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Environmental Protection Agency

Chlorinated phosphorous-based flame retardants in children's articles containing foam

Background for content and possibilities for prevention in the EU

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Title:

Chlorinated phosphorous-based flame retardants in children's articles containing foam

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Preface

A recent project carried out for the Danish EPA (DEPA) discovered three phosphorous-based chlorinated flame retardants (TCPP, TDCP and TCEP) in children's articles containing foam. The substances were identified in both foam and textile parts by quantitative chemical analysis and were also shown to migrate into artificial sweat.

The overall objective of the present project was to establish the scientific justification for a possible proposal for a regulation in the EU regarding the management of the risk from phosphorous-based chlorinated flame retardants in children's articles containing foam.

The aim was to conduct a technical and economic assessment of options to avoid TCPP, TDCP and TCEP in children's articles marketed in the EU, as well as to evaluate the suitability of possible alternatives, their availability and risk profile. The results are intended to be included in an assessment of the need to prepare a draft EU restriction on these substances. Toys are not included in the scope of this study, as the content in toys is already regulated.

Steering group
The project has been followed by a steering group consisting of:

- Lars Fock, DEPA
- Shima Dobel, DEPA
- Jesper Gruvmark, DEPA
- Thomas Brønnum, Danish Plastics Federation
- Carsten Lassen, COWI A/S
- Caspar Corden, Amec Foster Wheeler Environment & Infrastructure UK Limited

Working group
The project has been carried out from April 2015 to August 2015 by a working group consisting of Carsten Lassen (project manager), Anna Brinch, Sonja Mikkelsen and Jesper Kjølholt (COWI A/S) in cooperation with Caspar Corden, Araceli de Carlos and Javier Esparrago (Amec Foster Wheeler Environment & Infrastructure UK Limited.

Conclusion and Summary

The aim of this study was to conduct a technical and economic assessment of options to avoid the chlorinated phosphorous flame retardants TCPP, TDCP and TCEP in children's articles marketed in the EU, as well as to evaluate the suitability of possible alternatives, their availability and risk profile. The results are to be used for an assessment by the Danish EPA regarding the need to prepare a proposal for regulation of the substances at EU level.

Overall use of TCPP, TDCP and TCEP

TCPP is the least-cost and most-used of the main flame retardants used in flexible polyurethane (PUR) foams. EU consumption was about 40,000 t/y in 2000 and the registered volume under REACH is in the 11,000-110,000 t/y range. TCPP is an all-round flame retardant for all types of flexible PUR foams. TDCP is more expensive and the total EU consumption is less than 10,000 t/y, being used mainly for automotive applications, where TDCP is preferred due to lower fogging potential (lower potential to form a thin film on the windshield). TCEP is currently not used as flame retardant for flexible PUR foams in the EU, but may be present at low levels in a flame retardant which has traditionally been traded under the name V6 or V66 (and may hence be present in articles).

Intentional use of the substances in children's articles

None of the article manufacturers that provided inputs to the study acknowledge the use of TCEP in their products. Furthermore, some article manufacturers have added this substance to a black list of chemicals to be avoided. On the other hand, consultation revealed that both TCPP and TDCP are currently used as flame retardants in PUR foam for children's articles, such as pushchairs and baby mattresses. No examples of the use of the three chlorinated flame retardants in textiles were identified through the consultation.

Manufacturers consulted claim that the main driver to use the flame retardants in children's articles is the UK fire safety regulations. In fact, all the manufacturers that confirmed use of one or more of the flame retardants are either UK-based or add the flame retardants only to those products destined for the UK and Irish market. They also all agreed that their preference was to not add these substances, claiming potential health risks and consumer concerns as the main reasons. According to consultees, PUR foam containing flame retardants has an inferior technical performance compared to standard non-FR foam, particularly regarding durability, comfort and smell. Cost is also listed as a reason for some products with high PUR foam content, with FR foam being around 15% more expensive than non-FR foam. In addition to these costs, non-UK manufacturers consulted suggest that complying with UK fire regulations implies significant logistical costs, linked to keeping separate stocks, production and distribution lines for products destined for the UK and Irish markets.

Analysis of the substances in children's articles

The three chlorinated phosphorous flame retardants have been shown to be present in various children's articles in surveys by the Danish EPA and the Danish Consumer Council. In several surveys of children's car seats, TCPP and TCDP have been identified in one third to one half of the tested car seats, while TCEP was identified in a few of the car seats. The substances were also present in a significant portion of the tested baby slings, prams, carrrycots and baby strollers, as well as in a few earphones and baby changing mats. Similar results were obtained in a survey by Washington State.

It is characteristic of all the surveys that TCPP and TCDP are typically present together. In many products the levels are far below the concentration expected if the FRs had been added intentionally in order to meet fire safety standards such as those in the UK and Ireland. Due to its lower price, TCPP would be expected to be the main FR for flame retarded foams in children's articles except for car seats, but this is not confirmed by actual measurements. In most of the surveys, however, composite samples consisting of both PUR foams (sometimes several layers of foam) and textile were analysed and this may to some extent explain the low levels. According to manufacturers in the EU, TCDP and TCPP are usually not used in combination, but most tested articles are produced outside the EU (mainly Asia), and no information on the typical use pattern of the flame retardants in Asia is available. The results of these tests could indicate that rebonded foams from production scrap are used in the products. The type of tested foams was not indicated in the study results and it has not been possible to clarify whether the explanation for the test results is the use of rebonded foams.

Alternatives to the substances

Several chemical alternatives with a better environmental and health profile than the profiles for the chlorinated phosphorous FRs exist, as evaluated by US EPA Design for the Environment programme. In addition to the overall better score on key parameters as concerns PBT and CMR[1] properties, reactive flame retardants and polymeric flame retardant alternatives are considered to result in lower levels of user exposure and lover releases to the environment compared to the three chlorinated phosphorous flame retardants (which are additive flame retardants).

In particular, the alternatives have been developed for use in automotive applications where requirements for low fogging and low VOC emissions have been the driving forces for their development. In general, the available alternatives thus have better properties for these parameters. The lower fogging potential may also indicate a lower potential for evaporation of the substances from articles in use. The low levels of migration of reactive flame retardants has made these flame retardants attractive for foams marketed as "green", and the reactive flame retardants are in particular applied in PUR foams from bio-based polyols marketed as "green" for the US market.

The applications of PUR foam using alternative flame retardants has mainly been for automotive applications and furniture complying with regulation in the USA. Limited experience with the use of the evaluated alternative flame retardants for furniture complying with the UK fire safety regulations has been identified. For some dense foams, melamine (also used in combination with e.g. TCPP) can be used alone, but melamine is only applicable for a limited range of foams. None of the available alternatives can be used as a simple substitute for the chlorinated phosphorus flame retardants for all applications, but different alternatives may be needed for different foams. The use of the alternative flame retardants for children's articles for the UK market may be challenging and substantial R&D is needed. However, the manufacturers of alternative flame retardants contacted for this study have not indicated that it would be impossible to meet the requirement by using the alternative flame retardants. Time needed for R&D is indicated to be in the range of 3 months to one year for each application. It is estimated by one manufacturer of alternatives that, for a full transition, the build-up of additional capacities for alternatives may be necessary, and the time required for this would be 3-5 years.

The alternative flame retardants are substantially more expensive than the chlorinated phosphorous flame retardants and, even though lower loadings are necessary, additional costs in the 20-200% range have been indicated by manufacturers. More information on additional costs is provided in a confidential Annex for the Danish EPA only.

[1] PBT = Persistent, bioaccumulative and toxic; CMR: carcinogenic, mutagenic or toxic to reproduction

Presence of TCPP, TDCP and TCEP as impurities
The available data on children's articles indicate that the substances are present at low levels, far below the levels needed to meet the UK fire safety requirements, in many of the products. Possible explanations are contamination during manufacture of the foams/articles, the presence of the substances as impurities in other flame retardants or plasticisers (not covered by the surveys), or the use of rebonded foam.

Contamination - Foams may be contaminated during manufacturing at sites producing both flame retardant (FR) and non-FR grades. Most production sites in the EU produce both grades. According to the European trade association EUROPUR, it may be challenging to meet a limit value of 5 mg/kg (0.0005%), which is the limit value applied in the toy directive for the targeted substances. According to EUROPUR, to determine a realistic tolerance would require much verification work at production-site-level, and the organisation suggests that a limit value of 0.1% is applied if a restriction proposal is prepared.

Rebonded foam - About 10% of the produced PUR foam ends up as production scrap from the cutting; this is shredded, mixed and moulded into rebonded foams. It is common to mix scraps of FR and non-FR foam and the rebonded foam may therefore contain varying levels of mixed flame retardants. As most manufacturers in the EU produced both FR and non-FR grades, a significant proportion of all rebonded foam used in the EU may be contaminated with flame retardants. A restriction on the three chlorinated phosphorous flame retardants in children's articles, regardless of the limit value applied, would probably imply that only rebonded foam of pure non-FR grades could be used for manufacture of children's articles marketed outside the UK and Ireland. Similarly, it would only be possible to base rebonded foam for the UK market on scrap foam with alternative flame retardants. No data indicating the extent to which rebonded foam is used in children's articles has been obtained.

Compliance control - If a limit value of 5 mg/kg is applied, manufacturers and importers of children's articles would need more extensive controls; a contractual agreement that the substances are not intentionally added to the product would not ensure that the substances are not present as an impurity in concentrations above the limit value. Moreover, the concentration of flame retardants may vary even within one batch and it would be necessary to take more samples of each batch than is currently the case. For the authorities, a low limit value would imply extra control costs as the likelihood of articles not in compliance with the restriction would be much higher as compared with the situation if a limit value of 0.1 % is applied.

Konklusion og sammenfatning

Formålet med denne undersøgelse er at tilvejebringe en teknisk og økonomisk vurdering af muligheder for at undgå tre klorerede fosforbaserede flammehæmmere, TCPP, TDCP og TCEP, i børneartikler, der markedsføres i EU, samt at vurdere egnetheden af mulige alternative flammehæmmere med hensyn til deres tilgængelighed og risikoprofil. Resultaterne skal indgå i Miljøstyrelsens overvejelser omkring behovet for at udarbejde et forslag til regulering af de pågældende stoffer på EU-plan.

Overordnet anvendelse af TCPP, TDCP og TCEP
TCPP er den billigste og mest anvendte flammehæmmer i fleksibelt polyurethan (PUR) skum. Forbruget i EU er opgjort til ca. 40.000 tons i år 2000. Det registrerede forbrug under REACH er i intervallet 11.000-110.000 tons/år. TCPP er en "all-round" flammehæmmer, som kan anvendes i alle typer af fleksibelt PUR skum. TDCP er dyrere end TCPP og det samlede EU-forbrug er på mindre end 10.000 tons/år. TDCP anvendes primært i bilindustrien, hvor TDCP foretrækkes på grund af et lavere potentiale for at resultere i dannelse af en tynd, tåget film (Eng: fogging) på forruden. TCEP anvendes i dag ikke som flammehæmmer i fleksibelt PUR-skum produceret i EU, men kan være til stede som forurening i en anden flammehæmmer, som traditionelt er blevet forhandlet under navnene V6 og V66 (og kan dermed være til stede i artikler).

Tilsigtet brug af stofferne i børneartikler
Ingen af producenterne af artikler til børn, som har leveret input til undersøgelsen angiver, at der anvendes TCEP i deres produkter. Desuden har nogle producenter tilføjet dette stof til deres liste over stoffer skal undgås i artikler. På den anden side viser dataindhentningen, at både TCPP og TDCP i øjeblikket anvendes som flammehæmmere i PUR-skum i børneartikler, såsom klapvogne og baby-madrasser. Der blev ikke fundet eksempler på, at de tre klorerede fosfor-baserede flammehæmmere anvendes i tekstiler.

Producenter af artikler til børn hævder, at den vigtigste drivkraft for at bruge flammehæmmere i børneartikler er de britiske brand-sikkerhedsbestemmelser. Alle de producenter, der bekræftede brug af én eller flere af flammehæmmerene er enten UK-baserede eller tilsætter flammehæmmerene til produkter bestemt for det britiske og irske marked. De kontaktede producenter angav at de ville foretrække ikke at anvende disse stoffer på grund af potentielle sundhedsmæssige risici og forbrugernes bekymringer. Ifølge producenterne, har PUR-skum indeholdende flammehæmmere en ringere teknisk ydeevne i forhold til ikke-flammehæmmet skum, især med hensyn til holdbarhed, komfort og lugt. Omkostninger til flammehæmning er også af betydning. Nogle produkter med højt indhold af flammehæmmet PUR-skum er omkring 15 % dyrere end tilsvarende produkter med ikke-flammehæmmet skum. Ud over disse omkostninger, angiver ikke-britiske producenter, at overholdelse af britiske brandkrav indebærer betydelige logistiske omkostninger, der er forbundet med at opretholde særskilte lagre, produktions- og distributionslinjer for produkter bestemt til de britiske og irske markeder.

Analyse af stofferne i børneartikler
De tre klorerede fosforbaserede flammehæmmere er blevet påvist i forskellige børneartikler i undersøgelser foretaget af Miljøstyrelsen og Forbrugerrådet Tænk i Danmark. TCPP og TCDP er i en række undersøgelser af børnesæder til biler blevet fundet i mellem en tredjedel og halvdelen af de testede børnesæder, mens TCEP blev fundet i nogle få af sæderne. Stofferne blev også fundet i en væsentlig del af de undersøgte bæreseler, barnevogne, babylifte og klapvogne samt i et par hovedtelefoner og en puslepude. Lignende resultater er opnået i en undersøgelse fra staten Washington. Det er karakteristisk for alle undersøgelserne, at TCPP og TDCP hovedsageligt er til stede samtidig. I mange af produkterne er niveauet langt under den koncentration, som kunne forventes, hvis flammehæmmerne var anvendt tilsigtet for at leve op til kravene i Storbritannien og Irland, som er de to lande, hvor der er krav til flammehæmning af disse artikler. På grund af den lavere pris ville TCPP forventes at være den vigtigste flammehæmmer i flammehæmmet skum i børneartikler, bortset fra børnesæder til biler, men dette er ikke bekræftet af de faktiske målinger. I de fleste af undersøgelserne er der dog udtaget og testet kompositprøver bestående af både PUR-skum (og måske flere lag af skum) og tekstiler, hvilket delvist kan forklare de relativt lave koncentrationer. Ifølge producenterne i EU anvendes TDCP og TCPP normalt ikke i kombination, men de fleste af de undersøgte artikler er produceret uden for EU (hovedsageligt i Asien), og der findes ingen oplysninger om det typiske forbrugsmønster af flammehæmmerne i Asien. Resultaterne kunne indikere, at såkaldt "rebonded" skum, som produceres af blandet produktionsspild fra udskæringen af skum, anvendes i produkterne. Da typen af de undersøgte skum ikke er angivet, har det har ikke været muligt at afklare, om forklaringen på testresultaterne er brugen af "rebonded" skum.

Alternativer til stofferne
Der findes en række kemiske alternativer, som i forbindelse med den amerikanske Miljøstyrelses "Design for Environment" (DfE) program er vurderet at have bedre miljø- og sundhedsprofiler end de tilsvarende profiler for de klorerede fosforbaserede flammehæmmere. Ud over at de overordnet set har en bedre score på de vigtige parametre, som omfatter PBT og CMR[2] egenskaber, anses brugen af reaktive flammehæmmere (som indbygges i polymerstrukturen) og polymere flammehæmmere at resultere i lavere niveauer af eksponering af brugerne af artiklerne og lavere emissioner til miljøet sammenlignet med de tre klorerede fosforbaserede flammehæmmere (som er additive).

Alternativerne er især udviklet til brug i bilindustrien, hvor kravene til lav filmdannelse (på forruden) og lave VOC-emissioner har været de drivende kræfter for udviklingen. De tilgængelige alternativer har derfor bedre egenskaber på disse parametre. Det lavere potentiale for filmdannelse indikerer et lavere potentiale for fordampning af stofferne fra artiklerne i brug. De lave niveauer af migration af udgangsstofferne fra reaktive flammehæmmere (som indbygges i polymerer) har også gjort disse flammehæmmere attraktive for brug i fleksible PUR skum, der markedsføres som "grønne", og de reaktive flammehæmmere er især anvendt i PUR skum, som er fremstillet på basis af biobaserede polyoler og markedsføres som "grønne" i USA.

PUR skum med alternative flammehæmmere er hovedsageligt anvendt i bilindustrien eller i møbler, som skal leve op til de amerikanske krav, mens der er begrænset erfaring med brug af alternative flammehæmmere til møbler, som opfylder de britiske brandsikkerhedskrav. For nogle kompakte typer af skum kan melamin (som også anvendes i kombination med fx TCPP) anvendes alene, men denne løsning er kun mulig for et begrænset udvalg af skum. Ingen af de tilgængelige alternativer kan anvendes som en simpel erstatning for de klorerede fosforbaserede flammehæmmerne til alle anvendelser, så der kan være behov for at anvende forskellige alternativer til forskellige typer af skum. Brug af de alternative flammehæmmere til skum i børneartikler til det britiske marked kan derfor indebære udfordringer, og der vil være behov for omfattende forskning og udvikling. De kontaktede producenter af alternative flammehæmmere har dog ikke tilkendegivet, at det skulle

[2] PBT = Persistent, bioakkumulerbart og toksisk; CMR: kræftfremkaldende, mutagent eller reproduktionstoksisk

være umuligt at opfylde kravene til brandsikkerhed med brug af de alternative flammehæmmere. Den nødvendige tid til forskning og udvikling er angivet til at være i størrelsesordenen tre måneder til et år for de enkelte anvendelser. Det vurderes af en enkelt producent af alternativer, at opbygning af den nødvendige kapacitet for alternativer vil tage i størrelsen 3-5 år.

De alternative flammehæmmere er væsentligt dyrere end de klorerede fosforbaserede flammehæmmere, og selvom de kan anvendes i lavere koncentrationer har producenter angivet, at der vil være ekstra omkostninger til flammehæmmere i størrelsen 20-200 %. Flere oplysninger om de ekstra omkostninger er angivet i et fortroligt bilag til Miljøstyrelsen.

Tilstedeværelse af TCPP, TDCP og TCEP som urenhed
Undersøgelserne af stofferne i børneartikler viser, at stofferne i mange af produkterne er til stede på lave niveauer, som er langt under de niveauer, der er nødvendige for, at artiklerne kan leve op til de britiske krav. Mulige klaringer på de lave niveauer kan være forurening under fremstilling af skummene/artiklerne, tilstedeværelse af stofferne som urenhed i andre flammehæmmere eller blødgørere (som ikke er omfattet af undersøgelserne), eller brug af "rebonded" skum.

Forurening - Skum kan være forurenet under fremstillingen på produktionsanlæg, der producerer både flammehæmmede og ikke-flammehæmmede kvaliteter. De fleste produktionsanlæg i EU fremstiller begge typer. Ifølge den europæiske brancheorganisation EUROPUR kan det være en udfordring at leve op til en grænseværdi på 5 mg/kg (0,0005 %), som er grænseværdien for de tre omfattede stoffer i legetøjsdirektivet. At bestemme en indholdsgrænse, der kan overholdes i praksis, vil i følge EUROPUR kræve omfattende verifikationsarbejde på de enkelte produktionsanlæg, og organisationen foreslår derfor, at der anvendes en grænseværdi på 0,1 %, i fald der udarbejdes et restriktionsforslag.

"Rebonded" skum - Ca. 10 % af den producerede PUR-skum ender som affald fra opskæringen af skum. Dette skæres i små stykker, blandes og støbes til "rebonded" skum. Det er almindeligt, at blande spild af flammehæmmet og ikke-flammehæmmet skum, og "rebonded" skum indeholder derfor varierende niveauer og blandinger af flammehæmmere. Da de fleste producenter producerer både flammehæmmede og ikke-flammehæmmede kvaliteter, kan en betydelig del af det "rebonded" skum, som anvendes i EU, indeholde en række forskellige flammehæmmere. En begrænsning af de tre klorerede fosforbaserede flammehæmmere i børneartikler vil, uanset hvilken grænseværdi der anvendes, sandsynligvis betyde, at kun "rebonded" skum af rene ikke-flammehæmmede kvaliteter kan anvendes til fremstilling af børneartikler, som markedsføres uden for Storbritannien og Irland, mens" rebonded" skum til det britiske marked skal baseres på produktionsaffald af skum med alternative flammehæmmere. Der er ikke fundet oplysninger, der viser, i hvilket omfang "rebonded" skum anvendes i børneartikler.

Kontrol af overholdelse af regler - Hvis en grænseværdi på 5 mg/kg anvendes, vil producenter og importører af børneartikler skulle udføre et omfattende kontrolarbejde, idet kontraktlige aftaler om, at stofferne ikke tilsigtet er anvendt i produktet, ikke vil sikre, at stofferne ikke er til stede i artiklerne som urenhed i koncentrationer over grænseværdien. Desuden kan koncentrationen variere inden for den enkelte levering, og det vil derfor være nødvendigt at tage flere prøver af hvert parti. Også for myndighederne vil en lav grænseværdi indebære ekstra kontrolomkostninger da sandsynligheden for, at artikler ikke overholder kravene vil være langt højere end hvis der eksempelvis etableres en grænseværdi på 0,1 %, som foreslået af industrien.

1. Introduction

1.1 The substances

This study concerns the following substances:

Abbreviation	Chemical name	CAS No.	EC No.	Harmonised classification according to the CLP Regulation *	
				Hazard Class and Category Code(s)	Hazard statement Code(s) **
TCPP	Tris(2-chloro-1-methylethyl) phosphate	13674-84-5	237-158-7	-	-
TDCP	Tris[2-chloro-1-(chloromethyl)ethyl] phosphate	13674-87-8	237-159-2	Carc. 2	H351
TCEP	Tris(2-chloroethyl)phosphate	115-96-8	204-118-5	Carc. 2 Repr. 1B Acute Tox. 4 * ' Aquatic Chronic 2	H351 H360F*** H302 H411

* Regulation (EC) No 1272/2008 on the classification, labelling and packaging of substances and mixtures

** H351: "Suspected of causing cancer"; H360F: "May damage fertility" (***"In order not to lose information from the harmonised classifications for fertility and developmental effects under Directive 67/548/EEC, the classifications have been translated only for those effects classified under that Directive."); H302: "Harmful if swallowed"; H411: "Toxic to aquatic life with long lasting effects".

The abbreviations TCEP, TCPP and TDCP are used both for the specific substances indicated above and the commercial flame retardant products.

1.1.1 Tris(2-chloro-1-methylethyl) phosphate, TCPP

The flame retardant products supplied in the EU that are marketed as TCPP (or other synonyms) are actually reaction mixtures containing four isomers (ECHA, 2008a). CAS number 13674-84-5 is used for one of the structures and also for the mixture of isomers as commercially produced. A typical purity (total of the four isomers) is >97.9%.

The registered volume under REACH is 11,000-110,000 t/y. TCPP has been registered by two individual submissions, from Shekoy Chemicals Europe B.V. and a confidential registrant. According to the transitional Annex XV dossier for TCPP, more than 40,000 tonnes of TCPP were consumed in the EU in the year 2000. Most TCPP (over 98%) was used as a flame retardant in the production of polyurethane (PUR) for use in construction and furniture. Most TCPP was used in rigid PUR foam (over 80%), mainly for construction applications. Flexible PUR applications, mainly for furniture for the UK and Irish market, accounted for approximately 17%, corresponding to 6,800 tonnes (ECHA, 2008a). TCPP tends not to be used in flexible PUR for automotive applications owing to its volatility and fogging[3] potential. TCPP has been used to substitute for TCEP and in turn these substances replaced the historical use of penta-BDE (penta-brominated diphenyl ether).

No data are available on whether TCPP is present as an impurity in other flame retardants.

[3] Fogging is the ability to form a fog on the windshield of the car due to volatization of the substance

1.1.2 Tris[2-chloro-1-(chloromethyl)ethyl] phosphate, TDCP

The impurity profile for commercial TDCP differs between suppliers but the impurity content is low (ECB, 2008c).

The registered volume under REACH is 1,000-10,000 t/y by a joint submission by Albemarle Europe SPRL, ICL-IP Bitterfeld GmbH and Shekoy Chemicals Europe B.V. Somewhat less than 10,000 tonnes of TDCP were consumed in the EU in the year 2000 (ECHA, 2008b). Most TDCP was used in the production of flexible polyurethane (PUR) foam. TDCP was added directly at the point of production of flexible foams. Most foams containing TDCP were used in the automotive industry, with small volumes used in furniture (tonnages were not further specified). TDCP operates in the same marketplace as TCPP. Owing to the price differential between these products (TDCP is around twice the price of TCPP), TDCP was only used in those applications where a more efficient flame retardant is required to meet specific standards, primarily the requirements for lower fogging in the automotive sector (ECHA, 2008b).

No data are available on whether TDCP is present as impurity in other flame retardants.

1.1.3 Tris(2-chloroethyl)phosphate, TCEP

According to the EU Risk Assessment for TCEP, the commercial product has a purity of 99.5 % (ECB, 2008a).

The registered volume is 10 - 100 t/y by a joint submission by confidential registrants. This volume is lower than the total EU tonnage of 1,007 t/y as estimated in the EU Risk Assessment (ECB, 2008a). TCEP is, according to an Annex XV SVHC dossier, today mainly used in the production of unsaturated polyester resins (~ 80 %) (ECHA, 2009). Other fields of application are reported to be acrylic resins, adhesives and coatings. The main industrial sectors that use TCEP as a flame-retardant plasticiser were the furniture, textile and building industries (roof insulation); it was also used in the manufacture of cars, trains and aircraft. The use in PUR foam is estimated at <1% of the total consumption. According to the REACH registration, the article categories related to subsequent service life are stone, plaster, cement, glass, ceramic articles and metal articles (i.e. not PUR foams).

According to EUROPUR, TCEP is not currently used as flame retardant in flexible PUR foams. The presence of TCEP as a contaminant in other flame retardants is described below.

TCEP is included in the REACH Authorisation List (Annex XIV to the REACH Regulation).

1.1.4 Application as flame retardants

The three substances are additive flame retardants, i.e. they are physically combined with the material being treated, rather than being chemically combined. The amount of flame retardant used in any given application depends on a number of factors, such as the flame retardancy required for a given product; the effectiveness of the flame retardant and synergist within a given polymer system; the physical characteristics of the end product (e.g. colour, density, stability, etc.); and the use to which the end product will be put. Data provided by the producers of flexible foams in response to the EU Risk Assessment for TCPP indicates loading rates between 2.5% and 14%, with two of the producers indicating a loading rate of around 7% to 8% TCPP in average foams (ECB, 2008b).

1.1.5 Presence as impurity in other FRs

Besides its presence in the commercial flame retardant product TCEP, according to the Risk Assessment for TCEP (ECB, 2008a) the substance TCEP may be present in concentrations of 5-8% in the commercial flame retardant Antiblaze V6 (Albemarle tradename), which is based on 2,2-bis(chloromethyl) trimethylene bis[bis(2chloroethyl)phosphate] (CAS No 38051-10-4, EC Number 253-760-2).

It has also been demonstrated in children's articles at levels of 5-18% of the level of V6 (as described in section 2.1.1).

The EU Risk Assessment for 2,2-bis(chloromethyl) trimethylene bis[bis(2chloroethyl)phosphate] has no information on the presence TCPP or TDCP in V6 (ECB, 2008a). Industry indicated for this EU Risk Assessment that products purer than V6, known as V66 (from Albemarle) and TL10 (manufacturer not identified), were produced at that time and that these products would replace V6. According to informal industry information, V6 has now been replaced by a product similar to V66.

2,2-bis(chloromethyl) trimethylene bis[bis(2chloroethyl)phosphate] (CAS No 38051-10-4) is registered under REACH with a manufacture and import in the 100-1000 t/y range by a joint submission by Albemarle Europe sprl and Shekoy Chemicals Europe B.V. (a subsidiary of Jiangsu Yoke Technology, China). Albemarle had ceased the production of the substance by 2013 (V66) and the product is now only placed on the market by Shekoy Chemicals Europe B.V. The REACH registration does not indicate the level of TCEP impurity in the commercial products. According to industry information the level of TCEP has been drastically reduced over the years and "V66" flame retardants sold today on the European market has TCEP levels below 1000 ppm (0.1% wt). It has not been possible to identify Safety Data Sheets or Material Data Sheets for the products from Jiangsu Yoke Technology, and hence it has not been possible to further characterise the impurities.

Apart from this, according to industry information from European manufacturers of flame retardants, the three flame retardants (TCEP, TCCP and TDCP) are not present as impurities in other flame retardants. For flame-retarded products produced outside the EU (e.g. in Asia) it cannot be ruled out that the three flame retardants may be present as impurities in other products.

1.2 Initiatives to reduce the exposure of children to the substances

On 20 June 2014, the European Commission published a new Directive 2014/79/EU in the Official Journal to amend Appendix C of Annex II to the Safety of Toys Directive (Directive 2009/48/EC) as regards TCEP, TCPP and TDCP. This Directive will come into force on 21 December 2015. The Directive sets a limit of 5 mg/kg for the content of TCEP, TCCP and TDCP in toys intended for children under 36 months and in toys intended to be put in the mouth, applicable to each of the three substances.

CertiPUR is a voluntary testing, analysis and certification programme for the environment, health and safety properties of PUR foam used in bedding and upholstered furniture applications. The initiative does not specifically address the exposure of children. CertiPUR is a registered trademark of EUROPUR. TCEP is prohibited in foams with the CertiPUR label, though no requirements are set for TCPP and TDCP. The requirements do not indicate any limit value for TCEP (EUROPUR, 2011) i.e. flame retardants where TCEP is present as impurity would also be prohibited.

The American CertiPUR-US (2014) is voluntary physical performance and environmental label for prime flexible polyether polyurethane foam for use in furniture and bedding in the US. According to the guidelines, both TCEP and TDCP are prohibited in CertiPUR-US labelled PUR foams without no indication of limit values.

1.3 Methodology applied in this study

1.3.1 Market survey for children's articles

In order to understand the market distribution of the three flame retardants in children's articles, consultation with manufacturers of children's articles and other stakeholders within the nursery products industry was undertaken. The consultation process was conducted in three steps.

Step 1 – Defining the scope
The first step was to define the scope of the consultation and establish information needs. Following the task description in the proposal and the subsequent indications from DEPA, the consultation was focused on:

- Whether the companies are undertaking assessments, or holding records, of the use of flame retardants present in relevant products.
- The type of articles where any of the three flame retardants can be found.
- The typical concentration of flame retardants in these articles.
- Estimated tonnage of foam and/or numbers of products that contain one or more of the three flame retardants.
- Uses of the flame retardants in textiles and other materials.
- Supply chain (e.g. origin of the foam and PUR product, countries where they sell their products).
- Why these flame retardants are chosen/required (i.e. relationship between use of flame retardants and fire regulation).

Specific questions were formulated to address the points above and a questionnaire was developed. The questionnaire can be found in Appendix 2.

Step 2 – Identifying consultees
The rationale for selecting potential consultees was to cover key steps in the supply chain (foam and article manufacturers) and also identify potential differences between UK and non-UK article manufacturers. Based on desk research a number of relevant organisations were identified. The main focus was on manufacturers of children's articles but the consultation also included industry associations, foam manufacturers and retailers. While all the organisations listed operate or market their products in the UK and/or Ireland, some companies were specifically identified because they manufacture or design their products in other EU countries and export them into the UK market. Whenever possible, key staff members within the organisation were identified in advance of contacting them.

Table 1 details the name and type of the 29 organisations contacted as well as the type of products they manufacture (if applicable).

TABLE 1
LIST OF ORGANISATIONS APPROACHED DURING THE CONSULTATION

Organisation	Type of organisation	Product
EUROPUR	European trade association	Polyurethane foam
BPF - British Plastics Federation, Flexible Foam group	UK trade association	Plastics (Flexible Foam)
BRPPA - British Rubber & Polyurethane Products Association	UK trade association	Plastics (Rigid polyurethane)
UKFT - UK Fashion & Textile Association	UK trade association	Textiles
FIRA, Furniture Industry Research Association	UK trade association	Furniture

Organisation	Type of organisation	Product
BPA - Baby products association	UK trade association	Baby products
Bebecar	Article producer	Pushchairs, car seats, carrycots
Cybex-online	Article producer	Car seats, pushchairs, baby carriers
Britax	Article producer	Car seats, pushchairs, baby carriers
Silver-cross	Article producer	Pushchairs, nursery furniture and textiles
Stokke	Article producer	Strollers, high chairs, car seats, carriers
Fisher-price (Mattel)	Article producer	Seats, swings, mats
Chicco	Article producer	All kind (toys, pushchairs, prams, carrier bags, mats, etc.)
Graco	Article producer	Car seats, pushchairs, highchairs
Maclaren	Article producer	Pushchairs
Dorel UK	Article producer	Including Maxi-cosi (car seats), Quinny (strolls) and Tiny love (baby carriers, toys, gear)
Mamas & Papas	Article producer / retailer	Various (pushchairs, strollers, prams, carrier bags, mats, etc.)
Cosatto	Article producer	Beds, pushchairs, car seats, highchairs
Red kite	Article producer	High chairs, baby carriers, nursery interiors, cots, pushchairs
Kit for kids	Article producer	Mattresses, sleep positioner, changing mats
The little green sheep	Article producer	Mattresses
Bugaboo	Article producer	Pushchairs
Jane	Article producer	Pushchairs / Car seats
Casualplay	Article producer	Pushchairs / Car seats
Torres Espic	Foam manufacturer	Polyurethane foam
Interplasp	Foam manufacturer	Polyurethane foam
Rivas	Foam manufacturer	Polyurethane foam
Tepol S.A.	Foam manufacturer	Polyurethane foam
Tespol espuma	Foam manufacturer	Polyurethane foam

Step 3 – Contacting the organisations
All the organisations above were contacted by phone and, were appropriate, with follow up emails. Consultation was conducted between mid-May and early August 2015. Industry associations were contacted first, followed by individual companies. Telephone interviews with key staff aware of the materials and substances present in the products (e.g. quality or compliance managers) was the preferred means of communication. When this was not possible, an email including details of the study and the questionnaire was sent to the address specified by the organisation.

Response rate and data limitations
Out of the 29 organisations approached, 10 agreed to take part in this study and provided useful information. Respondents differed in terms of the level of detail provided. While some only provided broad indications, others were willing to elaborate. The level of awareness about the use of flame

retardants in children's articles was generally high among the industry, with most article manufacturers claiming that they either test their products for chemicals or request information on chemical composition from their suppliers. However, consultees held limited quantitative data and/or were not willing to disclose it. Therefore the majority of the information collected through consultation is qualitative in nature.

Some of the challenges faced during the consultation that affected the number and quality of responses were:

- Many of the contacted organisations hold limited or no quantitative data regarding the presence of flame retardants in their articles.
- In many cases, companies operate a "no-name" policy requiring the researcher to send an email to a centralised address making it difficult to reach key staff.
- Some companies refused to take part on the study or to provide certain information arguing the topic of flame retardants is too sensitive to be disclosed to third parties and referred to the relevant industry association for more information.
- Some of the organisations replied that they are not concerned by the study as they do not use PUR foam or chlorinated flame retardants.

1.3.2 Survey of the European PUR market

In order to obtain information on the European PUR market, the European association of flexible polyurethane foam blocks manufacturers (EUROPUR) has been contacted and a meeting was held in June 2015. As described above, consultation also included a number of individual foam manufacturers.

1.3.3 Alternatives to the three flame retardants

In order to collect information on alternatives, contact was established with European associations and the manufacturers of relevant alternatives in Europe.

Information has been requested from (and meetings were held in June 2015) the two European associations of manufacturers of flame retardants (and meetings were held in June 2015):

- PINFA - Phosphorus, Inorganic and Nitrogen Flame Retardants Association
- EFRA - European Flame Retardants Association (represents manufacturers of halogenated flame retardants.

Only one manufacturer of flame retardants is a member of both organisations. It should be noted that some members of PINFA also manufacture halogenated phosphorous FRs and some members of EFRA also manufacture non-halogenated FRs. Both organisations are sector associations under CEFIC – the European Chemical Industry Council.

Furthermore, information on alternatives has been obtained directly from the following major manufacturers of non-halogenated alternatives:

- ICL-Industrial Products Europe B.V.
- Lanxess Deutschland GmbH
- Clariant Produkte GmbH
- BASF
- Thor Specialities (UK) Limited

Meetings were held in June 2015 with representatives of the first three of these manufacturers.

2. TCPP, TDCP and TCEP in children's articles on the EU Market

2.1 Overview of the use of TCPP, TDCP and TCEP in children's articles

2.1.1 Analysis of TCPP, TDCP and TCEP in children's articles

The three flame retardants have been demonstrated as being present in many types of children's articles with a content of foam material.

Danish EPA surveys of chemicals in consumer products

In a survey investigating chemical substances in child car seats and other textile products for children, TCPP was found in concentrations of 46 - 18,100 mg/kg in composite samples of textile and foam from car seats, TDCP was found in concentrations of 3,700 - 42,600 mg/kg sample and TCEP was found in concentrations of 41- 840 mg/kg sample (Kjølholt et al., 2015). The results are shown in Table 2. The survey included an X-ray pre-screening for selection of products of e.g. bromine and tin for further analysis, but no specific pre-screening was used for the selection of samples for analysis of TCPP, TDCP and TCEP. The relatively low concentration of TCEP may indicate that the substance is present as an impurity in other flame retardants (presumable V6, which was not tested for). TCPP and TDCP were found in higher concentrations (>1000 mg/kg) in five of eight car seats, in two of six baby slings, and in one baby mattress. The higher concentrations were found in samples of foam or combined foam/textile or foam/felt. The flame retardants were found in low concentrations (below the concentration where a flame retardant effect is expected) in many of the products, indicating that they are either present as an impurity in substances not tested for, or are present as contaminants e.g. from the manufacture of the foam.

The substances were shown to migrate to artificial sweat and the migration levels were estimated to constitute an undesirable risk, based on realistic worst case scenarios associated with a single car seat, a baby sling and a baby mattress. The migration to artificial sweat from the product during a 3-hour test period was up to 1,100 mg/m^2 for TCPP, up to 210 mg/m^2 for TDCP and up to 620 mg/m^2 for TCEP.

A manufacturer of children's car seats explained for the survey that the reason for the use of flame retardants in the car seats was the fire safety requirements for the products on the UK market.

In some of the samples, the foam and textiles were tested separately. In three samples with high total concentration of the three flame retardants in the foam (B12, B18, M24), the total concentration in the textiles ranged from 0.01% (M24) to 0.7% (B12) of the levels in the foam. The levels in the textiles were too low to serve as flame retardants in the textiles, and the content in textiles most likely is due to migration from the foam to the textiles. Triphenyl phosphate (TPP) is included in the table because this flame retardant may serve as a non-halogenated alternative. The concentrations of TPP are far below an effective level and it was probably present as an impurity.

TABLE 2
RESULTS OF ANALYSES FOR P-BASED FLAME RETARDANTS IN CAR SAFETY SEATS, BABY SLINGS AND BABY MATTRESSES IN DENMARK (MEAN OF DUPLICATE DETERMINATIONS) (KJØLHOLT ET AL., 2015)

	Origin	Concentration in the material in mg/kg			
		TCEP	TCPP	TDCP	TPP
Children's car seats					
A1, textile + foam	China	-	720	2,700	44
A2A, textile + foam	China	-	810	3,700	-
A2B, black plastic	China	-	30	14	-
A3A, textile + foam	Italy	-	2,200	20,300	34
A3B, textile + foam	Italy	-	4,800	21,100	65
A4, textile + foam	France	-	56	42,600	84
A5A, textile + foam	France	-	46	31,500	54
A5B, black rubber	France	-	-	23	-
A8A, textile + foam	n.i.	840	18,100	5,100	28
A8B, textile + foam	n.i.	41	2,490	6,700	30
A29, textile + foam	n.i.	-	-	-	330
A30, textile + foam	n.i.	-	-	-	28
Baby slings					
B9B, foam mat	China	-	21	-	18
B9C, textile and plastic	China	-	17	-	-
B10B, textile	Latvia	-	-	-	14
B12A, foam	China	75	11,200	160	43
B12B, textile	China	20	720	23	14
B12C, plastic	China	-	340	-	-
B16A, foam	n.i.	-	-	-	86
B17B, textile	n.i.	-	-	-	14
B18A, foam and felt	China	4,700	16,300	13,000	-

	Origin	Concentration in the material in mg/kg			
		TCEP	TCPP	TDCP	TPP
B18B, textile	China	57	140	45	-
B18C, textile	China	44	41	48	-
Carrycots					
M24A, textile	n.i.	-	-	92	-
M24B, foam	n.i.	-	-	89,700	74

- :Below the limit of detection: varies from 5 to 20 mg/kg among the samples.
TPP: Triphenyl phosphate, CAS nr. 115-86-6
n.i.: not indicated on product

A Danish EPA survey of chemical substances in toys and childcare products produced from foam plastic from 2006 analysed eight articles for the presence of TCEP (and other hazardous substances) (Borling et al., 2006). In all products tested, the concentration was below the relatively high applied detection limit of 50 mg/kg.

A more recent survey of flame retardants in textiles of furniture identified chlorinated phosphorous-based flame retardants in foam granules (Andersen et al., 2014). Out of four samples of foam granules from the furniture, TCPP and TDCP were found in combination in all samples in concentrations of 687 to 9,043 mg/kg for each of the substances (sum of the two substances ranging from approximately 2,000 to 15,000 mg/kg). None of the tested products were indicated as children's articles.

Danish Consumer Council test of children's articles
A test of 40 children's car seats by the Danish Consumer Council (2013) found that TCPP and TDCP were present in 14 and 6, respectively, of the 40 products (Table 3).

TCEP was found in one product at a low concentration where the concentrations of TCPP and TDCP was low as well (range of 130 - 255 mg/kg). The samples were not tested for V6.

The substances were found in both the textile cover and the textile pads made of textiles covering foam plastics. The substances were also found in a significant proportion of the baby slings and prams that were analysed (Table 3). In the latter two article types, the samples were composite samples of both foam and textiles. None of the analyses specifically concerned the foam plastics alone.

TABLE 3
RESULTS OF ANALYSES FOR TCEP, TCPP AND TDCP IN 40 CHILDREN'S CAR SEATS, 13 BABY SLINGS AND 6 PRAMS (DANISH CONSUMER COUNCIL, 2013, 2014 AS CITED BY KJØLHOLT ET AL., 2015)

Article group	Material	Detected substances, concentration range, comments (if any)	No. detect./ No. of samples
Children's car seats	Textile (cover)	TCEP 173 mg/kg TCPP 5.6 – 19,000 mg/kg TDCP 20 – 148,000 mg/kg	1/40 14/40 6/40

Article group	Material	Detected substances, concentration range, comments (if any)	No. detect./ No. of samples
	Textile (pads)	TCEP 255 mg/kg TCPP 5.7 – 12,000 mg/kg TDCP 26 – 56,900 mg/kg	1/40 11/40 6/40
Baby slings	Composite	TCEP 18 mg/kg TCPP 14 – 5,500 mg/kg TDCP 4,400 mg/kg	1/13 3/13 1/13
Prams	Composite	TCEP 320 mg/kg TCPP 6.9 – 23 mg/kg TDCP 44- 3300 mg/kg	1/6 4/6 2/6

Newer data from the tests by the Danish Consumer Council provided for this report are summarised in Table 4 below. TCPP was not detected in any of the car seats, whereas TDCP was found in fairly equal concentrations in 11 of the 20 car seats. As the car seats are different from the seats tested in previous tests it is not possible to conclude that the results reflect a general trend away from TCPP toward TDCP.

TABLE 4
RESULTS OF ANALYSES FOR TCEP, TCPP AND TDCP CHILDRENS ARTICLES SOLD I DENMARK * (DANISH CONSUMER COUNCIL, 2015)

Article group	Material	Detected substances, concentration range, comments (if any)	No. detect./ No. of samples
Children's car seats (fall 2014) - 14 of the products are not sold in Denmark but in other EU MS **	Composite samples	TCEP TCPP TDCP 2,600-9,300 mg/kg	0/20 0/20 11/20
Children's car seats (spring 2015)		TCEP TCPP 21-3,800 mg/kg TDCP 29 mg/kg	0/15 2/15 1/15
Baby stroller (10 samples)	Composite sample of parts close to child	TCEP, TDCP TCPP 6.5 – 400 mg/kg	0/10 6/10
	Handle	TCEP TCPP 17– 30,000 mg/kg TDCP 7 mg/kg	0/10 5/10 1/10

Article group	Material	Detected substances, concentration range, comments (if any)	No. detect./ No. of samples
Schoolbags	Composite sample front parts	TCEP; TCPP TDCP 21 mg/kg	0/9 1/9
	Back	TCEP, TCPP, TDCP	0/9
Earphones	Composite sample ear parts and cable	TCEP TCPP 16 mg/kg TDCP 29 mg/kg	0/16 1/16 1/16
Baby changing mats	Plastic part	TCEP; TDCP TCPP 163 mg/kg	0/7 1/7
	Foam	TCEP, TCPP, TDCP	0/7

* For car seats, some of the articles are not sold in Denmark

** The percentage of articles sold in Denmark containing the three substances was not significantly different from the percentage for articles sold in other EU Member States.

Children's articles in Austria
TCPP, TDCP and TCEP has also been demonstrated in a composite sample of a child car seats in Austria (Uhl et al., 2010). The sample contained 9,200 mg/kg TDCP, 4,700 mg/kg TCPP and 590 mg/kg TCEP. TDCP was found in one pillow at 8,700 mg/kg while the concentration in a push chair was 68 mg/kg. Low concentrations of 67 mg/kg TCPP and 14 mg/kg TDCP were found in the textile of a changing mat. The substances were not detected in various other articles for children.

TCPP, TDCP and TCEP in children's articles on the US market
Stapleton et al. (2011) surveyed baby articles on the US market containing polyurethane foam to investigate how often flame retardants were used in these articles. Information on when the products were purchased and whether they contained a label indicating that the product meets requirements for a California flammability standard were recorded. When possible, the flame retardants being used, and their concentrations in the foam, were identified. Foam samples collected from 101 commonly used baby products were analysed. Eighty samples contained an identifiable flame retardant additive, and all but one of these was either chlorinated or brominated. The most common flame retardant detected was TDCP with a detection frequency of 36%. The frequency for TCPP and TCEP is not reported; neither is the detection frequency for the individual article types. The three flame retardants were detected in concentrations of more than 1000 mg/kg foam in car seats, changing pads, sleep positioners, portable mattresses, nursing pillows, baby carriers, rocking chairs, high chairs, infant bath mats, and baby walkers.

Based on the results, the authors predicted that infants may receive greater exposure to TDCP from these products compared to the average child or adult from upholstered furniture, all of which are higher than acceptable daily intake levels of TDCP set by the US Consumer Product Safety Commission (CPSC). The authors therefore suggest further studies to specifically measure infants' exposure to these flame retardants from intimate contact with these products and to determine if there are any associated health concerns.

The State of Washington Department of Ecology tested for flame retardant chemicals in 169 general consumer and children's articles purchased between August 2012 and August 2013 from local retailers and online retailers in a specific area of the state (Washington State, 2014). The purpose was to determine the compliance with Washington State's ban on the PBDE class of flame retardants, to evaluate the level of substitute flame retardants and to verify compliance with local regulations. The study revealed that numerous products were found to contain chlorinated phosphorous-based flame retardants and particularly TDCP and TCPP. The results for children's articles are shown in Table 5. The three flame retardants were identified in children's chairs (5 of 14 samples), a child's chair accessory (1 of 1), changing mats and pads (3 of 4), a crib wedge (1 of 1), a booster seat (1 of 1), a portable crib pad (1 of 1), pee protector (1 of 2), a child's tablet (1 of 3), and baby carriers (2 of 3). The substances were identified in the fabric of the baby carriers, in the plastics of the tables and in the foam of the other products. The substances were not found in the other products analysed, which were baby activity gyms (4 samples), baby neck supports (2), belly pillow (1), car seats (4), mattresses (6), pyjamas (4), bathrobes (2), pillows (3), play pad (1), security blanket (1), stuffed animals (2), and stuffed toy (1).

As indicated in Table 5, most products contained multiple flame retardants, suggesting that mixtures are being used. The study also showed that a flame retardant mixture called Antiblaze® V6 (V6) is being used in several children's products; in two of the foams apparently in a mixture with TDCP and/or TCPP. TCEP which is known to be an impurity in V6, was found in all products containing V6, at a level of 6-19% of the level of V6. From the data, it is not possible to determine whether TCEP was present only as an impurity in V6, or as a component of flame retardant mixtures containing several of the chlorinated phosphorous substances.

TABLE 5
TCEP, TCPP, TDCP AND V6 IN CHILDREN'S ARTICLES (WASHINGTON STATE, 2014)

Product Description	Matrix	Sample	Concentration, mg/kg			
			TDCP	TCPP	TCEP	V6
Child's chair	Foam	OS003-F03	29,000	12,000	2,100	*
Child's chair	Foam	TR098-F01	26,000	16,000	3,000	16,200
Child's chair	Foam	OS002-F01	5,300	1,800	< 97	*
Child's chair	Foam	OS001-F01	< 97	12,000	3,400	37,200
Child's chair	Foam	WM094-F01	< 96	23,000	< 96	*
Child's chair accessory	Foam	OS004-F01	7,000	890	< 98	*
Changing pad	Foam	TG028-F02	25,000	4,900	< 87	*
Changing pad	Foam	TR015-F01	370	5,000	< 93	*
Changing Mat	Foam	TG024-F02	15,000	2,800	270	*
Crib wedge	Foam	TR017-F01	25,000	7,700	< 93	*
Booster seat (for car)	Foam	TG027-F01	44,000	15,000	550	*
Portable crib pad	Foam	TR016-F01	16,000	9,700	< 92	*
Pee protector	Foam	TR021-F02	270	< 98	< 98	*
Child's tablet	Plastic	BY002-F08	250	< 92	< 92	*
Baby carrier	Fabric	TR103-F12	< 97	870	510	*
Baby carrier	Fabric	TR103-F01	< 96	640	2,700	42,500

* It is unclear whether the products were tested for the presence of V6.

2.1.2 Consultation with industry

Consultation with EU stakeholders in the PUR foam and children's product industry has provided limited quantitative information for the reasons set out above. Only one consultee has provided a typical concentration of chlorinated flame retardants in PUR foam (4-5% by weight) based on their expert judgement.

TCEP - None of the respondents acknowledged use of TCEP. Moreover, two nursery article manufacturers have indicated that, following the classification of TCEP as a CMR substance in the EU and its restriction in products for children in Canada, this chemical is specifically avoided in the manufacture of children's articles. The PUR manufacturing industry stated that TCEP has not been used in the manufacture of flexible polyurethane foam in the UK or in the rest of the EU for years. Following this information, it is deemed unlikely that TCEP is voluntarily added to foam being used in children's articles manufactured in the EU. However, the potential presence of this substance as an impurity or in imported articles remains unclear.

TCPP - One European PUR foam manufacturer indicated they use TCPP as a flame retardant in the manufacture of foam that is compliant with the UK standard BS5852 Crib 5. Another respondent from the PUR industry claimed that presence of TCPP in children's articles is "possible", this being the most widely used flame retardant in the PUR industry. One non-UK European manufacturer of children's articles confirmed the presence of TCPP in the foam of some pushchairs; but only for those units manufactured for sale on the UK and Irish market.

TDCP - Regarding TDCP, respondents in the PUR foam industry indicated that, although its presence is possible, the use of this fire retardant in the manufacture of PUR foam is more limited than e.g. TCPP. Quantitative information was not available. However, two non-UK European manufacturers of children's articles confirmed they use TDCP in certain foam articles such as baby mattresses and foam parts of pushchairs. Once again, these manufacturers claim they use foam treated with TDCP only in articles for the UK and Irish market.

Three UK manufacturers of children's products acknowledged the use of foam containing flame retardants but did not specify which substances are being added. Finally, two non-UK manufacturers confirmed they are not using any of the three chlorinated flame retardants covered in this study. However, they use alternative flame retardants on those upholstered products to be sold on the UK market. The name of the alternatives was not disclosed as they considered it proprietary information.

Consultation was not able to reveal examples of chlorinated flame retardants being added to textiles. According to industry information, a small percentage of TDCP in Europe is used for textile applications. In the REACH registration for TCPP and TDCP uses in textiles are not included [and no downstream registration information on such uses have been submitted], and thus volumes in EU may not be used in textiles. According to industry, there might have been some niche uses defined in confidential uses, but this is marginal. However it cannot be excluded that some textile finished goods imported from China to Europe contain some TDCP or TCPP.
. Regarding migration from foam to textiles, an industry association pointed out that flame retardants added to foam are unlikely to migrate beyond/into textiles or other covers, citing the EU Risk Assessment for TCPP (ECB 2008b).

While the focus of the survey was on articles containing foam and the possibility of textiles being treated with these substances should not be ruled out.

2.2 Drivers for the use of flame retardants in children's articles

National fire safety regulations for furniture and textiles in the Member States have been reviewed in a study by Arcardis and EBRC for the European Commission, Health & Consumer Protection DG (Arcardis, 2011). According to the review, it is clear that furniture and textiles are required to respect strict fire safety regulations in the UK and Ireland, but not in the rest of Europe. The number of products that are covered by the regulations in the UK and Ireland is generally larger than in other countries. The non-flammability requirements are also stricter in the sense that the ignition sources used for testing the non-flammability are generally larger. The UK and Ireland also have a long tradition of regulating fire safety of consumer products compared to the other Member States that have only some requirements in this respect. Most Member States, however, do not have any fire safety regulations for furniture and textiles at all. An overview of national fire safety regulations for furniture and textiles in some Member States from the Arcadis (2011) report is shown in Table 6. More detailed and updated information on the regulation in the UK is provided in the following section.

TABLE 6
OVERVIEW OF NATIONAL FIRE SAFETY REGULATIONS FOR FURNITURE AND TEXTILES IN SOME MEMBER STATES (ARCADIS, 2011)

Country	Entry into force	Regulation	Scope	Requirement	Standard
Finland	1988	Guidelines for public buildings	Seats	No ignition by smouldering source (cigarette) and match flame	EN 1021-1 and 2
France	2005, replacing a regulation from 1980	Fire safety regulation in healthcare - U23	Bedding	No ignition by smouldering source (cigarette)	EN ISO 12952-1 and 2
France	2005, replacing a regulation from 1980	Fire safety regulation in public buildings – AM18	Bedding	No ignition by smouldering source (cigarette)	EN 597-1
France	2005, replacing a regulation from 1980	Fire safety regulation in public buildings – AM18	Seats	No ignition by 20g paper cushion	NF 60013 NF P92 501 NF P92 507
France	-	GPEM DI 90 for prisons	Mattresses	No ignition by smouldering source (cigarette), match flame and higher ignition source	EN 597-1 and 2 GPEM DI 90
Denmark	2008	Public buildings	Seats	No ignition by smouldering source (cigarette)	EN 1021-1
United Kingdom	Existing places entertainment	Guidance issued by The Home Office	Furniture	No ignition by smouldering source (cigarette), match flame and Crib 5.	BS 5852
United Kingdom	-	Guidance for hotels and boarding houses issued by The Home Office	Furniture, mattresses and bed bases	No ignition by smouldering source (cigarette), match flame and Crib 5.	BS 5852 BS 7176
United Kingdom	2006	Guidance for healthcare issued by The Department of health	Furniture, mattresses and bed bases	No ignition by smouldering source (cigarette), match flame and Crib 5 or Crib 7	BS 5852 BS 7176 BS 7177
United Kingdom	-	Guidance for residential care homes issued by The British Standards Institution	Furniture, mattresses and bed bases	No ignition by smouldering source (cigarette), match flame and Crib 5	EN 597-1 and 2 EN 1021-1 and 2 BS 5852 BS 7176 BS 7177 BS 6807

2.2.1 UK and Ireland

The Furniture and Furnishings Fire Safety Regulations are designed to ensure that upholstery components and composites used for furniture supplied in the UK meet specified ignition resistance levels (FIRA, 2011).

The regulations specify that:

- Filling materials must meet specified ignition requirements
- Upholstery composites must be cigarette resistant
- Covers must be match resistant (with certain exceptions).

The requirements for nursery furniture are the same as those for domestic upholstered furniture and the Regulations apply to the nursery equivalents of domestic upholstered furniture and beds, and to other upholstered products which are designed to contain a baby or small child (FIRA, 2011). This includes mattresses, cushions and pillows. The Regulations also apply to the following items which contain upholstery (FIRA, 2011):

- baby seats, bouncing cradles and baby rockers
- baby car seats that are designed for home as well as car use
- baby walking frames
- cots and travel cots, carry-cots, carry-cribs, cribs and Moses baskets
- highchairs, chair harnesses and playpens (including mattresses for playpens)
- prams and push-chairs
- baby nests
- upholstery liners supplied with all of the items listed above.

The Regulations do not apply to (FIRA, 2011):

- baby bouncers that are suspended from doorways
- bed-clothes, bumpers for cots, play mats, foot muffs and cosy toes
- baby carriers, slings and rucksacks which are designed to be worn outdoors
- baby changing mats and dresser units
- the cover fabric of any removable hoods or covers of prams, push-chairs or carry-cots, which are intended to act as a sunshade or waterproof cover when these articles are used in the open air.

Flammability tests

Regarding flammability requirements for polyurethane foam, the Furniture and Furnishings (Fire) (Safety) Regulations in its Schedule 1 (Part 1) specifies that polyurethane foam used as filling in furniture in slab or cushion form, including in children's articles as listed above, must pass the ignitability test specified in the standard BS 5852, Part 2. In this test, a cover fabric made of 100% retardant polyester fibre and the PUR filling to be tested are put in a test rig to create a small sofa with a 90° angle between seat and back. A wooden crib (Ignition Source 5) is located in the junction between seat and back. Charring, flaming and loss of material is recorded during the test. This test is commonly referred in industry as the "Crib 5 test".

Schedule 1 (Part 2) regulates the ignitability test for polyurethane foam in crumb form, referring also to BS 5852, Part 2. In this case, Ignition Source 2 is used, equivalent to a lit match being in contact with the testing material. This test is commonly known as the "match test".

Possible amendment

In 2014, the UK Department for Business Innovation and Skills (BIS) launched a public consultation regarding a possible new amendment to the match test for cover fabrics, with the aim of reducing the amount of flame retardant chemicals that tend to be used in UK furniture. Following the consultation, BIS decided not to go ahead with the proposed amendments. Instead, the proposals on changes to the testing regime will be considered as part of the full review of the regulations which was already underway. It should be noted, however, that the proposed amendment was targeted at the match test conducted to test cover fabrics and did not concern the test required for PUR foam in slab or cushion form used in furniture (Crib 5).

Consultation with the children's article industry on drivers for the use of flame retardants

All the manufacturers of children's articles that took part in the consultation (a total of seven) stressed that the main driver for the addition of flame retardants is the UK fire safety regulations, arguing that flammability requirements can only be achieved in PUR foam by adding these substances. There appears to be common agreement among this industry that current UK fire standards are too stringent and force the addition of chlorinated flame retardants in articles. In their view, this is unnecessary and burdensome, resulting in avoidable potential risks for consumers and the environment. Consultees indicated that industry is lobbying to try to lower the fire standards for children's articles.

Manufacturers commented that their main objective to avoiding flame retardants is the potential health and safety risks associated with the use of these substances and the increasing concerns of their customers on this topic. In addition, they claimed that PUR foam containing chlorinated flame retardants offer inferior technical performance than FR-free foam, particularly regarding durability, comfort and smell. One foam manufacturer confirmed that PUR foam treated with TCPP has less durability and gives off a strong smell of chemicals that may be unattractive to customers.

According to the PUR foam industry, there are halogen-free foam grades available for children's articles that do comply with UK flammability regulations and which have been on the market for over 20 years. However, alternative substances behave differently during the foam processing process and can have an impact on costs and performance. It has not been possible to obtain data on flame retardants used in the halogen-free foam grades.

One foam manufacturer argued that TCPP is the flame retardant that interacts the least with the polymer structure. This was confirmed by the wider PUR foam industry stating that TCPP is the only flame retardant that can be easily integrated into formulations across the board. Comparing chlorinated flame retardants to other substances, one of the respondents argued that dense foams (like the ones they use in cots and baby mattresses) can pass fire tests using only melamine as a flame retardant, while lighter foams (like in pushchairs and high seats) require chlorinated flame retardants. It was argued that dense foams cannot be used in all types of applications as different products require different degrees of cushioning for the comfort of the baby. Dense foams are generally more expensive than lighter foams.

The cost differential between PUR foam treated with chlorinated fire retardants and standard FR-free PUR foam was also investigated during the consultation exercise. One article manufacturer and one PUR foam manufacturer indicated that foam treated with FRs is around 15% more expensive. After checking with their suppliers, a different article manufacturer specified that the additional cost of using foam treated with FRs compared to standard foam was €0.36 per pushchair. It should be noted that the cost of the foam in pushchairs represents only a small fraction of the total cost of the article. This may not be the case with other articles with higher foam content (e.g. baby mattresses). One manufacturer also pointed out that recent changes to the California Regulation TB117 may lead to a significant reduction in demand for foams treated with flame retardants in the US and thus a reduction in volumes of production, resulting in a potential price increase for this type of foam. No other consultees provided information on price differential between FR-containing and FR-free foam.

Besides the potential impact on the cost of PUR foam, consultation also revealed that UK fire regulations have a significant impact on the supply chain of non-UK manufacturers. They claim current regulations force them to keep a separate production and supply chain for the British Isles and the rest of Europe, as detailed in Section 2.4. The four non-UK manufacturers that participated in the consultation claimed that the full economic implications of this impact was very difficult to estimate quantitatively, but insisted it had a significant impact on their production costs and logistics.

Summarising the points above, the children's article companies contacted all claimed that the UK fire safety regulation is driving the addition of FRs to children's articles. Manufacturers argued that they would prefer not to use FRs due to increased cost and, especially, due to potential health risks and customer concerns. This leads non-UK manufacturers to incur significant costs to keep separate product types and supply chains for the UK market.

2.2.2 USA

California regulation - According to Stapleton et al. (2011), the flammability standard primarily driving the use of flame retardant chemicals in polyurethane foam in the USA is Technical Bulletin 117 (TB117), promulgated by the California Bureau of Electronic and Appliance Repair, Home Furnishings and Thermal Insulation. TB117 requires that polyurethane foam in upholstered furniture sold in the State of California to withstand exposure to a small open flame for 12 seconds. Though the standard does not specifically require the addition of flame retardant chemicals to the foam, polyurethane foam manufacturers typically use chemical additives as an efficient method of meeting the TB117 performance criteria. According to Stapleton et al. (2011), some baby products are considered to be juvenile furniture and the polyurethane foam used in baby products must also comply with TB117. However, the extent of baby product compliance with TB117 and whether or not the types of chemicals added to the polyurethane foam are similar to those in non-juvenile furniture is unknown (Stapleton et al., 2011).

The newest version of the TB117, Californian Technical Bulletin-117-2013, updates the flammability standards from the open flame method of testing to a smouldering test. The revised standard sets new testing requirements for smoulder resistance of cover fabrics, barrier materials and resilient filling materials for use in upholstered furniture. TB 117-2013 can be met without the use of flame retardant chemicals, although the standard does not prohibit their use and many manufacturers are today selling flame retardant-free furniture in California (CEH, 2015).

Furthermore, the California 1019 Senate Bill further requires that furniture is labelled if the concentration of flame retardants in any component is above 1000 ppm (0.1%). The limit is used to define the flame retardants as an "added" chemical. (California, 2014).

Washington State regulation - According to State of Washington regulation concerning flame retardants (House Bill 1174 - 2015-16) the manufacture, sale, or distribution of residential upholstered furniture or children's products containing TDCP and TCEP in any product component in amounts greater than 100 ppm (=0.01%) is prohibited as of July 1, 2016. (Washington State, 2015).

Children's cushioned articles - The US House of Representatives (2013), in their bill H.R.2934 to amend the Consumer Product Safety Improvement Act (CPSIA) in order to restrict the presence of flame retardants, lists the following examples of children's cushioned articles: high chairs, strollers, infant walkers, booster seats, car seats, changing pads, floor play mats, highchair pads, highchairs, infant swings, bassinets, infant seats, infant bouncers, nursing pads, play yards, playpen side pads, infant mattresses, infant mattress pads, and portable hook-on chairs.

2.2.3 Long list of children's articles potentially containing TCPP, TDCP and TCEP

A long list has been compiled from the list of children's articles addressed by the UK fire safety regulation (FIRA, 2011), products in which TCPP, TDCP and TCEP have been identified (Stapleton et al., 2011; SoW, 2014; Kjølholt et al., 2015) and other identified cushioned children's products:

- Chairs and seats
  - Child car seats
  - High chairs
  - Children's chairs (e.g. upholstery chairs)

    - Rocking chairs
    - Infant swings
    - Foam block seats
- Baby carriers
    - Baby prams
    - Strollers/pushchairs
- Mattresses, mats, pillows, etc.
    - Children's mattresses (of beds, bassinets, etc.)
    - Portable mattresses
    - Baby changing mats or pads
    - Playpen side pads
    - Crib wedges
    - Sleep positioners
    - Nursing pillows
    - Bath mats
- Other
    - Baby walkers
    - Floor play mats (which may be considered toys)

In principle, the three flame retardants may be found in any of these products, even no formal requirements of flame retardancy exist for some of the products.

2.3 Overall information on EU market for flexible PUR foams with TCPP, TDCP and TCEP

The European trade association EUROPUR has been asked for information on the quantity of FR flexible PUR for children's articles produced in the EU and the number of companies manufacturing FR flexible PUR for these articles. Such information does not exist, but the following information on the manufacture of PUR foams with TCPP, TDCP and TCEP in Europe may indicate the size of the market and the market actors that may be affected by a restriction.

The tonnage of FR flexible PUR produced in the EU may be calculated on the basis of the tonnage of flame retardants used for manufacture of flexible PUR foams in the EU. Available information indicates that the three flame retardants account for about 90% of the total FR flexible PUR market in the EU.

As indicated in section 1.1.1, according to the transitional Annex XV dossier for TCPP, about 6,800 tonnes (17% of the total volume) was used for the manufacture of flexible PUR foam (17% of total TCPP consumption) used in upholstery and bedding for the UK and Irish markets. The loading varies by foam type and whether other FRs are used. TCPP is commonly used in combination with melamine. The EU risk assessment for TCPP indicated that a German government report gives TCPP loading rates for flexible foams of between 3% and 5% by weight. Data provided by the producers of flexible foams in response to the Risk Assessment questionnaire widens this range to between 2.5% and 14%, with two of the producers indicating a loading rate of around 7% to 8% TCPP in average foams (ECB, 2008b). The risk assessment uses a concentration in the final foam of 8%. If an average of 8% of foam weight is used, the 6,800 tonnes TCPP corresponds to 85,000 tonnes flexible PUR foam flame retarded with TCPP.

As indicated in section 1.1.1, somewhat less than 10,000 tonnes of TDCP were consumed in the EU in the year 2000 (ECHA, 2008b). Most TDCP was used in the production of flexible polyurethane (PUR) foam. Foam with TDCP is in particular used in the automotive industry because of its lower fogging potential as compared to TCPP. Neither the EU Risk Assessment nor the transitional Annex XV dossier for TDCP indicate the loading rates. The majority is used for automotive applications with other flammability requirements than the UK requirements for furniture. A comparison of

TDCP with alternatives indicates in the examples loads of TDCP of 9-14 php (parts per hundred polyols) depending on foam type and standard to comply with (Great Lakes, 2012) i.e. the percentage in the final foam ranges from approximately 5-9%. It is assumed here, for a rough calculation, that the average percentage is 8% and that the quantity of FR foams with TDCP produced is approximately 110,000 tonnes.

On this basis, the total production of FR foams is estimated at 195,000 tonnes per year. These are the foams containing TCPP and TDCP (it is assumed that TCEP is not used).

The total manufacture of flexible PUR foams in the EU28 + Norway + Switzerland was approximately 893,000 tonnes in 2014, divided into 826,000 tonnes ether foam and 67,000 tonnes ester foam (EUROPUR, 2015d). The total number of operational PUR foam plants is 107 of which 57 are members of EUROPUR (EUROPUR, 2015d). Some of the manufactured foam will be used for production of rebonded foam from production scrap. According to EUROPUR (2015c), import of flexible PUR slabstock from countries outside the EU is considered to be insignificant compared to the volume manufactured within the EU. The report does not indicate the quantities of FR foams manufactured. If the total quantity of FR foams is 195,000 tonnes per year this corresponds to approximately 22% of the total.

If it is assumed that the majority of foams with TCPP and a small part of the foam with TDCP are used for furniture and other non-automotive applications the total can be estimated at some 90,000-120,000 t/y corresponding to 10 to 13% of the total European production. Some of this will be used for articles exported out of the EU and at the same time some import within articles may take place. The main application areas for the non-automotive FR flexible PUR foams are bedding and upholstered furniture. The total import from countries outside the EU of bedding and upholstered furniture, however, is estimated to be relatively small. According to the EU Risk Assessment for TCPP (ECB, 2008b), the majority of furniture used in the UK in 2000 was produced in the UK (>80%), and non-EU import corresponded to 3.8% of the UK production. Children's bedding (primarily mattresses) may likely account for some 10-20% of the total consumption of PUR foams for bedding, while the percentage for upholstered furniture is probably less.

On this basis, the likely total content of FR flexible PUR foams in children's articles can be roughly estimated at some 5,000-20,000 t/y of which the majority would be in bedding (0.6-2.2% of total EU flexible PUR production). A significant part of this would be produced in the UK and Ireland.

2.4 Market for children's articles with TCPP, TDCP and TCEP

Information on the markets for children's articles with TCPP, TDCP and TCEP has been collected in this study with a focus on the EU market, while information on the Danish market is based on two previous Danish studies on chemicals in children's articles (Kjølholt et al., 2015; Tønning et al., 2008). In the following, the description will be divided into a description of the total EU market for the articles and a description of the percentage of the marketed articles likely to contain TCPP, TDCP and TCEP.

Production and trade statistics

The statistics on international trade from Eurostat contain import/export data for baby carriages (CN code 8715 00 10) (prams and pushchairs) whereas other children's articles addressed here are included in aggregate commodity codes together with other types of articles. The UK fire safety regulation require prams and pushchairs to be flame retarded and in surveys in Denmark the FRs were found at low concentrations in a significant portion of the analysed prams. As the baby carriages are the only for which statistical data are available they are described in detail below to illustrate the market for these articles.

The prams are also covered by the Prodcom production statistics from Eurostat under the Prodcom code 30924030: "Baby carriages". The consumption in the EU may be estimated from the equation:

Consumption = Production + Import - Export

The Prodcom statistics for the prams is, however, confidential for most Member States and for 2013 the total non-confidential EU28 production was 3,854 pieces at a value of EUR 0.4 million, which is likely much too low. It is consequently not possible to estimate the consumption using the above equation, but the data on net-import may indicate the magnitude of the consumption. The statistical data are shown in Table 7.

EU28 - For the EU28, the net import of baby carriages from countries outside the EU was 6.0 million pcs at a value of EUR 332 million. To this should be added the baby carriages produced in the EU and sold on the EU market in order to estimate the total consumption. The intra-EU import (import to one Member State from another Member State) was nearly as the same size as EU extra import, but a part of this may be re-export within the EU of baby carriages originally imported from countries outside the EU (e.g. after some modifications and repackaging). In principle, the total EU28 intra import should balance the total EU intra export but it does not, in particular as concerns the figures in pcs. which illustrates the uncertainty with the data. The total value of the EU28 net import from countries outside the EU for baby carriages is in the order of magnitude of EUR 170 million and the total market including EU production will be significantly higher.

UK – The nursery articles market value in the UK was estimated to be around £1 billion (€1.4 billion) in 2014 with an annual growth rate of 5.4% (GfK, 2015). However, this figure includes a large range of items for babies, most of them not containing foam, such as feeding devices or baby monitors.

Regarding baby carriers, the data shows that, of the total net import into the UK of 1.6 million pcs, nearly 100% came from countries outside the EU. As the data for production are confidential, it is not possible to estimate the percentage of the total UK market which was imported from countries outside the EU and the total consumption is probably higher than the 1.6 million pcs. The total export of baby carriages from the UK to other Member States was 0.14 million pcs which illustrates the potential for export of flame-retarded articles to the rest of the EU. The total value of the UK net import of baby carriages is in the order of magnitude of EUR 88 million. Local production for the domestic market must be added to this figure.

Denmark - As data are available for production in Denmark, the total consumption in Denmark in 2013 can be estimated at 51,790 pcs. Of the imported baby carriages, 58% was imported from countries outside the EU. As the reported production in Denmark is only 15 pcs, the data demonstrates that a significant part of the imported baby carriages are re-exported mainly to countries within the EU.

TABLE 7
EU28 INTRA AND EXTRA IMPORT AND EXPORT OF BABY CARRIAGES IN 2014 (CN CODE 8715 00 10 AND PRODCOM CODE 30924030)

	EU intra, pcs	EU extra pcs	EU intra, €	EU extra €
EU28				
Import	4,058,508	5,985,219	248,081,649	332,386,204
Export	2,859,413	1,531,215	294,085,559	161,770,394
Net import		4,454,004		170,615,810
UK				
Import	77,385	1,709,629	12,417,435	88,453,051
Export	136,524	45,164	10,258,493	2,380,825
Net import	-59,139	1,664,465	2,158,942	86,072,226
Denmark				
Import	29,740	40,661	5,640,183	2,280,091
Export	13,934	4,677	2,803,908	420,634
Net import	15,806	35,984	2,836,275	1,859,457
Production	15			
Consumption *	51,805			

* Calculated as production + net import EU extra + net import EU intra

Comparison with number of births - The figures above may be compared with the numbers of live births in 2012, which according to Eurostat was[4] :

- EU: 5,231,000
- UK: 813,000 (UK + Ireland: 885,000, data used later)
- Denmark: 57,900

For Denmark, the number of baby carriages sold is quite similar to the number of live births and the same may be true for the EU28 where the number of baby carriages sold is at least 4.5 million pcs and the number of live births 5.2 million. In the UK, the number of baby carriages sold is apparently at least twice the number of births. Baby carriages include both prams and different kinds of push-chairs, strollers, etc. and a child commonly during its upbringing uses 2-3 baby carriages. In some countries e.g. Denmark the carriages are commonly reused for several children which explains why the number may be quite similar to the number of births in Denmark, whereas it in other countries may be less common to reuse the equipment.

Other children's articles
As mentioned, no statistical data are available for other articles.

The consumer product project on "babies products" by Tønning et al. (2008) estimated that the number of prams sold in Denmark was 25,000 to 40,000 pcs./year while the number of each of the other children's articles was estimated at close to the number of births 40,000 to 60,000 pcs./year. The number for prams did not include pushchairs, strollers etc. and is thus quite well in accordance with the statistical data shown above. As demonstrated for the baby carriages, the total EU market

[4] http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Demographic_balance,_2012_(1_000)_YB14.png

and the Danish market are quite similar as concerns the number of babies products compared to the number of live births. For the baby products the likely total EU market is in the range of 2-5 million pieces for each product type.

Kjølholt et al. (2015) estimate that most children's articles (except child car seats discussed below) such as cradle seats, baby slings and buntings mostly originate from countries outside the EU (about 80%).

Articles with foams used by older children, and which that cannot be considered "babies products", are mainly child car seats, mattresses and upholstered furniture for children. These products are considered to represent the highest volume of FR flexible PUR foams and the highest market value, and are briefly described below.

Child car seats - A survey of chemicals in child car seats was undertaken in Denmark in 2014 (Kjølholt et al., 2015). According to the survey, around 75-80% of child car seats on the Danish market originated from non-EU countries, and of these the majority were imported from China. The remaining 20-25% was produced in the EU, mostly in Germany but also in Italy. Typically, child car seats produced in the EU are more expensive than the Asian products, and therefore the vast majority of child car seats found in discount stores, DIY centres and supermarket chains typically come from countries outside the EU. Many brands are marketed as being European, although the actual production takes place outside the EU. The total number of child car seats sold in Denmark was estimated at 60,000-100,000 seats per year i.e. one to two times the number of live births. The car seats include foam materials for fillings and upholstery of the chair itself and possible support cushions. The average volume of flexible PUR foam in a car seat is not reported. If the market for car seats in the UK and Ireland is comparable to the Danish market, 0.9 to 1.8 million car seats would be sold every year in these countries. Kjølholt et al. (2015) reports that FRs are added to child car seats for the UK/Irish market, but as discussed in section 2.1.1 about 1/3 of all tested child car seats on the Danish market contained FRs, even this in not required by national regulation. TCPP has also been demonstrated in child car seats in Austria (Uhl et al., 2010), and may probably be found in some child car seats across Europe.

Mattresses and other bedding - Mattresses and bedding probably account for the majority of flexible PUR foams in children's articles. During childhood, the mattresses may be changed several times and the average volume of foam in mattresses is higher than in any other articles.

Upholstered furniture - No data have been collected on the market for upholstered furniture for children. The market volume is more difficult to estimate on the basis of the number of births. Many children have one or several items, whereas other do not have these articles. According to the EU Risk Assessment for TCPP (ECB, 2008b), the majority of furniture used in the UK in 2000 was produced in the UK (>80%), and non-EU import corresponded to 3.8% of the UK production.

Total market value of flame retarded children's products

The total value of the UK net-import for baby carriages was EUR 88 million in 2014 and to this value of the domestic production for the domestic market needs to be added. Baby carriages are relatively expensive equipment, but auto chairs, bedding and furniture may be changed several times during the child's upbringing and the total costs of these may likely be higher than the costs of the baby carriages (i.e. the total is likely more than twice the EUR 88 million, but likely less than 10 times this figure). On this basis, the market value of flame retarded children's articles for the UK and Irish market likely is in the order of magnitude of EUR 200-500 million (expressed as gross dealer prices without VAT).

Tonnage
No information regarding tonnage of children's articles or tonnage of flexible PUR foams used in these articles could be obtained from consultation.

Supply chain for children's articles sold in the UK market
Consultation suggested that a large proportion of the foam used in children's articles for the UK market is produced in Asia, particularly China. However, the European foam industry pointed out that foam is unlikely to be imported as slabstock blocks but as part of the components of the articles. According to article manufacturers, upholstered pieces are frequently manufactured in China, with the foam being sourced locally and requested to meet a certain flammability standard by the manufacturer. Assembly may occur in China, with the final article being imported, or may occur in the EU. Although this supply pattern seems to be common, some manufacturers pointed out that it depends on the type of piece/article. For example, one EU manufacturer claimed that part of the foam they use is sourced in the EU. A UK manufacturer specified that they source specialised foams, usually denser and more expensive foams, from UK factories with the rest being sourced and assemble in China.

Consultation also revealed that UK fire regulations have a significant impact on the supply chain of non-UK manufacturers. These manufacturers claim that, in order to comply with UK legislation, they are forced to operate a separate production line and supply chain for upholstered items to be sold in the UK. This includes sourcing different materials (e.g. compliant flame retardant foam), separate labelling and ensuring that the inventory is tracked and segregated. They also argue that they cannot ship excess inventory from other EU countries to the UK and that this impact extends to some of their retail customers, who need to put controls in place to ensure non-compliant articles are not distributed to the UK market. This suggests that products from non-UK manufacturers sold in the rest of the EU are unlikely to contain chlorinated flame retardants.

Regarding UK manufacturers, one of those confirmed that they purchase PUR foams with varying specifications of flame retardancy depending on the final use of the product. In this way, articles that do not need to pass fire safety tests do not contain unnecessary flame retardants. On the other hand, a different manufacturer claimed they buy off-the-shelf foam for several purposes, which is then used in the manufacture of different types of children's articles. It was unclear if this includes articles that are not covered by fire regulations as listed in Section 2.2.1 In addition, the PUR foam industry indicated that mixing FR and non-FR foams is a common practice when producing rebonded foam which, although not meeting the BS 5852 requirements, could still contain flame retardants. Therefore, information available suggests that the presence of chlorinated flame retardants in products that are not covered by the UK fire safety legislation cannot be completely ruled out.

It remains unclear whether products manufactured by UK companies and then exported into other EU Member States are likely to contain flame retardants. In an open internal market, it is possible that articles manufactured in UK and Ireland and containing chlorinated flame retardants are exported to other countries. This would eventually depend on the company and would be voluntary under current legislation. It can be argued that, for a small UK manufacturer for which exports to the rest of EU represent a small fraction of their market compared to domestic sales, developing a different product and supply chain may result in prohibitive costs.

The overall supply chain for PUR foams in children's articles can be illustrated as shown overleaf:

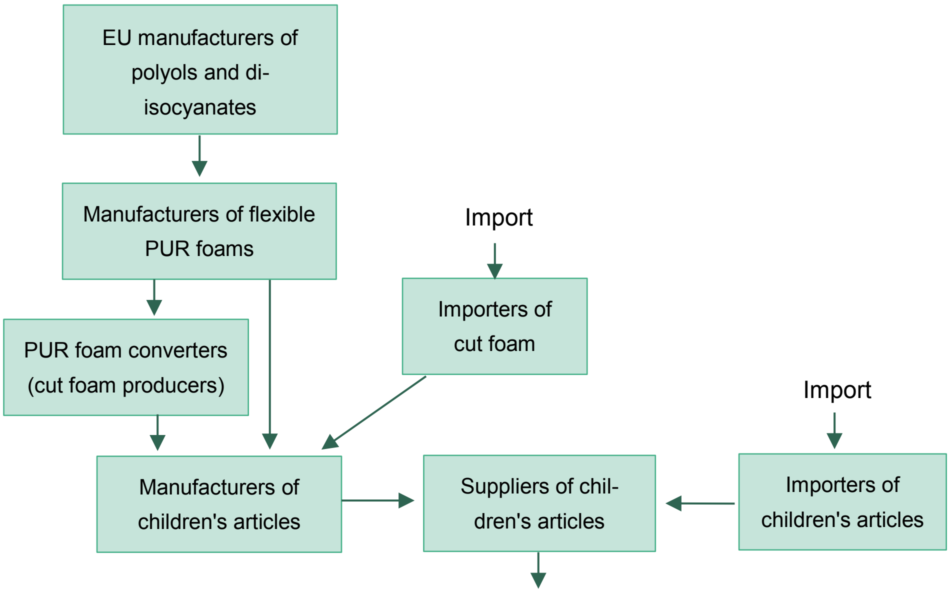


FIGURE 1
OVERALL SUPPLY CHAIN FOR FLEXIBLE PUR FOAMS IN CHILDREN'S ARTICLES

3. Chemical alternatives to TCPP, TDCP and TCEP in children's articles

3.1 General considerations regarding assessment of chemical alternatives

Today, no "drop in" alternatives for TCPP or TDCP exist (TCEP is not considered further as it is no longer used) i.e. it is not possible to replace these flame retardants (FRs) with an alternative FR without changing the formulation of the flexible PUR. Furthermore, the TCPP or TDCP may be used in combination with other FRs, e.g. TCPP is often used in conjunction with melamine, which acts as a synergist. As part of the reformulation, it will often be necessary to replace one FR system with another FR system, and it may be also be necessary to change the composition of other raw materials.

Only a small percentage of all flame retarded flexible PUR foams in the EU is today produced with non-halogenated flame retardants and no overview exists of which types of foams the non-halogenated flame retardants can be used for, and which fire safety standards the foams produced with non-halogenated flame retardants can meet. This information would need to be collected from individual manufacturers of flame retardants and manufacturers of foams.

Flexible PUR foam chemistry is quite complex as many different raw materials are used in combination, and each of these may be changed by a reformulation.

Polyurethane foams are produced by reacting polyols and diisocyanates, either derived from crude oil or biomass based. A formulation for a flexible PUR foam would typically consist of:

- Aromatic diisocyanates - two major groups: MDI (methylene diphenyl diisocyanate) and TDI (toluene diisocyanate). Formulations may include more than one type of diisocyanate.
- Polyols – of which there are many different types, the main groups being polyester and polyether polyols - a formulation typically consists of several different polyols.
- Catalysts are used to increase the reaction rate between diisocyanates and polyols. There is a wide variety, with metals salts or amine-based catalysts the most commonly used.
- Blowing agents are used to produce the foam's cellular structure. The blowing agents for flexible polyurethane foam are usually water and carbon dioxide (CO_2).
- Stabilisers are used in some formulations.
- Flame retardants are added if required – these may be liquid or solid flame retardants, additive or reactive. Reactive flame retardants are polyols with flame retarding properties.

The addition of flame retardants changes the properties of the foam both during the polymerization and in terms of the properties of the final foam. Properties of the foams considered are among others density, cream time, rise time, open cell content, CLD 40% (Compression Load Deflection) and compression set.

The targeted flame retardants have other properties than flame retardancy and e.g. may serve as emulsifiers during the polymerization process and affect the reactivity of the raw materials. Their presence in some toys imported from Asia before the ban (Directive 2014/79/EU) has been attributed to use as plasticisers rather than a use of the substances as flame retardants (informal information from industry).

Flexible PUR foams are inherently highly flammable due to the open cell structure. The flammability, and thus the need for addition of flame retardants in order to meet a specific standard, is highly dependent on the density of the foam. An example of the loading in php (parts per hundred polyols) is shown in the figure below. Php cannot be recalculated into percentage of foam weight without knowing the formulation. A typical formulation for automotive applications would include approximately 40-50 php in total for the diisocyanate (mainly) and other ingredients. A FR load of 10 php correspond to approximately 6-7% in the final foam.

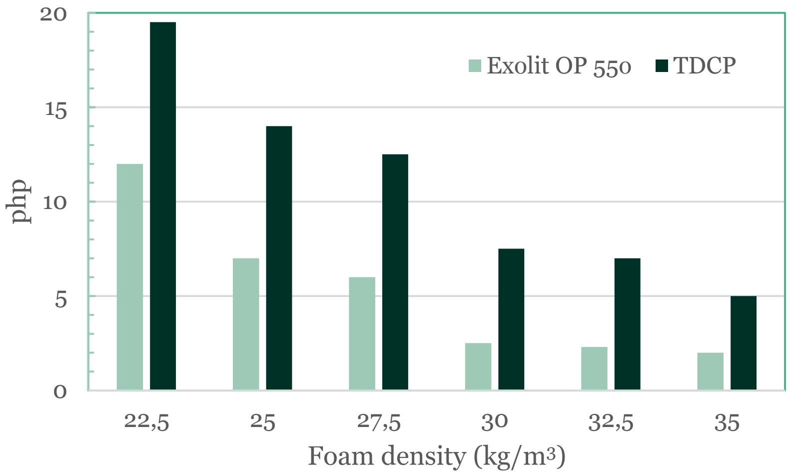


FIGURE 2
MINIMUM FR LEVELS TO ACHIEVE CLASS SE OF FLEXIBLE POLYETHER FOAMS AT DIFFERENT FOAM DENSITIES (CLARIANT, 2007)

This means that extra costs of using a more expensive FR will be highly dependent on foam density. Furthermore, it would be easier to replace the targeted FRs in foams with a high density because the lower loadings means that the impact of the FR on the properties of the foams may be lower. The flammability of the foams depends on a number of factors and may vary even if the same formulation is used, due to small variations in the raw material composition. In order to ensure that all foams can pass a given test it may be necessary to add FRs in loads well above the minimum level required.

A number of different foam types exist. The British Plastics Federation categorised the foams as follows (BPF, 2015):

- Standard ether or high resilience (HR) foams
- Combustion-modified ether (CME) foams
- Combustion-modified high resilience (CMHR) foams
- Viscoelastic (VE) foams
- Ester foams
- Re-bonded foams

Standard ether or HR foams are likely to be found only in packaging and non-furniture applications as they do not pass the stringent flammability tests required for use in UK furniture by law. CME and CMHR foams are most likely to be found in furniture and bedding applications. They contain flame retardants and comply with the UK furniture and furnishings fire safety legislation. Viscoelastic foams are used more in bedding applications as they were developed for pressure reduction. Those made in the UK also contain flame retardants in order to comply with UK fire safety regulations. Rebonded foams are manufactured using production scrap and trimmings and are bound together to make a new foam block. These are used mostly in carpet underlay and in lower cost areas of furniture such as bed or sofa bases. In the UK they are typically based on FR foams (BPF, 2015). Ester foams are resistant to oil and used for technical purposes such as automotive filter foams.

Some manufacturers of flexible PUR foams produce more than 100 different foam grades, many of these with flame retardants.

According to information from one major manufacturer of foams, it is particularly difficult to find alternative FRs for the viscoelastic (VE) foams, but this information has so far not been confirmed by other sources.

Costs of developing flexible PUR foams with alternative FRs
As mentioned previously, flexible PUR foam chemistry is quite complex. In addition, most flexible PUR foam slabstock is produced using large machinery in a continuous process. In this process a mixture of polyols and diisocyanates “foams” and rises within seconds on a moving conveyor and then solidifies. The additive flame retardants are added to the mixture of polyols and diisocyanates at the time of foam production. This manufacture of slabstock is a continuous process and in theory foam blocks of several kilometres in length could be produced this way. In reality, the foam blocks are typically cut at a length of between 15 and 120 m and then stored. Blocks can also be cut into foam rolls for further use (EUROPUR, 2015). Each production site typically has only one production line.

Consequently, the R&D costs for introducing new formulations for slabstock production may be relatively high.

The development of flame retarded flexible PUR foams with alternative FRs would typically include the following steps:

- Development and testing of new FRs. Description of the technical, environmental and health properties of the FRs. This is done by the manufacturers of the FRs, and the R&D costs are reflected in the price of the alternative FRs.
- Development of new formulations with the alternative FR by the polyol manufacturers or PUR manufacturer includes laboratory testing of alternative FRs formulations with respect to flammability properties and other technical properties of the foams. This is mainly done by the polyol manufactures but, at larger PUR foam manufacturers, laboratory tests may be undertaken in designated R&D centres.
- Pilot scale testing may take place in R&D centres or at the production site.
- Full scale implementation takes place at the production site. Adjustments are madeto the specific machinery used in the site. In larger companies this may be done by local staff assisted by specialists from the R&D centres.

The development of new formulations is mainly done by the polyol manufacturers. The European manufacturers of polyols and diisocyanates for PUR production are organised in the European

Diisocyanate and Polyol Producers Asssociation, ISOPA[5]. The organisation has eight member companies; of these six manufacture polyols.

According to information from individual companies, the introduction of a new FR formulation would typically require 1-2 man-months work in the laboratory and 1-3 man-months for pilot testing and full scale implementation. If the full scale implementation fails, the costs of lost foams (and time spent) may be significant.

Possible consequences of introducing a restriction on the targeted FRs in children's articles
The market for FR foams for children's articles is relatively small (1-2% of total EU flexible PUR production). If the costs of R&D are high compared to the market for this segment in the individual companies, the manufacture of FR foams for children's articles is likely to be concentrated at fewer production facilities. For the larger companies with many facilities, the concentration of the production of flexible PUR for children's articles at fewer facilities would mainly imply higher costs of transport to the customer. Most likely, the manufacture of these grades would be in the UK and the foams would be exported to manufacturers of children's articles for the UK market in continental Europe.

3.2 Overview of chemical alternatives for PUR foams

Chemical alternatives to the targeted flame retardants in children's articles have been identified through a recently published assessment by US EPA (2014) and by contact with the Phosphorus, Inorganic and Nitrogen Flame Retardants Association (Pinfa, 2015).

It should be noted that some of the identified FRs may only be used in combination with other FRs.

US EPA assessment of flame retardants in flexible PUR foams
In June 2014, the US EPA (2014) published a draft assessment of alternatives to flame retardants used in flexible PUR foam. The report was issued in relation to the US EPA Design for the Environment Program (DfE), and it updates assessments included in a previous report from 2005 identifying and evaluating alternatives to pentaBDE flexible PUR foam with a focus on improving furniture fire safety (US EPA, 2005). As stated in the updated report, the marketplace for flame retardants used in flexible PUR foam has changed significantly since 2005 with some flame retardant chemicals being withdrawn from the market, and others being introduced. The updated report is intended to identify all flame retardants either known to be used, or marketed to be used and to meet the fire safety requirements for upholstered consumer products containing flexible PUR foam on the US market, i.e. not just furniture. Alternatives are assessed with regard to health and environmental hazard and fate data according to a uniform set of criteria. Considerations regarding exposure, risk, performance or cost are not included. The alternatives assessed also include the three substances that are the focus of the present study - TCEP, TCPP and TDCP - as these have been used as alternatives to pentaBDE. The report primarily reflects the US market but also includes information relevant for the European market, specifically the UK market. TCPP and melamine are mentioned as the major flame retardants used in the UK to meet the stringent “Crib 5” standard (BS-5852; see section 2.2.1). The assessment indicates that several new non-halogenated alternatives are being used. Some of the new flame retardants have proprietary CAS number and chemical names, which make an environmental and health assessment of the alternatives difficult.

The use of melamine as an alternative flame retardant was confirmed during the consultation for the present study. One of the article manufacturers claimed to use melamine instead of halogenated flame retardants in dense foams, which are then mainly used in cots and baby mattresses. The re-

5 The European Association of Polyol Producers organise companies manufacturing polyols used as sugar-free sweeteners

spondent pointed out that dense foams need less additional flame retardancy as the air content in the foam is lower. However, they also use halogenated flame retardants for lighter foams used in other upholstered children's products.

The non-halogenated flame retardants indicated to be marketed for, or currently used, in flexible PUR foams are listed in Table 8. The table includes information on REACH registration status and EC Number collected as part of the present assessment. Actual experience with the use in flexible PUR foams, their market penetration and the technical and economic feasibility of substitution is not indicated for the individual flame retardants in the US EPA (2014) DfE report.

The screening level hazard summary for the flame retardants is shown in Appendix 1.

Reactive and polymeric flame retardants

The US EPA DfE report includes one reactive flame retardant with a relative good scoring, oligomeric phosphonate polyol, which is further described in Section 3.5. For use in PUR, reactive flame retardants are polyols and they are built into the polymer structure by the reaction between the diisocyanates and the polyols. The substance isonly present at trace levels as unreacted raw material in the final PUR foam.

In US EPA (2014), oligomeric ethyl ethylene phosphate is indicated as being an additive FR but by Clariant it is indicated as being a reactive FR.

According to US EPA (2014), while polymers would be expected to have lower mobility and thus reduced exposures during the consumer use phase, they are difficult to use in the manufacture of flexible PUR foams. Reactive products are available in other product sectors (e.g. in printed circuit boards), and there is great interest in the manufacturing industry in finding reactive flame retardants for flexible PUR foams (US EPA, 2014). In spite of the difficulties, commercial products with the oligomeric phosphonate polyol are available today as described in Section 3.5 while some commercially available polymeric flame retardants are described in Section 3.6.

TABLE 8

FLAME RETARDANTS EVALUATED IN THE DFE FURNITURE FLAME RETARDANCY UPDATE EXCL. THE THREE SUBSTANCES TARGETED IN THIS ASSESSMENT (BASED ON US EPA, 2014 SUPPLEMENTED REACH REGISTRATION DATA AND DATA FROM PINFA PRODUCT SELECTOR)

CAS No	EC No	Name (as indicated by US EPA, 2014)	Synonyms	Reactive additive	Examples of trade names	Molecular formula	REACH registration status and volume, t/y	Pinfa 2015 product selector
Halogenated								
183658-27-7	-	Benzoic acid, 2,3,4,5-tetrabromo-, 2-ethylhexyl ester	TBB; EH-TBB	A	-	$C_{15}H_{18}Br_4O_2$	not registered not pre-registered	-
26040-51-7	247-426-5	1,2-Benzenedicarboxylic acid, 3,4,5, 6-tetrabromo-, 1,2-bis(2-ethylhexyl) ester	TBPH; BEH-TEBP	A	-	$C_{24}H_{34}Br_4O_4$	100 - 1,000	-
38051-10-4	253-760-2	Phosphoric acid, P,P'-[2,2-bis(chloromethyl)1,3-propanediyl] P,P,P',P'-tetrakis(2-chloroethyl) ester	V6, V66; BCMP-BCEP	A	-	$C_{13}H_{24}Cl_6O_8P_2$	100 - 1,000	-
Non-halogenated								
68333-79-9	269-789-9	Polyphosphoric acids, ammonium salts	APP; Ammonium polyphosphate	A	Aflammit® PCI 202 Exolit® AP 42x FR CROS 484	$[NH_4PO_3]_n$	not registered - probably because the substance is a polymer	applicable
12777-87-6	235-819-4	Sulfuric acid, compd. with graphite (1:?)	Expandable graphite	A	-	$[C]_n[SO_3H]_x$	1,000-10,000	similar substance CAS No 7782-42-5 indicated as applicable
108-78-1	203-615-4	1,3,5-Triazine-2,4,6-triamine	Melamine	A	Aflammit PMN 500	$C_3H_6N_6$	100,000 - 1,000,000	applicable
115-86-6	204-112-2	Phosphoric acid, triphenyl ester	TPP; Triphenyl phosphate; TPHP	A	-	$C_{18}H_{15}O_4P$	1,000 - 10,000	not indicated

CAS No	EC No	Name (as indicated by US EPA, 2014)	Synonyms	Reactive additive	Examples of trade names	Molecular formula	REACH registration status and volume, t/y	Pinfa 2015 product selector
26444-49-5	247-693-8	Phosphoric acid, methylphenyl diphenyl ester	Cresyl diphenyl phosphate; Methylphenyl diphenyl phosphate; Disflamoll DPK; MPHDPHP	A	-	$C_{19}H_{17}O_4P$	not registered pre-registered	not indicated
26446-73-1	247-708-8	Phosphoric acid, bis(methylphenyl) phenyl ester	Methylated triphenyl phosphates; Bis(methylphenyl) phenyl phosphate; MPHP	A	-	$C_{20}H_{19}O_4P$	not registered pre-registered	not indicated
1330-78-5	215-548-8	Phosphoric acid, tris(methylphenyl) ester	Tricresyl phosphate; Disflamoll TKP; TMPHP	A	-	$C_{21}H_{21}O_4P$	1,000 - 10,000	not indicated
68937-41-7	273-066-3	Phenol, isopropylated, phosphate (3:1). Commercial product may include mono-, di-, tri- and higher substitutions with appropriate CAS numbers. IPPP; ITP; IPTPP; Isopropylated triphenyl phosphate; Isopropylated phenol phosphate; TIPPP	IPPP; ITP; IPTPP; Isopropylated triphenyl phosphate; Isopropylated phenol phosphate; TIPPP	A	not indicated	$C_{27}H_{33}O_4P$ Formula for tripropyl substitution	10,000 - 100,000	applicable

CAS No	EC No	Name (as indicated by US EPA, 2014)	Synonyms	Reactive additive	Examples of trade names	Molecular formula	REACH registration status and volume, t/y	Pinfa 2015 product selector
78-33-1	201-106-1	Phenol, 4-(1,1-dimethylethyl)-, 1,1',1''-phosphate. Includes mono-, di-, tri-, and higher substitutions with appropriate CAS Numbers	TBPP; tris(4-(tertbutyl)phenyl phosphate; tertbutylphenyl diphenyl phosphate; bis(4-(tertbutyl)phenyl) phenyl phosphate; TTBPHP	A	Disflamoll TP LXS 51092	$C_{30}H_{39}O_4P$ Formula for tributylated substitution	not registered pre-registered	not indicated
2781-11-5	220-482-8	Phosphonic acid, P-[[bis(2hydroxyethyl)amino]methyl], diethyl ester	N,N-(bis)-hydroxyethylaminomethane phosphonic acid diethyl ester; BHEAMPDE	R	Levagard® 4090 N	$C_9H_{22}NO_5P$	pre-registered not registered	applicable
184538-58-7	*606-033-2	Phosphoric acid, triethyl ester, polymer with oxirane and phosphorus oxide (P2O5)	Oligomeric ethyl ethylene phosphate; Alkylphosphate oligomer	A, R		$(C_6H_{15}O_4P{\cdot}C_2H_4O{\cdot}O_5P_2)_n$	not registered pre-registered probably because the substance is a polymer	not indicated

CAS No	EC No	Name (as indicated by US EPA, 2014)	Synonyms	Reactive additive	Examples of trade names	Molecular formula	REACH registration status and volume, t/y	Pinfa 2015 product selector
363626-50-0	-	Poly(oxy-1,2-ethanediyl), α,α`(methylphosphinylidene)bis[ω-hydroxy-	Oligomeric phosphonate polyol; Bis(polyoxyethylene) methylphosphonate; Polyethylene glycol methylphosphonate (2:1)	R	-	$CH_5O_3P{\cdot}(C_2H_4O)_n{\cdot}(C_2H_4O)_n$	not registered, not pre-registered probably because the substance is a polymer	not indicated
Proprietary	-	Halogen-free flame retardant		-	Emerald Innovation NH-1		-	
Proprietary	-	Halogen-free phosphorus-based		-	Fyrol HF-5 *		-	

* Fyrol HF-5 has recently been supplemented by Fyrol-HF10 introduced as halogen-free TDCP-alternative for automotive flexible foam applications (ICL, 2014)

Non-halogenated flame retardants for flexible PUR foams suggested by Pinfa

The product selector of the Pinfa (Pinfa, 2015) lists a number of non-halogenated flame retardants which are applicable in flexible PUR foams. Substances other than those listed in Table 8 are listed in Table 9. Table 9 includes two flame retardants based on ammonium polyphosphate (the ammonium polyphosphate itself is included in Table 8, and expandable graphite is included in Table 8 as "expandable graphite" identified by another CAS number). Table 9 includes two high-volume aluminium-based flame retardants which have a wide application spectrum as flame retardants. The two substances are included in a list of substances specifically not evaluated in the US EPA DfE report because they are considered inefficient, requiring very high loadings and therefore they are probably not used in flexible PUR foams (US EPA, 2014). Furthermore, the Pinfa list includes three flame retardants not described in detail. The products with proprietary CAS numbers and chemical names might be the same as those listed with proprietary CAS numbers in the US EPA DfE report (for individual selected substances that is further elaborated below).

TABLE 9
FLAME RETARDANTS INDICATED IN THE PINFA (2015) PRODUCT SELECTOR AS APPLICABLE FOR FLEXIBLE PUR FOAMS (IN ADDITION TO THOSE LISTED IN TABLE 8)

CAS No	EC No	Name (as indicated by Pinfa, 2015)	Synonyms (as indicated in registrations)	Molecular formula	REACH registration status and volume, t/y
21645-51-2	244-492-7	Aluminium tri-hydroxide		AlH_3O_3	1,000,000 - 10,000,000
1318-23-6	215-284-3	Boehmite (Aluminium oxide hydroxide)	Aluminum oxygen(2-) hydroxide	Al(OH)O	10,000 - 100,000
68333-79-9	269-789-9	Ammonium polyphosphate (with synergists) [ammonium polyphosphate included in Table 8]		[See Table 2 for Ammonium polyphosphate]	not registered - probably because the substance is a polymer
68333-79-9	269-789-9	Ammonium polyphosphate (coated) [ammonium polyphosphate included in Table 8]		[See Table 2 for Ammonium polyphosphate]	not registered - probably because the substance is a polymer
7782-42-5	231-955-3	Expandable graphite [Expandable graphite with CAS No. 12777-87-6 included in Table 8]	Graphite	C	100,000 - 1,000,000
68953-58-2	-	Surface treated, inorganic, mineral based FR synergist	-	-	Not preregistered
Proprietary	-	Melaphos FR (blend)	-	-	-
Proprietary	-	Phosphorus polyol	-	-	-

Other alternatives

In addition to the FRs listed above, two phosphorous FR have recently been introduced on the market for use in flexible PUR foams and these have been suggested by manufacturers as part of the stakeholder consultation for this study. The FRs are listed in Table 10. One of the FRs is registered under REACH with a tonnage of 10-100 t/y and is marketed by several companies.

TABLE 10
ADDITIONAL FLAME RETARDANTS APPLICABLE FOR FLEXIBLE PUR FOAMS IDENTIFIED AS PART OF THIS STUDY

CAS No	EC No	Name (as indicated by in ECHA registration database	Trade name (example)	Reactive additive	Molecular formula	REACH registration status and volume, t/y
Proprietary	-	proprietary (similar chemistry to 184538-58-7)	Levagard TP LXS 51078	A	-	-
848820-98-4	805-659-5	6H-Dibenz[c,e][1,2]oxaphosphorin-6-propanoic acid, butyl ester, 6-oxide	Levagard TP LXS 51114 DOB11	A	-	10-100

3.3 Chemical alternatives for textiles

Chlorinated phosphorous FRs may to some extent be used for textiles, but other halogenated FRs are more commonly used (usually in combination with antimony trioxide/ATO) as well as non-halogenated FRs, which are already widely used in textile applications (Thor, 2015). The price differences between the chlorinated phosphorous FR and alternatives are usually relatively small and cost considerations should not be a barrier to substitution (Thor, 2015).

3.4 Selection of alternatives for further assessment

In order to identify FR alternatives that may be used for the different applications of flexible PUR foams in children's articles for the UK and Irish market, information has been requested from EUROPUR, EFRA and Pinfa. This includes information on applications for which alternatives does not exist. According to the answers received, the organisation does not hold any overview information and has forwarded the requests to the individual companies. According to EUROPUR (2015c), viscoelastic foam formulations notably are very sensitive to any change.

Major manufacturers of FRs have been asked for information on alternatives and have provided information for a range of both additive and reactive FRs. Information on the selected alternatives is provided in the following sections. It was beyond the scope of this assessment to collect and present information for all possible alternatives. The main objective of the description is to demonstrate whether alternatives with better environmental and health profiles are actually marketed and to describe to possible costs and expected time for transition. For a broader description of phosphorus-based alternatives, reference is made to the results of an ongoing assessment of phosphorus-based flame retardants carried out for the Danish EPA.

The FRs have been selected for this evaluation on the basis of:

- Few indications of High or Very High hazards for key parameters in the US EPA screening assessment (see appendix 1)
- The FRs are marketed today and actually used for the manufacture of FR flexible PUR foams
- The FR can act alone or is the main FR in the formulations.
- Information on technical advantages and disadvantages as well as cost information has been provided by manufacturers.

Several manufacturers have recently introduced new non-halogenated flame retardants and there is still limited experience with the use of these.

Based on these criteria, the following FRs have been selected for further description:

- Oligomeric phosphonate polyol (CAS No 363626-50-0), reactive FR. Used as representative for more reactive FRs.
- Oligomeric ethyl ethylene phosphate (CAS No 184538-58-7), additive/reactive FR. Representative for more FRs with a similar chemistry.
- Diethyl bis(2hydroxyethyl)aminomethyl phosphonate (CAS No 2781-11-5), additive FR.
- 6H-Dibenz[c,e][1,2]oxaphosphorin-6-propanoic acid, butyl ester, 6-oxide, additive FR.
- Melamine, additive FR, used together with other FR, but can be used alone for some applications.

The description is for some of the FRs supplemented with information on other FRs with a similar chemistry.

3.5 Oligomeric phosphonate polyol

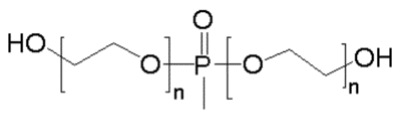
Oligomeric phosphonate polyol is a reactive flame retardant for flexible PUR foams and was evaluated by US EPA (2014) as a promising flame retardant for flexible foam from an environmental and health perspective.

Several pre-active FRs are one the market. Below the groups are exemplified by the FR product Exolit OP 360 from Clariant. Aflammit PLF 140 (CAS No 184538-58-7) from Thor seems to apply a similar chemistry and is briefly described in section 3.5.4.

3.5.1 Identification, physical and chemical properties

Identification data and physical and chemical properties of oligomeric phosphonate polyol are summarised in Table 11. The substance is a polymer and thus not preregistered or registered under REACH and not identified by an EC number.

TABLE 11
IDENTIFICATION, PHYSICAL AND CHEMICAL PROPERTIES OF OLIGOMERIC PHOSPHONATE POLYOL

Property	Data	Reference
EC number	Not identified in EC inventory (EINECS, ELINCS and NLP inventories) or REACH pre-registration or registration database	ECHA, 2015a
CAS number	363626-50-0	US EPA, 2014
Chemical name	Oligomeric phosphonate polyol (methylphosphonate substituted with polyethylene glycol.)	Clariant, 2012; US EPA, 2014
Synonyms	Poly(oxy-1,2-ethanediyl), α,α`-(methylphosphinylidene)bis[ω-hydroxy-; Bis(polyoxyethylene) methylphosphonate; Polyethylene glycol methylphosphonate; Exolit OP 360 (trade name)	Clariant, 2012
Molecular formula	$CH_5O_3P{\cdot}(C_2H_4O)_n{\cdot}(C_2H_4O)_n$	US EPA, 2014
Molecular weight	<1,000; average MW of 311	US EPA, 2014
Chemical structure		US EPA, 2014

Property	Data	Reference
Physical state	Liquid	Clariant, 2012
pH	Approx. 4.5 (10 g/L)	Clariant, 2012
Melting point	< -30 °C	Clariant, 2012
Boiling point	> 150 °C (1.013 hPa)	Clariant, 2012
Flash point	196 °C (Method: CLEVELAND DIN 51376, open cup)	Clariant, 2012
Relative density	Approx. 1.20 g/cm³ (25 °C)	Clariant, 2012
Thermal decomposition	> 150 °C (Method : DTA)	Clariant, 2012
Vapour pressure	n=1: 6.9 x 10^{-6} n=2: 3.6 x 10^{-8} $<10^{-8}$ at 25°C for n≥3-7 (Estimated)	EPI v4.11*; EPA, 1999 as cited by US EPA 2014
Water solubility	Hydrolyses (measured)	Clariant, 2012
	1 x 10^{6} for n=1-7 (Estimated)	As estimated EPI v4.11 * used by US EPA 2014
Log Kow)	<-2 for n=1-7 (Estimated)	EPI v4.11 * used by US EPA 2014
Viscosity	Approx. 100 - 500 mPa s^{-1}	Clariant, 2012
Phosphorus content	~11.5%	Clariant, 2012

* EPI v4.11 = US EPA's Estimation Programs Interface (EPISuite™) version 4.11 for physical-chemical property and environmental fate endpoints

3.5.2 Availability and technical and economic feasibility

Data on availability and technical and economic feasibility of oligomeric phosphonate polyol are summarised in Table 12.

TABLE 12
AVAILABILITY AND TECHNICAL AND ECONOMIC FEASIBILITY

Property	
Registration status under REACH	Not pre-registered, not registered (ECHA dissemination database). The substance is a polymer.
Availability	Commercially available from Clariant Corporation under the trademark Exolit OP 360 (Clariant, 2012). The product has been marketed for more than 10 years. Market data included in confidential annex
Mode of action	Reactive flame retardant (phosphor-based polyol) i.e. it is incorporated into a polymer backbone (e.g. polyurethane) by chemically bonding with raw materials during the polymerization process.
Experience with the use of the FR for flexible PUR foams	The FR seems in particular to be used together with PUR foam with a "green" polyurethane foam technology partly based on biomass-derived natural oil polyols and according to the manufacturer, Exolit, OP types FRs are especially suited for these polyols. Natural Foams Technology (2015) in the UK (parent company: Green Urethanes) specialis-es in green chemistry to develop foams based on natural oil polyol for the soft furnishing,

Property	
	bedding and automotive industries. The company use Exolit OP 560 in FR grades. (Natural Foams Technology 2015). The company is a developing company. According to the company the technology is used by the US-based Lee Industries which produce "eco-friedly" furniture (Natural Foams Technology, 2015). According to Clariant (2014), NCFI Polyurethanes, a North Carolina-based manufacturer, has been utilizing the technology in their BioLuxMax line for several years. After running extensive trials with Exolit OP 560, they plan to introduce a commercial product in the 4th quarter of 2014 (Clariant, 2014). Commercial products with Exolit OP 560, are (May 2015) not identifiable from the company's website. Flexible PUR foams with Exolit OP 560 can pass the Cal 117 flammability standard (Robinson, 2013)
Technical advantages	As the substance is reactive, it is only present in the final foam at trace levels as unreacted monomer. It has been highlighted that the levels are so low that the presence of flame retardants in foams in furniture do not need to be labelled in accordance with the Californian furniture labelling regulations (UTI, 2015). Exolit OP 560 has had good success in demanding low-VOC automotive flexible polyurethane applications (i.e. passes stringent Daimler Chrysler VOC/Fog Test).
Technical difficulties	According to US EPA (2014), polymeric and reactive flame retardants typically have high viscosities incompatible with flexible PUR, and are not compatible with the extremely small pores used in the blending nozzle, and have difficulty blending with the polyol. According to the manufacturer, reactive FRs need adaptation of recipes and fine tuning of physical properties. It is the general impression that the technical difficulties may be overcome, but the R&D costs may be relatively high.
Loadings as compared to TCPP	Loading is, according to manufacturer, 2-10 php in flexible foams depending on requirements. The concentration of Exolit OP 560 is about 20% of the level of non-reactive FRs, which would normally be required to pass the Californian standard Cal 117 (Rowlands, 2013) No data regarding meeting the UK Crib 5 test has been identified. Some informal information has indicated that with this FR it would be more challenging to develop foams that can pass the Crib 5 test as compared with the Cal 117.
Price as compared with TCPP	Included in the confidential annex For Aflammit PLF 140, the manufacturer indicates the price is a factor 5-10 higher than TCPP, TCEP or TDCP, even in such cases where the dosage can be lower compared to TCPP, TCEP, TDCP. When comparing the cost of a FR foam, the price gap may be in the order of 10-20% (Thor, 2015).
Overall cost comparison	Included in the confidential annex
Expected time for transition	Adaptation of recipes and sometimes equipment is necessary; this may take 3-6 months. Please note that this indicates the calendar time and not the number of man-months which may be needed as several people may work at the same time on the development. For a full transition, the build-up of additional capacities for alternatives may be necessary; the time needed is 3-5 years.

3.5.3 Human health and environmental profile

Selected data of particular importance for the present assessment are summarised in Table 13. Further human health and environmental properties of oligomeric phosphonate polyol are described in US EPA (2014).

TABLE 13
SELECTED HUMAN HEALTH AND ENVIRONMENTAL DATA PROPERTIES OF OLIGOMERIC PHOSPHONATE POLYOL

		Reference
Harmonised classification according to the CLP Regulation (Regulation (EC) No 1272/2008)	No harmonised classification	
Self-classification according to the C&L Inventory (Classification and Labelling Inventory)	Not included in C&L Inventory	ECHA, 2015b
CMR properties	**Carcinogenicity**: "*MEDIUM: There is uncertainty due to lack of experimental data for this substance; carcinogenic effects cannot be ruled out*". **Mutagenicity** (genotoxicity): "*MEDIUM: There is uncertainty due to the lack of experimental data for this endpoint. This substance was not a mutagen in bacteria in one study. DfE criteria for this endpoint require both gene mutation and chromosomal aberration assays. For instances of incomplete or inadequate mutagenicity/genotoxicity data, a low hazard designation cannot be assigned*". **Reprotoxic effects**:" *LOW: Estimated based on expert judgment and lack of structural alerts for reproductive toxicity identified for this substance. No experimental data were located*".	US EPA, 2014
PBT properties	The substances in estimated to be neither P, B, nor T **Persistence:** "*MODERATE…Although no experimental biodegradation studies were located, estimates using representative components of the polymer indicate that the lower MW components (where n≤2) are expected to have ultimate persistence with a half-life ≥16-<60 days, equivalent to a moderate hazard designation using a conservative approach.*" **Bioaccumulation:** *"LOW: Estimated based on BCF values of 3.2 and BAF values of <1 for the representative structures of the polymeric mixture. "* **Toxicity:** *"LOW. The aquatic toxicity is estimated to be low based on estimated acute and chronic aquatic toxicity values for representative oligomers (n=1 and n= 7). "*	US EPA, 2014
Exposure of users	Once a reactive flame retardant is incorporated into a polymer, it is unlikely to be released. Compared to additive flame retardants the exposure of users to the flame retardants is considered lower. Small amounts of unreacted monomers may be present in plastics flame retarded with reactive flame retardant.	

		Reference
	Experimental data shows that the substance is not released from the final PUR foam	
Exposure of the environment	Same as above. The releases of the substance during use and disposal is considered to be relatively small.	
Metabolites	None identified	US EPA, 2014

3.5.4 Similar products
Other reactive flame retardants for flexible PUR are marketed.

Thor GmbH market the reactive flame retardant Aflammit PLF 140 (CAS No 184538-58-7), which has been designed for use in flexible foams in upholstery, in particular automotive seats applications, where restrictions in terms of fogging and VOC releases restrict the use of the chlorinated phosphates. Aflammit PLF 140 is preregistered under REACH as a polymer with the chemical name phosphoric acid, triethyl ester, polymer with oxirane and phosphorus oxide (P_2O_5), but the substance is not registered. The substance does not have a harmonised classification in accordance with the CLP Regulation and no self-classifications of the substance are available in ECHAs C&L database. Being a polyol of medium viscosity, it can be used in standard foam production equipment. Thanks to its moderately low hydroxyl number, it is easy to formulate although small reformulation work may have to be done when substituting other FRs, such as chlorinated phosphates (i.e. it is not a “drop in” solution). According to the manufacturer the price is 5-10 times the price of chlorinated phosphorous FRs, and even the loadings are smaller the price of the final foam may be 10-20% higher than the price of foam flame retarded with the chlorinated phosphorous FRs.

3.5.5 Conclusion
This reactive, non-halogenated flame retardant for use in flexible PUR foam is marketed in particular for use in combination with polyurethane foam technology partly based on biomass-derived natural oil polyols. The low fogging potential reportedly makes the FR suitable for demanding low-VOC automotive applications. According to the manufacturer, reactive FRs need adaptation of recipes and fine-tuning of physical properties and this may take 3-6 months of R&D by the PUR manufacturers. Confirmed uses of the FR are for furniture for the US market with less stringent flammability properties than the UK market. The available information indicates that foams suitable for children's articles for the UK market may be produced by use of the FR, but substantial R&D costs would be expected.

The available data indicate that the exposure of consumers and the environment is small because the FR is incorporated in the polymer structure i.e. the substance in itself is not present in the final foam. The substance is estimated to be neither P, B, nor T. All in all the health and environmental profile of the substance is considered to be significantly better than the profile of the targeted substances.

3.6 Oligomeric ethyl ethylene phosphate
Oligomeric ethyl ethylene phosphate has been evaluated by US EPA (2014). Apart from persistence, where the substance scores very high (VH) in the screening, the screening scores are relatively good as compared to the chlorinated phosphorous FRs.

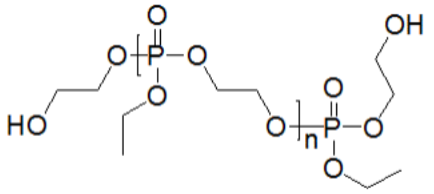
Several FRs based on oligomeric phosphate esters are available. Below the group is exemplified by oligomeric ethyl ethylene phosphate (CAS No 184538-58-7) which has been evaluated by US EPA (2014). The product is marketed as Fyrol™ PNX from ICL Industrial Products and Exolit® OP550 from Clariant.

A product based on similar (but not identical) chemistry is Levagard TP LXS 51078 from Lanxess. As some information on the technical feasibility of the Levagard TP LXS 51078 also has been obtained, this information is used below to supplement the information regarding the oligomeric ethyl ethylene phosphate.

3.6.1 Identification, physical and chemical properties

Identification data and physical and chemical properties of oligomeric ethyl ethylene phosphate are summarised in Table 14. The substance is a polymer and thus not preregistered or registered under REACH and not identified by an EC number.

TABLE 14
IDENTIFICATION, PHYSICAL AND CHEMICAL PROPERTIES OF OLIGOMERIC ETHYL ETHYLENE PHOSPHATE

Property	Data	Reference
EC number	*606-033-2 - list number (without existing EC number)	ECHA pre-registration database
CAS number	184538-58-7	US EPA, 2014 Clariant, 2013 ICL Industrial Products, 2015
Chemical name	Phosphoric acid, triethyl ester, polymer with oxirane and phosphorus oxide (P2O5)	ECHA preregistration database
Synonyms	Oligomeric ethyl ethylene phosphate Phosphoric acid, triethyl ester, polymer with oxirane and phosphorus oxide Non-halogenated phosphorus polyol	US EPA, 2015 ICL Industrial Products, 2011 Clariant, 2013
Molecular formula	$(C_6H_{15}O_4P \cdot C_2H_4O \cdot O_5P_2)n$	US EPA, 2014
Molecular weight	Product molecular weight range from 300 to 4,000	US EPA, 2014
Chemical structure		US EPA, 2014
Physical state	Clear transparent liquid	ICL, 2015
pH	Not applicable	US EPA, 2014
Melting point	No data	US EPA, 2014
Boiling point	>300 °C for n≥1 (Estimated)	EPI v4.11 used by US EPA, 2014
Flash point	Setaflash CC, 208 °C	ICL, 2015
Relative density	1.31	ICL, 2015
Thermal decomposition	No data located	
Vapour pressure	3.6×10^{-6} Pa at 25°C for n=1 2.1×10^{-8} Pa for n=2-5 (Estimated)	EPI v4.11 used by US EPA, 2014
Water solubility	3375 mg/L for n=1	EPI v4.11 used by US EPA, 2014

Property	Data	Reference
	933 mg/L for n=2 233 mg/L for n=3 1 mg/L for n=6 (Estimated)	
Log Kow	-0.58 (Measured) 0.42 for n=1 -0.03 for n=2 -0.48 for n=3 -1.33 for n=6 (Estimated)	US EPA, 2014
Viscosity	1000 mPa.s at 25°C	
Phosphorus content	19% 16-18%	ICL, 2015 Clariant, 2013

* EPI v4.11 = US EPA's Estimation Programs Interface (EPISuite™) version 4.11 for physical-chemical property and environmental fate endpoints

3.6.2 Availability and technical and economic feasibility

Data on availability and technical and economic feasibility of oligomeric ethyl ethylene phosphate are summarised in Table 15.

TABLE 15
AVAILABILITY AND TECHNICAL AND ECONOMIC FEASIBILITY

Property	
Registration status under REACH	Not pre-registered, not registered (ECHA dissemination database). The substance is a polymer. The substance is pre-registered.
Availability	Commercially available from ICL Industrial Products as Fyrol™ PNX and from Clariant as Exolit® OP-550. Product with similar (but not identical) chemistry available from Lanxess.
Mode of action	US EPA (2014) and ICL (2015) indicate it to be an additive flame retardant i.e. not built into the polymer structure. Clariant (2013) indicates it to be a reactive flame retardant.
Experience with the use of the FR for flexible PUR foams	Fyrol™ PNX: It is most suitable for MVSS 302 (motor vehicle standard) and Cal 117 type foams (California standard for resilient filling materials), but also applicable in UL94HF foams (electrical and electronic equipment). Its high molecular weight is another advantage in automotive foams because in suitable formulations it is low fogging and can give foams low in VOC emissions, passing the general automotive volatile requirements. No data on market penetration has been obtained. Exolit® OP-550 is commercially available and used. Exolit OP types are especially suited for use in combination with (renewable based) natural oil polyols (Clariant, 2015). Levagard TP LXS 51078: Product has been introduced into the flexible PUR market in recent years. Full-scale experience is available. (Lanxess, 2015a)
Technical advantages	Low fogging and low VOC emissions for automotive applications. The fogging level of Levagard TP LXS 51078 is approximately 75% that of TDCP (Lanxess, 2015a). Low viscosity and easy processing for Levagard TP LXS 51078 (Lanxess 1105a). The fogging level of Exolit® OP-550 is indicated as approximately 15% of TDCO (Clariant, 2007).
Technical difficulties	Reactive FRs need adaptation of recipes and fine-tuning of physical properties. Due to

Property	
	limited resistance to hydrolysis of Exolit OP, storage in closed containers and direct mixing is recommended. (Clariant, 2007).
Loadings as compared to TCPP	The relative amount of Levagard TP LXS 51078 in a 33 kg/m3 density polyether foam in order to pass the automotive MVSS 302 standard is slightly lower than TCPP. The relative amount of Exolit® OP-550 is indicated at about 50% of the level of TDCP. (see figure 2)
Price as compared with TCPP	ICL (2015) indicates that the cost efficiency of FyrolTM FNX is worse than the efficiency of TDCP, which again is lower than the cost efficiency for TCPP. Exact figures are not available. Exolit OP-550: see confidential annex Levagard TP LXS 51078: Between 20% and 200% compared to TDCP (targeted FR) (Lanxess, 2015a).
Overall cost comparison	ICL (2015) indicates that the cost efficiency of FyrolTM FNX is lower than TDCP, which is lower than the cost efficiency for TCPP. Between 20% and 200% compared to TDCP (targeted FR).
Expected time for transition	In general, the time period to replace an existing flame retardant by an alternative one is estimated at 6 months to 1 year (Lanxess, 2015a). Adaptation of recipes and sometimes equipment is necessary (3-6 months). For a full transition, the build-up of additional capacities for alternatives may be necessary (3- 5 years) (Clariant,2015)

3.6.3 Human health and environmental profile

Selected data on human health and environmental properties of oligomeric ethyl ethylene phosphate are summarised in Table 16.

TABLE 16
SELECTED HUMAN HEALTH AND ENVIRONMENTAL DATA PROPERTIES OF OLIGOMERIC ETHYL ETHYLENE PHOSPHATE

		Reference
Harmonised classification according to the CLP Regulation (Regulation (EC) No 1272/2008)	No harmonised classification	
Self classification according to the C&L Inventory (Classification and Labelling Inventory)	No self classifications available in the C&L inventory	

		Reference
CMR properties	**Carcinogenicity:** "LOW: *The risk for carcinogenicity is estimated to be low considering that the residual monomers do not contain substituted terminal double bonds, and reactive-functional-group-bearing side chains. The higher MW components of this polymer (MW >1,000) are expected to have limited bioavailability and have low potential for carcinogenicity. No experimental data were located."* **Mutagenicity :** "MEDIUM: *There is uncertain concern for mutagenicity based on the structure, ethyl substituted phosphate. This substance did not cause gene mutations in bacteria; however, there is uncertainty due to the lack of experimental data for this endpoint". "The higher MW components of this polymer (MW >1,000) are expected to have limited bioavailability and have low potential for genotoxicity*" **Reprotoxic effects**: *"LOW: Estimated to have a low potential for reproductive effects based on expert judgment and a lack of structural alert for this endpoint. "*	US EPA, 2014
PBT properties	**Persistence**: "*VERY HIGH: The persistence designation for this polymer is based on its higher MW components (MW >1,000). The lower MW oligomers (MW <1,000; n ≤ 5) of this polymer are expected to have lower persistence because of their higher water solubility and increased bioavailability to microorganisms".* **Bioaccumulation: "**LOW: *Both the higher MW and lower MW oligomers are estimated to have Low potential for bioaccumulation."* **Toxicity**: "LOW: *Based on estimated acute aquatic toxicity values for representative oligomers that predict No Effects at Saturation (NES). Experimental data in fish also indicate a Low hazard though experimental data was not located for daphnia or algae". "Based on estimated chronic aquatic toxicity values for representative oligomers that predict No Effects at Saturation (NES). "*	US EPA, 2014
Exposure of users	No data on the potential for exposure of users and the environment is available. In general, the mobility of polymeric FRs in the materials as compared to the mobility of non-polymeric FRs is assumed to be lower (US EPA, 2014), but no data demonstrating the lower migration potential have been identified. Compared to reactive flame retardants the exposure of users to the flame retardants is considered to be higher but no data are available for a comparison with the chlorinated phosphorous FRs.	
Exposure of the environment	Same considerations as above for exposure of users.	
Metabolites	None identified, although biodegradation or hydrolysis pathways may yield diethyl phosphate, ethyl phosphate, ethanol, phosphate and ethylene glycol.	Professional judgment in US EPA, 2014

3.6.4 Conclusion

Oligomeric ethyl ethylene phosphate and an FR with similar chemistry are available from at least three of the major manufacturers of FRs. The substance is mainly used for flexible PUR foams for automotive applications where low fogging potential and low VOC emission potential makes the FR very suitable. Even lower concentrations of the FR are needed as compared to TDCP but the effective costs of the FR are higher than the effective costs of TDCP. The extra costs are at least 20% but may likely be somewhat higher.

Adaptation of recipes and sometimes equipment is necessary and the time needed is indicated at 3-6 months by one manufacturer and 6-12 months by another manufacturer.

Confirmed uses of the FR are for automotive applications with less stringent flammability properties than the properties for the UK furniture market. The available information indicates that foams suitable for the children's articles for the UK market may be produced but substantial R&D costs would be expected.

The available data indicate that the environmental and health profile of the FR is better than the profile for the chlorinated phosphorous FR. The FR is incorporated in the polymer structure i.e. the substance in itself is not present in the final foam. The substance is estimated to be very persistent but not bioaccumulative or toxic and consequently it is not considered a PBT substance. In general, the mobility of polymeric FRs in the materials as compared to the mobility of non-polymeric FRs is considered to be lower but no data to confirm the assumption for this substance have been identified.

3.7 Diethyl bis(2-hydroxyethyl)aminomethylphosphonate

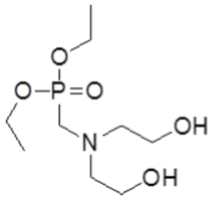
Diethyl bis(2-hydroxyethyl)aminomethyl phosphonate has been evaluated by US EPA (2014). Apart from persistence, where the substance scored high (H) in the screening, the screening scores for this FR are relatively good as compared to the chlorinated phosphorous FRs.

3.7.1 Identification, physical and chemical properties

Identification data and physical and chemical properties of diethyl bis(2-hydroxyethyl)aminomethyl phosphonate are summarised in Table 17.

TABLE 17
IDENTIFICATION, PHYSICAL AND CHEMICAL PROPERTIES OF DIETHYL BIS(2-HYDROXYETHYL)AMINOMETHYL PHOSPHONATE

Property	Data	Reference
EC number	220-482-8	Lanxess, 2007, REACH preregistration database
CAS number	2781-11-5	US EPA, 2014 Lanxess, 2007
Chemical name	Diethyl bis(2-hydroxyethyl)aminomethyl phosphonate	US EPA, 2014 REACH Preregistration
Synonyms	N,N-bis-(2-hydroxylethyl) aminomethane phosphonic acid diethyl ester	Lanxess, 2007
Molecular formula	$C_9H_{22}NO_5P$	US EPA, 2014
Molecular weight	255.25	US EPA, 2014

Property	Data	Reference
Chemical structure		US EPA, 2014
Physical state	Liquid	Lanxess, 2007
pH	8 [Conc. (% w/w): 10%]	Lanxess, 2007
Melting point	-43°C	Lanxess, 2007
Boiling point	190 °C	Lanxess, 2007
Flash point	Closed cup: 86,5°C (187,7°F) [EG A 9/DIN EN ISO 2719	Lanxess, 2007
Relative density	1.16 kg/L (20 °C)	Lanxess, 2007
Thermal decomposition	Decomposition temperature 200°C	Lanxess, 2007
Vapour pressure	2 hPa (20°C) 8 hPa (50°C)	Lanxess, 2007
Water solubility	Easily soluble in the following materials: cold water	Lanxess, 2007
Log Kow	-0.72, OECD 105 test guideline study.	US EPA, 2014
Viscosity	100 – 300 mPa-s	Lanxess, 2015b
Phosphorus content	12.1 %	Lanxess, 2015b

3.7.2 Availability and technical and economic feasibility

Data on availability and technical and economic feasibility of diethyl bis(2-hydroxyethyl)aminomethyl phosphonate are summarised in Table 18.

TABLE 18
AVAILABILITY AND TECHNICAL AND ECONOMIC FEASIBILITY

Property	
Registration status under REACH	Preregistered
Availability	Commercial available as Levagard® 4090 N from Lanxess and FC-450 from the Japanese manufacturer Adeka.
Mode of action	Reactive, reacts into the polymer during curing (US EPA, 2014)
Experience with the use of the FR for flexible PUR foams	Known product in the PUR industry; only used in flexible PUR foam in niche applications at the moment (Lanxess, 2015a). The product is mainly used in rigid PUR foams.
Technical advantages	No data obtained. Levagard® 4090 N is marketed for use in rigid PUR foams
Technical difficulties	No data obtained
Loadings as compared to TCPP	No data obtained
Price as compared with TCPP	More expensive (between 20% and 200%) compared to TDCP (targeted FR).

Property	
Overall cost comparison	No data obtained
Expected time for transition	No data obtained

3.7.3 Human health and environmental profile

Selected data on human health and environmental properties of diethyl bis(2-hydroxyethyl)aminomethyl phosphonate are summarised in Table 19.

TABLE 19
SELECTED HUMAN HEALTH AND ENVIRONMENTAL DATA PROPERTIES OF OLIGOMERIC PHOSPHONATE POLYOL

		Reference
Harmonised classification according to the CLP Regulation (Regulation (EC) No 1272/2008)	No harmonised classification	
Self classification according to the C&L Inventory (Classification and Labelling Inventory)	Skin Sens. 1, H317 (30 notifiers) Acute Tox. 4, H302 (24 notifiers) Skin Sens. 1, H317 (1 notifier) Not classified (2 notofiers)	REACH C&L Inventory
CMR properties	**Carcinogenicity:** "*MODERATE: Data for three structurally similar analogs indicate evidence of carcinogenicity in laboratory animals.*" **Mutagenicity :** "*MODERATE: Based on weight of evidence from multiple studies. Diethyl bis(2hydroxyethyl)aminomethyl phosphonate produced chromosomal aberrations and gene mutations in mammalian cells in vitro. In contrast, negative results were obtained in gene mutation tests in bacteria and no cell transformation was evident in mammalian cells.*". **Reprotoxic effects**: " *LOW: Based on a NOAEL of 750 mg/kg-day (LOAEL not established) in a combined reproductive/developmental toxicity screen in rats. No significant reproductive effects were observed.* "	US EPA, 2014
PBT properties	**Persistence**: "HIGH: Experimental studies on the commercial product, which is *estimated to contain approximately 85% diethyl bis(2-hydroxyethyl)aminomethyl phosphonate, determined the substance to be not readily biodegradable* ". **Bioaccumulation: "***LOW: Both the estimated BCF and BAF for fish are less than 100*". **Toxicity**: "*LOW: Based on experimental and estimated values for fish, daphnia and green algae*".	US EPA, 2014
Exposure of users	Once a reactive flame retardant is incorporated into a polymer, it is unlikely to be released. Compared to additive flame retardants the exposure of users to reactive flame retardants is considered lower. Small amounts of unreacted monomers may be present in plastics	

		Reference
	flame retarded with reactive flame retardant. Experimental data shows that the substance is not released from the final PUR foam.	
Exposure of the environment	Same as above. The releases of the substance during use and disposal is considered to be relatively small.	
Metabolites	Hydrolysis products are diethylphosphite (CAS No. 762-04-9) and the diethanolamine/formaldehyde reaction product (CAS No. 72624-00-1); this latter substance can further degrade to form diethanolamine (CAS No. 111-42-2) and formaldehyde (CAS No. 50-00-0)	Sturtz et al., 1977; Professional judgment as cited by US EPA, 2014

3.7.4 Conclusion

Diethyl bis(2-hydroxyethyl)aminomethyl phosphonate is marketed by at least two manufacturers. The main application area of the substance is as a FR in rigid PUR foams, but the substance is used for some niche applications in flexible PUR foams. Technical data sheets for the substance do not indicate that this substance is particularly suitable in flexible PUR foam applications and the FR would probably not be the first choice for flexible PUR foams in children's articles.

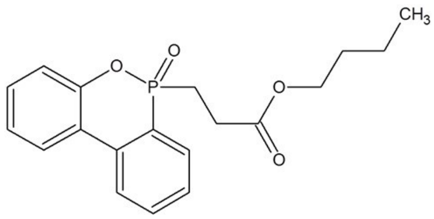
3.8 6H-Dibenz[c,e][1,2]oxaphosphorin-6-propanoic acid, butyl ester, 6-oxide

6H-Dibenz[c,e][1,2]oxaphosphorin-6-propanoic acid, butyl ester, 6-oxide has not been evaluated by US EPA (2014) as it has quite recently been introduced as FR for flexible PUR foams.

3.8.1 Identification, physical and chemical properties

Identification data and physical and chemical properties of 6H-Dibenz[c,e][1,2]oxaphosphorin-6-propanoic acid, butyl ester, 6-oxide are summarised in Table 26.

TABLE 20
IDENTIFICATION, PHYSICAL AND CHEMICAL PROPERTIES OF 6H-DIBENZ[C,E][1,2]OXAPHOSPHORIN-6-PROPANOIC ACID, BUTYL ESTER, 6-OXIDE

Property	Data	Reference
EC number	805-659-5	REACH Registration Database
CAS number	848820-98-4	
Chemical name	6H-Dibenz[c,e][1,2]oxaphosphorin-6-propanoic acid, butyl ester, 6-oxide	REACH Registration Database
Synonyms	DOPO-AC4	Metadynea, 2015
Molecular formula	$C_{19}H_{21}O_4P$	Metadynea, 2015
Molecular weight	344	Metadynea, 2015
Chemical structure		REACH Registration database
Physical state	clear viscous liquid	Lanxess, 2015c
pH	No data	

Property	Data	Reference
Melting point	-16.3°C	Lanxess, 2015c
Boiling point	362 °C	Lanxess, 2015c
Flash point	Closed cup: 230°C	Lanxess, 2015c
Relative density	1.20 g/cm3	Lanxess, 2015c
Thermal decomposition	Not available	Lanxess, 2015c
Vapour pressure	Vapour pressure at 20 °C 9.48* 10^{-08} Pa	REACH Registration database
Water solubility	0,17 g/l	Lanxess, 2015c
Log Kow	3.323 (OECD 117)	Lanxess, 2015c
Viscosity	6500 mPa-s	Lanxess, 2015c
Phosphorus content	9.0 % min. 8.5%	Lanxess, 2015c Metadynea, 2015

3.8.2 Availability and technical and economic feasibility

Data on availability and technical and economic feasibility of 6H-Dibenz[c,e][1,2]oxaphosphorin-6-propanoic acid, butyl ester, 6-oxideare summarised in Table 21.

TABLE 21
AVAILABILITY AND TECHNICAL AND ECONOMIC FEASIBILITY

Property	
Registration status under REACH	Registered with a tonnage in the 10-100 t/year range by Metadynea Austria GmbH
Availability	Available as Levagard TP LXS 51114 from Lanxess. Available as DOB11 from Metadynea Austria GmbH.
Mode of action	Additive FR
Experience with the use of the FR for flexible PUR foams	Product introduction into the flexible PUR market has just started; only lab experience is available (Lanxess, 2015). According to the Technical Data Sheet it is used as a flame retardant in polyurethanes, especially in flexible PUR foams. It is compatible with polyether polyols as well as with polyester polyols. (Lanxess, 2015c) The FR is used for various FR applications. DOB11 is especially suited for polyesters, PUR and epoxy-systems intermediate. (Metadynea, 2015)
Technical advantages	Low fogging. The fogging level is less than the half of the level of TDCP.
Technical difficulties	No information
Loadings as compared to TDCP	Approx. twice the concentration of TDCP to pass the automotive MVSS 302 test. (Lanxess, 2015a)
Price as compared with TDCP	More expensive (between 20% and 200%) compared to TDCP (Lanxess, 2015a)
Overall cost comparison	No data
Expected time for transition	In general, the time period to replace an existing flame retardant by an alternative one is estimated at 6 months to 1 year (Lanxess, 2015a).

3.8.3 Human health and environmental profile

The substance has not been evaluated by US EPA (2014). Selected data of particular importance for the present assessment are summarised in Table 22, but no attempt has been made to allocate a scoring using the methodology applied by UE EPA (2014). A GreenScreen profile (the same approach as used by USEPA, 2015) for the substance may be developed as part of an ongoing study for the Danish EPA.

TABLE 22
SELECTED HUMAN HEALTH AND ENVIRONMENTAL DATA PROPERTIES OF 6H-DIBENZ[C,E][1,2]OXAPHOSPHORIN-6-PROPANOIC ACID, BUTYL ESTER, 6-OXIDE

		Reference
Harmonised classification according to the CLP Regulation (Regulation (EC) No 1272/2008)	No harmonised classification	
Self classification according to the C&L Inventory (Classification and Labelling Inventory)	Skin Irrit. 2, H315 (28 notifiers) Aquatic Chronic 3, H412 (28 notifiers) Acute Tox. 4, H302 (1 notifier)	
CMR properties	**Carcinogenicity:** No data identified **Mutagenicity:** Negative in OECD 471 Bacterial Reverse Mutation Test Not considered mutagenic **Reprotoxic effects**: No data identified	Lanxess, 2015c REACH Registration Database
PBT properties	**Persistence**: KCCS DOB11 is not biodegradable following OECD 301B/EU C.4-C. Rate of degradation/elimination: 19% after 8 days OECD 301B Ready Biodegradability **Bioaccumulation:** No data **Toxicity**: The following results were determined for the test item KCCS DOB11 (species:*Daphnia magna*). 24h-NOEC = 30 mg/L 48h-NOEC = 30 mg/L 24h-EC50i> 69 mg/L 48h-EC50i= 66 mg/L	REACH Registration Database Lanxess, 2015c REACH Registration Database
Exposure of users	No data available. The substance is a non-polymeric additive FR and the exposure levels could be at the same level as exposure to the chlorinated phosphorous FRs.	
Exposure of the environment	Same considerations as above.	
Metabolites	No data	

3.8.4 Conclusion

The substance is available from at least two manufacturers, but the substance has only quite recently been introduced for use in flexible PUR foams and limited experience is available. The advantage of this FR is low fogging potential of importance for automotive applications. The substance has not been evaluated by US EPA (2014). Some data on human health and environmental effects are available from Safety Data Sheets and a REACH registration but the available data are not sufficient for a full PBT/CMR assessment of the substance. No attempt has been made to prepare "expert judgments" in accordance with the methodology used by US EPA, but a GreenScreen profile (using a similar methodology) is expected to be performed as part of an ongoing study for the Danish EPA.

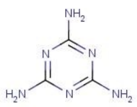
3.9 Melamine

Melamine has been evaluated by US EPA (2014). The substance scored high on reproductive effects and persistence and overall the profile is only slightly better than the profile of TCPP.

3.9.1 Identification, physical and chemical properties

Identification data and physical and chemical properties of melamine are summarised in Table 23.

TABLE 23
IDENTIFICATION, PHYSICAL AND CHEMICAL PROPERTIES OF MELAMINE

Property	Data	Reference
EC number	203-615-4	REACH registration database
CAS number	108-78-1	REACH registration database
Chemical name	1,3,5-triazine-2,4,6-triamine	REACH registration database
Synonyms	Melamine	REACH registration database
Molecular formula	$C_3H_6N_6$	US EPA, 2014
Molecular weight	126.13	US EPA, 2014
Chemical structure		REACH registration database
Physical state	Solid	US EPA, 2014
pH	7.5 and 9.5	US EPA, 2014
Melting point	361 °C	REACH Registration Database
Boiling point	>280 °C (Decomposes)	REACH Registration Database
Flash point	Flash point: >280°C (Measured)	REACH Registration Database
Relative density	1.57	REACH Registration Database
Thermal decomposition	no data	
Vapour pressure	1.1 10^{-7} Pa at 25 °C.	
Water solubility	3.48 g/l at 20 °C.	
Log Kow	-1.14 at 25 °C	REACH Registration Database
Viscosity	study technically not feasible	REACH Registration Database
Phosphorus content	not phosphor containing	

3.9.2 Availability and technical and economic feasibility

Data on availability and technical and economic feasibility of melamine are summarised in Table 24.

TABLE 24
AVAILABILITY AND TECHNICAL AND ECONOMIC FEASIBILITY

Property	
Registrations status under REACH	Registered in the 100,000 - 1,000,000 t/y range (many uses, main application area is for manufacture of melamine resin)
Availability	Available as Aflammit PMN 500 from Thor. Widely used in combination with other FRs.
Mode of action	Additive
Experience with the use of the FR for flexible PUR foams	According to UK manufacturer of children's products, dense foams (like the ones used in cots and baby mattresses) can pass fire tests using only melamine as a flame retardant.
Technical advantages	No data
Technical difficulties	For a majority of flame retarded PUR articles, melamine is not really suitable as a flame retardant when used alone: in the quantities required for the foam to meet relevant fire safety standards, the foam tends to suffer significant loss of material properties (Moore and Corden, 2000). According to an industry contact, limitations in terms of comfort are expected: high density foams are usually harder and less resilient than flexible foams of lower densities. Since melamine tends to make foams harder, this option may be restricted to a limited number of articles. Also, from an industrial/production standpoint, handling of melamine (powder) has limited acceptance, since the majority of raw materials of PUR foams are liquids (foam manufacturers usually use powders when there is no other option).
Loadings as compared to TCPP	No data
Price as compared with TCPP	The price of melamine is close to the price of TCPP according to industry.
Overall cost comparison	According to the available information the price is the melamine is not a main issue with regard to substitution, but R&D costs may be substantial due to the difficulties in meeting the fire safety requirements.
Expected time for transition	No data.

3.9.3 Human health and environmental profile

Selected data on human health and environmental properties of melamine are summarised in Table 25.

TABLE 25
SELECTED HUMAN HEALTH AND ENVIRONMENTAL DATA PROPERTIES OF MELAMINE

		Reference
Harmonised classification according to the CLP Regulation (Regulation (EC) No 1272/2008)	No harmonised classification.	

		Reference
Self classification according to the C&L Inventory (Classification and Labelling Inventory)	Not Classified (609 notifiers) STOT RE 2, H373 (9 notifiers) Various classifications by one to three notifiers	C&L inventory
CMR properties	**Carcinogenicity: "***MODERATE: The carcinogenicity hazard potential for melamine is based on evidence that oral exposure to melamine causes cancer in experimental animals*" **Mutagenicity:** *"MODERATE: Based a weight of evidence from multiple studies"* **Reprotoxic effects**: *"HIGH: Based on a NOAEL = 10 mg/kg-day (LOAEL of 50 mg/kg-day) for increased apoptotic index of spermatogenic cells in male mice orally administered melamine for 5 days"*	US EPA, 2014
PBT properties	**Persistence**: *"HIGH: Experimental data indicate melamine undergoes slow degradation under stringent guideline conditions, although melamine is readily degraded in acclimated treatment systems."* **Bioaccumulation: "***LOW: Measured BCF and estimated BAF values are below 100, the Low bioaccumulation designation criteria."* **Toxicity**: Acute "*LOW: Based on experimental acute aquatic values > 100 mg/L in fish, daphnia, and algae"*. Chronic: *"MODERATE: Based on an estimated chronic aquatic ChV of 1.3 mg/L (ECOSAR class: Anilines, amino-meta) in green algae"*	US EPA, 2014
Exposure of users	No data. Melamine is an additive FR and compared to the reactive FRs and polymeric FRs the mobility of melamine is expected to be higher. The vapour pressure is relatively low (about 100 times lower than the vapour pressure of TCPP) and the evaporation from products is assumed to be negligible.	
Exposure of the environment	Same as above	
Metabolites	Hydrolysis products: ammeline, ammelide and cyanuric acid; Metabolites: cyanuric acid; Pyrolysis: ammonia, melem, melone	US EPA, 2014

3.9.4 Conclusion

Melamine is commonly used in combination with other FRs (e.g. TCPP), but dense foam can pass fire tests using only melamine as a flame retardant. According to a manufacturer of melamine, this substance used alone will probably not be the FR of choice for most applications. The health and environmental profile for melamine is slightly better than the profile of TCPP. According to 99% of the notifiers to the C&L database, the substance should not be classified. The price of melamine is similar to the price of TCPP, but no data on the R&D costs and other costs has been obtained. Evaporation of the substance from articles may be lower than evaporation of TCPP, but the data do not allow any conclusion to be drawn on the possible exposure of humans and the environment as compared to the chlorinated phosphorous FR.

3.10 Summary on chemical alternatives

Several chemical alternatives with better environmental and health profiles than the profiles for the chlorinated phosphorous FRs exist, as evaluated by US EPA in the Design for the Environment programme. In addition to the overall lower scoring on key parameters concerning PBT and CMR properties, reactive FRs and polymeric FR alternatives are considered to result in lower levels of user and environmental exposure.

The alternatives have typically been developed for use in automotive applications where requirements for low fogging and low VOC emissions have been the driving forces for development of alternatives. The available alternatives in general have better properties with regard to these parameters. The lower fogging potential may also indicate a lower potential for evaporation of the substances from the articles in use. The low levels of migration of reactive FRs have made these FRs attractive for foams marketed as "green", and the reactive FRs are particularly applied in PUR foams from bio-based polyols marketed as "green" for the US market.

The use of PUR with alternative FRs has mainly been for automotive applications and furniture complying with regulations in the USA. Limited experience with the use of the evaluated alternative FRs for furniture complying with the UK fire safety regulations has been identified. For some dense foams, melamine (which is also used in combination with e.g. TCPP) may be used alone but melamine is only applicable for a limited range of foams. None of the available alternatives can be used as a simple substitute for the chlorinated phosphorus FRs, but different alternatives may be needed for different applications. The use of the alternative FRs for children's articles on the UK market may be challenging and substantial R&D is needed, but the manufacturers of alternative FRs contacted for this study have not indicated that it would be impossible to meet the requirements using the alternative FRs. Time needed for R&D is indicated to be in the range of 3 months to one year. As, apparently, none of the alternatives (apart from melamine in some foams) has been used for foams for children's articles a more extensive end user perspective on the use of alternatives would be necessary in order to fully understand the feasibility of substitution.

The alternative flame retardants are substantially more expensive than the chlorinated phosphorous FRs even though lower loadings are necessary. Additional costs in the 20-200% range have been indicated by manufacturers. More information on additional costs is indicated in a confidential Annex for the Danish EPA only.

4. Non-chemical alternatives to TCPP, TDCP and TCEP in children's articles

4.1 Non-chemical alternatives to avoid the use of TCPP, TDCP and TCEP in children's articles

The US EPA DfE reports from 2005 and 2014 briefly describe some techniques to avoid the use of the additive flame retardants in products containing flexible PUR foams and textiles (US EPA 2005, 2014).

Fire barriers - To meet the criteria of a more stringent test (e.g. an open flame test), a fire barrier may be used between the foam and the upholstery fabric. A fire barrier may be inherently fire resistant or may be coated with a flame retardant chemical. The fire barrier may be a blend of inexpensive natural fibres and expensive synthetic fibres. Synthetic fibres used in these blends include VISIL, Basofil, polybenzimidazole, KEVLAR, NOMEX and fiberglass (US EPA, 2005). Smaller manufacturers of furniture and mattresses in niche markets use these materials. These blends are commonly used in bus and airplane seating (US EPA, 2005). A group of fire barrier materials is composed solely of expensive, high-performance synthetic fibres. They are generally used in industrial or high-performance applications such as firemen's coats and astronaut space suits (US EPA, 2005).

A suitable fire barrier is likely to be able to achieve almost any flame retardancy standard; however, costs of such products are likely to be higher. Mattresses meeting the CPSC 1633 open flame standard most commonly use fire barriers, although designs of these barriers vary widely (Nazare et al., 2012).

Examples of the use of fire barriers were also found during the consultation. One UK manufacturer of cots and infant mattresses claimed they were able to pass the BS 7177 standard by using very finely woven cotton aimed at minimising air holes in the fabric, backed by a wool layer that acts as a natural fire retardant. Natural fibres such as wool and coconut coir were used for the filling. This reportedly eliminates the need to add chemical fire retardants. However, the costs of using these materials and technique are much higher (up to 100%) compared to conventional foams.

Graphite impregnated foams - As a non-chemical alternative US EPA (2005) include graphite impregnated foam (GIF) which can be considered an "inherently flame-resistant foam" that is self-extinguishing and highly resistant to combustion. No detailed information on the use of graphite impregnated foams in children's articles has been obtained, and these foams have not been mentioned as viable alternatives by the market actors contacted for this study.

Physical fire protection of foam seating by the introduction of graphite impregnated foam (GIF) as an inherently fire-resistant foam is widely used in aircraft (Stevens et al., 2010). GIF-foams may be recommended as the best environmental performing technology but concerns exist on potential cost implications. They also have a need for additional chemical FRs to assist gas phase retardancy.

Graphite-based foams have been available in the UK for more than 20 years and early marketing efforts were strongly directed towards the domestic furniture market (Stevens et al., 2010).

Inherently flame retarding textile covering - A guide to the UK furniture and furnishings Regulations note that, when inherently flame retarding fibres are used (e.g. flame retardant polyester or flame retardant polypropylene), the fabric produced from them tends to melt or split under the influence of the test flame so that the filling is exposed and then ignited. In this case, this fabric cannot be legally used as upholstery covering for domestic furniture in the UK (FIRA, 2011). One means of achieving compliance here could be to apply a flame retardant backcoat to the fabric to upgrade ignition behaviour (FIRA, 2011).

Use of alternative foams - Foams made from natural rubber (latex) are used for bedding and furniture for some of the same applications as the PUR foams. These latex foams need addition of flame retardants in order to comply with the UK regulations. One example is furniture from John Ryan (2013) which use a thin slice, 1 cm each side, of graphite FR Latex to ensure that the mattress complies with regulations under BS 5852 (the crib 5 test). Foams made of latex are considerably more expensive than PUR foams.

5. Other techniques to reduce the use of TCPP, TDCP and TCEP

5.1 Techniques to reduce the content of TCPP, TDCP and TCEP as impurity

TCPP, TDCP and TCEP have been found at low concentrations in children's articles, far below the concentrations needed for flame retarding the foam to meet fire safety standards. The following sources of contamination have been identified:

- TCEP is present as impurity in commercial products based on 2,2-bis(chloromethyl) trimethylene bis[bis(2-chloroethyl) phosphate]
- If different flame retardants are used, small quantities left in pipes and tanks may contaminate the subsequent batch
- When changing from FR to non-FR grades in the continuous production process, some metres of foam slabstock may be cross-contaminated
- By storage of foam, the flame retardants in FR grades may migrate to adjacent non-FR foams if the foams are in direct contact.
- Rebonded PUR foam based on production scrap may contain pieces of FR foams
- Rebonded PUR from post-consumer scrap may contain pieces of FR foams
- Contamination by storage via air takes place but is not considered to result in measureable concentrations in the foams

TCEP present as impurity in other FRs

As described in section 1.1.3, TCEP is present as impurity in flame retardants based on 2,2-bis(chloromethyl) trimethylene bis[bis(2chloroethyl)phosphate]. According to informal industry information, the V6 flame retardant has in Europe now been replaced by a product similar to the former V66 from Albemarle. The flame retardant is manufactured by a Chinese company and it has not been possible to identify information on TCEP content of the commercial product or the concentration in the final PUR foam. The extent to which a restriction on TCPP, TDCP and TCEP would be a *de facto* restriction on the flame retardants based on 2,2-bis(chloromethyl) trimethylene bis[bis(2chloroethyl)phosphate depends on the limit value applied. If a limit value in the final foam of 5 mg/kg is applied, the actual commercial flame retardants based on 2,2-bis(chloromethyl) trimethylene bis[bis(2chloroethyl)phosphate] could certainly not be used. More data on the commercial products are needed in order to assess the possible impact of a limit value of 0.1% (1000 mg/kg) in the final foam.

Cross contamination during manufacture

Cross contamination during production may take place and, with current industry practices, according to information from EUROPUR, it may be challenging to avoid cross contaminated at levels above 5 mg/kg (more than 10,000 lower than the effective concentration in FR foams).

Most flexible PUR plants in Europe produce FR grades to some extent (in particularly for the automotive industry). The situation is not that all foams are contaminated, rather that it is difficult to ensure that all non-FR grades (or grades with alternative FRs) are not contaminated. According to a major manufacturer of flexible PUR foams, most of the problems may be overcome by running foams with alternative FRs after non-FR foams, and by using separate piping and tanks for each flame retardant. An option would also be for foams intended for children's articles to be produced on specific production lines. For speciality foams, it is normal practice that they are produced by only a few companies, but these foams are in general more expensive than the bulk foams.

It is not possible based on the available data to estimate the possible costs of applying a limit value of 5 mg/kg.

If a limit value of 0.1% in the final foam is applied (approximately 100 times lower than the effective concentration), the precautions to be taken during production to avoid cross contamination is considered to be small and with very small costs.

A limit value of 5 mg/kg is applied in the Toys Directive, and notably no objections to this limit value from the industry were voiced. According to EUROPUR the reasons for this was that the manufacture of PUR foams in Europe for toys was very small, as nearly all toys are imported from outside the EU. A limit of 5 mg/kg may therefore not be achievable in plants producing both FR and non-FR foams, and it is therefore not straightforward to extrapolate the findings from the Toys Directive to PUR foams for other children's articles.

According to EUROPUR (2015c) "*The determination of a realistic tolerance would however require a huge verification work made at production plant level, based on different layouts, different formulations and different process parameters. Our members voiced a strong preference for a tolerance of 0.1% w/w which would be easier to achieve and more in line with typical tolerance levels accepted under the REACH Regulation."*

Cross contamination by storage
During storage of foam, the flame retardants from FR grades may migrate to adjacent non-FR foams if the foams are in direct contact. The extent to which this takes place is not known, but this could be overcome by avoiding direct contact between FR and non-FR foams. Cross contamination via the air in storage areas may take place but, according to industry contacts, it would not result in concentration above 5 mg/kg.

Rebonded foams
Rebonded foams (also designated "rebond") may, depending on the scrap used, contain any concentration of the flame retardants from zero to approximately ten percent. Rebonded foam is a moulded PUR product made from pieces of shredded flexible PUR foam, held together with a binder. In the EU Risk Assessment for TDCP (ECB, 2008c) it was estimated that approximately 60,000 tonnes of rebonded foams was produced in Europe in total. A high proportion of this was produced in the UK (approximately 22,000 tonnes). Across the EU, only a low proportion of this would contain flame retardants. Less expensive non-FR foam trim can be obtained exclusively but it is likely that a site which is rebonding FR-PUR will also be handling non-FR foam (ECB, 2008c). This has been confirmed by EUROPUR (2015c) which indicates that it seems to be common practice to mix FR and non-FR foams when producing bonded foam.

The relatively high density and resilience of rebonded foam make it suitable for applications including vibration sound dampening, sport mats, cushioning, packaging and carpet underlay. According to the risk assessment (ECB, 2008c) re-bonders in mainland Europe handle the two lines of scrap together (the flame retarded foam from the UK, and foam produced elsewhere in Europe, a smaller proportion of which contains flame retardants), avoiding the need to clean out the machines in between a run of each type.

As mentioned previously, some of the rebonded foams are used for cushioning. In cushioning, a strip of re-bonded foam is used along the front of some cushions on the basis that it is more hard wearing (ECB. 2008c). The application seems to be quite similar to some of the applications in children's articles e.g. in car seats and as discussed elsewhere, the use of rebonded foams may explain why many of the foams tested contain a mixture of flame retardants.

A restriction on TCPP, TDCP and TCEP in children's articles may limit the use of rebonded foams in these articles unless the rebonded foam is produced entirely from non-FR foams. If a limit value of 5 mg/kg is applied, just 0.01% FR foams (with 8% FR) in the rebonded foam would result in concentrations above the limit value. Even a limit value of 0.1% would probably be challenging to meet as a content of just 1% FR foams would result in concentrations above the limit value. The stakeholder consultation has not identified any manufacturers of children's articles using rebonded foam and no data are available to estimate the extra costs of using rebonded foams without any trace of flame retardants or using virgin foams for the same applications.

Summary
According to industry, it may be challenging to ensure that foams for children's articles do not contain trace impurities in concentrations above 5 mg/kg. Besides the possible costs of changed production practices, the compliance control costs may be significantly higher if a limit value of 5 mg/kg is applied as compared to a limit value of e.g. 0.1 %. The flexible PUR industry indicates that the determination of a realistic tolerance would require a huge amount of verification work and suggest a limit value of 0.1 %. If a limit value of 5 mg/kg is applied, manufacturers and importers of children's articles would need extensive control regimes, as a contractual agreement that the substances are not intentionally added to the product would not ensure that the substances are not present as an impurity. Moreover, the concentration may vary within one batch and it would be necessary to take more samples of each batch. For the authorities, a low limit value would imply extra control costs as the likelihood of articles not being in compliance with the restriction would be much higher.

5.2 Techniques to reduce the use of FR foams where it is not required

For most flexible PUR foams used in children's articles the following steps in the product chain exist (see also Figure 1):

- Manufacturers of PUR raw materials (polyols and diisocyanates)
- Manufacturers of the flexible PUR slabstock (foam blocks)
- Manufacturers of cut foam from slabstock - in the PUR industry termed "converters" (these may be the same companies as the manufactures of the slabstock)
- Manufacturers of children's articles

As the FR grades are usually more expensive than non-FR grades, neither the manufacturers of the flexible PUR nor the converters have any incentives to mix FR grades and non-FR grades.

The risk of using FR-grades for articles where flame retardants are not required relates to the practices applied by the manufacturers and importers of children's articles. As mentioned elsewhere some UK manufacturers of children's articles also use FR foams for articles exported to continental Europe even this is not required. The techniques to reduce this would be to have separate production lines for articles for the UK market and articles for other markets.

The risk of using rebonded foams with flame retardants for applications where it is not required is described in the section above.

6. Development trends and initiatives to avoid TCPP, TDCP and TCEP in children's articles

6.1 Trends in the use of the substances in children's articles

As previously mentioned, the use of TCEP in Europe has in general ceased. No significant trend in the use of TCPP and TDCP has been identified. Many manufacturers of FRs market non-halogenated alternatives and some alternatives have just been introduced on the market, in the expectation that the market will move away from the halogenated FRs. The main driver for introduction of alternatives seems to be requirements for automotive applications (low fogging and VOC releases).

Frame retardants in children's articles have received much public attention in recent years in the USA and in Northern Europe. The stakeholder consultation has not identified any trends by the manufacturers and importers of children's articles away from the use of the targeted FRs. No examples have been identified of marketing based on the fact that articles do not contain the three FRs.

The results of tests of the three targeted FRs in childen's car seats and other articles varies from year to year, and the data do not allow any conclusion about trends to be drawn.

6.2 Initiatives to avoid the substances in children's articles

The use of TCEP in flexible PUR foams is generally avoided. TCEP is included in the list of prohibited substances under the CertiPUR certification programme implemented by EUROPUR.

No initiatives to avoid the use of TCPP of TDCP in children's articles have been identified.

7. Abbreviations and acronyms

BAF	Bioacumulation factor
BCF	Bioconcentration factor
CAS	Chemical Abstract Service
CLD	Compression Load Deflection
CPSC	US Consumer Product Safety Commission
DEPA	Danish Environmental Protection Agency
DfE	Design for the Environment Programme (US EPA programme)
DG	Directorate General
EC	European Community
ECHA	European Chemicals Agency
EFRA	European Flame Retardants Association
EPA	Environmental Protection Agency
EPI v4.11	US EPA's Estimation Programs Interface (EPISuite™) version 4.11
EU	European Union
EUROPUR	European association of flexible polyurethane foam blocks manufacturers
FR	Flame retardant or flame retarded (depending on context)
PBDE	Polybrominated diphenyl ethers
pentaBDE	Pentabrominated diphenyl ether
php	Part per hundred polyols
PINFA	Phosphorus, Inorganic and Nitrogen Flame Retardants Association
PUR	Polyurethane (same as PU)
REACH	Registration, evaluation, authorisation & restriction of Chemicals (Regulation (EC) No 1907/2006)
R&D	Research and development
TB117	Technical Bulletin 117
TCEP	Tris(2-chloroethyl)phosphate
TCPP	Tris(2-chloro-1-methylethyl) phosphate
TDCP	Tris[2-chloro-1-(chloromethyl)ethyl] phosphate
TPP	Triphenyl phosphate
UK	United Kingdom
US EPA	United States Environmental Protection Agency
US	United States (same as USA)
V6	Commercial products of 2,2-bis(chloromethyl) trimethylene bis[bis(2chloroethyl)phosphate]
V66	Commercial products of 2,2-bis(chloromethyl) trimethylene bis[bis(2chloroethyl)phosphate]
VOC	Volatile organic carbon

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Appendix 1. Summary table from US EPA DfE study

The screening level hazard summary for flame retardants used in PUR foams as alternatives to penta-BDE prepared by the US EPA (2014) is shown in the following table.

TABLE 26

SCREENING LEVEL HAZARD SUMMARY FOR FLAME RETARDANTS USED IN PUR FOAMS AS ALTERNATIVES TO PENTA-BDE (US EPA, 2014) *1

THIS TABLE ONLY CONTAINS INFORMATION REGARDING THE INHERENT HAZARDS OF FLAME RETARDANT CHEMICALS. EVALUATION OF RISK CONSIDERS BOTH THE HAZARD AND EXPOSURE ASSOCIATED WITH SUBSTANCE INCLUDING COMBUSTION AND DEGRADATION BY-PRODUCTS. THE CAVEATS LISTED IN THE LEGEND AND FOOTNOTE SECTIONS MUST BE TAKEN INTO ACCOUNT WHEN INTERPRETING THE HAZARD INFORMATION IN THE TABLE

Chemical	CAS No	Human Health Effects											Aquatic Toxicity		Environmental Fate	
		Acute toxicity	Carcinogenicity	Genotoxicity	Reproductive	Developmental	Neurological	Repeated Dose	Skin Sensitization	Respiratory Sensitization	Eye Irritation	Dermal Irritation	Acute	Chronic	Persistence	Bioaccumulation
Halogenated Flame Retardants - Firemaster® 550 Components																
Firemaster® 550*	Mixture	L	M	M	H	H	H	H	M		L	L	VH	VH	H	H
Benzoic acid, 2,3,4,5-tetrabromo-, 2-ethylhexyl ester (TBB) ¥	183658-27-7	L	M	L	M	M	M	M	M		L	L	L	L	H	H
Di(2-ethylhexyl) tetrabromophthalate (TBPH) ^ ¥	26040-51-7	L	M	M	M	M	M	M	L		L	L	L	L	H	H
Isopropylated triphenyl phosphate (IPTPP) ^	68937-41-7	L	M	L	H	H	H	H	L		L	L	VH	VH	M	H
Triphenyl phosphate (TPP) ^	115-86-6	L	M	L	L	L	L	H	L		L	VL	VH	VH	L	M
Halogenated Flame Retardants - Chlorinated Phosphorus Alternatives																
Tris (2-chloroethyl) phosphate (TCEP)	115-96-8	H	H	M	M	H	M	M	L		L	L	H	H	M	L
Tris (2-chloro-1-methylethyl) phosphate (TCPP)	13674-84-5; 6145-73-9	L	M	L	H	H	M	M	L		L	L	M	H	H	L
Tris (1,3-dichloro-2-propyl) phosphate (TDCPP)	13674-87-8	L	H	M	H	M	L	H	L		L	L	H	H	H	L
Phosphoric acid, P,P'-[2,2-bis(chloromethyl)-1,3propanediyl] P,P,P',P'-tetrakis(2-chloroethyl) ester (V6)	38051-10-4	L	M	L	M	H	L	M	L		L	L	M	H	H	L
Non-Halogenated Flame Retardant Alternatives																
Ammonium polyphosphate (APP) ¥	68333-79-9	L	L	L	L	L	L	L[d]	L		VL	L	L	L	VH	L

Chemical	CAS No	Human Health Effects											Aquatic Toxicity		Environ-mental Fate	
		Acute toxicity	Carcinogenicity	Genotoxicity	Reproductive	Developmental	Neurological	Repeated Dose	Skin Sensitization	Respiratory Sensitization	Eye Irritation	Dermal Irritation	Acute	Chronic	Persistence	Bioaccumulation
Expandable graphite ¥	12777-87-6	L♦	M♦	L♦	L♦	L	L	M♦	L♦	♦	M♦	M♦	L♦	M♦	H	L
Melamine	108-78-1	M	M	M	H	M	L	M	L		L	VL	L	M	H	L
Triphenyl phosphate (TPP) †	115-86-6	L	M	L	L	L	L	H	L		L	VL	VH	VH	L	M
Tricresyl phosphate (TCP) 1	1330-78-5	M	L	L	H	M	M	H	M		L	L	VH	VH	M	H
Isopropylated triphenyl phosphate (IPTPP) †	68937-41-7	L	M	L	H	H	H	H	L		L	L	VH	VH	M	H
Tris (p-t-butylphenyl) phosphate (TBPP)	78-33-1	L	M	L	M	L	M	H	M		L	M	VH	VH	M	H
Diethyl bis(2hydroxyethyl)aminomethylphosphonate	2781-11-5	L	M	M	L	L	M	M	M		L	VL	L	L	H	L
Oligomeric ethyl ethylene phosphate	184538-58-7	L	L	M	L	M	M	L[d]	L		M	L	L	L	VH	L
Oligomeric phosphonate polyol	363626-50-0	L	M	M	L	M	M	L	L		L	VL	L	L	M	L
New-to-Market Proprietary Mixtures																
Emerald Innovation™ NH-1*	Proprietary	H	M	L	M	L	M	H	M		M	M	VH	VH	M	H
Fyrol™ HF-5 *	Proprietary	L	M§	M	L	M	M§	M[d]	L		M	L	VH	VH	H	H‡

Notes from the cited report:

VL = Very Low hazard **L** = Low hazard **M** = Moderate hazard **H** = High hazard **VH** = Very High hazard –
Endpoints in coloured text (**VL**, **L**, **M** **H**, and **VH**) were assigned based on empirical data.
Endpoints in black (VL, L, M, H, and VH) were assigned using values from predictive models and/or professional judgment.

* This mixture is made up of four components contained in the hazard summary table. Hazard designations in bold and colour are based on test data for the mixture, as summarized in the hazard profiles for the components. Hazard designations in italics are based on the most conservative results from one of the four components.

^ This component of Firemaster® 550 may be used alone or in other mixtures as an alternative.

¥ Aquatic toxicity: EPA/DfE criteria are based in large part upon water column exposures, which may not be adequate for poorly soluble substances such as many flame retardants that may partition to sediment and particulates.

1This assessment also includes information for other methylated triphenyl phosphate isomers (phosphoric acid, bis(methylphenyl) phenyl ester (CASRN 26446-73-1) and phosphoric acid, methylphenyl diphenyl ester (CASRN 26444-49-5)).

Appendix 2. Questionnaire to UK market actors

Chlorinated phosphorous based flame retardants in children's articles containing foam - survey to inform a possible restriction

Introduction

The Danish Environmental Protection Agency (DEPA) is considering whether to propose a restriction on the use of three chlorinated phosphorous flame retardants (TCPP, TDCP and TCEP) in children's articles. The DEPA has contracted COWI and Amec Foster Wheeler to gather information on the presence and concentration of these flame retardants in children's articles and to investigate their current market distribution.

The three flame retardants (TCPP, TDCP, and TCEP) are used in flexible polyurethane foam (PUF) products as a cost-effective option to comply with flammability requirements and standards. Following concerns regarding the effects these substances could have on the health of children, EU Member States decided in 2014 to introduce a restriction on their use in toys up to a limit of 5mg/kg. However, the presence of these substances in children's articles other than toys is not regulated and available data on other uses is very limited.

The objective of this short survey is to help DEPA understand how widely the three flame retardants are used in children's articles and in what concentrations. We also aim to assess the extent to which fire safety regulations (e.g. those in the UK and Ireland) drive the use of these substances, including for products sold in the rest of the EU. The following questionnaire can be completed in a brief telephone interview. Alternatively, please feel free to provide a written submission by completing all of the questions that you are able to and leaving blank those for which you have no information.

The information you provide will help DEPA to decide whether a restriction on these three substances may be warranted.

Confidentiality and protection of commercially-sensitive information

Please be assured that the information provided will be treated confidentially. Specifically, any confidential information that you provide will not be passed on to third parties without your consent. Whilst the information provided is likely to be taken into account in the outputs (reports) from the work, the confidentiality of the data will be preserved by: making anonymous all information relevant to specific companies; not using the information provided for any purpose other than for this project; presenting uncertainty ranges and aggregated data for all companies (e.g. on quantities); and excluding other information that you specify should not be included in the report.

Details on the three substances

For reference, the full names of the substances concerned are:

TCEP: Tris (2-chloroethyl) phosphate, CAS No 115-96-8,

TCPP: Tris (2-chloro-1-methylethyl) phosphate, CAS No 13674-84-5

TDCP: Tris [2-chloro-1-(chloromethyl)ethyl] phosphate, CAS No 13674-87-8

Contact details for the project team

Please provide information to Amec Foster Wheeler directly either by a phone interview or by submitting a completed questionnaire to:

Javier Esparrago: +44 203 215 1674 / +44 7812 231362, javier.esparrago@amecfw.com

1. Your details

Contact name in case of queries:	
Company / organisation:	
Job title:	
Telephone number:	
E-mail address:	
Your role in the supply chain	☐ Manufacturer of children's products ☐ Importer/Seller of children's products ☐ Manufacturer of PUF ☐ Tester/Laboratory ☐ Other – please specify:

2. Uses of chlorinated flame retardants in PUF for childcare products

2.1 Do you collect information on whether these three flame retardants are present in any of your products?

Substance	**Do you collect information on its presence in articles?**	
TCEP	☐ YES	☐ NO
TCPP	☐ YES	☐ NO
TDCP	☐ YES	☐ NO

2.2 The table below details some of the products where the three flame retardants have been found in previous studies. Please indicate whether you are aware of the presence of any of the three substances in each type of article produced/imported/sold by your organisation and their concentration (if known). If this information is available for any other childcare article types please provide details.

Product	**TCEP**		**TCPP**		**TDCP**	
	Y/N	**Concentration (% w/w)**	**Y/N**	**Concentration (% w/w)**	**Y/N**	**Concentration (% w/w)**
Child car seats	☐		☐		☐	
Strollers/pushchairs	☐		☐		☐	
High chairs	☐		☐		☐	
Baby changing mats	☐		☐		☐	
Sleep positioners	☐		☐		☐	
Portable mattresses	☐		☐		☐	

Nursing pillows	☐		☐		☐	
Baby carriers	☐		☐		☐	
Bath mats	☐		☐		☐	
Other (please specify)	☐		☐		☐	

2.3 Estimated tonnage of foam and/or numbers of products sold that contain one or more of the three flame retardants (tonnes of foam or number of articles per year).	

3. Uses of the flame retardants in textiles and other materials in childcare products

3.1 Are any of the three flame retardants present in textiles or other materials in childcare articles produced/imported/sold by your organisation? If so, please provide details of the product types and concentrations of the flame retardants?	
3.2 If present, are the flame retardants added to the textile / other material or do they migrate from PUF present in the product?	

4. Supply chain

The following questions are aimed at identifying the origin of the articles.

4.1 Based on your answers to the questions above, are the final products containing the flame retardants produced in the EU or outside the EU?	
4.2 For those produced in the EU, is the PUF itself manufactured in the EU or somewhere else?	

5. Flame retardants and fire regulation

These questions are aimed at understanding how fire safety regulations (especially those in the UK and Ireland) affect the use of the three flame retardants at EU level. Information available thus far suggests that companies may often use these three flame retardants specifically to meet the UK and Irish regulations on fire safety.

5.1 Why specifically are the flame retardants used in your articles (e.g. to meet specific national fire safety regulations)?	
5.2 Are the three FRs used in any articles that are not specifically covered by these fire safety rules? If so, please provide details.	
5.3 Is it possible to comply with UK fire safety regulations without these flame retardants (or using reduced concentrations)? If so, please provide details.	
5.4 Please provide details of any alternative chemicals or technologies that could be (or are already) applied to meet the fire safety standards? How do these compare in terms of technical performance and cost?	

Chlorinated phosphorous-based flame retardants in children's articles containing foam

English summary
The study analyses technical and economic options to avoid the chlorinated phosphorous flame retardants TCPP, TDCP and TCEP in children's articles marketed in the EU. Furthermore it identifies suitability, availability and risk profile of possible alternatives.

Dansk resumé
Projektet analyserer tekniske og økonomisk muligheder for at undgå tre klorerede fosforbaserede flammehæmmere, TCPP, TDCP og TCEP, i børneartikler, der markedsføres i EU. Endvidere vurderer egnethed, tilgængelighed og risikoprofil for mulige alternative flammehæmmere.

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