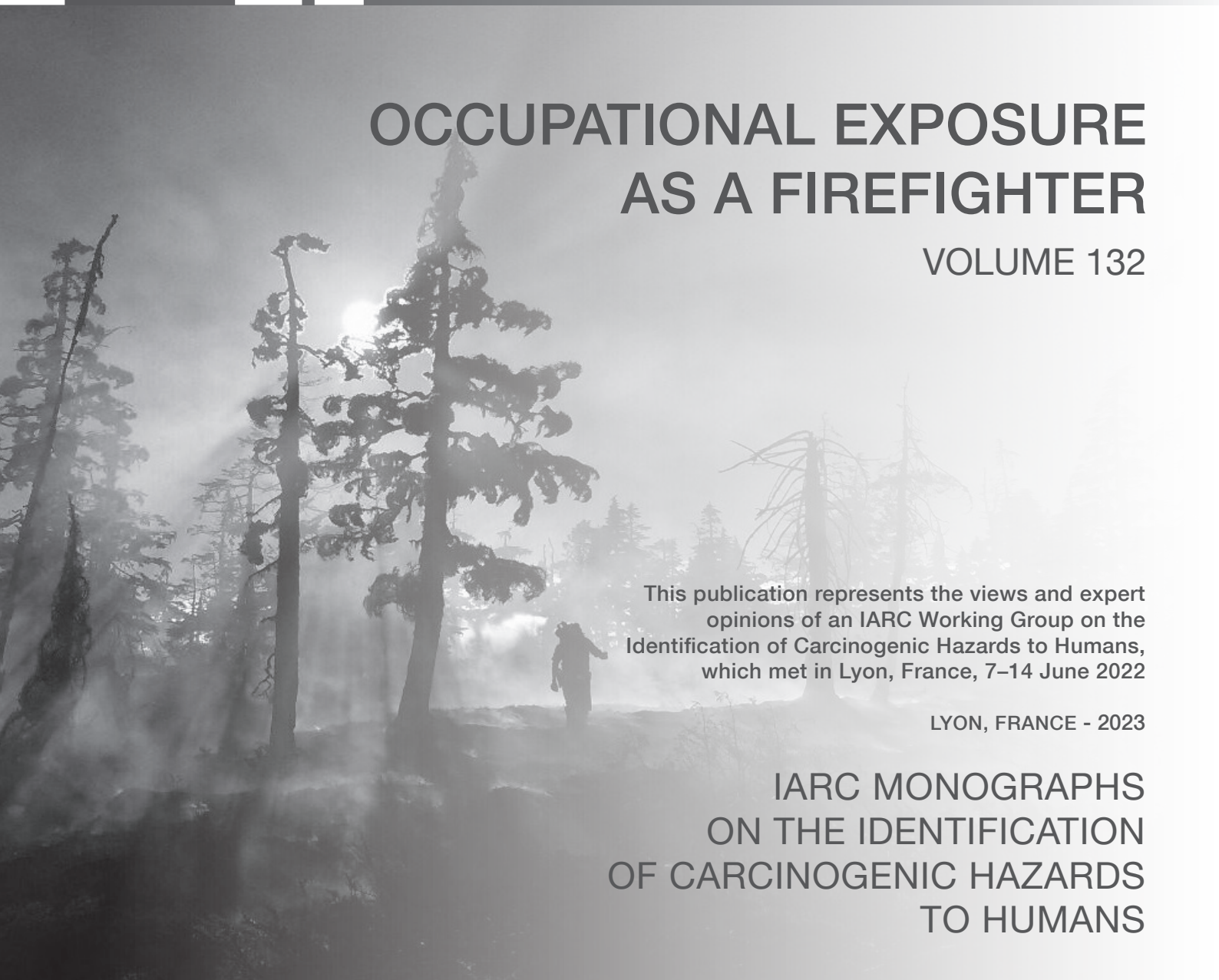
IARC MONOGRAPHS



OCCUPATIONAL EXPOSURE AS A FIREFIGHTER

VOLUME 132

This publication represents the views and expert opinions of an IARC Working Group on the Identification of Carcinogenic Hazards to Humans, which met in Lyon, France, 7–14 June 2022

LYON, FRANCE - 2023

IARC MONOGRAPHS ON THE IDENTIFICATION OF CARCINOGENIC HAZARDS TO HUMANS

International Agency for Research on Cancer

World Health Organization

Table S1.22 Measures of compounds other than fire smoke and polycyclic aromatic hydrocarbons in the firefighting setting

Sample type	Type of fire	Location and sampling date	Sampling period and duration	No. of individuals sampled and type of firefighter	No. of samples	Mean ± SD *geometric mean (± GSD or 95% CI) **median (range)	Units	LOD and/or LOQ	Comments and other relevant information	Reference
Asbestos (IARC Group 1)										
Area air	Structure	Arizona, USA, 1998	Overhaul, unknown	NA, career firefighters	46	0.073 ± 0.063	f/cm^3	0.03	15 samples above LOD	Bolstad-Johnson et al. (2000)
Surface (PPE, tunics)	Structure	United Kingdom, 1994	Attack, unknown	2, unknown	6	2.7 (range, 1–4)	f/ft^2	NR	Control measured 0 f/ft^2	Bridgman (2001)
Surface (municipal fire apparatus)	NA	Kentucky, USA, ~2018	NA	NA	29	Actinolite: < 1590 Chrysotile: < 792–1570	f/cm^3	792–1590	Only 1 sample above LOD	Hwang et al. (2019)
Personal air	Wildland (former vermiculite mine)	Montana, USA, 2018	Specific wildland firefighting tasks, 12–326 min	19, wildland firefighters	42	0.0013–0.13	f/cm^3	0.002–0.03	22 samples were overloaded with debris	NIOSH (2019)
Per- and polyfluoroalkyl substances (PFAS)										
PPE (turnout gear) extraction	NA	USA, 2019	NA	Used PPE from municipal firefighters	8	*IARC Group 2B* PFOA: ND–250 *Selected others* PFOS: ND–7 PFNA: ND–25.3	ng/g	1.64–7.79	Included used and unused gear, thermal liner, moisture barrier, and outer shell samples	Peaslee et al. (2020)
Surface (fire station dust)	NA	Massachusetts, USA, 2018	NA	15 career municipal fire stations	88	*IARC Group 2B* PFOA: 4.85 (ND–60)** *Selected others* PFOS: 4.95 (1.26–91.5)** PFHxS: 1.77 (ND–12.2)** PFNA: 1.59 (0.446–29.8)**	ng/g	0.12–0.41	Gear locker rooms had significantly higher total fluorine concentrations than living areas did	Young et al. (2021)

Table S1.22 (continued)

Sample type	Type of fire	Location and sampling date	Sampling period and duration	No. of individuals sampled and type of firefighter	No. of samples	Mean ± SD *geometric mean (± GSD or 95% CI) **median (range)	Units	LOD and/or LOQ	Comments and other relevant information	Reference
Chemical flame retardants: polybrominated diphenyl ethers (PBDEs) and other brominated flame retardants										
Area air	Controlled residential fires	Illinois, USA, 2015	During fire attack, 4–14 min	NA, sampling from inside structure	12	BDE-47: 3.47 (ND–13.9)** BDE-99: 4.94 (0.03–13.8)** BDE-153: ND BDE-209: 15.6 (0.03–67.7)** TBBPA: 0.24 (ND–18.5)** TBB: 7.71 (ND–25.2)** TBPH: 0.86 (ND–3.65)** DBDPE: 0.18 (ND–1.45)**	µg/m^3	0.06–0.5		Fent et al. (2020)
Area air	Controlled residential fires	Illinois, USA, 2015	During overhaul, ~15 min	NA, sampling from inside structure	11	BDE-47: 0.02 (ND–0.39)** BDE-99: 0.02 (ND–0.12)** BDE-153: 0.02 (ND–0.40)** BDE-209: 1.08 (0.02–29.4)** TBBPA: ND TBB: 0.03 (ND–26.5)** TBPH: 0.02 (ND–7.01)** DBDPE: ND	µg/m^3	0.04–0.06		Fent et al. (2020)

Table S1.22 (continued)

Sample type	Type of fire	Location and sampling date	Sampling period and duration	No. of individuals sampled and type of firefighter	No. of samples	Mean ± SD *geometric mean (± GSD or 95% CI) **median (range)	Units	LOD and/or LOQ	Comments and other relevant information	Reference
Wipe (PPE: gloves)	Controlled residential fires	Illinois, USA, 2015	After firefighting	7 right-handed gloves worn by firefighters	7	BDE-47: 2.36 (0.27–5.06)** BDE-99: 3.34 (0.32–7.59)** BDE-100: 0.05 (ND–1.70)** BDE-153: 2.68 (ND–4.02)** BDE-209: 74.8 (9.06–148)** TBBPA: 0.05 (ND–0.53)** TBB: 10.2 (0.24–296)** TBPH: 4.96 (0.11–116)** DBDPE: 12.5 (2.29–30.5)**	ng/cm²	0.1		Fent et al. (2020)
Wipe (PPE: cuffs from turnout jackets and pants)	NA	Australia, ~2019	Wipes collected after laundering	NA	69	BDE-47: 0.051 ± 0.046 BDE-99: 0.098 ± 0.099 BDE-100: 0.018 ± 0.017 BDE-153: 0.012 ± 0.016	ng/cm²	NR	Also sampled brand new gear, and all PBDEs were ND. This study also found little change in PBDE contamination after laundering	Banks et al. (2021b)
PPE (turnout jacket outer shell) extraction	NA	Pennsylvania, USA, 2013	NA	7 sets of turnout gear from municipal fire department	28	BDE-47: 113 ± 309 BDE-99: 155 ± 425 BDE-100: 32 ± 105 BDE-153: 16 ± 41	mg/kg	NR		Easter et al. (2016)

Table S1.22 (continued)

Sample type	Type of fire	Location and sampling date	Sampling period and duration	No. of individuals sampled and type of firefighter	No. of samples	Mean ± SD *geometric mean (± GSD or 95% CI) **median (range)	Units	LOD and/or LOQ	Comments and other relevant information	Reference
PPE (hood) extraction	Controlled residential fires	Illinois, USA, 2015	After firefighting	NA, 4 knit hoods worn by firefighters	4	BDE-47: 9.98 ± 2.82 BDE-99: 21.3 ± 3.20 BDE-153: 7.22 ± 5.8 BDE-209: 1010 ± 952 TBBPA: 18.7 ± 20.1 TBB: 34.2 ± 25.9 TBPH: 13.9 ± 9.48 DBDPE: 93.1 ± 60.5	ng/g	2	Samples also collected after laundering (not shown). Many of the compounds were not effectively removed via laundering	Mayer et al. (2019)
Vacuum cleaner dust (fire station)	NA	California, Minnesota, New Hampshire, New York, Texas, USA, 2015	NA	NA, 26 fire stations	26	BDE-28: 24.1 (5.1–1000)** BDE-47: 3050 (404–161 000)** BDE-99: 4180 (465–338 000)** BDE-100: 756 (87.9–82 000)** BDE-153: 489 (73–29 400)** BDE-209: 57 000 (1990–351 000)**	ng/g	0.14–74	BDE-209 levels in fire stations were among the highest measured in any occupation setting. Similar levels as reported in Shen et al. (2015)	Shen et al. (2018)
Vacuum cleaner dust (fire station)	NA	British Columbia, Ontario, Alberta, Manitoba, Canada, 2017–2018	NA	NA, 19 fire stations	19	BDE-28: 2.4 (ND–469)** BDE-47: 174 (3.0–42 200)** BDE-99: 326 (7.1–123 000)** BDE-100: 62 (1.6–19 700)** BDE-153: 32 (ND–15 200)** BDE-209: 7060 (232–56 300)**	ng/g	NR		Gill et al. (2020)

Table S1.22 (continued)

Sample type	Type of fire	Location and sampling date	Sampling period and duration	No. of individuals sampled and type of firefighter	No. of samples	Mean ± SD *geometric mean (± GSD or 95% CI) **median (range)	Units	LOD and/or LOQ	Comments and other relevant information	Reference
Chemical flame retardants: organophosphate flame retardants (OPFRs)										
Area air	Controlled residential fires	Illinois, USA, 2015	During fire attack, 4–14 min	NA, sampling from inside structure	12	TCPP: 0.12 (ND–4.04)** TDCPP: 0.13 (ND–113)** TPP: 408 (ND–2110)** TCP: 0.04 (ND–897)**	µg/m³	0.02–0.7		Fent et al. (2020)
Area air	Controlled residential fires	Illinois, USA, 2015	During overhaul, ~15 min	NA, sampling from inside structure	11	TCPP: ND TDCPP: ND TPP: 2.81 (1.07–45.8)** TCP: 0.01 (ND–13.9)**	µg/m³	0.008–0.012		Fent et al. (2020)
Wipe (PPE: gloves)	Controlled residential fires	Illinois, USA, 2015	After firefighting	7 right-handed gloves worn by firefighters	7	TCPP: 0.78 (ND–13.6)** TDCPP: 7.54 (ND–38.8)** TPP: 20.0 (4.79–93.5)** TCP: 0.88 (0.55–1.28)**	ng/cm²	0.1–1.5		Fent et al. (2020)
Wipe (PPE: cuffs from turnout jackets and pants)	NA	Australia, ~2019	Wipes collected after laundering	NA	69	TDCPP: 4.40 ± 2.30 TPP: 0.87 ± 0.29 TBOEP: 0.15 ± 0.29 TEHP: 0.11 ± 0.10 TMPP: 0.034 ± 0.022 EHDPP: 0.072 ± 0.042	ng/cm²	NR	Also sampled brand new gear, and TPP and EHDPP were detected. This study also found little change in OPFR contamination after laundering	Banks et al. (2021b)
PPE (hood) extraction	Controlled residential fires	Illinois, USA, 2015	After firefighting	NA, 4 knit hoods worn by firefighters	4	TCPP: 2.15 ± 1.25 TDCPP: 72.0 ± 63.8 TPP: 294 ± 259 TCP: 71.9 ± 39.1	ng/g	2	Samples also collected after laundering (not shown), which showed a reduction of 15–98%	Mayer et al. (2019)

Table S1.22 (continued)

Sample type	Type of fire	Location and sampling date	Sampling period and duration	No. of individuals sampled and type of firefighter	No. of samples	Mean ± SD *geometric mean (± GSD or 95% CI) **median (range)	Units	LOD and/or LOQ	Comments and other relevant information	Reference
Vacuum cleaner dust (fire station)	NA	California, Minnesota, New Hampshire, New York, Texas, USA, 2015	NA	NA, 26 fire stations	26	TCEP: 1040 (178–4660)** TCPP: 3880 (499–37 400)** TDCPP: 10 900 (1650–218 000)** TPP: 10 800 (1150–85 400)**	ng/g	0–1240		Shen et al. (2018)
Vacuum cleaner dust (fire station)	NA	British Columbia, Ontario, Alberta, Manitoba, Canada, 2017–2018	NA	NA, 19 fire stations	19	TCEP: 534 (ND–3800)** TCPP: 2350 (1470–10 700)** TDCPP: 3370 (1300–78 600)** TPP: 4780 (1270–26 600)**	ng/g	NR		Gill et al. (2020)
Diesel exhaust (IARC Group 1): elemental carbon										
Area air	NA	USA, 2016	7–8 h	NA, locations in 3 fire stations	28	Living area: 1.2–2.7 Office area: 0.86–1.5 Sleeping quarters: 0.43–1.3 Apparatus bay: 0.91–13	µg/m³	NR		NIOSH (2016)
Area air	NA	Ontario, Canada, 2016–2017	24 h	NA, locations in 12 fire stations	69	Living quarters: < 0.50–< 0.60 Sleeping quarters: < 0.50–1.3 Apparatus bay: < 0.5–2.7	µg/m³	0.5	Respirable fraction was measured	Chung et al. (2020)
Area air	NA	Queensland, Australia, ~2016	10 h	NA, locations in 9 fire stations	33	Sleeping quarters: ND–2 Office area: ND to > 6 Apparatus bay: 1–26 Outdoors: ND to > 7	µg/m³	1	Concentrations were higher at the start of the shift	Bott et al. (2017)

Table S1.22 (continued)

Sample type	Type of fire	Location and sampling date	Sampling period and duration	No. of individuals sampled and type of firefighter	No. of samples	Mean ± SD *geometric mean (± GSD or 95% CI) **median (range)	Units	LOD and/or LOQ	Comments and other relevant information	Reference
Diesel exhaust (IARC Group 1): total particulate matter										
Personal air	NA	Los Angeles, Boston, New York, USA, 1985	8 h	228 municipal firefighters (truck and engine companies)	228	1st shift: 91–748 2nd shift: 100–480 3rd shift: 35–182	µg/m³	NR	Study also included real-time measurements that showed increases with start and operation of vehicles	Froines et al. (1987)
Heavy metals										
Personal air	Structure fires	Ottawa, Canada, 2015	During fire responses	28 municipal firefighters	29	*IARC Group 1* Cadmium: 0.04* (0.0002–6.85) *Selected others* Antimony: 3.41* (0.02–170) Lead: 0.95* (0.0016–665)	µg/m³	0.0087–0.019	Two air concentrations of lead exceeded the adjusted occupational exposure limit (46.9 µg/m³)	Keir et al. (2020)
PPE (hood) extraction	NA	Pennsylvania, USA, 2013	NA	10 used knit hoods from municipal fire department	10	*IARC Group 1* Cadmium: 2.2 ± 1.2 Arsenic: 4.1 ± 6.4 *Selected others* Antimony: 31 ± 13 Chromium: 37 ± 20 Lead: 283 ± 264 Mercury: 0.2 ± 0.1 Manganese: 25 ± 13	mg/kg	0.05	Other metals than those listed here were detected. Used hoods had higher levels of all metals that were measured compared to the unused control hood	Easter et al. (2016)

Table S1.22 (continued)

Sample type	Type of fire	Location and sampling date	Sampling period and duration	No. of individuals sampled and type of firefighter	No. of samples	Mean ± SD *geometric mean (± GSD or 95% CI) **median (range)	Units	LOD and/or LOQ	Comments and other relevant information	Reference
Wipe (surface)	NA	Australia, NR	NA	Numerous surfaces from 15 fire stations	270 turnout gear surface samples	*IARC Group 1* Cadmium: < 5 *Selected others* Chromium: 405 Lead: 456 Manganese: 784 Nickel: 35.9	µg/m²	1–8	Turnout gear from full time firefighters had higher mean levels of lead, zinc, and manganese compared to part time firefighters	Engelsman et al. (2019)
Wipe (surface)	NA	Australia, NR	NA	Numerous surfaces from 15 fire stations	129 vehicle surface samples	*IARC Group 1* Cadmium: < 5 *Selected others* Chromium: 39.5 Lead: 130 Manganese: 166 Nickel: 49.6	µg/m²	1–8		Engelsman et al. (2019)
Wipe (surface)	NA	Australia, NR	NA	Numerous surfaces from 15 fire stations	60 fire station surface samples	*IARC Group 1* Cadmium: < 5 *Selected others* Chromium: 493 Lead: 480 Manganese: 638 Nickel: 2170	µg/m²	1–8	SCBA wash sink was found to be a major area of contamination for lead, manganese, copper, and chromium	Engelsman et al. (2019)
Polychlorinated dibenzo-para-*dioxins/dibenzofurans (PCDD/Fs)*										
Wipe (PPE: gloves)	Controlled residential fires	Illinois, USA, 2015	After firefighting	7 left-handed gloves worn by firefighters	7	HpCDD: 0.14 (0.02–0.24)** OCDD: 0.72 (0.08–2.29)** 2378-TCDF: 0.06 (0.03–0.08)**	pg/cm²	0.04–0.58		Fent et al. (2020)

Table S1.22 (continued)

Sample type	Type of fire	Location and sampling date	Sampling period and duration	No. of individuals sampled and type of firefighter	No. of samples	Mean ± SD *geometric mean (± GSD or 95% CI) **median (range)	Units	LOD and/or LOQ	Comments and other relevant information	Reference
Wipe (surface of helmets)	Following brewery, ironwork, textile, and dwelling fires	Taiwan, China, 2010	After firefighting	NA, wipe samples from 5 helmets	5	*Σ17 PCDD/Fs* Brewery: > 0.35 Ironwork: > 0.15 Textile: > 0.08 Dwelling: > 0.08 Clean helmet: 0.0013	pg/cm^2	NR		Hsu et al. (2011)
Polybrominated dibenzo-para-*dioxins/dibenzofurans (PBDD/Fs)*										
Wipe (PPE: gloves)	Controlled residential fires	Illinois, USA, 2015	After firefighting	7 left-handed gloves worn by firefighters	7	2378-TBDF: 0.14 (0.06–0.35)** 23 478-PeBDF: 0.12 (0.06–0.31)** 123 478-HxBDF: 0.41 (0.06–2.19)** 1 234 678-HpBDF: 0.74 (0.06–13.3)**	ng/cm^2	0.12	Method used was qualitative and results should be considered exploratory. Other brominated furans were detected, but exact species were unknown	Fent et al. (2020)

BDE, brominated diphenyl ether; CI, confidence interval; DBDPE, decabromodiphenylethane; EHDPP, 2-ethylhexyldiphenyl phosphate; f, fibre; FR, flame retardant; GSD, geometric standard deviation; HpBDF, heptabromodibenzofuran; HxBDF, hexabromodibenzofuran; LOD, limit of detection; LOQ, limit of quantification; NA, not applicable; ND, not detected; NR, not reported; PBDD/Fs, polybrominated dibenzo-*para*-dioxins/dibenzofurans; PBDEs, polybrominated diphenyl ethers; PCDD/Fs, polychlorinated dibenzo-*para*-dioxins/dibenzofurans; PeBDF, 1,2,3,7,8-pentabromodibenzofuran; PFHxS, perfluorohexanesulfonic acid; PFNA, perfluorononanoic acid; PFOA, perfluorooctanoic acid; PFOS, perfluorooctane sulfonate; PPE, personal protective equipment; SD, standard deviation; TBB, 2-ethylhexyl 2,3,4,5-tetrabromobenzoate; TBBPA, tetrabromobisphenol A; TBDF, tetrabromodibenzofuran; TBOEP, tris(2-butoxyethyl) phosphate; TBPH, di (2-ethylhexyl)-2,3,4,5-tetrabromophthalate; TCEP, tris(2-carboxyethyl) phosphate; TCP, tricresyl phosphate; TCPP, tris(2-chloropropyl) phosphate; TDCPP, tris(1,3-dichloro-2-propyl) phosphate; TEHP, tris(2-ethylhexyl) phosphate; TMPP, tris(2-methylphenyl) phosphate; TPP, triphenyl phosphate.

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