Gymnasium Foam Replacement Study:

Assessment of Flame Retardants in Foam and Dust Before and After Product Replacement

By

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For the

Environmental Assessment Program

Washington State Department of Ecology
Olympia, Washington

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Cover Photo: Foam cubes before replacement (left) and after replacement (right) at a gymnastics facility that participated in this study. Photos taken by Ecology staff.

[1] https://www.ecology.wa.gov/Research-Data/Data-resources/Environmental-Information-Management-database
[2] https://apps.ecology.wa.gov/consumerproducts

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Abstract

In a pilot project, the Washington State Department of Ecology's Product Replacement Program replaced toxic flame-retardant foam pit cubes with flame-retardant-free ones at two gymnastic facilities. This 2024 – 2025 product replacement study assessed flame-retardant levels in the foam pit cubes in use before replacement and in the replacement foam pit cubes, as well as levels in pit-adjacent floor dust before and after replacement. This report presents the results of this study.

All foam pit cubes that had been in use at both gymnastic facilities contained measurable concentrations of flame retardants. All replacement foam pit cubes were free of the flame retardants tested in this study. When dust results before and after replacement are compared, flame retardants in dust from one facility showed a reduction in four flame retardants of greater than 100 mg/kg, while those in dust from the second facility did not change by more than 100 mg/kg. Foam and dust results indicate that replacing old foam pit cubes reduced a source of toxic flame retardants. Dust results, in particular, highlight the importance of cleaning the entire foam pit and surrounding area, as well as replacing or deep cleaning porous textile surfaces near the foam pits to help reduce accumulated flame retardants in the facility.

Introduction

Ecology's Hazardous Waste and Toxic Reduction Program (HWTRP), in partnership with the Environmental Assessment Program (EAP), conducted a pilot project to evaluate the replacement of foam pit cubes containing toxic and unnecessary flame retardants with foam pit cubes free of flame retardants at two recreational gymnastic facilities. The pilot project was performed as part of HWTRPs Product Replacement Program (PRP) to identify opportunities, barriers, and the feasibility of a statewide reimbursement program for a Flame Retardant Foam Replacement Program.

This study was performed to assess how much toxic flame retardants were in foam pit cubes before replacement and in foam pit cubes after replacement. Since certain flame retardants are persistent in the environment, this study also assessed changes in flame retardant concentrations in pit-adjacent indoor floor dust before and after replacement activities.

Foam pits are large, in-ground cushioned areas filled with foam cubes used at gymnastics training facilities to provide a safe landing surface for gymnasts learning new skills or practicing complex maneuvers. Foam pits are generally filled with foam pit cubes of various sizes, but may be filled with foam sheets, noodles, or tubes of variable sizes depending on use. Foam pits typically have an additional support structure underneath the foam cubes, like a trampoline or larger foam mats (Figure 1).

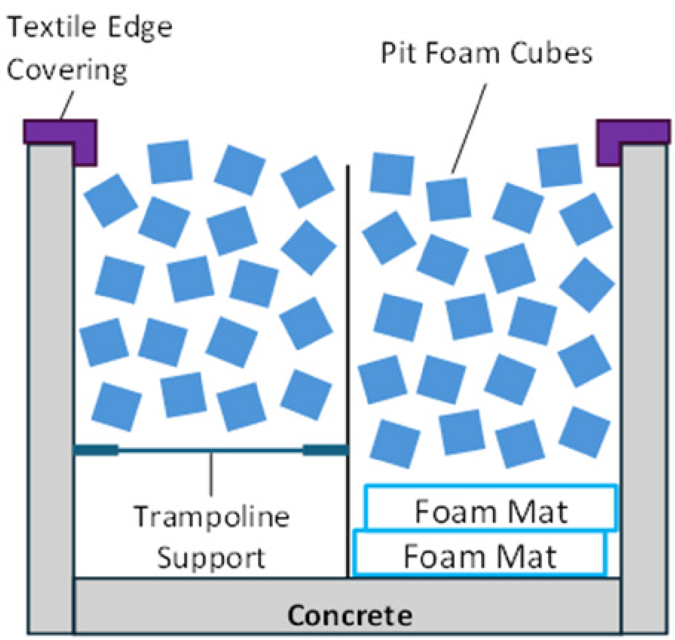

Figure 1. A cross-sectional view showing two different types of pit foam cube support structures, trampoline support, and foam mats.

Flame retardants have been added to foam pit cubes to inhibit combustion or delay the spread of fire after ignition (van der Veen and de Boer 2012). While fire safety measures are very important for the overall safety of gymnastic facilities, a 2019 study demonstrated that both pit cubes with and without added flame retardants resisted a smolder ignition source but produced severe fires when exposed to a small flame ignition source (Dembsey et al. 2019). The study further suggested that an existing sprinkler system adequate to control a gymnasium fire would likely also offer control of a fire involving flame-retardant-free foam since they burn similarly (Dembsey et al. 2019).

Foam pit cubes can be a significant source of flame retardants to the gym environment, as studies have shown substantially higher concentrations in dust and air near foam pits compared to other areas of the gym and other indoor environments (Carignan et al. 2013; La Guardia and Hale 2015; Ceballos et al. 2018; Dembsey et al. 2019). Aging, broken-down foam pit cubes can make up a large portion of the dust in and near the foam pit, and this “pit dust” is known to stick to the skin of people using the foam pit (Carignan et al. 2013; Dembsey et al. 2019). Flame retardants can volatilize from foam and accumulate in dust and on surfaces, including the skin, and enter the body (Stapleton et al. 2009; Carignan et al. 2013; Carignan et al. 2016; Ceballos et al. 2018). The most well-understood exposure routes for flame retardants to the general population include inhalation, skin contact, and incidental dust ingestion (Allen et al. 2007; Allen et al. 2008; Stapleton et al. 2009; La Guardia and Hale 2015; Schreder et al. 2016).

Different flame retardants have been used in recreational gym foam over time, and not all flame retardants are the same. Polybrominated diphenyl ethers (PBDEs) were used in many types of foam products from the 1980s until the mid-2010s. PBDEs include PentaBDE, a mixture used in many foam products until it was banned in 2004 by the U.S. Environmental Protection Agency. The PBDEs measured in this study are in the PentaBDE category. The manufacture and import of PBDE-containing products in the United States were phased out between 2004 and 2013. Over time, manufacturers started using alternative flame retardants in foam pit cubes, including but not limited to TBB, TBPH, TCEP, TCPP, TDCPP, and TPP.

The flame retardants assessed in this study are organohalogen flame retardants (OFRs), which contain halogens, bromine, and chlorine, and organophosphate flame retardants (OPFRs), which contain phosphorus. The PBDEs, TBPH, and TBB are OFRs, while TCEP, TCPP, TDCPP, and TPP are OPFRs. OFRs and OPFRs are hazardous to environmental and human health and are persistent in the environment (Ecology 2022b). Many OFRs and OPFRs can disrupt endocrine and immune systems, cause cancer, and have harmful effects on children’s growth, development, and neurological function (van der Veen and de Boer 2012; Lyche et al. 2014; Blum et al. 2019).

Under the Safer Products for Washington program (RCW 70A.350), Ecology established rules to regulate flame retardants in recreational polyurethane foam. The legislature identified the OFRs chemical class and five OPFRs previously identified in the Children’s Safe Product Act (Chapter 70A.430 RCW) as priority chemicals when the law was passed in 2019. The adopted rule, Chapter 173-337 WAC, specified restrictions and reporting requirements for OFRs and select OPFRs used in certain recreational polyurethane foam products, including foam pit cubes. The restrictions outlined in WAC Chapter 173-337 for flame retardants in recreational polyurethane foam took effect on January 1, 2025.

Methods

Study methods followed the quality assurance project plan (QAPP) (Salamone 2024) and standard operating procedure (SOP) PTP001 *Product Collection and Sample Processing* (Ecology 2021).

Participant Gymnasiums

This study took place at two recreational gymnastics facilities recruited and approved by the PRP. Both facilities offer gymnastics training and activity classes for children and adults, and are located in areas of Washington that rank high, level 9 – 10, on the Washington Environmental Health Disparities Map version 2.0 (published July 29, 2022).[3]

Both facilities report that aging and deteriorating foam cubes are disposed of as they are noticed on a semi-regular basis (i.e., heavily pitted foam cubes are removed a few times a year). When funding is available, new foam pit cubes are purchased to replace the cubes that have been removed. Neither of the participating facilities had undergone a full foam change-out since they were initially installed.

The foam cubes were reported to have aged differently depending on the location and depth within the foam pits. Foam cubes in sections of higher use and impact receive more compression and friction and are more likely to break down quickly. High-use areas can include sections along the perimeter with room to run and jump into the pit and room to exit the pit, fall zones beneath uneven bars, and springboard or vaulting safety zones. Foam cubes at the surface of the pits were observed to have faded more quickly than foam cubes deep within the pits, likely due to increased light exposure (França de Sá 2017).

Variable aging and incremental replacement mean these foam pits contained a mixture of older and newer foam cubes of multiple different types. The distribution of foam cube types within each foam pit was random and not homogeneous at both facilities.

Metropolitan Gymnastics (MET), located in Kent, Washington, has two foam pits that were included in this study (Figure 2). The two foam pits are in the main gym of the facility, which is a large, over 21,000 square feet, interconnected warehouse with about 30 feet high ceilings, and has multiple heating, ventilation, and cooling (HVAC) systems throughout. Both foam pits are surrounded by a mix of textile edge coverings like cut-pile carpet, foam-bonded carpet, and padded mats. Foam pit #1 measures 523 square feet, was installed in 2003, and has covered foam mats lining the base of the pit. Foam pit #2 measures 380 square feet, was installed in 2013, and has a trampoline installed at the base to support foam cubes on top of the netting.

[3] https://fortress.wa.gov/doh/wtnibl/WTNIBL/Map/EHD

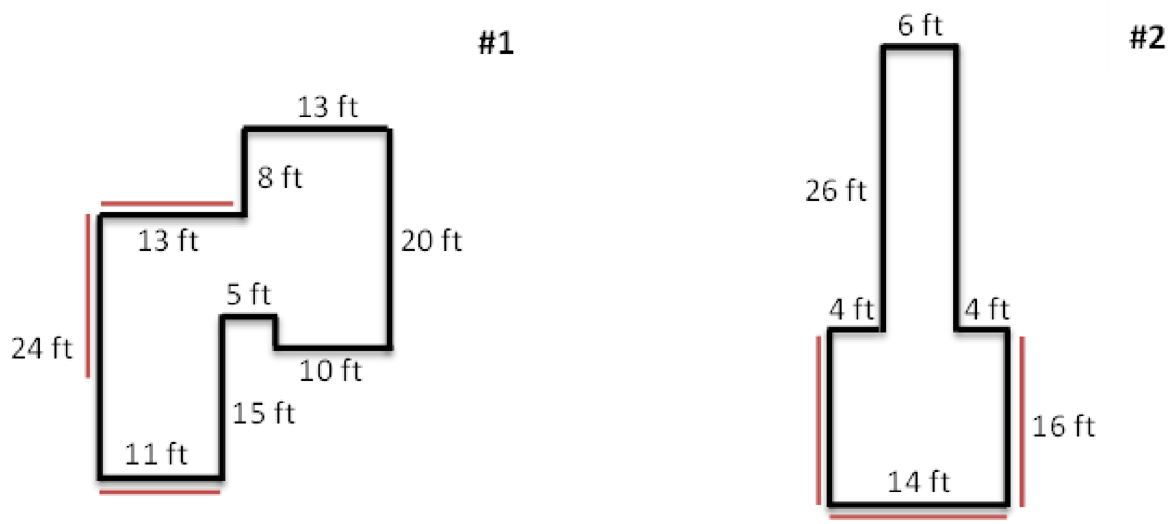

Figure 2. Schematic drawing of Metropolitan Gymnastics (MET) foam pits #1 and #2. Red bars indicate high-use areas of the foam pits.

Lakewood Family YMCA (LFY), located in Lakewood, Washington, has one foam pit that was included in this study (Figure 3). The gymnastics room at LFY is about 8,000 square feet with an estimated 30-foot-high ceiling and has its own HVAC system that is not shared with other areas of the facility. The LFY foam pit is surrounded by foam-bonded carpet edge covering and padded mats, measures 1,136 square feet, was installed in 1992, and has a trampoline installed at the base to support foam cubes on top of the netting.

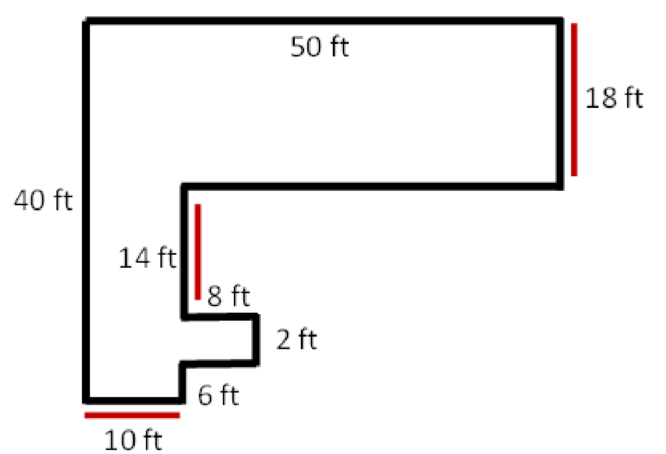

Figure 3. Schematic drawing of the Lakewood Family YMCA (LFY) foam pit. Red bars indicate high-use areas of the foam pit.

Foam Collection and Processing

Before Replacement

During before-replacement sampling, three foam pit cubes of each color were collected from each foam pit. While at the facility, sections of foam were removed from each of the three pit cubes and combined and packaged as one sample. At Ecology Headquarters, the interior sections of pit cube samples were hand-reduced and stored in labeled glass jars at ambient temperature prior to submitting to the lab.

Before foam replacement, MET foam pit #1 contained 9 different color types (Figure 4) and MET foam pit #2 contained 4 different color types (Figure 5). The LFY foam pit contained 7 different color types before replacement (Figure 6). Assigned sample IDs convey information about the place of collection, the collection event, product number, and component number (e.g., "MET-1-3-1" means Metropolitan Gymnasium, collection event 1, sample number 3, and component number 1 of the sample).

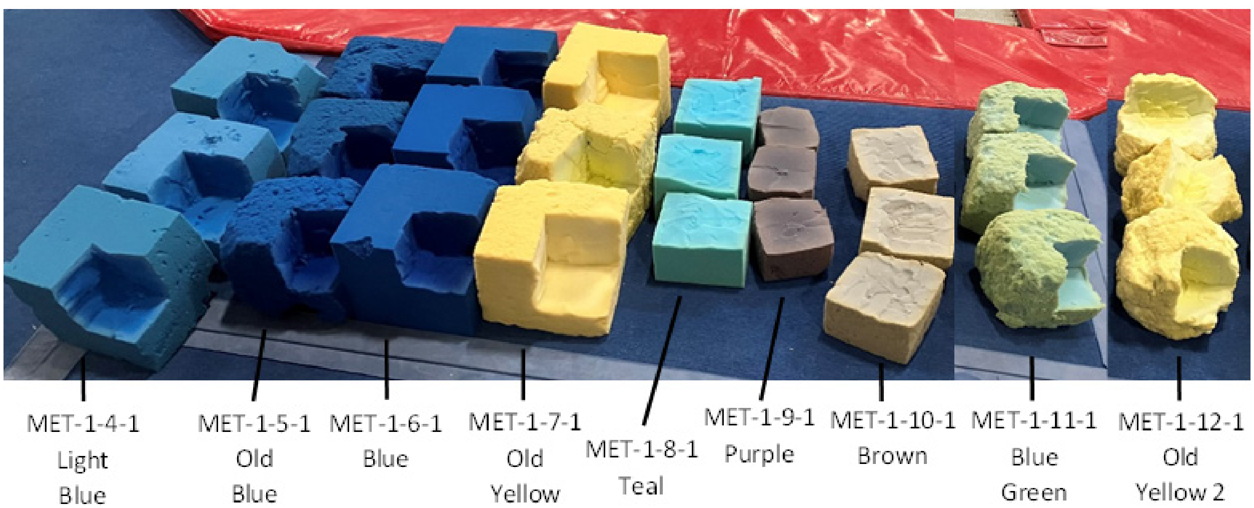

Figure 4. Nine foam pit cube color types collected from Metropolitan Gymnastics (MET) foam pit #1 before replacement.

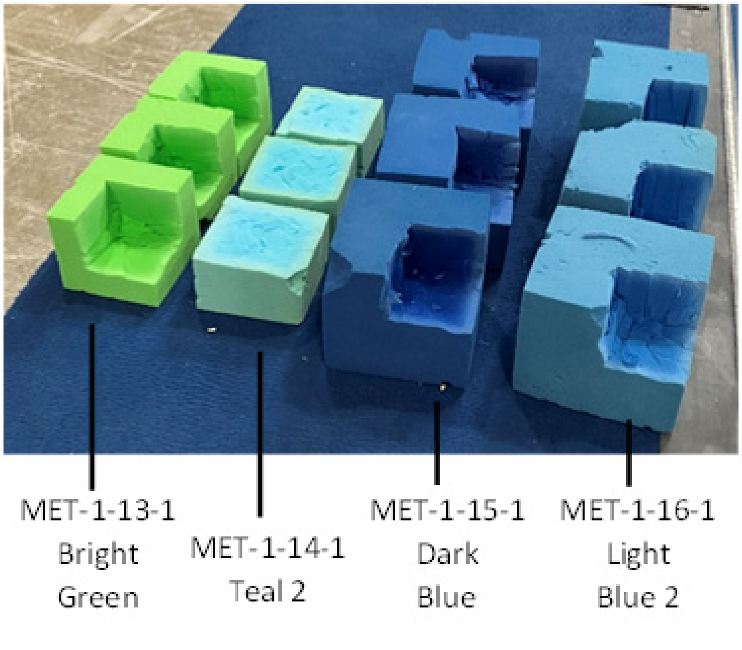

Figure 5. Four foam pit cube color types collected from Metropolitan Gymnastics (MET) foam pit #2 before replacement.

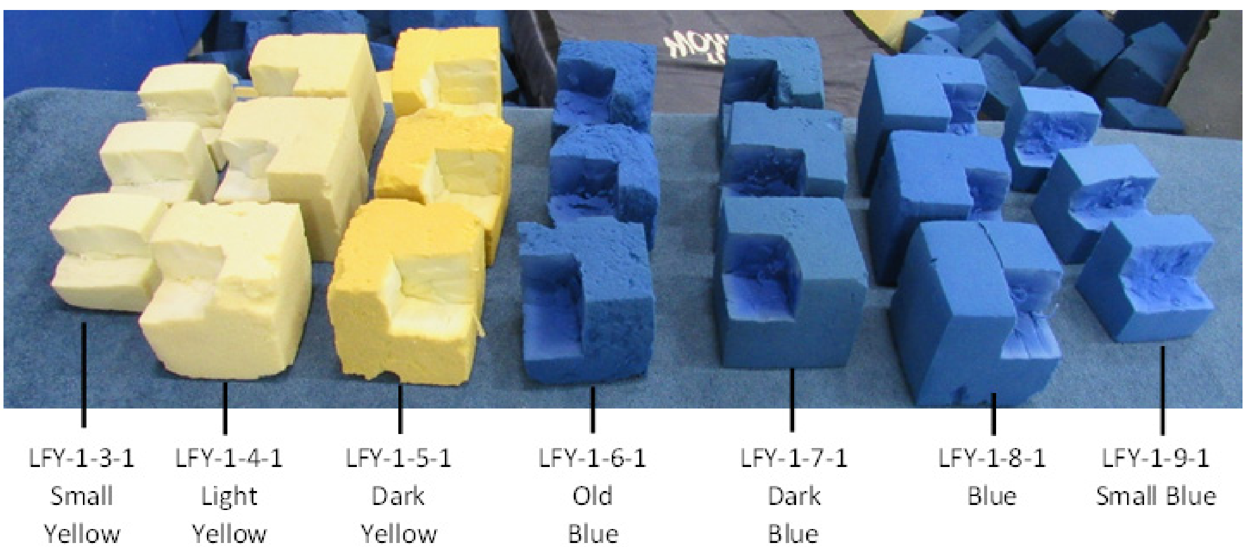

Figure 6. Seven foam pit cube color types collected from the Lakewood Family YMCA (LFY) foam pit before replacement.

After Replacement

During after-replacement sampling, three foam pit cubes of each color present were collected. The replacement foam pit cubes were collected whole, without removing sections of foam at the facility. At Ecology Headquarters, pit cubes were sectioned to collect samples from the interior of the cube. The interior sections were then hand-reduced and stored in labeled glass jars at ambient temperature before being submitted to the lab.

After foam replacement, MET foam pit #1 had one color type of foam (MET-2-3-1 is blue, Figure 7), and pit #2 had one color type of foam (MET-2-4-1 is red, Figure 8). LFY foam pit had two color types of foam (LFY-2-3-1 is purple and LFY-2-4-1 is blue, Figure 9) after replacement. Each gym selected the colors of its replacement foam cubes, but all cubes were of the same brand, size, and from the same vendor.

Figure 7. One foam pit cube color type (blue) collected from Metropolitan Gymnastics foam pit #1 after replacement.

Figure 8. One foam pit cube color type (red) collected from Metropolitan Gymnastics foam pit #2 after replacement.

Figure 9. Two foam pit cube types (purple and blue) collected from the Lakewood Family YMCA foam pit after replacement.

Dust Collection

Pit-adjacent indoor floor dust samples were collected from floor coverings immediately surrounding the foam pit area (within 2 feet of the perimeter) using a vacuum (Eureka MightyMite model 3670) fitted with a Kimwipe (Kimtech Science Delicate Task Kimwipes 34120) secured to the round wand extension (Figure 10). It was planned to use a cellulose filter; however, the filter impeded air flow for dust collection at the first sampling event. Kimwipes were substituted to collect dust, and one unused Kimwipe from the same box was submitted to the lab as a collection blank quality control sample.

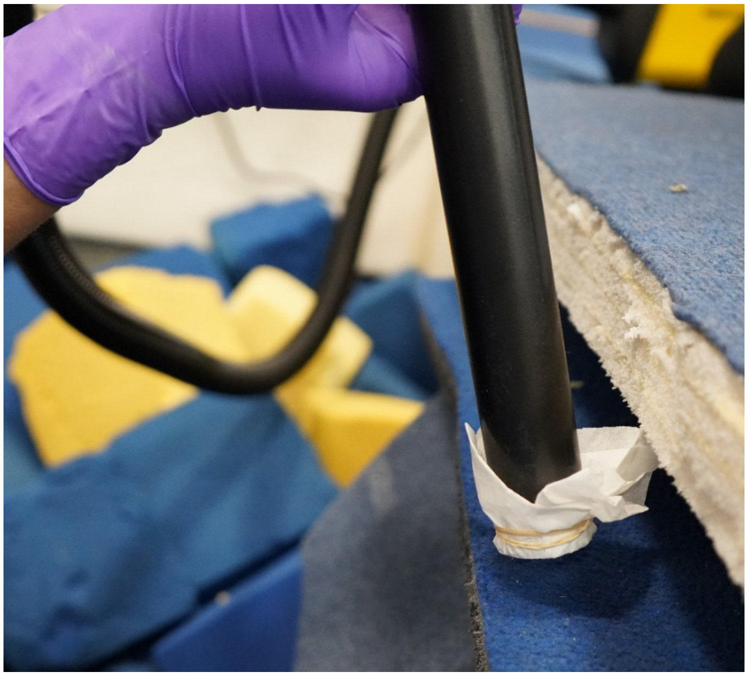

Figure 10. Floor dust sample collection using a vacuum wand extension fitted with a Kimwipe.

One field blank of sodium sulfate powder was collected off a sheet of aluminum foil at the beginning of each sampling event. One bulk sample of pit-adjacent floor dust was collected during each sampling event from three to four sections of flooring that appeared to be high-use areas. High-use areas were those that were accessible by directly running and jumping into the foam pit and are indicated by red bars in the foam pit schematics, Figures 1 and 2. Sections that were abutting a wall or blocked by equipment were not included in high-use areas.

Floor dust was collected by touching the mouth of the wand extension to the floor in an up-and-down motion to accumulate dust on the Kimwipe surface. Once the Kimwipe contained a visual layer of dust, the vacuum was turned off, and the dust was transferred into a glass jar. This process was repeated until an estimated weight of one gram was collected.

Dust samples were labeled and transported to Ecology Headquarters in a cooler with ice. Since they are categorized as environmental samples, dust samples were stored in a walk-in cooler at 4°C before being submitted to the lab.

Foam Removal and Pit Cleaning

The PRP led removal of old foam, cleaning the foam pits, and replacement with flame-retardant-free foam. The time between site cleaning and after-replacement sampling was 5 weeks for MET and 4 weeks for LFY. A vendor was contracted to complete all removal, cleaning, and disposal procedures in accordance with Washington State and Federal laws for the disposal of hazardous waste. Site cleaning is not equivalent to decontamination or remediation.

Steps performed by the vendor for removal of old foam, site cleaning, and waste disposal included:

- Removal of all existing foam cubes into trash bags and loading into an industrial roll-off bin sealable for transportation to a disposal facility.
- Vacuuming of the foam pit and surrounding flooring surfaces to a 5 ft perimeter with a HEPA-filtered vacuum cleaner.
- Wipe down all interior surfaces of the foam pit and trampoline structures inside the foam pit using rags and Simple Green Degreaser.
- Removal of all vacuumed particles and used rags in trash bags for disposal.
- Transported all foam cubes and bagged waste to an appropriate disposal facility.

One notable difference in site cleaning was that the trampoline support at the bottom of the LFY foam pit was not removed to clean the flooring underneath since doing so would compromise the securing spring and hook mechanisms. Therefore, the trampoline was vacuumed and wiped down in lieu of cleaning the flooring underneath. The trampoline at MET foam pit #2 was removed to facilitate cleaning underneath, and the large foam mats at the bottom of MET foam pit #1 were removed for cleaning as well.

Laboratory Analysis

Samples were analyzed for flame retardants in Table 1 following EPA Method 3546 and EPA Method 8270E at Manchester Environmental Laboratory (MEL). MEL staff and the principal investigator verified laboratory products following the study's QAPP (Salamone 2024) and SOP PTP002 *Data Entry and Data Entry Quality Assurance* (Ecology 2022a).

Table 1. Flame retardants assessed as part of this study.

Flame Retardant Chemical	Abbreviation	CAS RN
tris(1,3-dichloro-2-propyl) phosphate	TDCPP	13674-87-8
tris(2-chloroethyl) phosphate	TCEP	115-96-8
tris(1-chloro-2-propyl) phosphate	TCPP	13674-84-5
triphenyl phosphate	TPP	115-86-6
2-ethylhexyl-2,3,4,5 tetrabromobenzoate	TBB	183658-27-7
bis(2-ethylhexyl) tetrabromophthalate	TBPH	26040-51-7
2,2',4,4'-tetrabromodiphenyl ether	BDE-047	5436-43-1
2,3',4,4'-tetrabromodiphenyl ether	BDE-066	189084-61-5
2,2',4,4',5-pentabromodiphenyl ether	BDE-099	60348-60-9
2,2',4,4',6-pentabromodiphenyl ether	BDE-100	189084-64-8
2,2',4,4',5,5'-hexabromodiphenyl ether	BDE-153	68631-49-2
2,2',4,4',5,6'-hexabromodiphenyl ether	BDE-154	207122-15-4

CAS RN = Chemical Abstracts Service Registry Number

Results

This report presents results from sampling foam and dust before and after product replacement activities at two gymnastic facilities. All flame-retardant results from this study are presented in Table A-1.

Data Quality

Flame-retardant analyses met established method quality objectives (MQO) in the QAPP (Salamone 2024). Requested reporting limits were met except for samples that required dilution and reanalysis due to high flame retardant recoveries and matrix interferences with an internal standard. Recovery rates for method surrogate decachlorobiphenyl ranged from 93% to 106% and method surrogate triphenyl phosphate-d15 ranged from 101% to 103% across lab batches. Matrix spike and matrix spike duplicate recoveries ranged from 69% to 108% across lab batches. The relative percent difference (RPD) between sample replicates ranged from 0.1% to 4.9% across lab batches. All data for this study were accepted for use.

Foam

A total of 24 samples of foam cubes were submitted to MEL for analysis of flame retardants. All 20 foam samples collected before replacement from both gymnastics facilities contained measurable flame-retardant concentrations. In contrast, none of the four replacement foam samples contained detectable levels of flame retardants.

MET Foam Pit #1

Flame-retardant data for before-replacement foam pit cubes from MET pit #1 are in Table 2. Out of the nine foam cube samples from MET foam pit #1:

- Three foam cube samples contained higher levels of flame retardants compared to the others:
    - MET-1-11-1 at 56,300 mg/kg,
    - MET-1-8-1 at 50,056 mg/kg, and
    - MET-1-10-1 at 47,687 mg/kg.
- Three foam cube samples contained median levels of flame retardants compared to the others:
    - MET-1-4-1 at 26,560 mg/kg,
    - MET-1-12-1 at 21,344 mg/kg, and
    - MET-1-7-1 at 11,252 mg/kg.
- Three foam cube samples contained lower levels of flame retardants compared to the others:
    - MET-1-9-1 at 3,270 mg/kg,
    - MET-1-6-1 at 2,887 mg/kg, and
    - MET-1-5-1 at 2,309 mg/kg.

In four out of nine foam cube samples (MET-1-4-1, MET-1-7-1, MET-1-11-1, MET-1-12-1), TBB was the maximum detected flame retardant concentration. TPP was the highest level flame retardant in two foam cubes, MET-1-5-1 and MET-1-6-1. TDCPP was the highest level flame retardant in foam cube MET-1-8-1, which was also the maximum level of any flame retardant detected in MET pit #1 foam samples at 50,000 mg/kg. Total PentaBDE concentrations were highest in MET-1-10-1 (40,374 mg/kg) and MET-1-9-1 (2,445 mg/kg) in contrast to the other seven pit cubes, which ranged from 206 mg/kg down to not detected above 10 mg/kg (nd).

Table 2. Flame retardant concentrations (mg/kg) detected[1] in before-replacement foam samples from Metropolitan Gymnasium (MET) foam pit #1.

Flame Retardant	MET-1-4-1	MET-1-5-1	MET-1-6-1	MET-1-7-1	MET-1-8-1	MET-1-9-1	MET-1-10-1	MET-1-11-1	MET-1-12-1	Sum of All
BDE-047	nd	13	nd	88	nd	1,110	14,700	nd	20.8	15,932
BDE-066	nd	nd	nd	nd	nd	15	214	nd	nd	229
BDE-099	nd	12.7	nd	94.2	nd	968	17,600	nd	21.9	18,697
BDE-100	nd	nd	nd	23.7	nd	209	4,490	nd	nd	4,723
BDE-153	nd	nd	nd	nd	nd	77.3	1,870	nd	nd	1,947
BDE-154	nd	nd	nd	nd	nd	65.8	1,500	nd	nd	1,566
TBB	17,000	nd	nd	7,320	nd	218	415	37,500	14,000	76,453
TBPH	5,510	nd	nd	1,980	nd	47.5	88.1	11,600	4,300	23,526
TCPP	nd	nd	nd	nd	55.8	nd	nd	nd	nd	56
TDCPP	nd	123	97.3	45.3	50,000	335	2,200	nd	31.5	52,832
TPP	4,050	2,160	2,790	1,590	nd	224	4,610	7,200	2,970	25,594
Sum of All	26,560	2,309	2,887	11,141	50,056	3,270	47,687	56,300	21,344	221,554

[1] TCEP results were nd for all samples.

nd = not detected above 10 mg/kg.

After-replacement foam pit cube samples from MET pit #1, MET-2-3-1, did not contain any of the assessed flame retardants.

MET Foam Pit #2

Flame-retardant data for foam pit cubes from MET pit #2 are in Table 3. Out of the four foam cube samples from MET foam pit #2:

- Three contained higher levels of detected flame retardants compared to the others:
  - MET-1-14-1 at 58,210 mg/kg,
  - MET-1-13-1 at 42,654 mg/kg, and
  - MET-1-16-1 at 30,728 mg/kg.
- The fourth foam cube sample (MET-1-15-1) contained fewer measured flame retardants at 1,584 mg/kg total.

Two out of four foam cube samples from MET pit #2 contained TDCPP as the highest detected flame retardant, MET-1-14-1 at 57,700 mg/kg and MET-1-13-1 at 39,000 mg/kg, which were also the top two maximum concentrations of any flame retardant detected in MET pit #2 foam samples. TBB was the highest level flame retardant in foam cube MET-1-16-1, while TPP was the highest detected in MET-1-15-1. None of the PentaBDE mixture of flame retardants were detected in cube samples from MET foam pit #2.

Table 3. Flame retardant concentrations (mg/kg) detected[1] in before-replacement foam samples from Metropolitan Gymnasium (MET) foam pit #2.

Flame Retardant	MET-1-13-1	MET-1-14-1	MET-1-15-1	MET-1-16-1	Sum of All
TBB	2,860	301	146	18,900	22,207
TBPH	425	68.5	40.5	6730	7,264
TCPP	15.5	59.9	nd	nd	75
TDCPP	39,000	57,700	127	27.8	96,855
TPP	353	80.4	1,270	5,070	6,773
Sum of All	42,654	58,210	1,584	30,728	133,175

[1] BDE-047, BDE-066, BDE-099, BDE-100, BDE-153, BDE-154, and TCEP results were nd for all samples.
nd = not detected above 10 mg/kg.

After-replacement foam pit cube samples from MET pit #2, MET-2-4-1, did not contain any of the assessed flame retardants.

LFY Foam Pit

Flame-retardant data for before-replacement foam pit cubes from LFY are in Table 4. Out of the seven foam cube samples from the LFY foam pit:

- Two contained much higher levels of detected flame retardants above 65,000 mg/kg.
  - LFY-1-9-1 at 73,000 mg/kg and
  - LFY-1-5-1 at 66,802 mg/kg.
- Two foam cube samples contained median concentrations of flame retardant compared to the others:
  - LFY-1-4-1 at 23,472 mg/kg and
  - LFY-1-3-1 at 3,992 mg/kg.
- The remaining three foam cube samples contained much lower concentrations of total detected flame retardants, less than 1,000 mg/kg total:
  - LFY-1-6-1 at 944 mg/kg,
  - LFY-1-7-1 at 545 mg/kg, and
  - LFY-1-8-1 at 252 mg/kg.

Three out of seven foam cube samples from LFY contained flame retardants BDE-099 and BDE-047 as the top two maximum concentrations and total PentaBDE concentrations at 3,109 mg/kg for LFY-1-3-1, 24,346 mg/kg for LFY-1-4-1, and 62,622 mg/kg for LFY-1-5-1. The remaining four foam cube samples contained TBB as the highest level flame retardant, although concentrations were below 500 mg/kg in three of the four samples: LFY-1-9-1 at 44,600 mg/kg, LFY-1-6-1 at 423 mg/kg, LFY-1-7-1 at 247 mg/kg, and LFY-2-8-1 at 125 mg/kg.

Table 4. Flame retardant concentrations (mg/kg) detected[1] in before-replacement foam samples from Lakewood Family YMCA (LFY) foam pit.

Flame Retardant	LFY-1-3-1	LFY-1-4-1	LFY-1-5-1	LFY-1-6-1	LFY-1-7-1	LFY-1-8-1	LFY-1-9-1	Sum of All
BDE-047	1,200	8,100	18,200	62.4	37.2	15.4	nd	27,615
BDE-066	15.6	117	292	nd	nd	nd	nd	425
BDE-099	1,440	11,100	30,500	90.9	55.8	18.6	nd	43,205
BDE-100	226	2,630	6,270	20.7	13.2	nd	nd	9,160
BDE-153	132	1,530	4,240	13.4	nd	nd	nd	5,915
BDE-154	95.5	869	3,120	10.5	nd	nd	nd	4,095
TBB	337	46.8	nd	412	247	125	44,600	45,768
TBPH	112	nd	nd	156	93	51	14,600	15,012
TDCPP	198	78.9	nd	36.5	18.7	nd	nd	332
TPP	236	2,000	4,180	142	79.8	42	13,800	20,480
Sum of All	3,992	26,472	66,802	944	545	252	73,000	172,007

[1] TCEP and TCPP results were nd for all samples.
nd = not detected above 10 mg/kg.

After-replacement foam pit cube samples from LFY foam pit, LFY-2-3-1, and LFY-2-4-1 did not contain any of the assessed flame retardants.

Dust

Dust results collected before- and after-replacement, and the differences between the two, are displayed in Tables 5 – 6. Between before- and after-replacement at MET, four flame retardants were reduced by more than 100 mg/kg: BDE-047, BDE-099, TDCPP, and TPP (Table 5). None of the flame retardants in dust changed by more than 100 mg/kg between before- and after-replacement at LFY (Table 6).

Table 5. Flame retardant concentrations (mg/kg) detected[1] in dust samples from Metropolitan Gymnastics (MET).

Flame Retardant	Before-Replacement Dust (MET-1-3-1)	After-Replacement Dust (MET-2-2-1)	Difference
BDE-047	428	264	-164
BDE-066	10	nd[2]	0
BDE-099	818	366	-452
BDE-100	153	87	-67
BDE-153	80	49	-31
BDE-154	64	40	-25
TBB	353	292	-61
TBPH	180	158	-22
TCPP	21	nd[2]	-11
TDCPP	364	144	-220
TPP	205	83	-122

[1] TCEP results were nd for all samples.
[2] Difference calculated using 10 mg/kg for nd sample results.
nd = not detected above 10 mg/kg.

Table 6. Flame retardant concentrations (mg/kg) detected[1] in dust samples from Lakewood Family YMCA (LFY).

Flame Retardant	Before-Replacement Dust (LFY-1-2-1)	After-Replacement Dust (LFY-2-2-1)	Difference
BDE-047	39	75	+36
BDE-099	70	102	+32
BDE-100	16	23	+7
BDE-153	14	16	+2
BDE-154	10	12	+2
TBB	146	239	+93
TBPH	83	118	+35
TDCPP	42	23	-19
TPP	47	36	-11

[1] BDE-066, TCEP, and TCPP results were nd for all samples.
nd = not detected above 10 mg/kg.

Discussion

All foam pit cubes collected before replacement contained detectable levels of flame retardants, and all foam pit cubes collected after replacement were free of flame retardants assessed in this study. Product replacement activities removed a known source of toxic flame retardants from both gymnastics facilities.

The before-replacement foam cubes from both gymnastics facilities were reported to be of varying ages, which was supported by the differential flame-retardant patterns observed. The patterns of flame retardants detected in the before-replacement foam are consistent with previous studies that assessed the same flame retardants in pit foam cubes. Different flame retardants have been used in gym foam products over time. Previous studies have regularly found PentaBDE mixtures in older foam and co-detections of TBB, TBPH, and TPP in newer foam samples, indicating the use of commercial mixture Firemaster 550/600 (La Guardia and Hale 2015; Carignan et al. 2016; Ceballos et al. 2018; Dembsey et al. 2019). Additional alternative flame retardants in newer foam samples were TDCPP, TCPP, and TCEP (La Guardia and Hale 2015; Carignan et al. 2016; Ceballos et al. 2018; Dembsey et al. 2019), which may be used singularly or in mixtures, and are sold under several trade names.

MET provided estimated ages for some of their foam cubes from pits #1 and #2. Samples MET-1-4-1, MET-1-5-1, MET-1-6-1, MET-1-7-1, MET-1-15-1, and MET-1-16-1 were purchased between 2015 and 2017. Samples MET-1-11-1 and MET-1-12-1 were purchased before 2015. Samples MET-1-8-1, MET-1-9-1, MET-1-10-1, MET-1-13-1, and MET-1-14-1 were purchased used from another gym, and were originally purchased sometime before 2018.

Regardless of year of purchase, there are four observable flame-retardant patterns for samples from MET foam pit #1. Foam cube samples MET-1-9-1 and MET-1-10-1 predominantly contain the PentaBDE mixture of flame retardants. Foam cube sample MET-1-8-1 almost exclusively contains TDCPP. Foam cube samples MET-1-5-1 and MET-1-6-1 predominantly contain TPP. Foam cube samples MET-1-4-1, MET-1-7-1, MET-1-11-1, and MET-1-12-1 predominantly contain TBB, TBPH, and TPP. Seven out of nine samples contained low amounts (less than 100 mg/kg) of other flame retardants that did not contribute to the dominant patterns.

Foam cube samples from MET foam pit #2 show three observable flame-retardant patterns. Foam cube samples MET-1-13-1 and MET-1-14-1 predominantly contain TDCPP. Foam cube sample MET-1-15-1 predominantly contains TPP. Foam cube sample MET-1-16-1 contains TBB, TBPH, and TPP. All four samples contained low amounts (less than 100 mg/kg) of other flame retardants that did not contribute to the dominant patterns.

LFY provided estimated years of purchase for their foam cubes. Samples LFY-1-3-1, LFY-4-1, and LFY-1-5-1 were purchased between 1992 and 2003 and predominantly contain the PentaBDE mixture of flame retardants. Cubes LFY-1-6-1, LFY-1-7-1, and LFY-1-8-1 were purchased between 2006 and 2008 and do not contain any of the tested flame retardants greater than 500 mg/kg. The newest cubes, LFY-1-9-1, were purchased in 2012 – 2013 and predominantly contain TBB, TBPH, and TPP. Five out of seven samples contained low amounts (less than 100 mg/kg) of other flame retardants that did not contribute to the dominant patterns.

While there were observable dominant patterns of flame retardants in most samples, there were also consistently low amounts, less than 100 mg/kg, of non-dominant flame retardants in most samples. Altogether, 16 out of 20 foam cube samples contained measurable amounts of other flame retardants that did not contribute to their dominant patterns. Flame retardants have been found to leach, volatilize, or otherwise escape from foam cubes (Stapleton et al. 2009; Carignan et al. 2013; Carignan et al. 2016; Ceballos et al. 2018). The results of this study indicate that flame retardants may migrate among cubes used in the same foam pit over time.

The concentrations of flame retardants in the before- and after-replacement dust samples are consistent with previous studies of the same flame retardants in gym dust that used the same vacuum collection method (Carignan et al. 2013; La Guardia and Hale 2015). The presence of certain flame retardants in before-replacement dust was correlated with their presence in before-replacement foam cubes. At LFY, the greatest contributor to the sum of flame retardants in the before-replacement dust and foam cube samples was TBB. TBB was 31% of total flame retardants in the before-replacement dust and 27% of total flame retardants in foam cube samples from LFY. Similarly, but less correlated, at MET, TBB made up 13% of total flame retardants in before-replacement dust and 34% of total flame retardants in foam cube samples.

Since none of the after-replacement foam cubes contained flame retardants, the flame retardants in after-replacement dust samples were likely residual from before-replacement foam cubes or from other products in the facility. This study had a small sample size, which limited the inclusion of other products or factors that may have influenced the concentrations of flame retardants in dust. Both participating gyms have additional gymnastics equipment with foam padding and large areas of foam-bonded carpet flooring, which may have contributed to flame retardants detected in dust samples. At LFY, flame retardants in dust may have been influenced by the remaining dust underneath the trampoline support, as residual dust particles may migrate over time up to the surface with foam pit usage. Results indicate that residual dust, foam particles, and flame retardants may build up in textile floor coverings surrounding the foam pit, highlighting the importance of thorough, deep cleaning.

Conclusions

Results of this study support the following conclusions:

- Replacement activities reduced a source of toxic flame retardants in participating gymnastics facilities.
- A full foam change-out is recommended over incremental replacement since flame retardants may migrate between cubes used in the same foam pit over time.
- More sources of flame retardants in the facility may have contributed to the presence of flame retardants found in the after-replacement dust.
- Cleaning the entire pit structure, including under trampoline or foam supports, may lead to a reduction in the presence of flame retardants in after-replacement dust.
- Replacing or deep cleaning porous textile surfaces near the foam pits may reduce accumulated flame retardants.
- Further studies could assist in identifying additional sources of flame retardants in gymnastics facilities.
- Further reduction in flame-retardant levels in gymnastics facilities may be achieved by replacing other, older foam products with those that are certified flame-retardant-free.
- Further evaluation of flame retardants in dust may indicate that removal of the foam source lessens the flame retardant burden in the environment over time.

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Acronyms and Abbreviations

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BDE	brominated diphenyl ether
CPD	Consumer Products Database
EAP	Environmental Assessment Program
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
EPA	U.S. Environmental Protection Agency
HVAC	heating, ventilation, and air conditioning
LFY	Lakewood Family YMCA
MEL	Manchester Environmental Laboratory
MET	Metropolitan Gymnastics
OFR	organohalogen flame retardant
OPFR	organophosphate flame retardant
PRP	Product Replacement Program
RPD	relative percent difference
SOP	standard operating procedures
TBB	2-ethylhexyl-2,3,4,5 tetrabromobenzoate
TBPH	bis(2-ethylhexyl) tetrabromophthalate
TCEP	tris(2-chloroethyl) phosphate
TCPP	tris(2-chloroisopropyl) phosphate
TDCPP	tris(1,3-dichloro-2-propyl) phosphate
TPP	triphenyl phosphate
WAC	Washington Administrative Code

Units of Measurement

ft	feet
g	gram, a unit of mass
kg	kilograms, a unit of mass equal to 1,000 grams
mg	milligram
mg/kg	milligrams per kilogram (parts per million)

Appendix A. Study Results

Table A-1. Flame retardant results in milligram per kilogram (mg/kg) from foam and dust samples collected for this study.

Sample ID	Sample Description	BDE-047	BDE-066	BDE-099	BDE-100	BDE-153	BDE-154	TBB	TBPH	TCEP	TCPP	TDCPP	TPP
LFY-1-2-1	Before Replacement Dust	39	nd	70	16	14	10	146	83	nd	nd	42	47
LFY-1-3-1	Small Yellow Foam Block	1,200	16	1,440	226	132	96	337	112	nd	nd	198	236
LFY-1-4-1	Light Yellow Foam Block	8,100	117	11,100	2,630	1,530	869	47	nd	nd	nd	79	2,000
LFY-1-5-1	Dark Yellow Foam Block	18,200	292	30,500	6,270	4,240	3,120	nd	nd	nd	nd	nd	4,180
LFY-1-6-1	Old Blue Foam Block	62	nd	91	21	13	11	412	156	nd	nd	37	142
LFY-1-7-1	Dark Blue Foam Block	37	nd	56	13	nd	nd	247	93	nd	nd	19	80
LFY-1-8-1	Blue Foam Block	15	nd	19	nd	nd	nd	125	51	nd	nd	nd	42
LFY-1-9-1	Small Blue Foam Block	nd	nd	nd	nd	nd	nd	44,600	14,600	nd	nd	nd	13,800
LFY-2-2-1	After Replacement Dust	75	nd	102	23	16	12	239	118	nd	nd	23	37
LFY-2-3-1	Replacement Purple Foam Block	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
LFY-2-4-1	Replacement Blue Foam Block	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
MET-1-3-1	Before Replacement Dust	428	10	818	153	80	64	353	180	nd	21	364	205
MET-1-4-1	Light Blue Foam Block	nd	nd	nd	nd	nd	nd	17,000	5,510	nd	nd	nd	4050

Sample ID	Sample Description	BDE-047	BDE-066	BDE-099	BDE-100	BDE-153	BDE-154	TBB	TBPH	TCEP	TCPP	TDCPP	TPP
MET-1-5-1	Old Blue Foam Block	13	nd	13	nd	nd	nd	nd	nd	nd	nd	123	2,160
MET-1-6-1	New Blue Foam Block	nd	nd	0	nd	nd	nd	nd	nd	nd	nd	97	2,790
MET-1-7-1	Old Yellow Foam Block	88	nd	94	24	nd	nd	7,320	1,980	nd	nd	45	1,590
MET-1-8-1	Teal Foam Block	nd	nd	nd	nd	nd	nd	nd	nd	nd	56	50000	nd
MET-1-9-1	Purple Foam Block	1,110	15	968	209	77	66	218	48	nd	nd	335	224
MET-1-10-1	Brown Foam Block	14,700	214	17,600	4,490	1,870	1,500	415	88	nd	nd	2,200	4,610
MET-1-11-1	Blue Green Foam Block	nd	nd	nd	nd	nd	nd	37,500	11,600	nd	nd	nd	7,200
MET-1-12-1	Old Yellow 2 Foam Block	21	nd	22	nd	nd	nd	14,000	4,300	nd	nd	32	2,970
MET-1-13-1	Bright Green Foam Block	nd	nd	nd	nd	nd	nd	2,860	425	nd	16	39,000	353
MET-1-14-1	Teal 2 Foam Block	nd	nd	nd	nd	nd	nd	301	69	nd	60	57,700	80
MET-1-15-1	Dark Blue Foam Block	nd	nd	nd	nd	nd	nd	146	41	nd	nd	127	1,270
MET-1-16-1	Light Blue 2 Foam Block	nd	nd	nd	nd	nd	nd	18,900	6,730	nd	nd	28	5,070
MET-2-2-1	After Replacement Dust	264	nd	366	87	49	40	292	158	nd	nd	144	83
MET-2-3-1	Replacement Blue Foam Block	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd

Sample ID	Sample Description	BDE-047	BDE-066	BDE-099	BDE-100	BDE-153	BDE-154	TBB	TBPH	TCEP	TCPP	TDCPP	TPP
MET-2-4-1	Replacement Red Foam Block	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd

LFY = Lakewood Family YMCA
MET = Metropolitan Gymnastics
nd = not detected below 10 mg/kg
BDE = brominated diphenyl ether
TBB = 2-ethylhexyl-2,3,4,5 tetrabromobenzoate
TBPH = bis(2-ethylhexyl) tetrabromophthalate
TCEP = tris(2-chloroethyl) phosphate
TCPP = tris(2-chloroisopropyl) phosphate
TDCPP = tris(1,3-dichloro-2-propyl) phosphate
TPP = triphenyl phosphate