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A TECHNICAL REPORT BY HEALTHYSTUFF.ORG
A Project of the Ecology Center

HIDDEN PASSENGERS

Chemical Hazards in Children's Car Seats

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ECOLOGY CENTER

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HealthyStuff.org, which researches and analyzes hazardous chemicals in everyday products, is a project of the Ecology Center.

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Find this document online at *www.ecocenter.org/healthy-stuff/hidden-hazards.*

CONTENTS

TABLES

EXECUTIVE SUMMARY

FIFTEEN CAR SEATS FROM 2014 representing twelve brands were tested for known flame retardant chemicals and heavy metals. Key findings are as follows:

No car seats were free of chemical hazards

Despite efforts by some companies, chemical flame retardants are still used to make car seats meet federal flammability regulations. Eleven out of 15 (73%) of seats contained halogenated flame retardants. Four seats contained one or both of the "chlorinated tris" chemicals TDCPP (a known carcinogen) and TCPP.

While one seat was analyzed for a more limited set of chemicals, the other 14 seats were analyzed for a wide range of known flame retardant chemicals. Of these fourteen seats,

- 64% contained brominated flame retardants (BFR).
- 29% contained chlorinated organophosphate flame retardants (CFR).
- 64% contained non-halogenated organophosphate flame retardants (PFR).
- No polybrominated diphenyl ethers (PBDEs) were detected in any of the seats.
- Hazardous heavy metals were detected in very few samples.

Chemicals used are associated with the material type

- More than half of the **polyurethane** foam samples contained halogen-free organophosphates. About a quarter of the **polyurethane** samples contained chlorinated organophosphates. Both classes of phosphates were very uncommon in the other foam types and textiles.
- More than half of the **expanded polystyrene** foams contained a brominated flame retardant chemical. Several of these were hexabromocyclododecane (HBCD), a chemical slated for global phase-out under the Stockholm Convention.
- Three of the four **expanded polypropylene** foams contained no known flame retardants. Expanded polypropylene can meet automotive fire test standards without added chemicals.
- Five **textile** samples were analyzed; all contained brominated chemicals.

Safer Substitution is important

Some car seat companies are moving away from halogenated flame retardant chemicals and replacing these with phosphate-based chemicals. We support the efforts of companies to remove halogens, but we caution that some of the halogen-free phosphates may present significant health concerns as well and require more study.

Green design works

The best approach is to redesign the product to eliminate the need for hazardous chemicals. Britax and Clek, for example, have implemented green engineering solutions that reduce the need for added flame retardants. We challenge car seat companies to develop seats without any added flame retardant chemicals.

We also recommend that companies:

- Develop a comprehensive chemical policy for suppliers to restrict chemicals of concern in all products. These policies should be reevaluated and updated on a regular basis.
- Evaluate each material component to eliminate chemical flame retardants wherever possible. When chemicals must be added, choose the least hazardous of the non-halogenated options based on the most current available research.

Flammability regulations must be updated

The federal fire test standard is demonstrably outdated and does not provide meaningful fire safety for vehicles in general or for children in car seats. For regulators, we recommend:

- The federal fire test standard for vehicles, FMVSS 302, be updated to reflect causes of fire in modern cars and to minimize or eliminate the need for chemical flame retardants. In this report we outline several strategies to prevent and suppress vehicle fires. An updated fire test standard should require these non-toxic fire safety strategies.
- We also urge regulators to consider making child car seats exempt from FMVSS 302.

Consumer friendly product ratings, as well as a shorter overview report of this study, can be found at *www.healthystuff.org*.

INTRODUCTION

MULTIPLE HOURS EACH WEEK IN A CAR SEAT: that's normal for the average American baby or toddler. The seat has undergone extensive testing for its safety performance in crashes—but what about chemical safety? Child car seats must meet the same federal fire test requirements as car interiors. In practice, that means a suite of hazardous chemicals are added to the foams and fabrics of cars and car seats. The chemicals commonly used are not bound to the foam or fabric, so they migrate out of products and can be present in the air and dust in vehicles. Exposure can occur from ingestion of dust, inhalation, or by absorption through the skin.

It's not just car seats, of course. Babies and young children often spend their time moving from one flame retardant-containing surface to another, such as carpets, couches, even some cribs and strollers.

And what's around us is in us. Many research studies have found flame retardants in the bodies of humans and other animals. A recent study, for example,[1] found breakdown products of the flame retardant chemical TDCPP in the urine of all 22 mothers and 26 children tested. The children's levels in the study were almost five times higher than their mothers'. Also known as chlorinated tris, this carcinogen was removed from children's pajamas in the 1970s[2] but remains in widespread use.[3,4,5,6,7]

Halogenated flame retardants containing bromine or chlorine, like TDCPP, have been in use for decades as a low-cost way to make synthetic fabrics and foams meet flammability regulations. Such regulations were created in an effort to reduce injuries and losses from fires; however, many of the regulations in place do not provide a real fire safety benefit.[8] Many of the common FRs are, in the vocabulary of toxicology, both persistent and bioaccumulative. This means they remain for many years without breaking down into safer substances and they build up in living organisms. Because of toxicity concerns, flame retardants based on phosphates[9] instead of halogens are increasingly common.[10] These phosphate flame retardants have not yet been studied extensively for safety, and there is some evidence that they may also pose a health hazard.

Because the car environment is such a ubiquitous source of chemical exposure for most Americans, HealthyStuff.org carried out this study to increase consumer awareness and to push manufacturers to adopt improved fire safety strategies for their infant and child car seats. This report also highlights the role of vehicle flammability standards and questions the efficacy of those standards for car seats and vehicles. Our study assesses the presence of chemical hazards—flame retardants and hazardous metals—in children's cars seats purchased in 2014.

BOX 1 Abbreviations

BFR	brominated flame retardant
CFR	chlorinated flame retardant
EPP	expanded polypropylene
EPS	expanded polystyrene
FR	flame retardant
GC/MS	Gas chromatography/mass spectrometry
HBCD	hexabromocyclododecane
ITP	isopropylated triaryl phosphates
PBDE	polybrominated diphenyl ether
PFR	phosphate-based (halogen-free) flame retardant
PU foam	polyurethane foam
TBC	tris(2,3-dibromopropyl) isocyanurate
TBEP	tris(butoxyethyl) phosphate
TBPP	tris(4-butylphenyl) phosphate isomers
TCPP	tris(chloropropyl) phosphate
TDCPP	tris(1,3-dichloropropyl) phosphate
TPP	triphenyl phosphate
UBC	unidentified brominated compound
XRF	X-ray fluorescence

Prior Studies on Child Car Seats by HealthyStuff.org

Since 2006, HealthyStuff.org has screened 377 car seats. This sample set included car seats sold in 2006 (131 seats), 2008 (59 seats), 2011 (153 seats), 2013 (18 seats) and 2014 (16 seats, including the present study). The 2006-2013 car seats were primarily tested for hazardous metals and broad classes of flame retardants using X-ray fluorescence. In most cases, specific flame retardant chemicals were not identified in the samples before 2014, precluding any detailed comparison between the newest and older sample sets. There may have been a slight overall decline in the use of brominated flame retardants in seats. 59% (113 of 190) of the earlier group of seats (2006-2008) compared to 51% (95 of 187) of the later group of seats (2011-2014) had one or more components with BFRs.

Since 2006, HealthyStuff.org has screened 377 car seats. The seats in this sample set—including car seats sold in 2006 through 2013—were tested primarily for hazardous metals and broad classes of flame retardants using X-ray fluorescence.

Due to methodological limitations we were not able to identify usage trends regarding chlorinated, phosphorus or other classes of flame retardants.

Some car seat companies have made important strides toward less hazardous car seats in response to the work of HealthyStuff.org. Read about the Britax story in Box 2 (p.7).

Overview of Flame Retardant Chemicals

Exposure to halogenated (brominated or chlorinated) FRs has been associated with a wide range of impacts on animals and humans. These include immunotoxicity, reproductive toxicity, endocrine disruption, impairment of fetal and child development, interference in thyroid, liver, and neurological function, and cancer.[11,12,13] Halogen-free FRs such as phosphate-based flame retardants (PFRs) are increasing in popularity as possibly less hazardous alternatives. Nevertheless, some PFRs have been found to be toxic and bioaccumulative; many or most have not yet been adequately assessed.[6,14]

One class of formerly ubiquitous FRs is now subject to certain restrictions in the United States and in several states: polybrominated diphenyl ethers, or PBDEs. In 2004, two PBDEs, pentaBDE and octaBDE, were voluntarily phased out by manufacturers.[15] California also banned both chemicals. DecaBDE was voluntarily phased out by the end of 2013.[16] In the present study, PBDEs were not found in any car seat components.

Following is a brief overview of each flame retardant chemical detected in the child car seats studied for this report. *The specific seats and components and their test results are detailed in the Results section* (p.10). The FRs are grouped in the following categories: Brominated, Chlorinated, and Non-Halogenated.

Brominated Flame Retardants

HBCD, or hexabromocyclododecane (detected in 3 of 14 tested seats), is fairly common in child car seats containing expanded polystyrene foam (EPS). It is also used in carpet backing, computer housings, and building insulation.[11]

HBCD is slated for a global phase-out under the international Stockholm Convention on Persistent Organic Pollutants.[17] Unfortunately, the United States has not ratified this treaty. In the European Union, the chemical is being phased out of commercial use in 2015.

HBCD is classified as persistent, bioaccumulative, and toxic by Washington State (Chapter 173-333 WA Administrative Code) and as a chemical of high concern to children (Chapter 173-334), particularly for its neurotoxicity. In recent studies, low doses interfered with thyroid hormone action in the brains of rats and disrupted a key brain chemical.[18] Like many FRs, HBCD accumulates in fatty tissues. HBCD was recently found in wildlife and sediments in the San Francisco Bay[19] and has been found in Arctic air and polar bears along with many other contaminants.[20] A 2015 study detected HBCD in the Detroit River and Lake Erie.[21] HBCD is transported long distances through air and water.[22]

TBC, or tris(2,3-dibromopropyl) isocyanurate (detected in 2 of 14 tested seats), is a relative newcomer. It is used as an alternative to the prohibited PBDEs to treat polyester textiles, synthetic rubber, and many other products. In our study, it was found in two car seat textiles. Like other FRs, TBC has infiltrated the environment. It was detected in a majority of mollusks from nine coastal Chinese cities in 2009 and 2010[23] and from all soil samples collected around Beijing in 2011.[24]

TBC was found to be toxic to various organs in zebrafish and mice.[25–27] It also impairs photosynthesis and growth in algae.[28] Human studies are lacking.

Chlorinated Flame Retardants

TDCPP, or tris(1,3-dichloro-2-propyl) phosphate (detected in 2 of 14 tested seats), is better known as **chlorinated tris**. An established carcinogen, it was removed from children's pajamas in the 1970s.[29] It has since made a comeback: TDCPP is one of the primary flame retardants used in upholstery and furniture since the phase-out of PBDEs in 2004.[10,30] Prior to the phase-out, 29% of tested couches contained TDCPP. After 2004, 52% of tested couches contained TDCPP as the main flame retardant. Regulations pertaining to flammability of upholstered furniture have recently been updated, and the use of TDCPP in couches is expected to decrease as a result.

In addition to furniture, chlorinated tris has been widely used in children's products, tents, airplanes, automotive foams, and more.[3–5] A 2006 assessment found that adults and children were being exposed to levels of TDCPP several times higher than the acceptable daily dose for noncancer outcomes.[10,31]

According to the US Environmental Protection Agency, TDCPP also poses a high hazard to the human reproductive system and development.[30] TDCPP likely is hazardous to aquatic ecosystems and is persistent in the environment. Animal studies give further concern. TDCPP caused tumors as well as brain defects in rats[32] and affected the thyroid in zebrafish, causing reduced hatching, poorer survival, and malformation of the spine.[33]

Delaware, Massachusetts, Rhode Island, and Vermont ban TDCPP from children's products and residential upholstered furniture. Maryland and New York ban TDCPP in children's products only. In 2011, California added TDCPP to its Proposition 65 list as a chemical known to cause cancer.

TCPP, or tris(chloropropyl) phosphate (detected in 3 of 14 tested seats), is another form of chlorinated tris, which is similar in structure, but not identical to TDCPP.

A 2014 EPA hazard assessment found that TCPP poses a high health hazard to the human reproductive and developmental systems, is a chronic toxicant in aquatic ecosystems, and is highly likely to persist in the environment.[30]

TCPP has been found at significant levels in recent tests of air around the Great Lakes and the Arctic.[34,35]

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Non-Halogenated Flame Retardants

ITP, or isopropylated triaryl phosphates (detected in 1 of 14 tested seats), is a mix of organophosphate chemicals. ITP is part of the mixture known as FireMaster 550. The seat found to have ITP in this study, however, contained only ITP, not the full FireMaster mix.

The EPA reviewed ITP in 2014 to understand its hazard potential.[30] Carcinogenic effects could not be ruled out, as no relevant studies were found. ITP may pose a high risk to human reproductive, developmental, and neurological systems and is likely to bioaccumulate. ITP also appeared highly toxic to freshwater fish and invertebrates.

Two recent studies observed cardiac abnormalities in zebrafish exposed to ITP.[36,37] Another study showed that triaryl phosphates can be disruptive to human hormones.[38]

TBEP, or tris(butoxyethyl) phosphate (detected in 3 of 14 tested seats), has not been well studied to date. The chemical is sometimes used in floor polishes and as a plasticizer in plastics and rubbers. A study on rats found potential cardiovascular effects, while evidence of neurotoxic effects are inconsistent and the long term toxicity and carcinogenicity have not been studied.

> Most flame retardants are suspected of contributing to a variety of health problems, and unfortunately, research suggests these flame retardants do not provide meaningful fire safety in vehicle fires.

According to the World Health Organization, the general health risk posed by TBEP is very low.[39] TBEP has been detected in air samples from five sites around the Great Lakes and in Arctic air.[34,35]

TBPP, a mixture of isomers of tris(4-butylphenyl) phosphate (detected in 3 of 14 tested seats), has increased in usage following the partial PBDE phase-out in 2004. In a 2012 study, none of the tested couches contained TBPP prior to the phase out in 2004, while 13% of the couches purchased post-2005 contained TBPP.[10] TBPP has been detected in indoor dust in homes and child day care centers.[15]

A 2014 EPA assessment found that TBPP likely poses a low hazard to human development and a moderate hazard to reproductive and neurological function. The chemical is not absorbed through skin and is poorly absorbed through the lungs and gut. In contrast to the possibly moderate risks to humans, TBPP is likely highly toxic to aquatic life and is likely to bioaccumulate and persist in the environment.[30]

TPP, or triphenyl phosphate (detected in 3 of 14 tested seats), is a widely used flame retardant in plastic products, including car seat foams. Significant amounts of TPP have been found in children's products, furniture, and many other products in the U.S. and around the world.[3,5,10,15] Most household dust samples in a 2015 study contained TPP.[40] TPP is also found in environmental media such as soils, sediments, air, and water.

Despite its abundant usage, the health effects of TPP have not been thoroughly assessed. Some researchers have suggested possible neurotoxic effects from TPP,[41] but multiple animal studies have shown no neurotoxicity.[31] The EPA also found neurological risk to be low.[30] Limited studies suggest that TPP is not a mutagen or carcinogen[42] and presents a low hazard to human development and reproductive organs.[30] Some studies, however, suggest that TPP may adversely impact metabolism or the endocrine system and may contribute to obesity.[43,44]

Like the similar chemicals ITP and TBPP, TPP is highly toxic to aquatic life.

Melamine, or 1,3,5-triazine-2,4,6-triamine (detected in 3 of 14 tested seats), is the only FR detected in this study containing no halogens or phosphorus. Nitrogen-based flame retardants, including melamine compounds such as melamine cyanurate, have received attention for being relatively inert in the environment.[45] In a fire, melamine compounds produce little smoke and few toxic chemicals compared to traditional FRs.[46]

Melamine earned a frightening reputation after sickening a large number of babies and pets when it was illegally added to milk products,[47] but as a flame retardant added to foams or textiles, its exposure potential has not been studied. The EPA determined[30] that exposure to melamine poses a moderate hazard to DNA and development and a high risk to reproductive organs. Neurological hazard was low. Melamine is highly persistent in the environment but in the human body is eliminated quite rapidly.

Why are these flame retardants used? Are they effective?

Most flame retardants are suspected of contributing to a variety of health problems, and unfortunately, research suggests these flame retardants do not provide meaningful fire safety in vehicle fires. Interior components of vehicles, including child seats, must comply with an outdated U.S. fire safety standard that has been shown inadequate to protect car occupants from most fires.[48]

This regulation is mandated by the National Highway Traffic Safety Administration under Title 49 of the United States Code, Chapter 301. Automobile manufacturers must comply with Federal Motor Vehicle Safety Standards (FMVSS). The FMVSS No. 302 deals with the flammability of interior materials in all passenger vehicles. It also applies to accessories like infant and child seats. It requires that a "material shall not burn, nor transmit a flame front across its surface at a rate of more than four inches per minute."

The flame retardants now contaminating life across the entire globe constitute a low-cost way for

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child car seats to comply with FMVSS 302. While this standard, written over four decades ago, was intended to reduce deaths and injuries from vehicle fires (particularly from the ever-diminishing share of vehicle fires caused by cigarettes), it does not address the fire safety needs of modern cars.[48] A number of design modifications to make cars safer in the event of fire—that would not result in the addition of even more FRs—have been proposed by experts.[13] Read more about these non-toxic solutions in Box 4, "Non-toxic Fire Safety in Cars" (p.17).

Flame retardants may also contribute to injury when they burn. For example, when foam containing pentaBDE burned, it produced twice as much smoke, seven times as much carbon monoxide, and 70 times as much soot as foam without flame retardants.[49] It was also found that a typical foam containing pentaBDE provided only a three-second delay in ignition compared to the untreated foam.

In addition, increased levels of furans and dioxins are emitted during the burning of materials containing these chemicals. Furans and dioxins are potent carcinogens. Firefighters have higher rates of cancer than the general population, and exposure to flame retardants and their toxic combustion products may be a contributing factor.[50]

BOX 2 The Britax Story

HealthyStuff.org first tested several Britax car seats in 2007, and then again in 2011, using XRF. Like many other seats on the market at the time, the Britax seats contained brominated flame retardants. Some also contained lead and components made of vinyl plastic. Since then, the company has steadily worked to improve the safety of the materials used in their car seats and has become an industry leader in this area. The efforts undertaken by Britax include:

Material substitution

Expanded polystyrene (EPS) foam used in car seats and other applications often contains the brominated flame retardant HBCD; in the present study, three out of nine EPS samples contained HBCD. EPS is also brittle and not as durable as other polymers. Britax switched to expanded polypropylene (EPP) foam to both eliminate the need for flame retardants and increase durability of the product.

Chemical restrictions

Britax requires its suppliers to follow rules for multiple material types: hard plastic and foams, fibers, filling materials, webbing and non-woven materials. The standards were adopted in September 2012 and implemented over the following year. The standards explicitly prohibit halogenated flame retardants and ortho-phthalates and place limitations or prohibitions on nearly 100 other chemicals.

Safer chemical substitution and disclosure

Only phosphorus-based, halogen-free flame retardants (PFRs) are to be used and only as needed to meet the flammability requirements (described in the Introduction under the heading "Why are these flame retardants used? Are they effective?"). In contrast to many other companies, Britax also prohibits the use of "proprietary" or "black-box" chemical formulas by its suppliers, requiring that all formulations must be fully disclosed to Britax.

Although some of the available PFRs have serious health concerns and are not necessarily safer than CFRs and BFRs, eliminating halogens is an important first step. Companies should carefully evaluate every chemical used in their products to avoid regrettable substitutions. Even more importantly, non-chemical fire safety strategies for the entire vehicle interior must be further developed (see Box 4, p.17).

EXPERIMENTAL METHODS

FIFTEEN DIFFERENT SEAT MODELS, REPRESENTING TWELVE BRANDS, were obtained and cut apart to isolate samples of foams and fabrics. Descriptions of each seat are given in **Table 1** (p.9).

X-Ray Fluorescence

Healthystuff.org uses a High Definition X-ray Fluorescence (HD XRF) spectrometer, an elemental analysis technique with doubly curved crystal optics that enhances measurement intensities by capturing X-rays from a divergent source and redirecting them into an intense focused beam on the surface of the product. The major benefit of HD XRF is that monochromatic excitation eliminates the X-ray scattering background under the fluorescence peaks, greatly enhancing detection performance. The HD XRF uses monochromatic excitation energies of 7, 17, and 33 keV. The instrument also features a small spot size of 1 mm, which allows the examination of small features in samples.

Of the 15 tested seats, three were infant car seats, seven were convertible car seats, and five were boosters. A total of 114 components from the 15 seats were scanned with XRF. Some components were tested twice to verify repeatability.

A car seat strap being tested by XRF.

This analytical approach results in detection limits in the parts-per-million (ppm) range for many elements of interest in a variety of materials. The elemental composition of the materials reveals the presence of potentially hazardous metals and also allows researchers to infer the possible presence of toxic substances, including flame retardants and polyvinyl chloride plastic.

While XRF testing cannot directly identify molecular structure of organic chemicals, detecting bromine at levels greater than 400 ppm and chlorine at levels greater than 3,500 ppm has been successfully used to infer the presence of halogenated flame retardants, depending on the sample matrix.[5,51]

Of the 15 tested seats, three were infant car seats, seven were convertible car seats, and five were boosters. For XRF, the components of the car seats were generalized into three major component groups: Upholstery, Harness and Plastic, each with subcomponent categories, including foams located behind upholstery or plastic parts. A total of 114 components from the 15 seats were scanned with XRF (Table 6, p.20). Some components were tested twice to verify repeatability.

A subset of 35 car seat component samples (EPS, EPP, PU foams, and textiles) were selected for GC/MS analysis. We chose components likely to contain flame retardants: First, a sample of each foam type was taken from each seat. Then the textiles of all seats were screened for bromine content measured by XRF. Textiles with Br>400 ppm were selected for GC/MS analysis.

TABLE 1 **Car Seat Samples**

Brand Name	Model	Design/Color	Item / Model #	Date of Manufacture
Baby Trend	Hybrid 3-in-1 Car Seat	Edge	FB58718	16 April, 2014
Britax	Frontier Clicktight	Congo		May, 2014
Britax	Marathon	Wave		June, 2014
Britax	Parkway SGL	Phantom		1 March, 2014
Chicco	Keyfit 30 Infant Car Seat & Base	Graphica	7079021460070	May, 2014
Clek	Foonf	Blue/White		22 September, 2014
Cybex	Aton Q Infant Car Seat, Rear Facing	Charcoal	12-4020000	February, 2014
Eddie Bauer	XRS 65 Convertible Car Seat	Viewpoint		9 June, 2014
Evenflo	Symphony DLX All-In-One Car Seat	Porter		17 May, 2014
Graco	MySize 65 Convertible Car Seat	Everest	1896363	13 January, 2014
Graco	Highback TurboBooster Car Seat	Gio	1831778	9 June, 2014
Harmony	Dreamtime	Grey	0303002GMT	22 January, 2014
Orbit Baby	G3 Toddler Car Seat	Mocha		February, 2014
Peg Perego	Primo Viaggio 4-35	Aquamarine		16 April, 2014
Safety 1st	Advance LX 65 Air+ Convertible Car Seat	Hinshaw		17 July, 2014

Gas Chromatography/Mass Spectrometry (GC/MS)

Each component was prepared by acid digestion. All extracts were screened for added flame retardant chemicals using GC/MS as described in Stapleton et al. 2012.[10] Confirmation of each flame retardant identity was made based on a match with the NIST 2005 mass spectral database (greater than 80% match) and with comparison to authentic standards where available. The lower limit of detection for this technique is 0.1% by mass.

One car seat, the Clek Foonf, was obtained late and was analyzed by organic solvent extraction and GC/MS at a different laboratory than the other 14 seats. Because this lab does not test for all the FRs found in the rest of the seats, we have reported the Clek Foonf GC/MS results separately (see **Table 4B**, p.13).

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RESULTS

GC/MS Results

THE BRANDS, MODELS, AND OTHER DETAILS of the seats are displayed in **Table 1** (p.9). Summary results of FR testing are given in **Table 2** (p.10). In Table 2, we have grouped the identified FRs into four classes: melamine, brominated (BFR), chlorinated (CFR), and halogen-free organophosphate (PFR). Several samples contained unidentified brominated compounds (UBC). For the purposes of this analysis, we have assumed UBC indicates a flame retardant and included it in the BFR category, as there is no other likely source of bromine in the car seat samples. We have not, however, verified that the UBCs are in fact FRs; this should be addressed in future work.

Table 2 shows that of the 14 seats tested (excluding Clek, which will be discussed on page 11), nine contained BFRs, four contained CFRs, nine contained PFRs, three contained melamine, and one contained no known FRs.

It is important to note that "no known FRs" does not necessarily mean no FRs are present. Novel flame retardants could still be present. It does suggest that no *halogenated* FRs are present because FRs containing bromine or chlorine would be picked up by our analytical techniques. The seat with no known FRs may contain a halogen-free FR that was not identified by GC/MS.

Tables 3A (p.11) and **3B** (p.11) break the results down by material type. The components sampled from the car seats included textiles and three types of foam. The foam materials—polyurethane (PU), expanded polystyrene (EPS), and expanded polypropylene (EPP)—were determined by visual inspection and by infrared spectroscopy.

Table 3A shows that of the four EPP foam samples, only one contained any known FRs (EPP from the Orbit Baby G3 seat contained both melamine and TPP). Unlike PU and EPS foams, EPP meets automotive fire standards without added flame retardants.

Another notable finding is that none of the EPS or EPP foam samples contained CFRs. The majority of EPS foam samples (56%) contained BFRs, while only one of 17 PU samples contained a BFR. Instead, PU foam frequently contained PFRs (53%) and/or CFRs (24%). Textiles, which were generally upholstery fabrics, were highly likely to contain BFRs (100%) and less likely to contain any of the other FR classes (PFR, CFR, and melamine each in one of five textile samples).

PFRs and CFRs were detected almost exclusively in PU foam and textile samples, not in EPS or EPP samples. EPP foam, PU foam, and textiles contained melamine relatively infrequently.

Table 3B lists the number of samples in each material category that contained *specific* FRs as opposed to just the FR class.

TABLE 2 **Flame Retardant GC/MS Results Summary**

	Number Tested	Contains BFR	Contains CFR	Contains PFR	Contains Melamine	No Known FRs*
Seats	14	9 (64%)	4 (29%)	9 (64%)	3 (21%)	1 (7%)
Seat Components	35	11 (31%)	5 (14%)	11 (31%)	4 (11%)	10 (29%)

BFR: Brominated flame retardant

CFR: Chlorinated flame retardant

PFR: Phosphate-based (halogen-free) flame retardant

* No known FRs does not necessarily mean no FRs are present. New FRs could be present but unidentifiable at this time.

TABLE 3A **Number Of Samples By Material Type Containing FRs In Each Class**

Material Type	No. Samples	Melamine	BFR	CFR	PFR
EPP Foam	4	1	0	0	1
EPS Foam	9	0	5	0	0
PU Foam	17	2	1	4	9
Textile	5	1	5	1	1
All Materials	35	4 (11%)	11 (31%)	5 (14%)	11 (31%)

Note: 10 of the 35 samples contained no known FRs.

TABLE 3B **Number of Samples by Material Type Containing Specific FRs**

Material Type	No. Samples	Melamine	Brominated			Chlorinated		Organo Phosphate			
			HBCD	TBC	UBC	TCPP	TDCPP	TPP	TBPP	ITP	TBEP
EPP Foam	4	1	0	0	0	0	0	1	0	0	0
EPS Foam	9	0	3	0	2	0	0	0	0	0	0
PU Foam	17	2	0	0	1	3	2	2	3	1	3
Textile	5	1	0	2	3	1	1	1	0	0	0

Table 4A (p.12) displays the most detailed FR results, breaking them down by individual components of each seat and listing the specific FRs identified.

For most individual components, only one FR was detected per component, but two seats stand out for having as many as three different FRs within a single foam or textile sample: Harmony Dreamtime and Orbit Baby G3.

Table 4B (p.13) gives limited results for the Clek Foonf seat only. This seat was tested for HBCD and TDCPP as well as several other FRs. It was *not* tested for TBC, TCPP, ITP, TBEP, TBPP, TPP, or melamine. Of the FRs analyzed for the Clek seat, none were detected in either the fabric or the polyurethane foam. The XRF results (**Table 6**, p.20) showed Br and Cl levels too low to indicate BFRs or CFRs. We conclude the Foonf seat contains a non-halogenated FR as yet unidentified.

Correlation of XRF detection of Br, Cl, and P with GC/MS detection of FRs

As noted in the Experimental Methods, XRF measurement of the element bromine can be a reliable indicator of the presence of brominated flame retardants.[51] XRF measurement of chlorine can similarly indicate presence of chlorinated FRs, but with less accuracy.

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TABLE 4A **Detailed Flame Retardant Results by Seat and Component**

Seat	Component	Melamine	Brominated			Chlorinated		Organo Phosphate			
			HBCD	TBC	UBC	TCPP	TDCPP	TPP	TBPP	ITP	TBEP
Baby Trend, Hybrid 3-in-1 (Booster)	EPS Foam										
	PU Foam					●					
Britax, Frontier (Booster)	EPP Foam										
	PU Foam Black								●		
	PU Foam White										
Britax, Marathon (Convertible)	EPP Foam										
	PU Foam Black								●		
	PU Foam White										
Britax, Parkway (Booster)	EPP Foam										
	PU Foam Grey										
Chicco, Key Fit 30 (Infant Seat)	EPS Foam		●								
Cybex, Aton Q (Infant Seat)	EPS Foam				●						
	PU Foam	●									
Eddie Bauer, XRS 65 (Convertible)	EPS Foam										
	PU Foam				●			●			
Evenflo, Symphony (Convertible)	EPS Foam										
	PU Foam Grey									●	
	PU Foam White										●
	Textile Black				●						
Graco, My Size 65 (Convertible)	EPS Foam		●								
	PU Foam										●
	Textile Pattern			●							
Graco, TurboBooster (Booster)	EPS Foam				●						
	PU Foam White										●
	Textile Pattern			●							
Harmony, Dreamtime (Booster)	PU Foam White					●	●				
	Textile Black				●	●	●				
Orbit Baby, G3 (Convertible)	EPP Foam	●						●			
	PU Foam					●					
	Textile Black	●			●			●			
Peg-Perego, Primo Viaggio (Infant Seat)	EPS Foam		●								
	PU Foam Grey								●		
Safety 1st, LX 65 Air+ (Convertible)	EPS Foam										
	PU Foam							●			
	PU Foam 2	●					●				

● = Present

TABLE 4B **Flame Retardant GC/MS Results for Clek Foonf**

Seat	Component	Brominated		Chlorinated		Organo Phosphate
		PBDE's	HBCD	TCEP	TDCPP	TXP
Clek Foonf (Convertible)	Blue Fabric	nd	nd	nd	nd	nd
	Black PU Foam (Seat Back)	nd	nd	nd	nd	nd

TCEP = Tris(2-chloroethyl) phosphate

TXP = Trixylenyl phosphate

NOTE: Due to timing issues, the Clek Foonf was not included in the main sample set and was instead tested separately. The testing laboratory was only capable of testing for a more limited set of flame retardants. Clek states that organo-phosphate flame retardants are used in their PU Foam.

TABLE 5 **XRF and CG/MS Method Comparison**

		# of Samples	XRF					
			Br only	Cl+P only	P only	Br+Cl+P	Br+P only	No Br, Cl, or P
GC/MS	BFR only	8	5				3*	
	C/PFR only	4		3		1**		
	PFR only	10			9			1
	BFR+C/PFR	1				1		
	BFR+PFR	2			1		1	
	No known FR	11			1			10

Shaded Purple = GC/MS and XRF correspond correctly.

C/PFR= CFR also containing P. Both CFRs, TDCPP and TCPP, contain both Cl and P.

* These 3 samples were correctly identified by XRF as containing Br.

** This sample was correctly identified by XRF as containing Cl and P.

Previous studies have not demonstrated successful correlation between XRF and other analytical techniques for detection of CFRs in foams,[5] although in the present work an excellent correlation was found for both foams and textiles.

XRF measurement of **phosphorus** in materials likely to contain FRs has not, to our knowledge, been examined for its accuracy in predicting detection of PFRs by GC/MS. We report here for the first time a comparison of phosphorus detection in the XRF spectrum with phosphate detection by GC/MS.

We compared XRF detection of Br, Cl, and P to the GC/MS detection of BFRs, CFRs, and PFRs, respectively, in EPS, EPP, PU, and textiles from the car seats. Bromine and chlorine were quantified by XRF whereas phosphorus was not quantified, but visually identified by its peak around 2.0 keV. All 35 samples tested by GC/MS (excluding Clek) were included in this comparison. The results are summarized in **Table 5** (p.13).

The lefthand side of Table 5 lists GC/MS results in the form of FR classes detected. The top of the table lists XRF results in the form of relevant elements detected. The number of samples for which the two methods gave consistent results are shown in shaded cells. Mismatches are not shaded. Overall, the correspondence between the two methods was very good for all three classes of flame retardants. The frequency of errors was highest for phosphorus detection.

Another way of evaluating the correspondence between the two methods is to calculate a percentage of samples in each detection category (BFR detected, BFR not detected, etc.) that were consistent for GC/MS and XRF. For BFRs, XRF detection of Br was consistent with GC/MS detection of BFRs for 91% of samples. XRF *nondetection* of Br was consistent with GC/MS nondetection of BFRs for 96% of samples. For CFRs, the correspondences were 100% and 97%, respectively, for detection and nondetection. For

PFRs, the correspondences were 94% and 79%, respectively.

For a breakdown of the correspondences sorted by sample matrix (EPS, EPP, PU foam and textiles), see **Table 7** (p.23).

Parents and caregivers should always install and properly use a car seat appropriate for a child's age and size, regardless of the chemical hazards associated with the seat.

The weakest correspondence, 79%, was for samples in which GC/MS identified no PFRs, but in which XRF detected phosphorus. These mismatches are also shown in Table 5 in the row "BFR only." Three of these samples were textiles and one was a PU foam. (**Table 7**, p.23, specifies all sample matrices.)

BOX 3 Always Use a Car Seat

Vehicle child restraint systems are a success story in terms of protecting our children during car accidents. In the U.S., the number of children traveling unrestrained has dropped from 90% in 1976 to 13% in 2008. Prior to 2000, vehicle accidents were the number one cause of death for U.S. children between the ages of one and four years old. The number of deaths of children in vehicle crashes dropped by 41% from 2000 to 2009.[52]

Globally, however, there is a great disparity in safety seat usage: only about 50% of countries have laws requiring child restraints. The World Health Organization reports significant disparity based on income, reporting that over 90% of "high income" countries have national requirements; while only 20% of "low income" countries have similar requirements.[53] **Parents and caregivers should *always* install and properly use a car seat appropriate for a child's age and size, regardless of the chemical hazards associated with the seat.**

In the U.S., we still face a number of challenges to maximize car seat safety. Firstly, 13% of children do not regularly use restraints; secondly, most child restraints have a least one installation error.[52] Finally, far too many seats contain hazardous flame retardants, which have no proven safety benefit for the children.

Some of these apparent false positives for phosphorus from XRF may not actually be false positives, but could indicate 1) a novel phosphorus-containing FR that was not detected during GC/MS analysis or 2) polyester that has been made "inherently" flame retardant by adding a phosphorus-containing functional group during synthesis. Two of the apparent false positives are polyester fabrics that contained unidentified bromine compounds according to GC/MS.

XRF Results

In this study, XRF was primarily used to screen car seat components for bromine, chlorine, and phosphorus. We also examined the XRF results for heavy metals. The full set of 114 components from the 15 car seats and their XRF results for selected elements are shown in **Table 6** (p.20).

For chlorine, XRF measurements between 2,500 and 100,000 ppm (0.25% and 10%) likely indicate CFRs, as confirmed in this study by GC/MS. Values above 100,000 typically indicate polyvinyl chloride (PVC) plastic, but in this study, three samples containing above or near 100,000 ppm Cl were identified by infrared spectroscopy as polyester, not PVC: Baby Trend upholstery textile, Evenflo harness strap and Evenflo upholstery textile (Table 6). Of those three samples, only the Evenflo textile was tested by GC/MS; no CFRs were detected, so the source of Cl is unknown. The other two polyester samples with high Cl content were not tested by GC/MS, so it's possible they contain a CFR. Another sample, the Eddie Bauer upholstery strap, was measured to have about 32% Cl and was identified as PVC, which explains the Cl content.

Table 6 shows that toxic heavy metals were detected in very few seat components. No cadmium or mercury were detected in any samples. Out of 114 samples, only the following three showed somewhat elevated levels of heavy metals. The Chicco Key Fit 30 harness had a metal clip with 101 ppm arsenic (As). The Baby Trend Hybrid 3-in-1 harness had a metal clip with 108 ppm lead (Pb). The Evenflo Symphony harness strap, which is polyester, not metal, showed 199 ppm lead.

Relatively low levels (a few hundred ppm) of antimony (Sb) were measured in many of the seat components, which is consistent with antimony left over from its use as a catalyst in polymer production. One sample, however, had a high concentration of antimony (20,704 ppm) in the seat fabric: Eddie Bauer XRS 65. Antimony at that level suggests possible use of an antimony-based flame retardant.

DISCUSSION & CONCLUSION

SINCE 2006, WHEN WE FIRST STARTED TESTING CHILD CAR SEATS for flame retardants and heavy metals, consumers have demanded improvements and car seat companies have taken notice. New regulations have further pushed manufacturers away from some of the most hazardous FRs. This is reflected in the changing landscape of flame retardants found in car seats as well as in the use of EPP foam, which does not need chemical FRs to pass the flame test, in some seats.

A notable change is the reduction or elimination of PBDEs, with other FRs taking their place. No PBDEs were found in the car seat sample set of this study. Two seats contained the newer brominated chemical TBC and six seats contained unidentified brominated compounds (UBC). Although we could not identify the UBCs, we treated them here as brominated FRs, perhaps novel FRs, because there is no other reasonable source of bromine in these seat components. Future work should attempt to identify the chemical structure of the UBCs.

The brominated chemical HBCD, found in EPS foam in three of the car seats studied, is regulated in Europe and is slated for global phase-out under the

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Stockholm Convention on Persistent Organic Pollutants. Future studies should assess the use of HBCD in car seats after this year.

All five textile samples from the seats tested by GC/MS contained BFRs. These textiles are usually in direct contact with the child in the seat. We urge manufacturers to seek safer flame retardant strategies for all seat components, since flame retardants can be released from parts anywhere in the seat. We also urge regulators to consider amending flammability requirements for children's car seats, where there is no demonstrated fire problem and test methods are outdated.

Despite the elimination of PBDEs, brominated FRs remain in frequent use in car seats—almost two-thirds of the seats and one-third of all components sampled by GC/MS in this work. As a chemical class, BFRs are typically persistent, bioaccumulative, and toxic, and should be used as little as possible.

Organophosphates, either containing chlorine (TCPP and TDCPP, referred to as CFRs in this report) or halogen-free (referred to as PFRs in this report), were detected in a large majority of the PU foams and textiles of the car seats we sampled. In contrast, almost no CFRs or PFRs were detected in EPS or EPP foams. Overall, halogen-free PFRs were found in 79% of the tested seats, while CFRs were in 29% of the seats. These findings are consistent with other research that has found a wide range of different FRs in use after the PBDE phase-out.[50]

As a class, CFRs, like BFRs, are typically toxic and very persistent and also should be used as little as possible. CFRs and melamine were detected with the lowest frequency in this study, found in 14% and 11%, respectively, of the 35 car seat components from the 14 seats. The exposure potential of melamine used as a flame retardant[46] is unknown.

The hazard profile of PFRs is variable. TBEP might pose little hazard to humans or the environment, but needs more evaluation.[39] TBPP appears low risk to humans, but is expected to be persistent and highly toxic to aquatic life.[30] TPP has received disparate evaluations of health risk,[30,31,41–44] including some evidence it could have obesogenic effects, while ITP shows evidence of significant hazard.[30,36–38] We expect these evaluations to be refined and perhaps modified as more research is done.

In this study, the Britax and Clek seats demonstrate that car seats can be made without halogenated FRs. Overall, the shift from halogenated to non-halogenated FRs is expected to be a beneficial trend, but we caution that several of the non-halogenated FRs show evidence of significant health effects, so every candidate chemical must be thoroughly evaluated. Ideally, no hazardous chemicals should be used in children's car seats, but as long as car seats are subject to FMVSS 302, manufacturers will continue to add FRs.

Finally, we have shown a new method of using XRF to suggest the presence of phosphorus-containing FRs (PFRs and phosphate-based CFRs) in foams and textiles. In samples that are likely to contain flame retardants, such as foam and fabric components of child car seats, our results show that detecting the element phosphorus by XRF can indicate the presence of PFRs. Using XRF to screen for PFRs is useful because phosphate flame retardants normally can be detected only by a much more time-consuming and expensive analytical technique.

BOX 4 Non-Toxic Fire Safety in Cars

When an automobile engine catches fire, it takes less than two minutes for the passenger compartment to fill with smoke, potentially incapacitating passengers, and less than five minutes for the vehicle to catch fire.[54] Chemical flame retardants inside cars and in child car seats delay ignition only by seconds.[55]

Since the 1970s, municipalities have widely adopted a target response time of eight minutes or less for first responders to reach an emergency situation after a 911 call. This eight-minute target is even acknowledged by the National Fire Protection Association. In reality, however, emergency response vehicles often do not arrive within eight minutes due to delays that depend on the time of the accident, location and weather conditions.

These facts—the minimal delay in ignition afforded by chemical flame retardants, the rapid speed with which an engine fire spreads to the car interior, and the length of emergency response times—have led many experts to conclude that our fire safety standards for vehicles provide no meaningful safety benefit in many real world conditions.[54,55]

What can be done? Engineering the vehicle design to provide fire protection may lead to cars that are simultaneously safer from fires *and* safer from toxic chemicals. The auto industry has a long history of implementing, often after long periods of opposition, vehicle safety systems both passive and active. In light of the wide-ranging hazards of chemical flame retardants, the automobile industry must implement non-toxic engineering solutions to protect vehicle occupants. In addition, exempting children's car seats from the current version of FMVSS 302 should be considered.

The Motor Vehicle Fire Research Institute (MVFRI) was a five-year research program conducted by General Motors in accordance with a settlement agreement reached with the U.S. Department of Transportation. As part of the settlement, GM agreed to fund more than $4.1 million in fire-related research over the period 2001–2004. The MVFRI published dozens of studies about all aspects of fire safety in vehicles. In a final summary review of the MVFRI work,[56] opportunities to improve fire safety in vehicles are discussed in detail. Most of those opportunities involve non-toxic engineering approaches to fire safety, including the following:

Fire Prevention

Vehicles already use a range of fire prevention technologies, but they are not universally applied to all vehicles. Some of the non-chemical fire prevention technologies being implemented or researched include check valves for the tank filler tube, roll-over valves, shut-off mechanisms for electronic fuel pumps, return-less fuel systems that reduce exposure to damage, crash sensing battery disconnects or cut-offs, and collapsible drive shafts.

Delayed Fire Penetration

The two principle routes of entry of fire into the passenger compartment are through the firewall and the windshield. Firewall vulnerability can be reduced by minimizing the area through which fire can penetrate. There has been a trend towards replacing metal windshield cowls with plastic, resulting in *less* resistance to fire penetration.

Fire Suppression

Active fire suppression holds the clearest promise to providing truly protective fire safety in fire events. According to Digges (2007),[56] "fire suppression of underhood fires is in the early stages and offers considerable promise. Several technologies have been researched and there are fire suppression products for a variety of applications on the market. In an earlier research project, the University of Maryland demonstrated a foam-based underhood fire suppression system. The system demonstrated the ability to extinguish an 80kW fire fed by a pool of fuel located near the battery."

MVFR research can be viewed at *http://www.mvfri.org.*

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APPENDIX

TABLE 6 **XRF Results for Selected Elements (parts per million)**

Seat	Component	Subcomponent	As	Br	Cl	Cr	Pb	Sb	Sn
Baby Trend, Hybrid 3-in-1 (Booster)	Harness	Clip	1	15	3,028	524	108	0	0
		Strap	0	143	683	0	3	47	0
	Plastic	EPS Foam	0	7	538	0	16	0	114
		Exterior Plastic	0	1	185	0	2	0	0
		Interior Plastic	0	2	1,231	0	6	0	0
	Upholstery	Polyester Fiberfill	0	22	497	0	12	267	146
		PU Foam	0	2,099	18,873	0	14	688	469
		Textiles	0	204	97,919	0	6	126	69
Britax, Frontier (Booster)	Harness	Buckle	0	0	1,527	387	19	0	1,356
		Clip	0	0	0	0	1	0	0
		Strap	0	37	831	0	2	69	0
	Plastic	EPP Foam	0	14	418	0	15	0	138
		Exterior Plastic	0	0	0	0	1	0	0
	Upholstery	Polyester Fiberfill	0	2	354	0	8	213	140
		PU Foam	0	3	524	0	10	0	597
		Textiles	0	16	1,254	0	18	116	77
		Velcro	0	3	391	238	7	0	57
Britax, Marathon (Convertible)	Harness	Buckle	0	0	546	11	8	0	1,368
		Clip	0	0	2,705	3,629	81	0	0
		Strap	0	4	781	0	1	59	0
	Plastic	EPP Foam	0	5	465	0	17	0	208
		Exterior Plastic	0	0	140	0	0	0	0
	Upholstery	Polyester Fiberfill	0	4	424	0	18	297	173
		PU Foam	0	7	660	0	13	174	638
		Textiles	0	13	1,016	0	6	73	45
		Velcro	0	6	885	0	8	0	0
Britax, Parkway (Booster Seat)	Harness	Strap	0	6	784	0	2	137	0
	Plastic	EPP Foam	0	19	591	0	12	214	132
		Exterior Plastic	0	0	183	0	2	0	0
		Interior Plastic	0	1	0	0	1	0	0
	Upholstery	Polyester Fiberfill	0	5	467	0	26	298	269
		PU Foam	0	4	584	0	7	0	210
		Textiles	0	11	772	322	4	0	0

TABLE 6 **XRF Results for Selected Elements (parts per million)** CONTINUED

Seat	Component	Subcomponent	As	Br	Cl	Cr	Pb	Sb	Sn
Chicco, Key Fit 30 (Infant Seat)	Harness	Buckle	0	10	2,363	381	30	0	0
		Clip	101	0	1,372	117	5	0	678
		Strap	0	6	362	0	2	93	0
	Plastic	EPS Foam	0	2,603	497	0	11	182	181
		Exterior Plastic	0	0	0	0	2	0	0
		Interior Plastic	0	5	0	0	6	0	0
	Upholstery	Polyester Fiberfill	0	4	564	0	11	255	121
		Textiles	0	48	907	111	4	0	0
		Velcro	0	7	0	305	4	0	0
Clek, Foonf (Convertible)	Harness	Strap	0	218	505	0	0	186	0
	Upholstery	PU Foam	0	3	533	0	2	205	100
		Polyester Fiberfill	0	2	0	0	0	232	43
		Textiles	0	153	458	0	5	134	50
	Plastic	Plastic Base	0	0	0	0	1	0	0
Cybex, Aton Q (Infant Seat)	Harness	Buckle	3	0	964	6	13	0	29
		Strap	0	74	2,069	0	3	67	0
	Plastic	EPS Foam	0	2,344	1,425	0	13	0	134
		Exterior Plastic	0	61	536	11	7	192	58
	Upholstery	Polyester Fiberfill	0	11	1,385	0	17	255	248
		PU Foam	0	6	1,462	0	20	260	369
		Snaps	0	0	4,758	95	48	0	21,874
		Textiles	0	517	2,548	0	10	115	85
Eddie Bauer, XRS 65 (Convertible)	Harness	Buckle	0	2	1,363	492	26	0	0
		Strap	0	1	350	0	3	132	0
	Plastic	EPS Foam	0	4	440	0	8	0	105
		Exterior Plastic	0	1	193	0	1	0	0
	Upholstery	Polyester Fiberfill	0	6	686	0	12	224	109
		PU Foam	0	7	521	0	15	0	423
		Textiles	4	335	319,436	0	24	20,704	0
Evenflo, Symphony (Convertible)	Harness	Clip	1	0	1,413	423	43	0	0
		Strap	0	74	178,140	0	199	49	0
	Plastic	EPS Foam	0	3	433	0	12	0	192
		Exterior Plastic	0	0	155	0	1	0	0
	Upholstery	PU Foam	0	12	826	0	18	233	378
		Textiles	0	1,168	179,776	0	15	889	199
Graco, My Size 65 (Convertible)	Harness	Buckle	0	0	1,533	479	32	0	0
		Strap	0	172	647	0	3	206	0
	Plastic	EPS Foam	0	2,805	506	0	11	363	153
		Exterior Plastic	0	1	176	5	2	0	0
		Interior Plastic	0	2	317	0	2	0	0
	Upholstery	Polyester Fiberfill	0	108	470	0	14	378	205
		PU Foam	0	360	641	0	15	273	434
		Textile	0	38,909	2,210	0	10	183	120
		Velcro	0	24	530	118	7	118	132

TABLE 6 **XRF Results for Selected Elements (parts per million)** CONTINUED

Seat	Component	Subcomponent	As	Br	Cl	Cr	Pb	Sb	Sn
Graco, Turbobooster (Booster Seat)	Plastic	EPS Foam	0	2,541	427	0	15	165	173
		Exterior Plastic	0	2	380	0	1	0	0
		Interior Plastic	0	2	288	0	2	0	0
	Upholstery	Polyester Fiberfill	0	88	423	0	17	370	228
		PU Foam	0	46	563	0	24	324	314
		Textiles	0	21,824	1,049	0	8	162	101
		Velcro	0	11	432	163	3	0	50
Harmony, Dreamtime (Booster Seat)	Harness	Buckle	0	0	164	0	2	0	0
		Strap	0	4	321	10	15	0	0
	Plastic	Exterior Plastic	0	56	226	5	2	0	0
	Upholstery	PU Foam	0	100	38,746	0	21	290	486
		Textiles	0	1,692	23,749	0	12	178	403
		Velcro	0	549	1,510	0	4	221	94
Orbit Baby, G3 (Convertible)	Harness	Buckle	0	1	1,520	24	27	0	0
		Strap	0	3	397	0	3	154	0
	Plastic	EPP Foam	0	5	514	0	14	0	156
		Exterior Plastic	0	0	381	0	2	0	0
		Interior Plastic	0	29	397	0	7	0	0
	Upholstery	Polyester Fiberfill	0	10	466	0	20	343	208
		PU Foam	0	10	18,504	0	22	279	424
		Textiles	0	523	3,186	0	8	281	119
		Velcro	0	7,219	555	249	6	148	53
Peg Perego, Primo Viaggio (Infant Seat)	Harness	Buckle	0	0	3,223	2,059	0	0	363
		Clip	0	0	1,034	5	1	0	0
		Strap	0	2	336	0	2	107	0
	Other	Exterior Metal	25	0	1,777	551	61	0	151
	Plastic	EPS Foam	0	1,885	411	0	18	274	215
		Exterior Plastic	0	0	0	3	1	0	0
	Upholstery	PU Foam	0	4	20,447	0	11	145	246
		Textiles	0	65	2,552	0	6	147	0
Safety 1st, LX 65 Air + (Convertible)	Harness	Buckle	0	0	2,381	547	95	0	0
		Strap	0	3	335	0	2	70	0
	Plastic	EPS Foam	0	5	448	0	14	0	104
		Exterior Plastic	0	0	186	9	1	0	0
	Upholstery	Polyester Fiberfill	0	5	421	0	10	219	96
		PU Foam	0	8	47,123	0	34	206	520
		Textiles	0	492	758	0	10	306	218

NOTE: Cadmium and mercury were not detected by XRF for any samples.

TABLE 7 **XRF Results for Bromine, Chlorine, and Phosphorus Compared to GC/MS Results for BFRs, CFRs, and PFRs**

		Bromine		Chlorine		Phosphorus	
		XRF Br, ppm	GC/MS	XRF Cl, ppm	GC/MS	XRF P	GC/MS
EPS Foam Components	Eddie Bauer, XRS 65	4	ND	0	ND	ND	ND
	Safety 1st, LX 65 Air+	5	ND	0	ND	ND	ND
	Peg-Perego, Primo Viaggio	1,885	HBCD	411	ND	ND	ND
	Cybex, Aton Q	2,344	UBC	1,425	ND	ND	ND
	Chicco, Key Fit 30	2,603	HBCD	497	ND	ND	ND
	Graco, My Size 65	2,805	HBCD	506	ND	ND	ND
	Evenflo, Symphony	3	ND	433	ND	ND	ND
	Baby Trend, Hybrid 3-in-1	7	ND	538	ND	ND	ND
	Graco, TurboBooster	2,541	UBC	427	ND	ND	ND
EPP Foam Components	Britax, Parkway	19	ND	591	ND	ND	ND
	Britax, Frontier	14	ND	418	ND	ND	ND
	Britax, Marathon	5	ND	465	ND	ND	ND
	Orbit Baby, G3	5	ND	514	ND	ND	TPP
PU Foam Components	Cybex, Aton Q — PU Foam	6	ND	1,462	ND	ND	ND
	Eddie Bauer, XRS 65— PU Foam	7	UBC	0	ND	detected	TPP
	Orbit Baby, G3— PU Foam	10	ND	18,504	TCPP	detected	TCPP
	Graco, My Size 65— PU Foam	360	ND	641	ND	detected	TBEP
	Baby Trend, Hybrid 3-in-1 — PU Foam	2,099	ND	18,873	TCPP	detected	TCPP
	Safety 1st, LX 65 Air+— PU Foam 1	7	ND	445	ND	detected	TPP
	Safety 1st, LX 65 Air+— PU Foam 2	8	ND	47,123	TDCPP	detected	TDCPP
	Britax, Parkway— Grey Foam	4	ND	584	ND	detected	ND
	Evenflo, Symphony— Grey Foam	12	ND	826	ND	detected	ITP
	Peg-Perego, Primo Viaggio— Grey Foam	3	ND	325	ND	detected	TBPP
	Graco, TurboBooster— White Foam	46	ND	563	ND	detected	TBEP
	Harmony, Dreamtime— White Foam	100	ND	38,746	TDCPP and TCPP	detected	TDCPP and TCPP
	Britax, Frontier— Black Foam	3	ND	396	ND	detected	TBPP
	Britax, Marathon— Black Foam	4	ND	552	ND	detected	TBPP
	Britax, Frontier— White Foam	3	ND	524	ND	ND	ND

TABLE 7 **XRF Results for Bromine, Chlorine, and Phosphorus Compared to GC/MS Results for BFRs, CFRs, and PFRs** CONTINUED

		Bromine		Chlorine		Phosphorus	
		XRF Br, ppm	GC/MS	XRF Cl, ppm	GC/MS	XRF P	GC/MS
PU Foam Components (continued)	Britax, Marathon—White Foam	7	ND	660	ND	ND	ND
	Evenflo Symphony—White Foam	12	ND	484	ND	detected	TBEP
Textiles	Orbit Baby, G3—Black Polypropylene	523	UBC	948	ND	detected	TPP
	Evenflo, Symphony—Black Polyester	1,168	UBC	1,609	ND	detected	ND
	Harmony, Dreamtime—Black Polyester	1,692	UBC	4,343	TDCPP and TCPP	detected	TDCPP and TCPP
	Graco, TurboBooster—Black Polyester	21,824	UBC	369	ND	detected	ND
	Graco, My Size 65—Patterned Polyester	38,909	UBC	2,210	ND	detected	ND

ND = Not detected. For other acronyms, see Abbreviations (p.3).

Cells shaded in purple highlight inconsistent results.

NOTES:

For flame retardants, we use Br>400 ppm and Cl>2500 ppm as the thresholds for a positive result.

Phosphorous was not quantified by our XRF instrument. "Detected" here means we could visibly see the P peak near 2.0 keV.

Textile materials were determined by infrared spectroscopy.

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