the presence of enlarged periportal hepatocytes which the authors concluded was most likely an adaptive effect associated with induction of cytochrome P450 enzymes resulting in increased enzyme activity although no results were presented to support this. The authors attributed the increased adrenal weights to stress, associated with food avoidance. No treatment-related effects in the reproductive organs were observed. The NOAEL for reproductive effects of Fyrolflex RDP administered in the diet was therefore greater than 20,000 ppm (equivalent, in the F_0 generation, to 995 mg/kg bw/day for males and 1,199 mg/kg bw/day for females and, in the F_1 generation, to 1,260 mg/kg bw/day for males and 1,411 mg/kg bw/day for females).

Developmental toxicity

A GLP study conducted in 1996 to revised draft EPA OPPTS 870.3700 guidelines investigated the potential of tetraphenyl resorcinol diphosphate to adversely affect fetal development in New Zealand rabbits (Ryan *et al*. 2000). Pregnant rabbits (27 per group) were given doses of tetraphenyl resorcinol diphosphate (50, 200 or 1,000 mg/kg bw/day) in corn oil, by oral gavage at a constant volume of 1.5 ml/kg bw, during gestation days 6 to 28. Vehicle controls (27 animals) were given corn oil only, by oral gavage. All animals were observed up to twice a day for morbidity and mortality, and for signs of toxicity in the first three hours after dosing. Body weight and food consumption was measured at regular intervals on gestation days up to 29.

On day 29, does were sacrificed using an overdose of sodium pentobarbital and given a caesarean section to determine their pregnancy status; the presence of any gross lesions and/or abnormalities in the does or fetuses was recorded. The liver, spleen, kidneys, uterine horns, foetuses and ovaries were removed, trimmed of fat and weighed, and the numbers of corpora lutea in each ovary were counted. Fetuses underwent an external and wet visceral examination and approximately one third of each litter was decapitated and the heads examined. The skeletons of all fetuses were examined and anomalies and malformations classified according to severity. None of the pregnant animals died during the study and no dose-related clinical signs of toxicity were observed. Two premature deliveries (prior to gestation day 29) were observed in the lowest dose group (50 mg/kg bw/day) and one doe in the 200 mg/kg bw/day group gave birth to pups on day 29 gestation (full-term). No significant intergroup differences were observed in mean bodyweights or bodyweight gains. Occasional and isolated significant increases in bodyweight gain and food consumption were observed in high-dose animals relative to controls. No significant differences in organ weights of treated

animals compared with controls were observed, and no gross lesions were noted in any of the treated dams although one control animal had a mass in the left fallopian tube. No effects of tetraphenyl resorcinol diphosphate treatment were observed on the number of live fetal implants, total implants, resorptions, numbers of corpora lutea or preimplantation loss. The greatest number of dead fetuses occurred in one litter of the high-dose group and was considered to be a cluster effect and not treatment-related. No effects were observed on fetal male/female ratios or mean fetal bodyweights, and no treatment-related gross external, skeletal, visceral or cephalic anomalies were noted. The total numbers of fetuses with any combination of malformations were 1/217, 3/215, 3/215 and 3/219 in the control, 50, 200 or 1,000 mg tetraphenyl resorcinol diphosphate/kg bw/day dose groups, respectively, and incidences of fetal anomalies were within the range of historical controls. Based on the absence of maternal or fetal toxicity, the NOAEL for developmental toxicity for tetraphenyl resorcinol diphosphate is greater than 1,000 mg/kg bw/day.

Summary of toxicity to reproduction

Two EPA guideline studies conducted to GLP evaluated the effects of repeated tetraphenyl resorcinol diphosphate exposure on reproduction and development. No treatment-related effects on reproductive performance or fertility of F_0 rats or on the reproduction of rats or development of offspring in rats and rabbits were noted. Some other changes were noted in the two-generation rat reproductive toxicity study, including changes in food consumption, bodyweights and the weight of adrenal glands in treated animals (considered to be a result of food aversion) and hepatic periportal hypertrophy in high-dose rats (attributed to an adaptive response to metabolism of tetraphenyl resorcinol diphosphate). Based on the lack of reproductive toxicity, the NOAEL for tetraphenyl resorcinol diphosphate administered in the diet is greater than 20,000 ppm (equivalent, in the F_0 generation, to 995 mg/kg bw/day for male rats and 1,199 mg/kg bw/day for female rats and, in the F_1 generation, to 1,260 mg/kg bw/day for males and 1,411 mg/kg bw/day for females).

In the developmental study on rabbits, no treatment-related effects were observed in dams or fetuses. Thus, the NOAEL for developmental toxicity for tetraphenyl resorcinol diphosphate is greater than 1,000 mg/kg bw/day.

4.4.10 NOAEL and Margins of Safety (MOS) for assessment of human exposure via the environment

The reproductive study by Henrich *et al.* (2000) is the most appropriate repeated dose study, since it gave the lowest NOAEL of the valid studies. The result is 995 mg/kg bw/day for male rats. There are no data on the carcinogenic or neurotoxic potential of the compound.

A margin of safety of at least 1,000-fold is considered necessary to provide reassurance against effects on human health. This is based on applying uncertainty factors for interspecies variation (10), intraspecies variation (10), extrapolation from sub-chronic to chronic (2), with an additional factor of five to take account of the lack of neurotoxicity data.

4.4.11 Derivation of PNEC for secondary poisoning

The lowest NOAEL from the mammalian studies is 995 mg/kg bw/day, as described above. This corresponds to a concentration in food of 20,000 ppm (20 g/kg) in the

study. An assessment factor of 90 is appropriate for this study, of 90 days duration. Hence, the PNEC for secondary poisoning is 220 mg/kg.

No avian toxicology data relevant to the derivation of a $PNEC_{oral}$ were identified for tetraphenyl resorcinol diphosphate.

4.5 Hazard classification

4.5.1 Classification for human health

Tetraphenyl resorcinol diphosphate is not currently classified in Annex I of Directive 67/548/EEC. According to EU criteria, tetraphenyl resorcinol diphosphate need not be classified on the basis of its acute toxicity, skin or eye irritancy and corrosivity, mutagenicity, or reproductive and developmental toxicity.

Assuming that the changes observed in the lung and liver are, respectively, attributable to a non-specific response to insoluble material and adaptive in nature, no findings suggest that tetraphenyl resorcinol diphosphate should be classified in the EU for specific target organ systemic toxicity following repeated exposure.

There is a lack of adequate data with which to assess the skin-sensitizing potential or carcinogenic potential of tetraphenyl resorcinol diphosphate, and hence this compound cannot be classified for these aspects at this time.

4.5.2 Classification for the environment

Current classification

Tetraphenyl resorcinol diphosphate is not currently included in Annex I of Directive 67/548/EEC. A commercial product is currently classified as follows (Great Lakes Chemical Corporation 2002):

R52/53: Harmful to aquatic organisms. May cause long-term adverse effects in the aquatic environment.

Proposed classification

The fish BCF for tetraphenyl resorcinol diphosphate is estimated to be around 969 kg/l and the substance is considered to be inherently biodegradable. The substance has a 48-hour LC_{50} of 0.76 mg/l. Based on these data, the following classification would appear to be appropriate.

N: Dangerous for the environment.

R50/53: Very toxic to aquatic organisms. May cause long-term adverse effects in the aquatic environment.

4.6 PBT assessment

The criteria for persistence (P and vP), bioaccumulation potential (B and vB) and toxicity (T) included in the TGD are shown in Table 4.7.

Table 4.7 Criteria for identification of PBT and vPvB substances

Criterion	PBT criteria	vPvB criteria
P	Half-life above 60 days in marine water or above 40 days in freshwater* or half-life above 180 days in marine sediment or above 120 days in freshwater sediment*	Half-life above 60 days in marine water or freshwater or above 180 days in marine or freshwater sediment
B	BCF above 2,000	BCF above 5,000
T	Chronic NOEC below 0.01 mg/l or classification for certain human health end points, or endocrine disrupting effects	Not applicable

Notes: * For the purpose of marine environment risk assessment, half-life data in freshwater and freshwater sediment can be overruled by data obtained in marine conditions.

Persistence: tetraphenyl resorcinol diphosphate is considered to be inherently biodegradable but it is not possible to determine if the specific criteria are met (Section 3.1.1). The substance undergoes hydrolysis in water with a half-life at 10°C shorter than the criteria. However, this is for primary degradation, and the results also indicate that the reaction may reach equilibrium after one or two half-lives. This is not considered sufficient evidence that the substance does not meet the criteria. Hence, the substance is considered to meet the first stage screening criteria for P and vP.

Bioconcentration: a fish BCF of 969 l/kg is estimated in Section 3.1.3. Hence, the substance does not meet the B criterion.

Toxicity: the lowest measured NOEC value is 0.021 mg/l and the lowest estimated NOEC is 0.014 mg/l. The substance does not meet the T criterion.

The overall conclusion is that the substance meets one of the criteria on the basis of screening data, but does not meet the other two criteria and so is not a PBT/vPvB substance.

5 Risk characterisation

This section identifies the potential risks that tetraphenyl resorcinol diphosphate might pose for the freshwater and marine aquatic compartments, terrestrial compartment, air compartment and predatory organisms through secondary poisoning. The risk characterisation is performed by comparing the PECs with the PNECs to derive a risk characterisation ratio (RCR). An RCR of less than one implies that any risk resulting from that level of exposure is acceptable. An RCR above one implies a potential risk, and all such values are highlighted in bold in the following tables. Annex C considers the effect of a faster hydrolysis rate on the overall conclusions.

As discussed in Section 3.1.2, the adsorption potential of the substance (represented by the K_{oc}) is estimated, and this has a significant influence on its predicted partitioning behaviour in the environment. There is some evidence for triphenyl phosphate (see the risk evaluation report of that substance in this series) that the prediction method might underestimate the K_{oc} for this type of substance. A sensitivity analysis has been performed in Annex D, and this shows that a higher K_{oc} value would affect the conclusions, but not necessarily in a straightforward (or especially significant) way. Further testing for sediment sorption coefficient is suggested for triphenyl phosphate, and this could indicate a need for further studies with this substance.

5.1 Freshwater compartment

5.1.1 Surface water

A PNEC for surface water was estimated to be 2.1 μg/l. The resulting risk characterisation ratios are summarised in Table 5.1.

Table 5.1 Summary of risk characterisation ratios for surface water

Scenario		Predicted concentration (μg/l)	PEC/PNEC
Production of tetraphenyl resorcinol diphosphate		3.55 and 0.07	**1.69** and 0.03
Pigment dispersions	Production of dispersions	1.52	0.73
PVC – 1	Compounding	0.35	0.17
	Conversion	0.08	0.04
	Combined compounding and conversion	0.37	0.18
PVC – 2	Compounding	0.35	0.17
	Conversion	0.08	0.04
	Combined compounding and conversion	0.37	0.18
Paints and coatings	Formulation	0.32	0.15
	Application	0.45	0.22
Thermo-plastics/ styrenics	Compounding	16.7	**7.97**
	Conversion	1.58	0.75
	Combined compounding and conversion	18.2	**8.67**

Table 5.1 continued.

Scenario		Predicted concentration (μg/l)	PEC/PNEC
Polyurethane	Compounding	1.52	0.73
	Conversion	0.19	0.09
	Combined compounding and conversion	1.66	0.79
Regional sources		0.05	0.03

The PEC/PNEC ratio is above one for one production site. As noted in Section 3.2.2, further qualitative information relating to this production site has been received which indicates that the emissions of tetraphenyl resorcinol diphosphate from this site are much lower than those estimated here[12]. Although it is not possible to make revised estimates, the concentrations are expected to be of a similar order to those for the other site, and hence there is not considered to be a risk.

Risks are also identified from use in thermoplastics/styrenics. Further information is needed on process emissions to refine PECs for these scenarios, to determine whether there is a risk to surface water from these uses. The emission estimates are based on information for the industry area from the Emission Scenario Document (ESD 2004) or from other risk assessments, so could be revised with more specific information for the substance itself.

The sensitivity analysis in Annex C suggests that a faster hydrolysis rate than assumed here would only have a small impact on surface water concentrations.

The PNEC is derived from test data but uses predicted values to argue that fish and algae are not likely to be more sensitive than invertebrates (and hence an assessment factor of 10 is used). Therefore, although no long-term fish test is available (though one could be performed), such a test would not reduce the risk ratios. If the PNEC were based only on available test results, risk ratios would be five times higher; this would add risks for the production of pigment dispersions, application of paints, combined compounding and conversion of polyurethanes, and for conversion of thermoplastics.

The risk to surface water from regional sources appears to be low.

5.1.2 Waste water treatment

The PNEC for waste water treatment processes is 122 mg/l. Risk characterisation ratios were calculated and are under 0.01 for the production and all uses of tetraphenyl resorcinol diphosphate. These ratios are not included here.

Based on the PEC/PNEC ratios, no risk to waste water treatment plants would be expected from the production and use of tetraphenyl resorcinol diphosphate.

5.1.3 Sediment

The PNEC for sediment was tentatively estimated to be 0.336 mg/kg wet weight. The resulting risk characterisation ratios, increased by a factor of 10 to take into account the possibility of direct ingestion of the test substance, are summarised in Table 5.2.

[12] The estimate of releases in this assessment assumes that all of the phosphates produced at the site are released to a similar extent. The production and purification process for this substance is in fact different, and there is much less potential for contact with water, hence the water emissions will be lower. However, there is no specific quantitative information on this.

The PEC/PNEC ratio is above one for a production site. As noted for surface water, the concentrations at this site are in fact expected to be similar to those at the other site and so no risk is concluded.

The ratios are also above one for use in pigment dispersions, PVC, polyurethane, formulation and application of paints and for use in thermoplastics/styrenics. The information noted for the water compartment to improve the exposure estimates for thermoplastics would also be relevant here, and similar considerations apply to the other use areas showing a risk. The risk from regional sources appears to be low.

Table 5.2 Summary of risk characterisation ratios for sediment

Scenario		Predicted concentration (mg/kg wet wt.)	PEC/PNEC
Production of tetraphenyl resorcinol diphosphate		0.57 and 0.01	**16.9** and 0.32
Pigment dispersions	Production of dispersions	0.24	**7.25**
PVC – 1	Compounding	0.06	**1.65**
	Conversion	0.01	0.38
	Combined compounding and conversion	0.06	**1.78**
PVC – 2	Compounding	0.06	**1.65**
	Conversion	0.01	0.38
	Combined compounding and conversion	0.06	**1.78**
Paints and coatings	Formulation	0.05	**1.53**
	Application	0.07	**2.16**
Thermo-plastics/ styrenics	Compounding	2.68	**79.7**
	Conversion	0.25	**7.5**
	Combined compounding and conversion	2.91	**86.7**
Polyurethane	Compounding	0.24	**7.25**
	Conversion	0.03	0.89
	Combined compounding and conversion	0.27	**7.88**
Regional sources		0.01	0.44

The sensitivity analysis in Annex C suggests that a faster hydrolysis rate than assumed here could have a significant effect on local and regional sediment PECs. It may be possible to refine the PECs by carrying out further testing[13] to investigate the actual degradation (mineralization) half-life in sediment under relevant environmental conditions.

The PNEC for sediment is based on the equilibrium partitioning approach, and PEC/PNEC ratios have been increased by a factor of 10 to take into account the possibility of direct ingestion of sediment-bound substance. Sediment toxicity tests could be carried out to refine the PNEC for this endpoint if it is not possible to revise the exposure assessment. It is likely that three long-term tests would be required.

[13] The half-life determined in such a test would be the result of degradation by both biodegradation and hydrolysis to biodegradable substances.

5.2 Terrestrial compartment

The PNEC for soil is tentatively estimated to be 0.272 mg/kg wet weight. The resulting risk characterisation ratios, increased by a factor of 10 to take into account the possible direct ingestion of soil-bound substance, are summarised in Table 5.3.

The PEC/PNEC ratios are above one for use in pigment dispersions, PVC, polyurethane, thermoplastics/styrenics, formulation and application of paints and for regional industrial soil. Further information is needed on emissions from the processes to refine the PECs for these scenarios, as noted for the water and sediment compartments. The risk to regional agricultural and natural soil appears to be low.

Table 5.3 Summary of risk characterisation ratios for the terrestrial compartment

Scenario		Predicted concentration (mg/kg wet wt.)	PEC/PNEC
Production of tetraphenyl resorcinol diphosphate		2.14×10^{-4} and 1.47×10^{-4}	<0.01
Pigment dispersions	Production of dispersions	0.33	**12**
PVC – 1	Compounding	0.07	**2.4**
	Conversion	6.12×10^{-3}	0.23
	Combined compounding and conversion	0.07	**2.62**
PVC – 2	Compounding	0.07	**2.4**
	Conversion	6.12×10^{-3}	0.23
	Combined compounding and conversion	0.07	**2.62**
Paints and coatings	Formulation	0.06	**2.19**
	Application	0.09	**3.27**
Thermo-plastics/ styrenics	Compounding	3.7	**136**
	Conversion	0.34	**12.5**
	Combined compounding and conversion	4.03	**148**
Polyurethane	Compounding	0.33	**12**
	Conversion	0.03	**1.1**
	Combined compounding and conversion	0.36	**13.1**
Regional sources	Agricultural soil	1.59×10^{-4}	<0.01
	Natural soil	1.47×10^{-4}	<0.01
	Industrial soil	0.14	**5.15**

Notes: a) Sludge from the production sites is not applied to agricultural soil.

Like sediment, the sensitivity analysis in Annex C suggests that a faster hydrolysis rate than assumed here could have a significant effect on local and regional soil PECs. It may therefore be possible to refine the PECs by carrying out further testing to investigate the actual degradation (mineralization) half-life in soil under relevant environmental conditions.

The PNEC for soil is based on the equilibrium partitioning approach, and the PEC/PNEC ratio has been increased by a factor of 10 to take into account the possibility of direct ingestion of soil-bound substance. Toxicity tests with soil organisms would allow the PNEC for this endpoint to be refined. As for sediment, testing on three species in long-term tests would probably be required.

5.3 Atmosphere

No information is available on the toxicity of tetraphenyl resorcinol diphosphate to plants and other organisms exposed via air. The low vapour pressure of the substance means that volatilisation to the atmosphere is likely to be limited and the resulting concentrations are likely to be low. The possibility of tetraphenyl resorcinol diphosphate contributing to atmospheric effects such as global warming and acid rain is thus likely to be small. In addition, as the substance does not contain halogen atoms, it will not contribute to ozone depletion.

5.4 Secondary poisoning

The PNEC for secondary poisoning is estimated to be 220 mg/kg food. The resulting risk characterisation ratios are summarised in Table 5.4.

The PEC/PNEC ratios indicate a low risk of secondary poisoning from the production and current uses of tetraphenyl resorcinol diphosphate.

Table 5.4 Summary of risk characterisation ratios for secondary poisoning

Scenario		Fish food chain		Earthworm food chain	
		PEC (mg/kg)	PEC/PNEC	PEC (mg/kg)	PEC/PNEC
Production of tetraphenyl resorcinol diphosphate		1.68 and 0.06	<0.01	negligible[a]	<0.01
Pigment dispersions	Production of dispersions	0.64	<0.01	4.23	0.02
PVC – 1	Compounding	0.05	<0.01	0.85	<0.01
	Conversion	0.06	<0.01	0.08	<0.01
	Combined compounding and conversion	0.18	<0.01	0.93	<0.01
PVC – 2	Compounding	0.05	<0.01	0.85	<0.01
	Conversion	0.06	<0.01	0.08	<0.01
	Combined compounding and conversion	0.18	<0.01	0.93	<0.01
Paints	Formulation	0.16	<0.01	0.77	<0.01
	Application	0.05	<0.01	1.16	<0.01
Thermo-plastics and styrenics	Compounding	6.7	0.03	48	0.22
	Conversion	0.66	<0.01	4.42	0.02
	Combined compounding and conversion	7.28	0.03	52.3	0.24

Table 5.4 continued.

Scenario		Fish food chain		Earthworm food chain	
		PEC (mg/kg)	PEC/PNEC	PEC (mg/kg)	PEC/PNEC
Polyurethane	Compounding	0.05	<0.01	4.23	0.02
	Conversion	0.12	<0.01	0.39	<0.01
	Combined compounding and conversion	0.69	<0.01	4.62	0.02

5.5 Risks to humans following environmental exposure

A NOAEL of 995 mg/kg bw/day in rats was identified in Section 4.4.10 as the most appropriate value for use in this assessment. A margin of safety of at least 1,000 is considered necessary to provide sufficient reassurance against effects on human health with this result (see Section 4.4.10). Human exposures via the environment were estimated in Section 3.3.4 and are included in Table 5.5 together with the resulting margins of exposure.

All of the margins of exposure are above the required value, and so no risks are indicated for any scenario.

Table 5.5 Margin of exposure between daily human doses and the NOAEL (995 mg/kg bw/day)

Scenario		Total daily human intake (mg/kg bw/day)	Margin of exposure
Production of tetraphenyl resorcinol diphosphate		5.5×10^{-3} and 1.2×10^{-4}	180,900 and 8,292,000
Pigment dispersions	Production of dispersions	0.03	33,170
PVC – 1	Compounding	6.6×10^{-3}	150,800
	Conversion	7.5×10^{-4}	1,327,000
	Combined compounding and conversion	7.7×10^{-3}	129,200
PVC – 2	Compounding	6.6×10^{-3}	150,800
	Conversion	7.5×10^{-4}	1,327,000
	Combined compounding and conversion	7.7×10^{-3}	129,200
Paints and coatings	Formulation	6.4×10^{-3}	155,500
	Application	9.0×10^{-3}	110,600
Thermoplastics/ styrenics	Compounding	0.39	2,551
	Conversion	0.04	24,880
	Combined compounding and conversion	0.43	2,313
Polyurethane	Compounding	0.03	33,170
	Conversion	3.3×10^{-3}	301,500
	Combined compounding and conversion	0.04	24,880
Regional sources		1.0×10^{-4}	9,950,000

5.6 Marine risk assessment

Although a PEC/PNEC approach can be applied to the marine environment, there are additional concerns which may not be adequately addressed using the above methods. Chief among these concerns is the possibility that hazardous substances may accumulate in parts of the marine environment. The effects of such accumulation are unpredictable in the long term, and once such accumulation has occurred it may be practically difficult to reverse. The properties which lead to substances behaving in this way also lead to greater uncertainty in estimating exposures and/or effect concentrations, and so make a quantitative risk assessment more difficult. To identify substances which are likely to behave in this way, criteria have been developed relating to the persistence, accumulation and toxicity of the substance. The first part of the marine assessment is therefore a comparison of the properties of the substance with these criteria. This is presented in Section 4.6.

PEC values for the marine assessment are presented in Sections 3.3.1 and 3.3.4. These were calculated using EUSES. PNECs for marine aquatic species are included in Section 4.1.6. The PNEC for secondary poisoning for the marine environment is the same as that for the freshwater fish and terrestrial food chains (Section 4.4.11). The resulting PEC/PNEC ratios are in Table 5.6.

Table 5.6 Summary of risk characterisation ratios for the marine compartment

Scenario		PEC/PNEC ratio			
		Local marine compartment	**Local marine sediment compartment**	**Fish-eating birds and mammals**	**Top predators**
Pigment dispersions	Production of dispersions	**1.32**	**13.2**	<0.01	<0.01
PVC – 1	Compounding	0.28	**2.81**	<0.01	<0.01
	Conversion	0.05	0.45	<0.01	<0.01
	Combined compounding and conversion	0.30	**3.04**	<0.01	<0.01
PVC – 2	Compounding	0.28	**2.81**	<0.01	<0.01
	Conversion	0.04	0.45	<0.01	<0.01
	Combined compounding and conversion	0.30	**3.04**	<0.01	<0.01
Paints and coatings	Formulation	0.26	**2.57**	<0.01	<0.01
	Application	0.38	**3.75**	<0.01	<0.01
Thermo-plastics/ styrenics	Compounding	**14.7**	**147**	<0.01	<0.01
	Conversion	**1.36**	**13.6**	<0.01	<0.01
	Combined compounding and conversion	**16**	**160**	<0.01	<0.01
Poly-urethane	Compounding	**1.32**	**13.2**	<0.01	<0.01
	Conversion	0.14	**1.39**	<0.01	<0.01
	Combined compounding and conversion	**1.43**	**14.3**	<0.01	<0.01

Risks are indicated for the use of the substance in pigment dispersions, thermoplastics and polyurethane for both marine waters and sediments, and for use in PVC and paints and coatings for marine sediments. No risks are indicated for marine food chains.

The further information on emissions from these processes indicated for the freshwater environment would also help to refine these results. More specifically for the marine assessment, information on whether any of these processes avoid discharging to the marine environment, or do so only after effluent treatment (the calculations above assume a direct discharge to the marine environment without waste water treatment) would be helpful.

Testing on freshwater organisms would also affect the marine PNEC, although the same comments on this given in Section 5.1.1 apply. Testing on sediment organisms would be of more value for the sediment assessment. There is also the possibility of testing on marine species, which would allow the assessment factor to be reduced.

The size of some of the PEC/PNEC ratios suggests that no one part of the further information requirements would be sufficient on its own to reduce ratios to below one.

6 Conclusions

Tetraphenyl resorcinol diphosphate can enter the environment from its production and use, and from the use of articles made from materials containing it. Based on the available information, potential risks are identified for all of the life cycle steps for one or more of the protection goals. The overall conclusions are summarised in Table 6.1 in a simplified form. In particular, the different steps within the use of each material have been combined here, and risks are indicated for PVC provided at least one of the different uses shows a risk for the specific protection goal. Section 5 should be consulted for the detailed results.

Table 6.1 Summarised potential environmental risks identified for tetraphenyl resorcinol diphosphate

Life cycle stage	Surface water	Sediment	WWTP	Air	Soil	Aquatic food chain	Terrestrial food chain	Marine water	Marine sediment
Production	-	-	-	-	-	-	-	-	-
Pigment dispersions	-	✸	-	-	✸	-	-	✸	✸
PVC	-	✸	-	-	✸	-	-	-	✸
Paints and coatings	-	✸	-	-	✸	-	-	-	✸
Thermoplastics/styrenics	✸	✸	-	-	✸	-	-	✸	✸
Polyurethane	-	✸	-	-	✸	-	-	✸	✸
Regional	-	-	-	-	-	-	-	-	-

In addition, there are no risks for humans exposed via environment, and no risks for marine food chain exposure for any of the life cycle stages.

The risks could be reassessed following additional work, in particular:

- Collation of further site and industry-specific information on releases of tetraphenyl resorcinol diphosphate from use in the different types of materials indicated. This work could include:
  - An improved description of practices at sites using tetraphenyl resorcinol diphosphate, to determine the realism of the emission estimates, ideally through surveys of representative sites.
  - Targeted monitoring to confirm or replace the calculated PEC values (especially in water, sediments and WWTP sludges). No monitoring data have been located for tetraphenyl resorcinol diphosphate. Environmental monitoring is taking place in England and Wales, at one WWTP per Environment Agency region, in both final effluent and associated receiving waters (6 samples at 4 week intervals). Sampling is expected to take place from September 2008 until March 2009.
  - Information on the fate of sludges from sites using the substance.
  - Surveys to locate user sites, especially in relation to marine discharges.
- Long-term sediment and soil organism toxicity testing.
- Studies on the fate of the substance in WWTP (municipal and industrial).

- Further testing to investigate the actual degradation (mineralization) half-life in sediment and soil under relevant environmental conditions.

There may be opportunities to read across information and test results from this substance to the other aryl phosphates assessed in this group (and vice versa). Therefore, the additional work indicated above should be considered in relation to that proposed for other members of the group. The overview document should be consulted for more information on this.

7 References

AKZO NOBEL, 2003. Personal communication, as reported in comments from European Flame Retardants Association, 01/07/03.

COVANCE LABORATORIES INC, 1998. *Mutagenicity Test with Fyrolflex RDP in the Salmonella - Escherichia coli Mammalian Microsome Reverse Mutation Assay with a Confirmatory Assay.* Study No. 19494-0-409OECD. Covance Laboratories Inc. Study conducted for Akzo Nobel Chemicals Inc. Cited IUCLID 2001.

EC, 2003. *Technical Guidance Document on Risk Assessment in Support of Commission Directive 93/67/EEC on Risk Assessment for New Notified Substances and Commission Regulation (EC) No 1488/94 on Risk Assessment for Existing Substances and Directive 98/8/EC of the European Parliament and the Council Concerning the placing of biocidal products on the market. Part II.* Report EUR 20418 EN/2. Available from: http://ecb.jrc.ec.europa.eu/tgd/

ECB, 2005. *European Union Risk Assessment Report: alkanes, C_{14}-$_{17}$, chloro (MCCP). Part 1 – Environment. 3rd Priority List Volume 58.* European Chemicals Bureau. Available from: http://ecb.jrc.ec.europa.eu/DOCUMENTS/existing-chemicals/.

ENVIRONMENT AGENCY, 2003. *Prioritisation of flame retardants for environmental risk assessment*. Science Report SC030285/SR. Available from: http://publications.environment-agency.gov.uk/pdf/SCHO1008BOTE-e-e.pdf.

FREUDENTHAL, R.I., MCDONALD, L.J., JOHNSON, V., MCCORMICK, D.L. AND HENRICH, R., 2000. Comparative Metabolism and Toxicokinetics of 14C-Resorcinol Bis-Diphenylphosphate (RDP) in the Rat, Mouse, and Monkey. *International Journal of Toxicology*, 9 (4), 232-242.

GEURTS, M.G.J., KLUSKENS, B.J.H. AND VOS, A., 2006a. *Acute toxicity of Fyrolflex RDP to Danio rerio.* Akzo Nobel Chemicals Research report CER F04 T 05021 ODA. January 2006.

GEURTS, M.G.J., KLUSKENS, B.J.H. AND VOS, A., 2006b. *Acute toxicity of Fyrolflex RDP to Daphnia magna.* Akzo Nobel Chemicals Research report CER F T 05021 OFA. January 2006.

GREAT LAKES CHEMICAL CORPORATION, 2002. *Technical Information and Safety Data Sheet for Reofos RDP.*

GREAT LAKES CHEMICAL CORPORATION, 2003. *Safety Data Sheet Reofos RDP.* Available from: http://www.e1.greatlakes.com/common/msdspdf/04410187.pdf.

HENRICH, R., RYAN, B.M., SELBY, R., GARTHAWAITE, S., MORRISSEY, R. AND FREUDENTHAL, R.I., 2000. Two-generation oral (diet) reproductive toxicity study of resorcinol bis-diphenylphosphate (Fyrolflex RDP). *International Journal of Toxicology*, 19 (4), 243-255.

IIT, 1992. *Immunotoxicity Study in Mice of Fyrolflex RDP.* Study No. L08488-2. IIT Research Institute. Study conducted for Akzo Nobel Chemicals Inc. (Study also published in the *International Journal of Toxicology*,19(4), 265-275, by SHERWOOD R. L., HOUSE R.V., RATAJCZAK H. V., FREUDENTHAL R.I., HENRICH R.T., 2000). Cited in IUCLID 2001.

IIT, 1994a. *Acute Oral Toxicity of Fyrolflex RDP in Rats (Limit Test).* Study No. L08489-1. IIT Research Institute. Study conducted for Akzo Nobel Chemicals Inc. Cited in IUCLID 2001.

IIT, 1994b. *Acute Nose-Only Inhalation Toxicity Study of Fyrolflex RDP in Rats.* Study No. L08465-SN1. IIT Research Institute. Study conducted for Akzo Nobel Chemicals Inc. Cited in IUCLID 2001.

IIT, 1994c. *Acute Dermal Toxicity Study of Fyrolflex RDP in Rats.* Study No. L08489-SN2. IIT Research Institute. Study conducted for Akzo Nobel Chemicals Inc. Cited IUCLID 2001.

IIT, 1996. Twenty-*Eight Day Nose Only Inhalation Toxicity Study of Resorcinol Bis-Diphenylphosphate (Fyrolflex RDP) in Rats.* Study No. LO8588-6. IIT Research Institute. Study conducted for Akzo Nobel Chemicals Inc. (2000) (Study also published in *International Journal of Toxicology*, 19(4), 223-231 by HENRICH, R.T., JOHNSON, W.D., RAJENDRAN, N., FREUDENTHAL, R.I., TOMLINSON, M.J., and ARANYI, C., 2000). Cited in IUCLID 2001.

IUCLID, 2001*. IUCLID Data set for phosphoryl chloride, polymer with resorcinol phenyl ester, CAS number 125997-21-9.* Akzo Nobel Functional Chemicals. Submitted to USEPA HPV Challenge, October 2001.

KLUSKENS, B.J.H., GEURTS, M.G.J. AND VOS, A., 2006. *Effects of Fyrolflex RDP on the growth of the freshwater alga Pseudokirchneriella subcapitata.* Akzo Nobel Chemicals Research report CER F06003 T 05021 AL. January 2006.

KROON, A.G.M., GEURTS, M.G.J. AND STEGEMAN, G., 1995. *Toxicity of Fyrolflex RDP to the freshwater alga Selenastrum capricornutum.* Akzo Nobel Final Report RGL F95084 T95008 AL.

KROON, A.G.M., GARTTENER-ARENDS, I.C.M., GEURTS, M.G.J. AND STEGEMAN, G., 1996. *Acute toxicity of Fyrolflex RDP to the freshwater fish Brachydanio rerio.* Akzo Nobel Final Report RGL F96062 T95008 OFB.

LEVCHIK, S.V., DASHEVSKY, S. AND BRIGHT, D.A., 2000. Studies on the mode of fire retardant action of aryl phosphates in engineering resins. Eleventh Annual BCC Conference on Flame Retardancy, *Recent Advances in Flame Retardancy of Polymeric Materials*, 11, 164-178.

OECD, 2004. OECD *Series on Emission Scenario Documents. Number 3. Emission Scenario Document on plastics additives.* ENV/JM/MONO(2004)8.

RCC NOTOX, 1988. *Evaluation of the Mutagenicity of CR 733-S in the Micronucleus Test in the Mouse.* Study No. 1149/MN 1520. RCC NOTOX BV, The Netherlands/ Study conducted for GE Plastics Europe. Cited in IUCLID 2001.

RCC NOTOX, 1989a*. Primary Skin irritation/Corrosion Study of CR 733-S in the Rabbit.* Study No. 1149/1494. RCC NOTOX BV, The Netherlands/ Study conducted for GE Plastics Europe. Cited in IUCLID 2001.

RCC NOTOX, 1989b. *Acute Eye Irritation/Corrosion Study of CR 722-S in the Rabbit.* Study No. 1149/1495. RCC NOTOX BV, The Netherlands/ Study conducted for GE Plastics Europe. Cited in IUCLID 2001.

RCC NOTOX, 1989c. *Evaluation of the Ability of CR 733-S to Induce Chromosomal Aberrations in Cultured Peripheral Human Lymphocytes.* Study No. 1149/ECH169. RCC NOTOX BV, The Netherlands/ Study conducted for GE Plastics Europe. Cited in IUCLID 2001.

RYAN, M.B., HENRICH, R., MALLETT, E. AND FREUDENTHAL, R.I., 2000. Development toxicity study of orally administered resorcinol bis-diphenylphosphate (RDP) in rabbits. *International Journal of Toxicology*, 19 (4), 257-264.

SAEGER, V.W., HICKS, O., KALEY, R.G., MICHAEL, P.R., MIEURE, J.P. AND TUCKER, E.S., 1979. Environmental fate of selected phosphate esters. *Environmental Science and Technology*, 13, 840-844.

VAN GINKEL, C.G. AND STROO, C.A., 1996. *Biodegradability of Fryrolflex RDP in the closed bottle test.* Akzo Nobel Final Report RGL F95141 T95008 C.

WEIL, E.D., 1993. Flame retardants (Phosphorus). *Kirk-Othmer Encyclopedia of Chemical Technology*, Volume 10, Fourth Edition, 976-998. John Wiley and Sons, Inc., 1993.

WETTON, P.M. AND MULLEE, D.M., 2001. *Fyrolflex RDP: Daphnia magna reproduction test.* SPL Project Number: 106/051, Study Sponsor Akzo Nobel Chemicals B.V.

WILDLIFE INTERNATIONAL, 2000*. Fyrolflex RDP: An evaluation of hydrolysis as a function of pH.* Wildlife International, Ltd, Project Number 497C-110.

8 Glossary of terms

Term	Description
Biochemical oxygen demand (BOD)	A measure of degradation potential
Bioconcentration factor (BCF)	A measure of chemical uptake, being the ratio between the concentration in an organism and the concentration in an environmental compartment (usually water)
CAS number (no.)	An identifying code number assigned to chemicals by the Chemical Abstract Services. The CAS number is a generally recognised identification reference for a chemical; a substance can have more than one such number
Inherently biodegradable	Some potential for environmental degradation to carbon dioxide and water, and so on, as measured by laboratory screening tests involving microorganisms
Lowest observed effect concentration (LOEC)	The lowest concentration in a toxicity test that gives rise to adverse effects (relative to a control)
Median effective concentration (EC_{50})	The concentration in a toxicity test at which a particular effect is observed in half of the organisms exposed for a specified time
Median lethal loading (LL_{50})	The loading of substance in a water-accommodated fraction that leads to death in half of the organisms exposed for a specified time
Median lethal concentration/dose (LC/D_{50})	The concentration in a toxicity test that can be expected to cause death in half of the organisms exposed for a specified time
No observed effect concentration (NOEC)	The highest concentration in a toxicity test that does not give rise to adverse effects (relative to a control)
Octanol-water partition coefficient (K_{ow})	This parameter gives an indication of the partitioning behaviour of a substance between water and lipid-containing materials such as cell membranes or organic matter in soils and sediments
Readily biodegradable	Rapid environmental degradation to carbon dioxide and water, and so on, as measured by laboratory screening tests involving microorganisms

9 Abbreviations

Acronym	Description
ABS	Acrylonitrile-styrene-butadiene
B	Bioaccumulative
BCF	Bioconcentration factor
BMF	Biomagnification factor
BOD	Biochemical oxygen demand
bw	Bodyweight
CAS	Chemical Abstract Services
CMR	Carcinogenic, mutagenic and toxic to reproduction
DEHP	Di(2-ethylhexyl)phthalate
EC	European Communities
EC_{50}	Median effect concentration
EC_x	As EC_{50}, but for x% effect; x usually being 0, 10, or 100
ECB	European Chemicals Bureau
EEC	European Economic Communities
EINECS	European Inventory of Existing Commercial Chemical Substances – this lists all chemical substances that were supplied to the market prior to 18th September 1981
EPA	Environmental Protection Agency (USA)
ESD	Emission Scenario Document
ESR	The Existing Substances Regulation – Council Regulation (EEC) 793/93 on the evaluation and control of the risks of 'existing' substances.
EU	European Union
EUSES	European Union System for the Evaluation of Substances (software tool in support of the TGD on risk assessment)
HPLC	High performance liquid chromatography
HPV	High Production Volume (supply above 1,000 tonnes per year)
IUCLID	International Uniform Chemical Information Database: contains non-validated tonnage, use pattern, property and hazard information for chemicals, submitted by industry under the Existing Substances Regulation (ESR)
K_{oc}	Organic carbon normalised distribution coefficient
K_{ow}	Octanol-water partition coefficient
Kp	Solids-water partition coefficient
$L(E)C_{50}$	Median lethal (effect) concentration
LD_{50}	Median lethal dose
LL_{50}	Median lethal loading

LO(A)EL	Lowest observed (adverse) effect level
LOEC	Lowest observed effect concentration
log K_{ow}	Log of the octanol-water partition coefficient (K_{ow})
NO(A)EL	No observed (adverse) effect level
NOEC	No observed effect concentration
n.t.p.	Normal temperature and pressure
OECD	Organisation for Economic Cooperation and Development
P	Persistent
PBT	Persistent, bioaccumulative and toxic
PEC	Predicted environmental concentration
pH	Logarithm (to the base 10) of the hydrogen ion concentration [H+]
pK_a	Logarithm (to the base 10) of the acid dissociation constant
PNEC	Predicted no effect concentration
ppm	Parts per million
PVC	Polyvinyl chloride
RDP	Tetraphenyl resorcinol diphosphate
TGD	Technical Guidance Document
USEPA	Environmental Protection Agency, USA
UV	Ultraviolet region of the electromagnetic spectrum
vB	Very bioaccumulative
vP	Very persistent
vPvB	Very persistent and very bioaccumulative
WAF	Water-accommodated fraction
wt	Weight
wwt	Wet weight
WWTP	Waste water treatment plant

10 Data collection and peer review process

This report has been produced using publicly available data gathered and assessed by the contractor for the Environment Agency. Additional information has been submitted voluntarily by member companies of the Phosphate Ester Flame Retardant Consortium (PEFRC, http://www.pefrcnet.org/), and the Environment Agency would like to thank them for their cooperation.

The Environment Agency has been keen to ensure that the data used in this report are as complete and accurate as possible. Original reports and literature articles for key studies were retrieved and assessed for reliability wherever possible (it is clearly indicated where this was not the case).

The main scientific literature search was performed in 2002, with some further limited searching to consider specific issues up to 2007.

Drafts of this report have been circulated to key stakeholders in UK and European Industry for comment on several occasions, as well as members of the UK and European chemical regulatory community in July 2007. The Advisory Committee on Hazardous Substances has also provided helpful comments as part of its own deliberations on this substance group (their last review was in September 2007).

In addition, certain technical aspects of the report were peer-reviewed by an independent expert group set up by the Environment Agency for this purpose in April 2007. The experts were:

- Dr Kay Fox (independent consultant);
- Dr Tamara Galloway (University of Plymouth).

Their comments have not been published but are available on request. All comments received have been addressed in the final report where appropriate.

The Institute for Environment and Health wrote the human health effects assessment, and this was peer-reviewed by colleagues at the Health and Safety Executive and Health Protection Agency.

Would you like to find out more about us, or about your environment?

Then call us on

08708 506 506* (Mon-Fri 8-6)

email

enquiries@environment-agency.gov.uk

or visit our website

www.environment-agency.gov.uk

incident hotline 0800 80 70 60 (24hrs)
floodline 0845 988 1188

* Approximate call costs: 8p plus 6p per minute (standard landline).
Please note charges will vary across telephone providers

Environment first: This publication is printed on recycled paper.