Evaluation of Occupational Exposure to Flame Retardants at Four Gymnastics Studios

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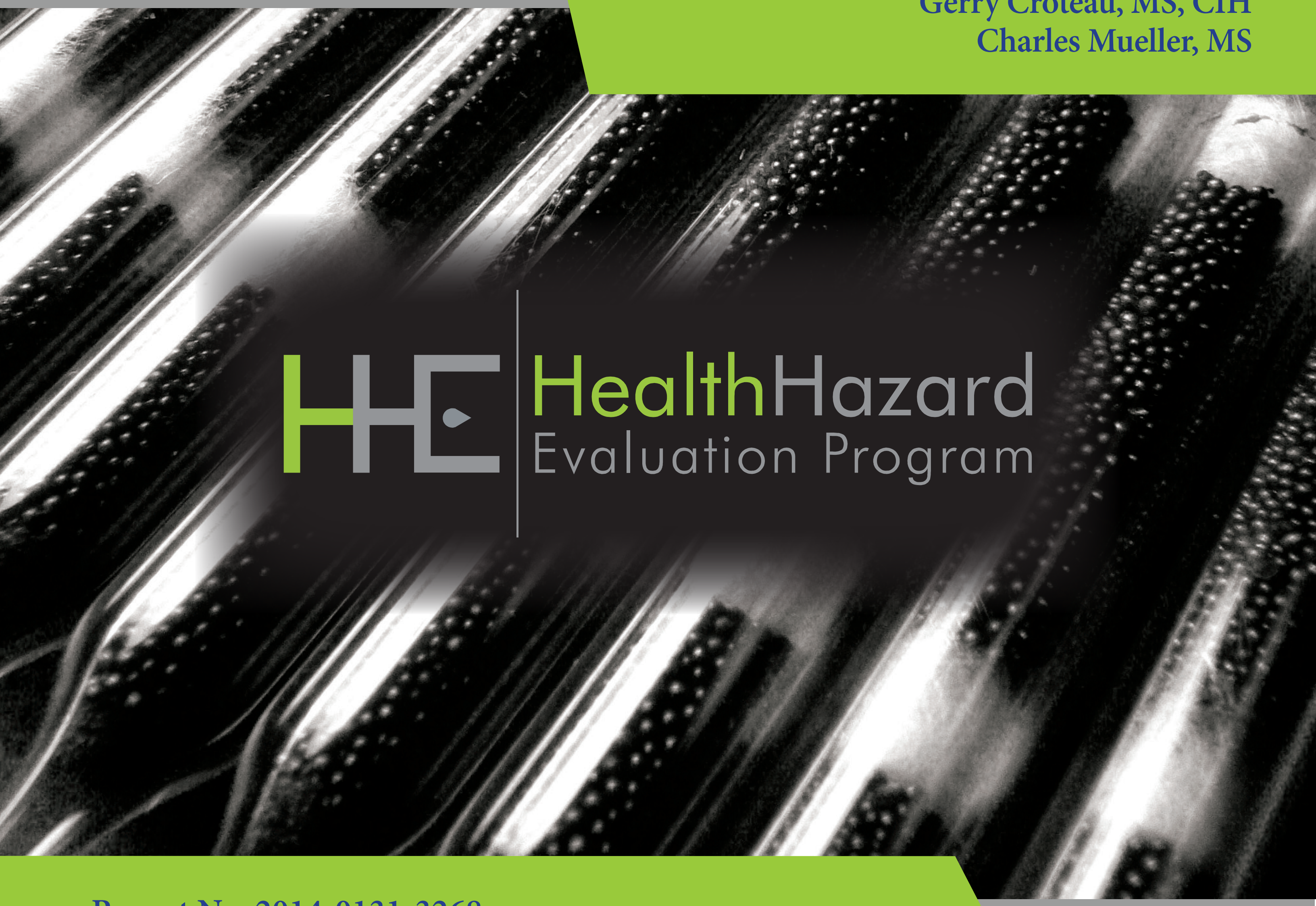

Report No. 2014-0131-3268
September 2017

Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

Contents

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The cover photo is a close-up image of sorbent tubes, which are used by the HHE Program to measure airborne exposures. This photo is an artistic representation that may not be related to this Health Hazard Evaluation. Photo by NIOSH.

Highlights of this Evaluation

The Health Hazard Evaluation Program received a request from the owner of four gymnastics studios. He was concerned about employee exposure to flame retardants from polyurethane foam blocks, mats, and other padded equipment in the gymnastics studios. During the period of our evaluation, the owner replaced the foam blocks in the pits with foam blocks reported by the manufacturer to be free of some types of flame retardants, and thoroughly cleaned the gymnastics studio.

What We Did

- We evaluated the four gymnastics studios in June 2014, October 2014, and April 2015.
- We measured bromine in the polyurethane foam of mats, equipment, and foam blocks in the four gymnastics studios. Bromine is present in some flame retardants.
- We tested old foam blocks and new replacement foam blocks in the laboratory for flame retardants.
- We measured levels of flame retardants used in polyurethane foam on the hands of employees in two gymnastics studios at the beginning and end of the work day. We did this once before the foam blocks were replaced and the gymnastics studios were cleaned (June 2014), and once after (April 2015).
- We measured levels of flame retardants used in polyurethane foam on the hands of two employees immediately before and after they helped remove old foam blocks and clean the in-ground pit (October 2014).
- We measured levels of flame retardants used in polyurethane foam on two windows at each of the four gymnastics studios, one window inside the gymnastics area and one window outside the gymnastics area (for example, in an office). We did this on two visits, once before the foam blocks were replaced (June 2014) and the gymnastics studios were cleaned, and once after (April 2015).

We evaluated employee exposure to flame retardants in four gymnastics studios. Old foam blocks in the pits contained flame retardants (including polybrominated diphenyl ethers that were banned in new products starting in 2004). Mats and other padded equipment contained bromine, which is present in some flame retardants. New blocks did not contain polybrominated diphenyl ethers but contained some of the other flame retardants that were also in the old blocks. Levels of some flame retardants on employees' hands were higher after work than before. We recommended ways to minimize employee exposure to flame retardants at work.

What We Found

- We found bromine in the foam blocks, mats, and other padded equipment in all four gymnastics studios. This means flame retardants were present in them.

- Old foam blocks contained flame retardants, including the types of flames retardants that have not been used in new products in the United States since 2004. New replacement foam blocks had some of the same newer flame retardants as the old foam blocks, but none of the banned ones.
- During routine gym operations, geometric mean levels of the three most common flame retardants in foam were higher (on employee hand wipes) at the end of the work day than at the beginning. The difference was significantly greater for one of the three flame retardants before replacing the old foam blocks and cleaning the gymnastics studios. This finding suggests that replacing the blocks and cleaning the pits may have helped reduce employee exposure to this flame retardant.
- On the day when the old foam blocks were replaced in one gymnastics studio, the employees removing the blocks had much higher hand levels of the three most common flame retardants used in foam after they removed the blocks and cleaned the pit than before.
- Compared to windows outside the gymnastics area, windows inside had higher median levels of some flame retardants, including the types of flame retardants that have not been used in the United States since 2004. This means that the flame retardants were present in the air at some point in time. These differences between levels on windows inside the gymnastics area and outside the gymnastics area were greater before replacing the old foam blocks and cleaning the gymnastics studios than after.

What the Employer Can Do

- Continue the daily housekeeping program and periodic deep cleaning to reduce levels of dust that contains flame retardants.
- Continue to use vacuums with high efficiency particulate air (HEPA) filters for cleaning to prevent dust containing flame retardants from getting into the air.
- Replace foam blocks and other equipment containing foam as soon as the foam begins to deteriorate. Look for materials without flame retardants when replacing foam blocks, floor mats, equipment, and padding in the gymnastics studios.
- Follow the Occupational Safety and Health Administration (OSHA) requirements for voluntary use of respirators if you choose to allow voluntary respirator use.

What Employees Can Do

- Wash hands with soap and water several times during your shift and at the end of your shift.
- Use the HEPA-filtered vacuum or wet methods, such as a damp cloth, for cleaning surfaces in the gymnastics studios. Wear gloves if using a cloth. Use disposable towels or wash cleaning cloths after each day of use. Do not dry sweep.
- Wear long sleeve shirts, closed-toed shoes, and gloves when doing deep cleaning. Remove these clothes when finished deep cleaning and wash them separately from other laundry.
- Do not eat or drink in the gymnastics area.

Abbreviations

α-HBCD	α-hexabromocyclododecane (CAS 134237-50-6)
β-HBCD	β-hexabromocyclododecane (CAS 134237-51-7)
γ-HBCD	γ-hexabromocyclododecane (CAS 134237-52-8)
μg/gram	Microgram per gram
BDE-28	2,4,4’-tribromodiphenyl ether (CAS 41318-75-6)
BDE-47	2,2’,4,4’-tetrabromodiphenyl ether (CAS 5436-43-1)
BDE-66	2,3’,4,4’-tetrabromodiphenyl ether (CAS 189084-61-5)
BDE-85	2,2’,3,4,4’-pentabromodiphenyl ether (CAS 182346-21-0)
BDE-99	2,2’,4,4’,5-pentabromodiphenyl ether (CAS 60348-60-9)
BDE-100	2,2’,4,4’,6-pentabromodiphenyl ether (CAS 189084-64-8)
BDE-153	2,2’,4,4’,5,5’-hexabromodiphenyl ether (CAS 68631-49-2)
BDE-154	2,2’,4,4’,5,6’-hexabromodiphenyl ether (CAS 207122-15-4)
BDE-183	2,2’,3,4,4’,5’,6-heptabromodiphenyl ether (CAS 207122-16-5)
BDE-206	2,2’,3,3’,4,4’,5,5’,6-nonabromodiphenyl ether (CAS 63387-28-0)
BDE-209	Decabromodiphenyl ether (CAS 145538-75-5)
BTBPE	1,2-bis (2,4,6-tribromophenoxy) ethane (CAS 37853-59-1)
CAS	Chemical Abstract Service number
CFR	Code of Federal Regulations
DecaBDE	Decabromodiphenyl ether
DBDPE	Decabromodiphenyl ethane (CAS 84852-53-9)
EDS	Energy-dispersive X-ray spectroscopy
HEPA	High efficiency particulate air
mL	Milliliter
ND	Not detected
NIOSH	National Institute for Occupational Safety and Health
OctaBDE	Octabromodiphenyl ether
OSHA	Occupational Safety and Health Administration
PBDE	Polybrominated diphenyl ethers
PentaBDE	Pentabromodiphenyl ether
SEM	Scanning electron microscope
TBB	2-ethylhexyl 2,3,4,5-tetrabromobenzoate (CAS 183658-27-7)
TBBPA	tetrabromobisphenol-A (CAS 79-94-7)
TBPH	2-ethylhexyl 2,3,4,5-tetrabromophthalate (CAS 26040-51-7)
TCEP	Tris(2-chloroethyl) phosphate (CAS 115-96-8)
TCPP	Tris(1-chloro-2-propyl) phosphate (CAS 13674-84-5)
TDCPP	Tris(1,3-dichloro-2-propyl) phosphate (CAS 13674-87-8)
TPP	Triphenylphosphate (CAS 115-86-6)
XRF	X-ray fluorescence

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Introduction

The Health Hazard Evaluation Program at the National Institute for Occupational Safety and Health (NIOSH) received a request from the owner of four gymnastics studios. The owner was concerned about employee exposure to flame retardants present in the polyurethane foam blocks in large in-ground pits (Figure 1), and from mats and other padded equipment containing polyurethane foam (Figure 2). We made site visits in June 2014, October 2014, and April 2015.

Figure 1. In-ground pit at one gymnastics studio. Each pit is about 5 feet deep. Photo by NIOSH.

Figure 2. Foam mats and padded equipment at one gymnastics studio. Photo by NIOSH.

Background

Flame Retardants

Flame retardants are added to materials to inhibit, suppress, or delay the production of flames and impede the spread of fire. Polychlorinated and polybrominated biphenyls were used as flame retardants until the 1970s, when they were banned or withdrawn from the market because of toxicity [Allen et al. 2013]. Polybrominated diphenyl ethers (PBDEs) were used from the 1980s until recently. PBDEs include pentabromodiphenyl ether (PentaBDE), which was used in polyurethane foam until being banned in 2004. The manufacture and import of PBDE formulations were phased out between 2004 and 2013 in the United States, and manufacturers of flame retardants introduced replacements for the PBDEs. The toxicities of the replacements have not been as well characterized as that of the PBDEs [Allen et al. 2013]. Evidence suggests some are endocrine disruptors (interfere with the hormone systems) and carcinogens (cancer-causing) [Dishaw et al. 2014; Johnson et al. 2013; Meeker and Stapleton 2010; Meeker et al. 2013; van der Veen and de Boer 2012]. More information about flame retardants can be found in Appendix A.

Gymnastics Studio

The four gymnastics studios ranged in size from 11,000 square feet to 19,000 square feet. Each gymnastics studio had at least one in-ground pit filled with foam blocks. In total for the four gymnastics studios, 130 coaches worked on the gymnastics floor and about 20 employees worked in offices away from the gymnastics floor. Coaches spent some time in the office areas and were responsible for cleaning the gymnastics studio facilities.

The gymnastics studios' owner became concerned about exposure to flame retardants after reading a study that noted blood levels of PentaBDE flame retardants in collegiate gymnasts were higher than those in the general population [Carignan et al. 2013]. Investigators in the study also reported that some classes of flame retardants were 2–3 times higher in hand wipes from gymnasts after practice than before. Surface and foam pit dust contained flame retardants. The concentrations of some flame retardants were 5–6 times higher in the air near the foam pit than on the opposite side of the gymnastics studio.

The owner hired a consultant to do air sampling for flame retardants on one coach from each of the four gymnastics studios while working and while at home. Dust samples were also collected at each gymnastics studio and home. Concentrations of some flame retardants were significantly higher in air and dust samples from the gymnastics studios than from homes [LaGuardia and Hale 2015]. The consultant also found that all foam blocks contained multiple flame retardants, with the exception of the newest block, which contained mainly 2-ethylhexyl 2,3,4,5-tetrabromobenzoate (TBB) and 2-ethylhexyl 2,3,4,5-tetrabromophthalate (TBPH) [LaGuardia and Hale 2015]. This consultant tested for the same 22 flame retardants that we tested for in this evaluation.

After our first visit in June 2014, the owner started replacing foam blocks in the pits (Figure 3) with CertiPUR-US® certified foam. CertiPUR-US is a nonprofit organization that conducts voluntary testing and analysis of flexible urethane foams and certifies that products are made without PBDEs, tris(1,3-dichloro-2-propyl) phosphate (TDCPP), or tris(2-chloroethyl) phosphate (TCEP) flame retardants (http://certipur.us/about-certipur-us/).

CertiPUR-US certified products can contain other flame retardants. The owner contracted with researchers to evaluate the replacement foam. They determined that a sample of the replacement foam did not contain any of the seven most common flame retardants (TDCPP, Firemaster 550 [contains TBB and TBPH], Firemaster 600, tris(1-chloro-2-propyl) phosphate [TCPP], tris-isobutylated triphenyl phosphate [TBPP], PentaBDE, and V6 [a chlorinated organophosphate containing TCEP]).

In all four gymnastics studios, the old foam blocks were removed and the interior of each pit was vacuumed several times using vacuums equipped with high efficiency particulate air (HEPA) filters (Figure 3). Walls, windows, floors, ceilings, and equipment were then washed with soap and water. Since the gymnastics studios did not keep cleaning records, we do not know if non-gymnastics area windows were cleaned at the same time. New foam blocks were placed in the pits to a depth of about 2 feet. Catamaran netting was installed in the pits to create a trampoline. About 3 feet of loose foam blocks were placed on top of the netting. The netting was installed to prevent foam at the bottom of the pit from being compacted and damaged, which leads to release of smaller foam pieces (Figure 4). The catamaran netting allows loose foam pieces to fall to the bottom of the pit through the netting where they can easily be cleaned up.

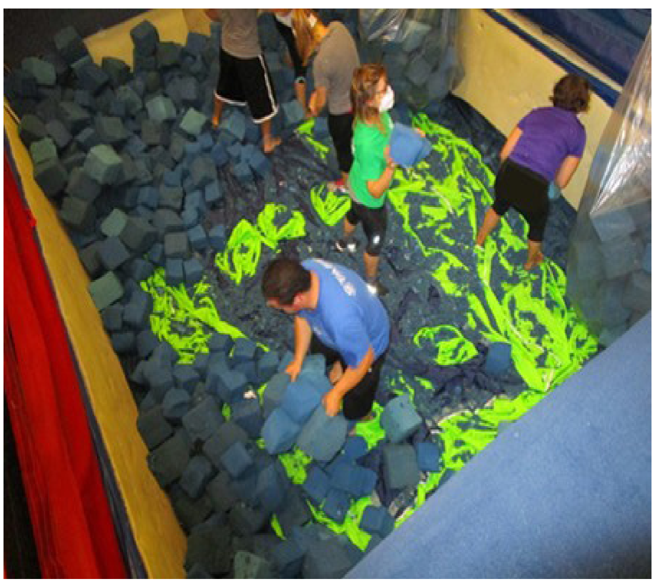

Figure 3. Cleaning of the in-ground pit at one gymnastics studio. Photo by Gerry Croteau.

Figure 4. Old foam blocks and foam dust in the bottom of the in-ground pit at one gymnastics studio. Photo by Gerry Croteau.

Figure 5. In-ground pit at one gymnastics studio containing replacement foam blocks. Photo by NIOSH.

Methods

This evaluation was conducted during three site visits. The site visits took place before (June 2014), during (October 2015), and after (April 2015) foam block replacement.

The primary objectives of this evaluation were to:

1. Assess employees' skin exposure to flame retardants in the gymnastics studio during routine operations.
2. Assess employees' skin exposure to flame retardants in the gymnastics studio during pit foam block replacement and deep cleaning.
3. Determine if there was potential for airborne exposure to flame retardants in the gymnastics studios.
4. Determine if replacement foam and intensive cleaning at the gymnastics studio reduced exposure to flame retardants in the workplace.

Site Visit Activities

June 2014 – Before Foam Block Replacement and Gymnastics Studio Cleaning

We toured the four gymnastics studios during a normal work day to observe work activities and practices, employee use of personal protective equipment, and employee hygiene practices. We assessed flame retardant exposure using several approaches:

- We took surface wipe samples from one window inside the gymnastics area and from one window inside the office area at each of the four gymnastics studios. We chose windows where one side was in the gymnastics area and the other side was in an office or observation area. At one gymnastics studio, this was not possible, so one window was in the gymnastics area and the other window was in the administrative offices. They were separated from one another by a shop and reception area.
- We took samples of the new replacement foam blocks and of the old foam blocks from each gymnastics studio.
- We took preshift and postshift wipe samples from the employees' hands at two gymnastics studios. Preshift wipe samples were collected from the employees' hands as soon as they clocked into work, and postshift wipe samples were collected immediately before clocking out. We instructed employees to perform their usual duties and to wash their hands as they would typically do during their shift. However, we asked employees to not wash their hands between the time they finished work and the time they clocked out.
- We tested the foam blocks and mats at all four gymnastics studios using an energy-dispersive x-ray fluorescence (XRF) device. The device determines the presence of bromine, which is a component of some flame retardants. We also sent foam blocks to a laboratory to be analyzed for flame retardants.
- We collected samples of settled surface dust from floor mats near a foam pit, chalk

powder, and foam blocks from one gymnastics studio. NIOSH laboratory staff analyzed the bulk samples via scanning electron microscopy (SEM). They used energy-dispersive X-ray spectroscopy (EDS) to determine the presence of bromine and chlorine in the dust.

October 2014 – During Foam Block Replacement and Gymnastics Studio Cleaning

We observed the removal of foam blocks from the pits at one gymnastics studio, and the subsequent cleaning of the pits and the gymnastics studio. We took hand wipe samples for flame retardants from employees before and after they removed foam and cleaned the pit.

April 2015 – After Foam Block Replacement and Gymnastics Studio Cleaning

We took preshift and postshift hand wipe samples for flame retardants at the same two gymnastics studios as in June 2014. We also took surface wipe samples from the same windows at each of the four gymnastics studios and samples of the replacement foam blocks from two gymnastics studios.

Detailed methods for sample collection and analysis are provided in Appendix B. All wipe and bulk samples were analyzed by the same researcher whom the gymnastics studios' owner had contracted with for the work done before we began our evaluation. Our samples were analyzed for the following flame retardants:

Components of PentaBDE (used in polyurethane foam in the United States until 2004):

2,4,4'-tribromodiphenyl ether (BDE-28)
2,2',4,4'-tetrabromodiphenyl ether (BDE-47)
2,3',4,4'-tetrabromodiphenyl ether (BDE-66)
2,2',3,4,4'-pentabromodiphenyl ether (BDE-85)
2,2',4,4',5-pentabromodiphenyl ether (BDE-99)
2,2',4,4',6-pentabromodiphenyl ether (BDE-100)
2,2',4,4',5,5'-hexabromodiphenyl ether (BDE-153)
2,2',4,4',5,6'-hexabromodiphenyl ether (BDE-154)

Other flame retardants currently or historically used in polyurethane foam:

2-ethylhexyl 2,3,4,5-tetrabromobenzoate (TBB)
2-ethylhexyl 2,3,4,5-tetrabromophthalate (TBPH)
tris(2-chloroethyl) phosphate (TCEP)
tris(1-chloro-2-propyl) phosphate (TCPP)
tris(1,3-dichloro-2-propyl) phosphate (TDCPP)

Flame retardants neither currently nor historically used in polyurethane foam (included because they are part of the laboratory's analysis panel). Results for these will only be reported in Appendix C:

2,2',3,4,4',5',6-heptabromodiphenyl ether (BDE-183)
2,2',3,3',4,4',5,5',6-nonabromodiphenyl ether (BDE-206)
decabromodiphenyl ether (BDE-209)

1,2-bis(2,4,6-tribromophenoxy) ethane (BTBPE)
decabromodiphenyl ethane (DBDPE)
α-hexabromocyclododecane (α-HBCD)
β-hexabromocyclododecane (β-HBCD)
γ-hexabromocyclododecane (γ-HBCD)
tetrabromobisphenol-A (TBBPA)

Results

Observations

The gymnastics studios were located inside large warehouses. There were exhaust fans in the upper walls of the gymnastics studio. Garage-style doors could be opened to the outside to facilitate air movement and cooling, but they were closed during our site visits. Forced air heaters were present but were not in use during our evaluation. The office area in gymnastics studio #1 was the only area in any of the gymnastics studios ventilated with a residential style heating and air-conditioning system. In three gymnastics studios, the gymnastics areas were separated from non-gymnastics areas with walls and swinging doors, where the neutral position was closed. In the remaining gymnastics studio, the separating doors were standard doors that alternated between opened and closed throughout the site visits.

Polyurethane foam was present in landing mats, padding materials, and in-ground pit foam blocks. Many of the mats and padded equipment were not fully covered by a plastic case. In many instances, the foam was covered by mesh to provide airflow during compression and expansion.

The foam blocks removed and replaced in October 2014 were of mixed ages. The owner reported that, historically, foam blocks were added to the pits as older blocks degraded, as opposed to on a regular schedule. Prior to the replacement of foam blocks, the owner reported that the in-ground pits were cleaned two or three times a year. Disposable N95 respirators and nitrile exam gloves were available, but not required, for employee use during routine pit cleaning. To clean the pits, employees manually removed whole foam blocks and large pieces of broken foam, vacuumed foam dust from the pits, and returned whole foam blocks to the pits. Coaches spent some of their work shift in the offices and some on the gymnastics floor with students or organizing and cleaning. On occasion, coaches went into the in-ground pits to help students.

In October 2014, we observed 13 employees removing foam blocks from the in-ground pits at gymnastics studio #2, bagging foam blocks, rolling up the in-ground pit bottom tarp that had visible foam residue, and vacuuming and sweeping residue from the pits. The pit cleaning operation took 1 hour and 10 minutes. Five employees voluntarily wore N95 disposable filtering facepiece respirators which the employer provided. Employees did not wear gloves, and most were barefoot. The employer did not provide employees with Appendix D from the respiratory protection standard (29 CFR 1910.134), which is an Occupational Safety and Health Administration (OSHA) requirement for voluntary particulate filtering facepiece respirator use.

Measurement of Bromine Content and Flame Retardants in Equipment and Foam Blocks

Table 1 summarizes the bromine content of equipment at the gymnastics studios, as measured using an XRF instrument. The pit foam blocks and floor mat foam had greater mean percentage bromine content than other material in the gymnastics studios (Table 1).

Table 1. Bromine content in equipment in two gymnastics studios measured using a direct reading XRF instrument

Material	Bromine content (percent by weight)		
	Mean	Minimum	Maximum
Equipment covers (n = 30)	0.21	ND	2.3
Floor mat foam (n = 27)	1.1	0.0001	2.9
Pommel horse pad foam* (n = 3)	0.0024	0.0024	0.0024
Pit foam blocks (n = 12)	1.8	0.0001	3.0
Carpet (n = 2)	—	0.02*	0.13*
Hard foam equipment and ring foam (n = 4)	0.34	0.0029	1.3

ND = not detected at or above the limit of detection of 0.0001% by weight

*Only at one gymnastics studio

The bromine content in old (non-white) and new (white) foam pit blocks determined by chemical analysis in the laboratory correlated well (r = 0.85) with the bromine content measured using the XRF instrument in the field (Table 2). For one dark blue and two light blue samples the total flame retardant mass was higher than the mass of brominated flame retardants due to the presence of chlorinated flame retardants (i.e., TCEP, TCPP, TDCPP) in these samples. Table C1 in Appendix C displays the individual flame retardant concentration in each block analyzed.

Table 2. Average bromine and flame retardant content (percent by weight) in pit foam blocks determined by XRF and by laboratory analysis

Sample ID	Foam color	Bromine content by XRF average (standard deviation)	Bromine-containing flame retardants by laboratory analysis	All measured flame retardants by laboratory analysis
1	White*†	0.002 (0.0003)	ND	ND
2	White*	1.6 (0.05)	2.9	2.9
3	White*	1.6 (0.06)	3.3	3.3
4	White*	0.001 (0.0003)	0.0012	0.0012
5	Light blue	0.001 (0.0004)	0.0036	3.5
6	Dark blue	0.029 (0.001)	0.023	2.1
7	Dark blue	1.2 (0.07)	1.9	1.9
8	Turquoise	3.3 (0.04)	4.1	4.1
9	Pale yellow	4.1 (0.04)	2.3	2.4
10	Dark blue	1.3 (0.01)	1.4	1.4
11	Light blue	0.002 (0.0003)	0.0034	6.0
12	Turquoise	2.0 (0.02)	2.6	2.6

ND = not detected at or above the minimum detectable concentration of 1 μg/g of foam or 0.0001% bromine by weight

*White foam was the new replacement foam.
†This was an unused block.

Newer blocks contained lower levels of flame retardants by weight than the older blocks but there was variability across blocks. Flame retardant content in older foam block samples, determined by laboratory analysis, varied from 1.4% to 6% by weight for all flame retardants measured, and from 0.0012% to 4% for bromine-containing flame retardants (Table 2 and Appendix C, Table C1). The predominant flame retardants in the old foam were TBB, TBPH, and TDCPP. Seven of the eight old blocks contained PBDEs. Of those seven blocks, five contained PBDEs at very low concentrations (0.48 microgram/gram [µg/g] foam to 14 µg/g foam), one contained somewhat higher concentrations (up to 290 µg/g foam), and only one contained relatively high concentrations (up to 11,000 µg/g foam).

The flame retardant content in the new foam blocks ranged from "not detected" to 3.3% for all measured flame retardants and for bromine-containing flame retardants by laboratory analysis. None of the four replacement blocks contained PBDEs by laboratory analysis. The new foam blocks did not contain chlorinated flame retardants, with the exception of one block that contained a very small amount of TDCPP (2.2 µg/g). Two of the four had measurable bromine content by XRF and three of the four had bromine-containing flame retardants by laboratory analysis. This was due the presence of TBB and TBPH in these blocks. In the three blocks with measurable levels of TBB and TBPH flame retardants, the levels varied widely with TBB ranging from 7.49 to 27,400 µg/g foam and TBPH ranging from 4.53 to 6,330 µg/g foam. No other flame retardants were detected in the new blocks.

Wipe Sampling of Gymnastics Studio Windows

The most abundant flame retardants present on windows in the gymnastics area before foam block replacement and gymnastics studio cleaning were TBPH and TBB (components of Firemaster 550, which is the second most common flame retardant used in polyurethane foam) and TDCPP (the most common flame retardant currently used in polyurethane foam) [Table 3]. These are the three most abundant flame retardants in 11 of the 12 blocks we tested (Appendix C, Table C1). TDCPP was only found in one new foam block sample, at a very low concentration. Also present on the gymnastics area windows, but at lower median levels relative to the most abundant flame retardants in the same sample, were TCPP and TCEP (used in polyurethane foam) and some components of PentaBDE, which was used in polyurethane foam manufactured before 2004. The most abundant flame retardants we measured on windows in the gymnastics area after foam block replacement were TBB and TDCPP. TBB, TBPH, and TDCPP levels were reduced more on the gymnastics area windows than on the office windows from the June 2014 to the April 2015 site visit (8.8% more for TBB, 9.5% for TBPH, and 24% for TDCPP). The results for the nine flame retardants not used in polyurethane foam are listed in Appendix C, Tables C2 and C3. Gymnastics area window levels of flame retardants were not similar across the four gymnastics studio sites. During the first site visit, the highest concentration of both TBB and TBPH on the gymnastics area windows was more than 100 times the lowest concentration and the highest TDCPP concentration was more than 30 times the lowest concentration across the four sites.

Table 3. Median levels (and ranges) of flame retardants on window wipe samples in nanograms per 4 square foot (ft^2) in four gymnastics studios before and after foam replacement and gymnastics studio cleaning

	Office window June 2014* (n = 4)	Gymnastics studio window June 2014* (n = 4)	Office window April 2015* (n = 4)	Gymnastics studio window April 2015* (n = 4)
PentaBDE				
BDE-28	ND	ND	ND	ND
BDE-47	74.6 (30–110)	445 (47–3,100)	21.1 (ND–700)	20.7 (8.6–84)
BDE-66	ND	12.6 (ND–160)	ND	ND
BDE-85	ND	ND	ND (ND–9.3)	ND (ND–8.8)
BDE-99	ND (ND–150)	537 (ND–8,500)	16.7 (14–100)	21.2 (11–86)
BDE-100	ND	164 (ND–1,300)	3.65 (ND–5.8)	2.04 (ND–6.3)
BDE-153	ND	97.7 (ND–1,400)	ND	ND
BDE-154	ND	ND (ND–130)	ND	ND
Other FRs used in polyurethane foam				
TBB	162 (110–1,100)	2,330 (220–31,000)	22.6 (18–220)	119 (17–220)
TBPH	79.8 (43–520)	1,660 (130–14,000)	9.85 (5.3–43)	47.3 (8.8–92)
TCEP	ND (ND–1,000)	343 (ND–1,100)	ND	ND
TCPP	439 (ND–1,700)	635 (ND–3,700)	ND (ND–140)	ND (ND–230)
TDCPP	518 (230–1,300)	9,370 (2,400–81,000)	150 (120–540)	495 (180–1,100)

ND = not detected; result was below the laboratory reporting limit of 10 nanograms per 4 ft^2

*June 2014 visit was before the foam block replacement and gymnastics studio cleaning. Our April 2015 visit was after the foam block replacement and gymnastics studio cleaning.

Surface Dust Sampling, Chalk Powder Sampling, and Spectroscopy Analysis

EDS elemental analysis revealed that the pit foam pieces and the surface dust from one gymnastics studio contained bromine and chlorine (Table 4). The bromine content in the pit foam pieces was about double the content in the dust. The chlorine content in the foam pieces and the surface dust was similar. The chalk powder sample did not contain bromine or chlorine, indicating that it did not contain detectable levels of brominated or chlorinated flame retardants. Analysis of chalk powder from one gymnastics studio using an SEM supported the EDS analysis findings.

Table 4. EDS elemental analysis showing bromine and chlorine content (percent by weight) of bulk samples from gymnastics studio #2

Sample	Bromine	Chlorine
Chalk powder (n = 1)	0	0
Pit foam (n = 1)	1.07	0.21
Surface dust (n = 1)	0.48	0.17

Hand Wipe Sampling

Exposure Assessment during Foam Replacement and Pit Cleaning

We collected hand wipe samples for flame retardant analysis from three employees immediately before and after they removed the foam blocks and cleaned two in-ground foam pits in one gymnastics studio in October 2014. Table 5 presents data for two of the three employees; the samples for the other employee were potentially contaminated during transport and were not analyzed. Employee 1 was in the pits for 60 minutes and employee 2 for 70 minutes. During this time they were in direct contact with the foam and did not wear gloves. Wipe sample results showed large increases in levels of TBB, TBPH, and TDCPP on employees' hands after the foam pit cleaning. These were the primary flame retardants present in the new and old polyurethane foam blocks. PDBE levels on hands were similar before and after cleaning the foam pits. Only one of the nine flame retardants (BDE-209 at 140 and 330 ng/sample) not used in foam was detected, but it is a flame retardant that was commonly used in other consumer products.

Table 5. Flame retardants on hand wipe samples in nanograms per sample before and after removing old foam blocks from and cleaning two in-ground foam pits, October 2014

Flame retardants	Employee 1 before cleaning	Employee 1 after cleaning	Employee 2 before cleaning	Employee 2 after cleaning
PentaBDE				
BDE-28	ND	ND	ND	ND
BDE-47	68	97	ND	28
BDE-66	ND	ND	ND	ND
BDE-85	ND	5.3	ND	ND
BDE-99	150	140	ND	40
BDE-100	27	24	ND	18
BDE-153	12	19	ND	ND
BDE-154	28	6.3	ND	ND
Other FRs used in polyurethane foam				
TBB	150	6,200	380	3,300
TBPH	5.9	1,800	24	930
TCEP	ND	ND	ND	ND
TCPP	ND	500	450	510
TDCPP	890	13,000	720	9,800

ND = not detected; result was below the laboratory reporting limit of 1 nanogram/sample.

Exposure Assessment during Routine Gymnastics Studio Operations

The flame retardants levels on employees' hands at the beginning and end of their shifts in June 2014 and April 2015 are summarized in Table 6. α-HBCD, β-HBCD, BDE-28, and BDE-183 were not detected at the laboratory reporting limit of 1 nanogram (ng) per sample. γ-HBCD was measured in one preshift sample for one participant on the first (June 2014) site visit; it was not detected in the remaining samples. The most abundant flame retardants postshift on both site visits were TBPH, TBB, and TDCPP. These are the most common flame retardants used in polyurethane foam. The same flame retardants were measured at significantly higher levels postshift than preshift before and after foam replacement. BDE-47, BDE-66, BDE-85, BDE-99, BDE-100, and BDE-153 (all components of PentaBDE, which was used in foam manufactured before 2004) were present at significantly higher levels postshift than preshift before foam block replacement and cleaning of the gymnastics studios, although at geometric mean levels much lower than TBPH, TBB, and TDCPP.

Geometric mean preshift levels on handwipes were higher during the April 2015 site visit than the geometric mean preshift levels during the June 2014 site visit for nine of the 13 flame retardants. The increase in geometric mean preshift levels varied across these flame retardants and were between 1 and 900 nanograms (or 4% and 2,200%) higher in the April 2015 preshift samples. Of these, the increases in geometric mean preshift levels were greatest for TCPP and TDCPP. Geometric mean preshift levels for TCPP and TDCPP were 480 and 2,200% higher, respectively, in April 2015 than in June 2014. For three of the 13 flame retardants the geometric mean preshift levels were not above the limit of detection during either site visit. For the one flame retardant where the geometric mean preshift level decreased between April 2015 and June 2014, TCEP, the geometric mean level decrease was from 1.48 nanograms to not detectable (less than 1 nanogram).

Table 6. Preshift and postshift geometric mean levels and ranges of flame retardants on employees' hands (in nanograms) before and after foam replacement and gymnastics studio cleaning

	Preshift June 2014† (n = 20) GM (range)	Postshift June 2014† (n = 20) GM (range)	Preshift April 2015† (n = 18) GM (range)	Postshift April 2015† (n = 18) GM (range)
PentaBDE				
BDE-28	ND	ND	ND	ND
BDE-47	28.8 (7.8–210)	93.0 (34–280)*	52.3 (12–680)	95.8 (7.0–730)
BDE-66	ND	1.12 (ND–6.4)*	ND	ND
BDE-85	1.31 (ND–7.0)	6.12 (1.9–16)*	2.29 (ND–16)	5.56 (ND–70)
BDE-99	24.0 (ND–160)	85.8 (27–280)*	36.2 (ND–160)	65.9 (7.80–590)
BDE-100	3.92 (ND–34)	18.3 (8.6–43)*	8.61 (ND–29)	14.7 (ND–140)
BDE-153	2.06 (ND–21)	11.0 (2.4–30)*	3.15 (ND–34)	9.07 (ND–110)*
BDE-154	ND	0.843 (ND–24)	ND	ND
Other FRS used in polyurethane foam				
TBB	76.2 (15–230)	1,100 (57.2–5,000)*	79.2 (13–840)	885 (31–6,400)*
TBPH	38.6 (9.50–110)	478 (39–2,200)*	50.3 (16–230)	267 (14–1,500)*
TCEP	1.48 (ND–130)	0.859 (ND–35)	ND	ND
TCPP	8.54 (ND–820)	8.63 (ND–520)	196 (ND–880)	210 (110–540)
TDCPP	187 (ND–1,400)	556 (60–4,600)*	1,090 (150–4,200)	1,580 (330–3,000)*

GM = geometric mean is a measure of central tendency, or the "middle" value.

ND = not detected, result was below the laboratory reporting limit of 1 ng/sample.

*Indicates a statistically significant difference ($P < 0.05$) between postshift and preshift levels of flame retardants during the same visit

†June 2014 visit was before the foam block replacement and gymnastics studio cleaning. Our April 2015 visit was after the foam block replacement and gymnastics studio cleaning.

The employees we sampled averaged 4 hours on the gymnastics area floor (range: 1–8.5) and 1.9 hours (range: 0–7.5) off the gymnastics area floor. During their time off the gymnastics area floor, employees worked in the office, took breaks and lunches, traveled between the two gymnastics studios and spent time offsite in between the beginning and end of their workday. Of the flame retardants used in polyurethane foam, there were significant correlations between hours on the gym floor and change in levels of TCEP ($r = 0.52$; $P < 0.02$) on the first site visit and BDE-47 ($r = 0.54$; $P = 0.02$) on the third (April 2015) site visit.

Employees reported washing their hands with soap and water an average of twice while at work (range: 0–7). We did not find a significant relationship between change in levels of flame retardants on the hands and number of times an employee washed his or her hands. Total shift length (including time on the gymnastics studio floor, in the office, and breaks and lunches, etc.) was significantly positively associated with the number of times employees washed their hands during their work shift for both the first (June 2014) site visit ($r = 0.80$; $P < 0.01$) and for the third (April 2015) site visit ($r = 0.55$; $P = 0.02$).

Discussion

While the predominant flame retardants in the old foam we sampled were TBB, TBPH, and TDCPP, PBDEs were found in widely varying concentrations across the seven of eight old blocks that contained PentaBDEs. These findings are consistent with those of the consultant who tested six blocks [LaGuardia and Hale 2015]. None of the four new blocks we tested contained PBDEs. TDCPP was not detected in the replacement blocks, with the exception of one block that contained a very low concentration. TBB and TBPH were present in widely varying concentrations across three of four new blocks, and not detected in the fourth. No other flame retardants were detected in the four new foam blocks we sampled. Therefore, replacement of the foam blocks removed a source of PentaBDEs and TDCPP in the gymnastics studio, therefore potentially reducing exposure to these flame retardants.

Our surface wipe samples from windows indicate that flame retardants likely were released from foam-containing products, became airborne, and then settled on surfaces (e.g., windows). The most abundant flame retardants we measured on windows before and after foam block replacement and gymnastics studio cleaning were TBB, TBPH, and TDCPP. Some components of PentaBDE and other flame retardants found in foam were also present; most of these were found in lower median concentrations than TBB, TBPH, and TDCPP. This is consistent with the consultant findings of significantly higher mean inhalable concentrations of TBB and TDCPP in air in the gymnastics area than in coaches' homes [LaGuardia and Hale 2015]. In contrast, the consultant found no significant difference in mean concentrations of PentaBDE between homes and the gymnastics studio. Ten of the 13 flame retardant medians on gymnastics area windows were lower after gymnastics studio cleaning and foam block replacement than before; however, we did not test these differences statistically due to small sample size. The largest differences were in TBB and TDCPP, which might imply that airborne concentrations were reduced after the gymnastics studio cleaning and the replacement of the foam blocks. The relatively high levels of TDCPP in window dust after the foam block replacement and gymnastics studio cleaning suggest that (1) residual foam dust from older blocks may have persisted, (2) other foam equipment (that contain TDCPP) may have contributed to airborne dust, or (3) a combination of these sources was contributing to the presence of TDCPP.

Our ability to arrive at a definitive interpretation of the window sampling results, however, is hampered by the fact that we do not know the last time the windows had been cleaned before our sampling. For example, if the time between window cleaning and our second sampling was shorter than the time between window cleaning and our first sampling, the lower levels measured after foam replacement and gymnastics studio cleaning could be due to recent cleaning rather than a reduction in levels of airborne flame retardants. In addition, if the time since the last cleaning of the gymnastics area windows was greater than that for the office windows, any higher levels of flame retardants measured on the gym windows may be due to the longer time period.

Levels of TBB, TBPH, and TDCPP on hand wipes were much higher after removing old foam blocks from a pit and cleaning the pit than before. These findings suggest employees doing the cleaning were exposed to the flame retardants in the old foam blocks. We did not statistically test the difference between the levels before and after cleaning due to small sample size.

We also found large and significant increases in levels of TBB and TBPH on employees' hands across their work shift during routine activities, both before the foam block replacement and gymnastics studio cleaning and after. This is not surprising given the new foam contained both TBPH and TBB. These findings are similar to those of Carignan et al. 2013, who noted that median PentaBDE, TBB, and TBPH levels in hand wipes were 2–3 times higher from gymnasts after practice than before. We found significant increases across the work shift during routine operations in levels of six of eight PentaBDE components before the foam was replaced and the gymnastics studio was cleaned and one of eight afterwards. However, the geometric mean levels of the postshift PentaBDEs were much lower than those of TBB, TBPH, and TDCPP even before the foam block replacement and gymnastics studio cleaning. We also found significant increases in levels of TDCPP on employees' hands across their work shift, both before the foam block replacement and gymnastics studio cleaning and after. Of note, the increase in TDCPP during the shift appears to be greater after foam replacement and gymnastics studio cleaning than before, although the difference was not statistically significant. The new blocks were certified to contain no TDCPP (although our analyses documented a minute amount of TDCPP in one block). While employees still had the potential for exposure to flame retardants in other foam-containing equipment such as mats and pommel horses, it seems unlikely that exposure to these items would explain our findings since the difference was not consistent across both visits and the other foam-containing equipment was not replaced or changed between site visits.

We noted that preshift levels of most flame retardants during the April 2015 site visits were higher than the preshift levels during the June 2014 site visit, especially for TCPP and TDCPP. With the information we have, we cannot attribute this increase to a single factor or a combination of factors either inside or outside the gymnastics studio. Since the change is almost exclusively positive (except for one flame retardant) between the preshift handwipes on June 2014 and April 2015 site visits, the increases in preshift levels were probably not caused by differences in collection efficiency from the hands. Preshift levels were used to account for non-occupational exposure, and the higher preshift levels before the second site visit may reflect higher exposures outside of work.

Overall, interpretation of the hand wipe sampling results is challenging. First, the hand wipe sampling procedure removes an unknown amount of flame retardants present on the hand and can vary depending on the wiping technique. If a participant wiped more thoroughly on the postshift wipe that the preshift wipe, it could appear there was an increase in the flame retardant levels. If a hand wipe removed more flame retardant preshift than was added to the hand during the shift, it could appear there was a decline in flame retardant levels even though exposure may have occurred. In addition, if a participant left the gym during the day after the preshift wipe was taken, the exposures on the postshift wipe might also reflect exposures from outside the gymnastics studio. Second, the efficiency of the wipe in collecting all the contamination that is present on the skin is unknown. We recently conducted a pilot study evaluating the efficiency of hand wipes in removing flame retardants from employee's hands in an electronics recycling facility [NIOSH 2016a]. The pilot study included 10 of the 13 flame retardants from Table 6. Six employees typically performed three sequential sets of hand wipes, which were analyzed separately. We determined the total amount of flame retardants removed by adding the results from all three wipes, then determined the percentage of that total removed by the first wipe. The percent removed by the first wipe varied by flame retardant and by participant and ranged from less than 10% to more than 90%, with an average of 41%. We also found that using sequential wipes with 99% isopropyl alcohol was very harsh to participants' skin. Therefore, we collected only one set of wipes per employee using gauze, which is the method used in the published studies cited previously.

The acceptable analytical variability for wipe flame retardant analysis in this study (70% to 130%) was larger than that for wipe sample analyses for other chemicals, such as metals or polyaromatic hydrocarbons (80% to 120%) [Boeniger 2007, 2008]. Analyses with variability outside of this range would not be considered accurate and would not be reported; a less restrictive variability criterion was chosen for this evaluation because of the experimental nature of flame retardant analysis.

The amount of flame retardants that can be recovered from the wipes in the laboratory is not well known. Recoveries for each set of analyses are estimated using the recovery rates of surrogates for flame retardants that have been added to the samples before analysis. In a recovery study, three gauze wipes were each spiked with 100 nanograms of each of the 22 flame retardants in the panel. The range of mean percent recoveries was 57% to 110%; the mean of the mean percent recoveries for each flame retardant was 84%. The range of coefficients of variation was 4 to 73; the mean coefficient of variation is 11.3 [NIOSH 2016b]. We do not know the efficiency of hand washing in removing flame retardants. If hand washing was very efficient in removing flame retardants from the workers' hands, then the postshift flame retardant levels would be far less than if hand washing had not been done. Participants with less time between their last handwashing and their postshift hand wipe sample might have lower amounts of flame retardants on their hands due to removal from washing. We instructed participants to wash their hands as they normally would during the work shift, but instructed them to refrain from washing them immediately before having their postshift hand wipe sampling done. We did not record the time interval from the last hand washing to the postshift wipe sampling.

While the limitations discussed above warrant consideration, our results appear consistent with those from studies in which hand wipes have been used to measure personal exposure to flame retardants in nonoccupational studies. TBB and TBPH on hand wipes of 11 collegiate gymnasts were significantly higher after a practice than before [Carignan et al. 2013]. These hand wipes were collected using the same materials with the same participant instructions as our samples. We also found significant increases preshift to postshift of TBB and TBPH.

We hypothesized that increased frequency of handwashing would be negatively correlated with change in flame retardant levels on the hands over the shift. However, there was no statistically significant correlation between individual levels of flame retardants and handwashing. One reason for this finding may be that because total number of hours at work was significantly positively associated with the number of times employees washed their hands and length of shift may have counteracted the protective effect of handwashing. Other reasons include the possibility that aspects of washing other than frequency, i.e., vigor and duration, may be important or we may not have had enough people throughout the frequency range to see a correlation. Other studies have shown an inverse association between frequency of handwashing and concentrations of some flame retardants on hands [Abdallah et al. 2016; Stapleton et al. 2014; Watkins et al. 2011].

Conclusions

Gymnastics studio employees can be exposed to flame retardants by airborne and skin exposure. The main flame retardants we measured on windows and hands were TBB, TBPH, and TDCPP. Replacing the foam blocks in the in-ground pits eliminated a source of PBDEs and TDCPP.

Recommendations

Scientists who research flame retardants exposure and toxicology have not reached a consensus on what levels of exposure to flame retardants are safe or harmful to health. Although it is not possible to eliminate all flame retardant exposure, the gymnastics studio management and employees can take the steps listed below to minimize exposure in the workplace. We encourage the gymnastics studios to use a labor-management health and safety committee or working group to discuss our recommendations and develop an action plan. Those involved in the work can best set priorities and assess the feasibility of our recommendations for the specific situation at the gymnastics studios.

Our recommendations are based on an approach known as the hierarchy of controls. This approach groups actions by their likely effectiveness in reducing or removing hazards. In most cases, the preferred approach is to eliminate hazardous materials or processes and install engineering controls to reduce exposure or shield employees. Until such controls are in place, or if they are not effective or feasible, administrative measures and personal protective equipment may be needed.

Elimination and Substitution

Eliminating or substituting hazardous processes or materials reduces hazards and protects employees more effectively than other approaches. Prevention through design, considering elimination or substitution when designing or developing a project, reduces the need for additional controls in the future.

1. Replace foam blocks, floor mats, padding, and other equipment containing foam as soon as the foam begins to deteriorate. Look for materials without flame retardants. This should become easier over time as the hazards of chemical flame retardants become more well-defined, the public becomes more aware of these hazards, and manufactured goods flammability standards, such as California Technical Bill 117 are revised.

Administrative Controls

The term administrative controls refers to employer-dictated work practices and policies to reduce or prevent hazardous exposures. Their effectiveness depends on employer commitment and employee acceptance. Regular monitoring and reinforcement are necessary to ensure that policies and procedures are followed consistently.

1. Continue daily housekeeping and periodic deep cleaning to reduce the amount of dust from degrading foam. Use vacuums that have HEPA filters for cleaning to prevent dust re-entrainment into the air. Do not dry sweep. Wet methods, such as using a damp cloth, can also be used for cleaning.

Personal Protective Equipment

Personal protective equipment is the least effective means for controlling hazardous exposures. Proper use of personal protective equipment requires a comprehensive program and a high level of employee involvement and commitment. The right personal protective equipment must be chosen for each hazard. Supporting programs such as training, change-out schedules, and medical assessment may be needed. Personal protective equipment should not be the sole method for controlling hazardous exposures. Rather, personal protective equipment should be used until effective engineering and administrative controls are in place.

1. Provide employees who choose to use filtering facepiece respirators on a voluntary basis with Appendix D from the OSHA respiratory protection standard 1910.134 (Information for Employees using Respirators When Not Required Under Standard). OSHA allows for voluntary use of respirators once the employer has determined that the respiratory protection is not necessary to protect the health of the worker and that the respirator itself does not present a health hazard if used during work. Other OSHA requirements for voluntary respirator use can be found at: https://www.osha.gov/dte/library/respirators/major_requirements.html.
2. Wear long sleeve shirts, gloves, and closed-toe shoes while performing annual pit cleaning operations to reduce dermal exposure to foam dust. Remove these clothes after deep cleaning and wash them separately from other laundry.
3. Practice good hand hygiene at work by washing hands before breaks, before eating meals, before leaving work, after removing gloves, and after cleaning the gymnastics studio. Do not eat or drink in the gymnastics areas.

Appendix A: Health Effects and Exposure Routes of Flame Retardants

Flame retardants are added to manufactured materials, surface finishes, and coatings to inhibit, suppress, or delay the production of flames and impede the spread of fire. Polychlorinated and polybrominated biphenyls were used until the 1970s, when they were either banned or withdrawn from the market because of toxicity [Allen et al. 2013]. Tris(2,3-dibromopropyl) phosphate was withdrawn from the market in the 1970s when it was discovered that it was mutagenic and children absorbed it from their pajamas [Blum et al. 1978]. In 1975, California Technical Bill 117 (TB117) required that upholstered furniture filling, which is usually polyurethane foam, meet an open flame test. Manufacturers added chemical flame retardants to foam to meet this standard. While the standard only applied in California, manufacturers sold TB117-compliant products across the North America to avoid having double inventory and to minimize liability. California updated the standard in 2014 (TB117-2013). While it does not ban flame retardants, it can be met without them.

PBDEs were used in a variety of products from the 1980s until recently. All PBDEs have a common structure of brominated diphenyl ether molecules with 1–10 bromine atoms attached. PDBEs have 209 different structural variations [Lorber 2008]. PBDEs include PentaBDE, octabromodiphenyl ether (OctaBDE), and decabromodiphenyl ether (DecaBDE). PentaBDE (which contains mostly BDE-47 and BDE-99, but also BDE-28, BDE-66, BDE-85, BDE-100, BDE-153, and BDE-154 in much smaller amounts) was used in polyurethane foam, which is present in much of the gymnastics studio equipment (e.g., foam blocks and mats) but also is found in many consumer products.

PBDEs have a molecular structure similar to thyroid hormones [McDonald 2002]. Some human epidemiologic studies have shown an association between exposure to PBDEs and changes in male reproductive hormones, semen quality, thyroid homeostasis, and hormone levels and fertility in women; cryptorchidism (undescended testicles); low birth weight and length; delayed motor skills; and decreased IQ [Abdallah et al. 2015; Czerska et al. 2013; Dallaire et al. 2009; Dishaw et al. 2014; Grant et al. 2013].

The manufacturing and import of the PentaBDE and OctaBDE formulations were phased out in 2004 in the United States, and the production of DecaBDE ended in 2013. Manufacturers of flame retardants have introduced replacements for the PBDEs, but the toxicity of the replacements has not been well characterized [Allen et al. 2013]. These replacement compounds include novel brominated flame retardants like TBB and TBPH, and phosphorus flame retardants like TDCPP and triphenylphosphate (TPP).

TPP, TBPH, TBB, and isopropylated triphenyl phosphate isomers are components of Firemaster 550, which appears to be the second most common flame retardant mixture currently applied to foam, after TDCPP [Hoffman et al. 2014]. Studies indicate that TBPH may affect thyroid hormones [Johnson et al. 2013]. TCEP and TCPP are also used in some polyurethane foam. Some phosphorus flame retardants have been associated with decreased fertility, reduced sperm motility, altered reproductive and thyroid hormones, and cancer in humans [Dishaw et al. 2014; Meeker and Stapleton 2010; Meeker et al. 2013; van der Veen and de Boer 2012].

In general, exposure to flame retardants in indoor environments like homes, schools, and offices is thought to be mainly from ingestion of dust, primarily during the transfer of the flame retardants from hands to mouth, with dermal absorption the next most important route of exposure [Abdallah et al. 2015]. However, a recent study estimated that inhalation exposure exceeded intake from ingestion of some chlorinated organophosphate flame retardants [Schreder et al. 2016]. Experimental data using human skin equivalent tissue demonstrates that absorption through skin increased as the number of bromine atoms decreased for PBDEs [Abdallah et al. 2015]. Animal studies show that TDCPP is easily absorbed through the skin and gastrointestinal tract [Nomeir et al. 1981], and recent studies of human ex vivo skin showed absorption of 28% for TCEP, 25% for TDPP, and 13% for TDCPP [Abdallah et al. 2016]. Neither NIOSH, OSHA, nor the American Conference of Governmental Industrial Hygienists has limits for flame retardants on hands or surfaces.

Appendix B: Methods

All wipe and bulk samples were analyzed for the following flame retardants:

2,4,4'-tribromodiphenyl ether (BDE-28)
2,2',4,4'-tetrabromodiphenyl ether (BDE-47)
2,3',4,4'-tetrabromodiphenyl ether (BDE-66)
2,2',3,4,4'-pentabromodiphenyl ether (BDE-85)
2,2',4,4',5-pentabromodiphenyl ether (BDE-99)
2,2',4,4',6-pentabromodiphenyl ether (BDE-100)
2,2',4,4',5,5'-hexabromodiphenyl ether (BDE-153)
2,2',4,4',5,6'-hexabromodiphenyl ether (BDE-154)
2,2',3,4,4',5',6-heptabromodiphenyl ether (BDE-183)
2,2',3,3',4,4',5,5',6-nonabromodiphenyl ether (BDE-206)
decabromodiphenyl ether (BDE-209)
2-ethylhexyl 2,3,4,5-tetrabromobenzoate (TBB)
2-ethylhexyl 2,3,4,5-tetrabromophthalate (TBPH)
1,2-bis (2,4,6-tribromophenoxy) ethane (BTBPE)
decabromodiphenyl ethane (DBDPE)
α-hexabromocyclododecane (α-HBCD)
β-hexabromocyclododecane (β-HBCD)
γ-hexabromocyclododecane (γ-HBCD)
tris(2-chloroethyl) phosphate (TCEP)
tris(1-chloro-2-propyl) phosphate (TCPP)
tris(1,3-dichloro-2-propyl) phosphate (TDCPP)
tetrabromobisphenol-A (TBBPA)

Hand Wipe Sample Collection

We used nitrile-gloved hands to open a 60 milliliter (mL) amber glass vial containing two 7.6 square centimeter sterile gauze pads soaked in 6 mL of 99% isopropyl alcohol. The employee took one gauze pad from the vial and wiped both palms from wrist to fingertips, as described by Carignan et al. [2013]. The employee then inserted the gauze pad into the glass vial with one hand while taking the second gauze pad with the other hand. The employee used the second gauze pad to wipe the back of both hands, then placed it into the vial. We asked employees how many times they washed their hands with soap and water or used alcohol hand gel during the shift. For quality assurance, we collected field and media blank samples. Samples and blanks were stored and shipped cold (on blue ice) to the Virginia Institute of Marine Sciences for analysis.

Window Wipe Sample Collection

We chose windows that had appeared to have not been cleaned recently, when possible, for wiping. We noted if there was a partition/enclosure between the office and gymnastics areas. We also noted if there was a ventilation system in offices and gymnastics area and if they were separated from each other. Sampling was similar to that described by Butt et al. [2004]. Four sterile gauze pads were presoaked with approximately 12 mL of 99% isopropyl alcohol in an amber glass vial. Four 1×1 square foot templates were placed on each window, forming a large square of 4 square feet (Figure A1). We donned a new pair of nitrile gloves and took the first gauze pad from the vial. Using only one side of the gauze pad, we thoroughly wiped one of the squares with repeated horizontal motions. We folded the gauze pad in half, then wiped the same area again at a right angle to the first wiping motion. We folded the gauze pad in half again, then wiped the same area again at a 45 degree angle to the first wiping motion. All four template squares were wiped, each with one gauze pad and the four wipes were analyzed as one sample. We collected field and media blanks for quality assurance. Samples and blanks were stored and shipped on ice to the Virginia Institute of Marine Sciences for analysis.

Figure B1. Investigator sampling the surface of a window in the gymnastics area. Photo by NIOSH.

Foam Block Sample Collection

We collected foam blocks, covered each one with aluminum foil, and bagged them individually for transport to the laboratory. We cut off the outer surface of each block until we had an approximate 0.5 cubic centimeter sample of the core of the block. We used a hand-held energy dispersive XRF analyzer to determine the bromine content in each sample (% by weight). We did this three times per sample and averaged the results. Foam sample and sub-sample collection was described by Carignan et al. [2013]. We sent an approximate 0.1 gram subsample of each block core sample to the Virginia Institute of Marine Sciences, which then analyzed the samples for each of the flame retardants listed above. They also analyzed three different sized foam samples (< 300 micrometer, > 300 micrometer, and approximately 0.5 cubic centimeter) to determine if surface area affected extraction efficiency.

Hand Wipe, Window Wipe, and Foam Block Sample Analysis

The hand wipes, window wipes, and foam blocks were analyzed for a panel of 22 flame retardants. Laboratory scientists created an extraction from each sample, purified the extraction, and analyzed the extraction. First, they spiked the foam samples with surrogate standards and deuterated tris(1,3-dichloro-2-propyl)phosphate and extracted the analytes using methylene chloride in an accelerated solvent extractor at 100°C and 68 atmospheres. Then, the lab purified each sample extract using a 2-gram silica solid phase extraction column. The extraction was eluted with 3.5 mL hexane, then with 6.5 mL of a 60% hexane and 40% methylene chloride mixture, and finally with 8 mL methylene chloride and 5 mL 50% acetone and 50% methylene chloride. The resulting samples were separated and analyzed via ultra-performance liquid chromatography and atmospheric pressure photoionization tandem mass spectrometry. Full analytical methods can be found in La Guardia et al. [2013, 2015].

Surface Dust and Chalk Powder Bulk Sample Collection

We collected one surface dust sample from the competitive gymnastics studio where chalk is used (gymnastics studio #2) by vacuuming a 1 foot × 1 foot mat surface area for 5 minutes, using a cellulose filter in a cassette attached to a personal sampling pump. Surface dust sample collection methods were adapted from methods described previously by Carignan et al. [2013]. We collected bulk samples of the chalk powder from the gymnasts' chalk bucket in glass containers with Teflon®-lined caps.

Foam Block Flame Retardant Analysis

Samples were spiked with surrogate standards (BDE-166 and deuterated tris(1,3-dichloro-2-propyl)phosphate) and extracted with methylene chloride in a Dionex ASE 200 accelerated solvent extractor at 100°C and 68 atmospheres. All Burdick & Jackson solvents used were residue grade. The extracts were cleaned up on a 2-gram silica solid phase extraction column eluted with 3.5 mL hexane (Fraction 1), followed by 6.5 mL of 60:40 hexane/methylene chloride and then 8 mL methylene chloride (Fraction 2) and 5 mL 50:50 acetone/methylene chloride (Fraction 3). Fraction 2 contained the PBDEs, and HBCDs. Fraction 3 contained the three chlorinated organophosphate flame-retardants and TBBPA. Decachlorodiphenyl ether was then added to each fraction as the internal standard. Analytes in Fraction 2 and 3 were further separated by a Waters Corporation ultra-performance liquid chromatography system and analyzed by an AB Sciex, Q-Trap3200 MS atmospheric pressure photoionization tandem mass spectrometer. Further details of the analysis can be found in La Guardia et al. [2013].

Scanning Electron Microscopy and Energy-Dispersive X-ray Spectroscopy Analysis

We looked at dust samples to determine if flame retardants adhered to the chalk powder. Bulk chalk powder, pit foam bits, or surface dust samples were sprinkled onto conductive carbon tape adhered to an aluminum stub, followed by sputter coating with a thin layer of gold. The samples were analyzed by EDS on the Hitachi S-3000N SEM at 5 kilovolts and 15 kilovolts to obtain images. EDS spectra were collected at 25 kilovolts to determine the presence of bromine and chlorine. The elemental mapping and composition analysis were performed by using EDS data.

Bulk Sample Bromine Analysis

We looked for bromine in foam blocks and mats at all four gymnastics studios using a Bruker (S1 Turbo) energy-dispersive x-ray spectroscopy device, as described by Carignan et al. [2013] and Allen et al. [2008]. We held the device to direct x-rays (generated by an x-ray tube) at a sample. The x-rays are absorbed by the atoms in the sample matrix, which results in the release of an x-ray photon. This photon is then analyzed by the instrument to determine which elements are present and their concentrations. We operated the device in the low density plastic mode, a mode that has been calibrated specifically for low density plastics. We took each measurement for 30 seconds. The device has a detection limit of 1 milligram per kilogram in the low density plastic mode. We analyzed different colored blocks obtained from near the foam pit surface, and polyurethane plastic covered mats (Figure A2 and A3). We analyzed mats near a zipper opening so both the foam and plastic covering could be analyzed separately.

Figure B2. Investigator using a direct reading instrument to measure the bromine content in foam pit blocks. Photo by NIOSH.

Figure B3. Investigator using the direct reading instrument to measure bromine content in the foam of a padded mat at a gymnastics studio. Photo by NIOSH.

Statistical Analysis

Flame retardant wipe data were corrected for recoveries reported by the laboratory on three replicate spikes of surrogate chemicals (100 nanograms per sample) on blank wipes. For sample results that were reported as "not detected" we used the laboratory reporting limit (1 nanogram per sample for hand wipes and 10 nanograms per cubic meter for window wipes) divided by the square root of 2 [Hornung and Reed 1990] as the estimate in calculating measures of central tendency. Hand wipes for all employees at the end of the shift were compared to those before the shift using a paired t-test or a paired sign test, depending on the distribution of the postshift to preshift differences. We used mixed models to test for any differences in the size of the post – pre change in flame retardant levels on hands between the June 2014 and April 2015 site visits. Given that some participants were sampled at both site visits, mixed models help account for the possible correlation between measures taken on the same participant. The Spearman correlation coefficient was used to determine the correlation between the total number of hours spent at work, the number of times employees washed their hands, and the difference between individual postshift and preshift flame retardant concentrations on the hands. We calculated the Pearson correlation coefficient for the relationship between bromine content of 8 foam blocks as found using the XRF instrument and via laboratory analyses. Due to the small sample size, we did not use statistical testing to compare window levels of flame retardants.

Appendix C: Tables

Table C1. New and old pit foam block flame retardant content (µg/g) by laboratory analysis (by age and color)

Flame retardant	1 New White	2 New White	3 New White	4 New White	5 Old Light Blue	6 Old Dark Blue	7 Old Dark Blue	8 Old Turquoise	9 Old Pale Yellow	10 Old Dark Blue	11 Old Light Blue	12 Old Turquoise
BDE-28	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BDE-47	ND	ND	ND	ND	1.3	ND	8.7	14	6400	3.9	3.2	180
BDE-66	ND	ND	ND	ND	ND	ND	ND	ND	92	ND	ND	4.2
BDE-85	ND	ND	ND	ND	ND	ND	0.48	ND	520	ND	ND	11
BDE-100	ND	ND	ND	ND	ND	ND	2.8	1.8	1900	1.4	ND	49
BDE-99	ND	ND	ND	ND	ND	ND	13	10	11000	6.0	1.8	290
BDE-154	ND	ND	ND	ND	ND	ND	1.1	ND	850	ND	ND	20
BDE-153	ND	ND	ND	ND	ND	ND	1.2	ND	990	ND	ND	22
BDE-183	ND	ND	ND	ND	ND	ND	ND	ND	3.2	ND	ND	ND
BDE-206	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BDE-209	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TBB	ND	24,000	27,000	7.5	27	190	13,000	29,000	1,300	9,500	21	19,000
TBPH	ND	5,200	6,300	4.5	7.4	41	5,800	12,000	320	4,300	8.0	6,500
BTBPE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DBDPE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
α-HBCD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
β-HBCD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
γ-HBCD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TCEP	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TCPP	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TDCPP	ND	2.2	ND	ND	35,000	21,000	2.5	ND	290	290	60,000	410
TBBPA	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = not detected at the limit of detection of 1 nanogram per sample.

Table C2. Flame retardant levels in gymnastics area window and office window wipe samples at each gymnastics studio facility (1–4) in June 2014 before foam block replacement and gymnastics studio cleaning (nanogram/4 ft^2)

Flame retardant	Windows - office area				Windows - gymnastics area			
	1	2	3	4	1	2	3	4
BDE-28	ND	ND	ND	ND	ND	ND	ND	ND
BDE-47	54	110	30	95	3,100	600	47	290
BDE-66	ND	ND	ND	ND	159	18	ND	ND
BDE-85	ND	ND	ND	ND	ND	ND	ND	ND
BDE-100	ND	ND	ND	ND	1,300	220	ND	100
BDE-99	ND	150	ND	ND	8,500	780	ND	300
BDE-154	ND	ND	ND	ND	130	ND	ND	ND
BDE-153	ND	ND	ND	ND	1,400	130	ND	65
BDE-183	ND	ND	ND	ND	122	17	14	ND
BDE-206	ND	ND	ND	ND	ND	ND	ND	ND
BDE-209	ND	ND	ND	ND	ND	ND	ND	ND
TBB	190	1,100	140	110	31,000	4,300	410	220
TBPH	43	520	54	110	14,000	3,200	150	130
BTBPE	ND	ND	ND	ND	ND	ND	ND	ND
DBDPE	ND	ND	ND	ND	ND	ND	360	ND
α-HBCD	ND	ND	ND	ND	ND	ND	ND	ND
β-HBCD	ND	ND	ND	ND	ND	ND	ND	ND
γ-HBCD	ND	ND	ND	ND	ND	ND	ND	ND
TCEP	ND	ND	ND	1,000	1,100	ND	ND	680
TCPP	870	ND	ND	1,700	3,700	ND	520	750
TDCPP	230	720	320	1,300	81,000	13,000	2,400	6,200
TBBPA	ND	ND	ND	52	50	ND	51	ND

ND = not detected at the limit of detection of 1 nanogram per sample.

Table C3. Flame retardant levels in gymnastics area window and office window wipe samples at each gymnastics studio facility (1–4) in April 2015 after foam block replacement and gymnastics studio cleaning (nanogram/4 ft^2)

Flame retardant	Windows office area				Windows - gymnastics area			
	1	2	3	4	1	2	3	4
BDE-28	ND	ND	ND	ND	ND	ND	ND	ND
BDE-47	42	ND	ND	701	84	28	13	8.6
BDE-66	ND	ND	ND	ND	ND	ND	ND	ND
BDE-85	9.3	ND	ND	ND	ND	8.8	ND	ND
BDE-100	5.8	3.3	ND	4.0	ND	3.4	ND	6.3
BDE-99	100	14	15	18	25	86	11	17
BDE-154	ND	ND	ND	ND	ND	ND	ND	ND
BDE-153	ND	ND	ND	ND	ND	ND	ND	ND
BDE-183	ND	ND	ND	ND	ND	ND	ND	ND
BDE-206	ND	ND	ND	ND	ND	ND	ND	ND
BDE-209	30	69	50	1,100	ND	17	120	73
TBB	220	25	18	21	220	220	17	17
TBPH	43	8.5	5.3	11	92	86	8.8	9.0
BTBPE	ND	ND	ND	ND	ND	ND	ND	ND
DBDPE	14	60	150	130	170	140	67	110
α-HBCD	ND	ND	ND	ND	ND	ND	ND	ND
β-HBCD	ND	ND	ND	ND	ND	ND	ND	ND
γ-HBCD	ND	ND	ND	ND	ND	ND	ND	ND
TCEP	ND	ND	ND	ND	ND	ND	ND	ND
TCPP	140	ND	ND	ND	230	ND	ND	ND
TDCPP	540	170	130	120	520	1,100	180	470
TBBPA	ND	ND	ND	ND	ND	ND	ND	ND

ND = not detected at the limit of detection of 1 nanogram per sample.

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Keywords: North American Industry Classification System 611699 (All Other Miscellaneous Schools and Instruction), Washington, Flame Retardants, Foam, Gymnastics Studio, Coaches Gymnasium, Gymnastics, Gymnast

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Acknowledgments

Analytical Support for Flame Retardants Analysis: Rosa Key-Schwartz, Paula Fey-O'Connor, Mark La Guardia at Virginia Institute of Marine Science, College of William & Mary
Analytical Support for Spectroscopy: Chen Wang
Desktop Publisher: Shawna Watts
Editor: Ellen Galloway
Logistics: Donnie Booher, Kevin Moore

Availability of Report

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Recommended citation for this report:
NIOSH [2017]. Occupational exposure to flame retardants at four gymnastics studios. By Broadwater K, Ceballos D, Page E, Croteau G*, Mueller C. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, NIOSH Health Hazard Evaluation Report 2014-0131-3268, http://www.cdc.gov/niosh/hhe/reports/pdfs/2014-0131-3268.pdf.

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