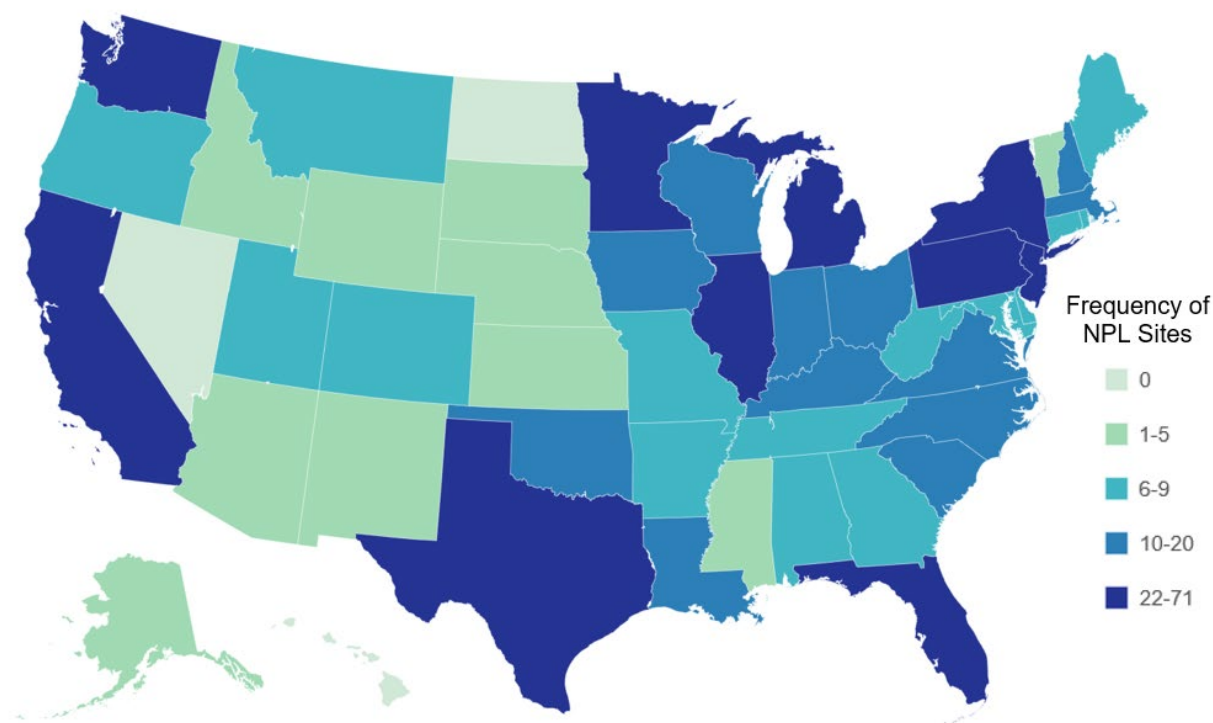


CHAPTER 5. POTENTIAL FOR HUMAN EXPOSURE

5.1 OVERVIEW

Naphthalene or methylnaphthalene has been identified in at least 682 of the 1,868 hazardous waste sites that have been proposed for inclusion on the EPA National Priorities List (NPL) (ATSDR 2022a). However, the number of sites in which naphthalene or methylnaphthalene has been evaluated is not known. The number of sites in each state is shown in Figure 5-1. Of these sites, 681 are located within the United States, and 1 is located in the Virgin Islands (not shown).

Figure 5-1. Number of NPL Sites with Naphthalene and Methylnaphthalene



Source: ATSDR 2022a

- People who use products which contain naphthalene (e.g., mothballs, inks, plastics), smoke tobacco, or burn organic material indoors may be exposed to naphthalene.
- For the general public, the most likely route of exposure to naphthalene and methylnaphthalenes is through inhalation. Most people will not be exposed to concentrations >2 ppbv (10 µg/m³) in ambient air.

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- Naphthalene and methylnaphthalenes are expected to primarily volatilize to air. They may be removed from the water column by sorption or retained in soil and sediment, especially where solids have a high organic carbon content.
- Naphthalene and methylnaphthalenes are readily degraded by indirect photolysis in air and water. Biodegradation in water, soil, and sediment is slow, but proceeds readily in historically contaminated media where microorganisms are adapted.

Most of the naphthalene entering the environment is discharged to the air. The largest releases result from the combustion of wood and fossil fuels; the largest amount to indoor air is from the off-gassing of naphthalene-containing moth repellents. Smaller amounts of naphthalene are introduced to water as the result of discharges from coal-tar production and distillation processes. The coal-tar industry is also a major source of the small amounts of naphthalene that are directly discharged to land. A large amount of naphthalene (often considerably >1,000 mg/kg) is present in soils contaminated with wastes from manufactured-gas plants. Urban soils may also have increased concentrations of naphthalene.

Naphthalene in the atmosphere is subject to a number of degradation processes, including reaction with photochemically produced hydroxyl radicals. Naphthalene has a short half-life in most natural waters and soils because of its tendency to volatilize and biodegrade, although biodegradation may be slow if the site was not previously contaminated and microorganisms are not adapted to naphthalene. As a consequence of these processes, there is little tendency for naphthalene to build up in the environment over time.

The concentration of naphthalene in air tends to be low in rural areas, but is elevated in urban areas. The highest atmospheric concentrations have been found in the immediate vicinity of specific industrial sources and hazardous waste sites, and around forest fires. Naphthalene is also a common indoor contaminant in households using naphthalene-containing moth repellents or where tobacco is smoked. Electronic cigarettes may also release naphthalene, but at lower concentrations than conventional cigarettes. Levels in water, sediments, and soil tend to be low, except in the immediate vicinity of point sources of release, such as chemical waste sites.

The most likely pathway by which the general public is exposed to naphthalene is by inhalation due to the release of this substance from combustion fuels, moth repellents, and cigarette smoke. The estimated average per capita daily intake from ambient air is 0.8 µg. Exposure by other routes is not likely.

High naphthalene exposure levels could occur near industrial sources or chemical waste sites, but the extent of such exposure to individuals can only be evaluated on a site-by-site basis. High naphthalene exposure levels could also occur in certain work environments in industries that produce and use

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naphthalene such as wood preserving, tanning, coal distillation, and ink and dye production, or workers who are in close proximity to naphthalene release during combustion, such as firefighters.

Based on limited data, potential human exposure to 1- or 2-methylnaphthalene is expected to be mainly by inhalation from ambient air. Exposure to these chemicals from tobacco smoke is likely.

Both 1- and 2-methylnaphthalene have also been detected in the environment, particularly in air. These are released from many of the same natural and industrial sources as naphthalene (combustion of wood and fossil fuels, tobacco smoke, coal distillation), but in smaller quantities.

5.2 PRODUCTION, IMPORT/EXPORT, USE, AND DISPOSAL

5.2.1 Production

Table 5-1 summarizes information on companies that reported the production, import, or use of naphthalene for the Toxics Release Inventory (TRI) in 2021 (TRI21 2023). TRI data should be used with caution since only certain types of industrial facilities are required to report. This is not an exhaustive list.

Naphthalene and methylnaphthalenes occur naturally in fossil fuels such as petroleum and coal, and are produced when organic materials (e.g., fossil fuels, wood, tobacco) are burned (EPA 2002; IARC 2002). Commercially, naphthalene may be produced from either coal tar or petroleum. Distillation and fractionation of coal tar was the most common production process until the late 1950s (Mason 2002). The middle fraction (containing most of the naphthalene) is cooled, crystallizing the naphthalene. The crude naphthalene may be refined by distillation, washing, and sublimation (EPA 1982; Hughes et al. 1985). 1-Methylnaphthalene and 2-methylnaphthalene are also produced from coal tar by first extracting the heteroaromatics and phenols, then filtering off the crystallized 2-methylnaphthalene and redistilling the filtrate to yield 1-methylnaphthalene (GDCH 1992; Sax and Lewis 1987). The individual isomers are not often isolated for commercial purposes in the United States; a methylnaphthalene-rich fraction of the coal tar or petroleum is distributed instead (Mason 2002).

From 1960, recovery of naphthalene from petroleum by dealkylation of methyl naphthalenes in the presence of hydrogen at high temperature and pressure had become a major commercial production process, accounting for over 40% of total naphthalene production (Mason 2002). The naphthalene is then recovered by fractionation, decolorized, and purified by crystallization. Naphthalene produced from

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petroleum is about 99% pure. In the United States, most naphthalene was produced from petroleum, but due to decreasing demand and production, this changed when the last petroleum processing plant for naphthalene was closed in 1991 (EPA 1982; Hughes et al. 1985; Mason 2002). Petroleum sources made a modest rebound later, however. In 2001, petroleum sources accounted for 20% of naphthalene production capacity, leaving 80% production capacity to coal tar (Collin et al. 2012). It is not known which is the current dominant process.

The 2019 nationally aggregated production volume for naphthalene was between 100,000,000 and <250,000,000 pounds (EPA 2022a). The same production volumes were reported for 2016 and 2017, but there was a temporary increase to $\geq 1,000,000,000$ pounds in 2018. The 2019 nationally aggregated production volume for 1-methylnaphthalene was about 1,900,000 pounds, comparable to reporting from 2016 to 2018; about 2,000,000 pounds were reported for 2-methylnaphthalene, also comparable to previous reporting years (EPA 2022a).

There are currently five companies that reported manufacturing naphthalene in 2019: Coopers Creek Chemical Corporation, Equilon Enterprises LLC dba Shell Oil Products US (a subsidiary of Shell Oil Company), Koppers Inc., Monument Chemical LLC, and Shell Chemical LP (EPA 2022a). Only one company, Shell Chemical LP, reported manufacturing 1- and 2-methylnaphthalene. This may not be an exhaustive list; companies must meet a reporting threshold per site to trigger reporting to the Chemical Data Reporting (CDR) rule.

Table 5-1 lists information on United States companies that reported the manufacture and use of naphthalene in 2020 (TRI21 2023). The Toxics Release Inventory (TRI) data should be used with caution since only certain types of facilities are required to report. The TRI is not an exhaustive list. No information is available in the TRI database on facilities that manufacture or process 1- or and 2-methylnaphthalene because these chemicals are not required to be reported under Section 313 of the Emergency Planning and Community Right-to-Know Act (Title III of the Superfund Amendments and Reauthorization Act of 1986) (EPA 2005).

Table 5-1. Facilities that Produce, Process, or Use Naphthalene

State ^a	Number of facilities	Minimum amount on site in pounds ^b	Maximum amount on site in pounds ^b	Activities and uses ^c
AK	28	1,000	9,999,999	1, 3, 4, 5, 7, 8, 9, 10, 12, 14
AL	23	100	9,999,999	1, 2, 3, 4, 5, 7, 9, 10, 12, 13, 14

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Table 5-1. Facilities that Produce, Process, or Use Naphthalene

State ^a	Number of facilities	Minimum amount on site in pounds ^b	Maximum amount on site in pounds ^b	Activities and uses ^c
AR	9	1,000	999,999	1, 5, 7, 9, 10, 12, 14
AZ	22	100	999,999	1, 5, 7, 9, 12
CA	79	0	49,999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14
CO	9	100	49,999,999	1, 5, 7, 9, 10, 12, 13, 14
CT	6	10,000	9,999,999	1, 5, 6, 7, 9, 12, 14
DE	5	10,000	9,999,999	1, 2, 3, 5, 7, 12, 13, 14
FL	37	0	49,999,999	1, 5, 7, 9, 12, 13, 14
GA	25	100	9,999,999	1, 5, 6, 7, 8, 9, 10, 12, 13, 14
GU	6	100	9,999,999	1, 5, 7, 9, 12
HI	19	0	9,999,999	1, 3, 4, 5, 6, 7, 9, 10, 12, 13, 14
IA	16	1,000	999,999	1, 4, 5, 7, 8, 9, 10, 11, 12
ID	6	1,000	999,999	1, 5, 7, 9, 12, 14
IL	45	0	49,999,999	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14
IN	39	0	49,999,999	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14
KS	18	0	99,999,999	1, 3, 5, 6, 7, 8, 9, 10, 11, 12, 14
KY	27	100	9,999,999	1, 3, 4, 5, 7, 8, 9, 10, 11, 12, 13, 14
LA	67	0	499,999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14
MA	12	1,000	9,999,999	1, 2, 4, 5, 7, 8, 9, 12
MD	16	10,000	999,999	1, 5, 7, 9, 12
ME	8	0	9,999,999	2, 3, 4, 7, 9, 12
MI	31	0	999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14
MN	7	0	999,999	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13
MO	27	0	9,999,999	1, 2, 5, 7, 8, 9, 10, 11, 12, 13
MP	2	10,000	999,999	1, 5, 7, 9
MS	18	1,000	9,999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 13, 14
MT	6	1,000	9,999,999	1, 2, 3, 4, 5, 6, 7, 9, 12, 13, 14
NC	19	1,000	999,999	1, 5, 6, 7, 8, 9, 10, 12
ND	6	100	9,999,999	1, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14
NE	4	10,000	99,999	9, 12
NH	7	1,000	9,999,999	1, 2, 3, 4, 5, 7, 9, 12
NJ	15	1,000	49,999,999	1, 3, 4, 5, 6, 7, 9, 12, 14
NM	12	100	999,999	1, 3, 5, 6, 7, 9, 12
NV	23	100	9,999,999	1, 2, 5, 7, 9, 12, 13, 14
NY	29	0	99,999,999	1, 2, 3, 4, 5, 7, 8, 9, 12, 13, 14

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Table 5-1. Facilities that Produce, Process, or Use Naphthalene

State ^a	Number of facilities	Minimum amount on site in pounds ^b	Maximum amount on site in pounds ^b	Activities and uses ^c
OH	56	0	9,999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14
OK	17	100	9,999,999	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14
OR	8	100	999,999	1, 5, 7, 9, 12
PA	39	100	9,999,999	1, 2, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14
PR	21	0	49,999,999	1, 2, 3, 4, 5, 9, 12
RI	5	10,000	9,999,999	1, 5, 7, 9, 12, 13, 14
SC	19	100	9,999,999	1, 5, 6, 8, 9, 10, 12, 14
SD	1	100,000	999,999	1, 12, 13
TN	26	100	9,999,999	1, 2, 3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14
TX	180	0	499,999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14
UT	17	0	49,999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12
VA	28	10,000	49,999,999	1, 5, 7, 9, 12
VI	4	1,000	49,999,999	1, 5, 7, 9, 12
WA	25	0	999,999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14
WI	17	0	999,999	1, 5, 7, 9, 10, 11, 12, 14
WV	16	100	999,999	1, 2, 3, 4, 5, 7, 8, 9, 10, 11, 12, 13
WY	11	1,000	9,999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14

^aPost office state abbreviations used.^bAmounts on site reported by facilities in each state.^cActivities/uses:

- | | | |
|----------------------|-----------------------------|--------------------------|
| 1. Produce | 6. Reactant | 11. Manufacture Aid |
| 2. Import | 7. Formulation Component | 12. Ancillary |
| 3. Used Processing | 8. Article Component | 13. Manufacture Impurity |
| 4. Sale/Distribution | 9. Repackaging | 14. Process Impurity |
| 5. Byproduct | 10. Chemical Processing Aid | |

Source: TRI21 2023 (Data are from 2021)

5.2.2 Import/Export

Around 74,000,000 pounds of naphthalene were reported as imported in 2019; around 1,900,000 pounds were reported as exported the same year (EPA 2022a). No imports of 1- or 2-methylnaphthalene were included in the CDR for 2019 and exported quantities of around 440,000 pounds of 1-methylnaphthalene and 650,000 pounds of 2-methylnaphthalene were reported. These values may be lower than the actual

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total amounts imported or exported; companies must meet a threshold to trigger reporting to the CDR reporting rule, and some quantities were not available in the public dataset.

5.2.3 Use

The principal end use for naphthalene is as an intermediate in the production of phthalic anhydride (>60% of consumption), which is used as an intermediate in the production of phthalate plasticizers, resins, phthaleins, dyes, pharmaceuticals, insect repellents, and other materials (Collin et al. 2012; Mason 2002). It is also used in the production of the insecticide carbaryl, synthetic leather-tanning agents, and surface-active agents (naphthalene sulfonates and derivatives, which are used as dispersants or wetting agents in paint, dye, and paper-coating formulations), and miscellaneous organic chemicals, including dyes and resins (Collin et al. 2012; EPA 2022a). Crystalline naphthalene is also used as a moth repellent; about 7% of total U.S. consumption in 2000 was used for this purpose (Mason 2002). Naphthalene is an active ingredient in 22 pesticide products with active registration under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) (EPA 2023a). These products include moth, small mammal, snake, and bat repellants.

It is anticipated that consumption of naphthalene for phthalic anhydride and production of naphthalene sulfonates will increase due to increased demand for these products, although some decline may occur based on increased usage of *o*-xylene feedstock for phthalic anhydride production (Mason 2002).

Mixtures rich in methylnaphthalenes have been used as dye carriers and as feedstock for naphthalene or phthalic anhydride production (Mason 2002). 1-Methylnaphthalene is used as a solvent, as feedstock in the synthesis of 1-methylnaphthoic acid, and, to a lesser degree, as a dyeing agent and as a test substance for determining the ignition capability of diesel fuels. 2-Methylnaphthalene is used in vitamin K production by oxidation to 2-methyl-1,4-naphthoquinone, which can then be reacted to yield phytymenadione (vitamin K). It can also be chlorinated and oxidized to form dyes and small amounts in sulfonated form are used as textile aids, wetting agents, and emulators (GDCH 1992).

5.2.4 Disposal

Naphthalene and waste containing naphthalene are classified as hazardous wastes by EPA and its disposal is regulated under RCRA (40 CFR §261). Rotary kiln or fluidized bed incineration methods are acceptable disposal methods for these wastes (EPA 1988a, 1989a).

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No information was located on disposal methods or quantities of wastes containing 1- or 2-methylnaphthalene. However, these chemicals have been detected at hazardous waste sites (see Section 5.1).

5.3 RELEASES TO THE ENVIRONMENT

The Toxics Release Inventory (TRI) data should be used with caution because only certain types of facilities are required to report (EPA 2022). This is not an exhaustive list. Manufacturing and processing facilities are required to report information to the TRI only if they employ ≥ 10 full-time employees; if their facility's North American Industry Classification System (NAICS) codes is covered under EPCRA Section 313 or is a federal facility; and if their facility manufactures (defined to include importing) or processes any TRI chemical in excess of 25,000 pounds, or otherwise uses any TRI chemical in excess of 10,000 pounds, in a calendar year (EPA 2022).

Most of the naphthalene entering environmental media is from combustion of wood and fossil fuels, and is released to the air (EPA 2017b). Methylnaphthalenes are released from similar sources (EPA 2017b). Smoking tobacco also releases small amounts of naphthalene and methylnaphthalenes into the environment.

5.3.1 Air

Estimated releases of 1,318,765 pounds (~598 metric tons) of naphthalene to the atmosphere from 1,202 domestic manufacturing and processing facilities in 2021, accounted for about 33% of the estimated total environmental releases from facilities required to report to the TRI (TRI21 2023). These releases are summarized in Table 5-2. There is no information on releases of 1- or 2-methylnaphthalene to the atmosphere from manufacturing and processing facilities because these releases are not required to be reported (EPA 2022).

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Table 5-2. Releases to the Environment from Facilities that Produce, Process, or Use Naphthalene^a

State ^c	RF ^d	Reported amounts released in pounds per year ^b							
		Air ^e	Water ^f	UI ^g	Land ^h	Other ⁱ	Total release		
							On-site ^j	Off-site ^k	On- and off-site
AL	23	20,961	37	0	42,949	472	20,997	43,421	64,418
AK	28	377,605	63	0	12	71	377,669	82	377,751
AZ	22	828	0	0	507	458	1,078	715	1,793
AR	9	1,142	1	0	3	0	1,142	3	1,145
CA	74	9,507	187	0	1,620,925	443	1,629,018	2,043	1,631,061
CO	9	303	1	0	14	76	318	76	394
CT	6	144	1	0	0	0	145	0	145
DE	5	1,844	6	0	0	571	1,849	572	2,421
FL	37	18,623	3	0	30	153	18,627	182	18,809
GA	25	5,525	3	0	5	258	5,529	263	5,792
HI	19	3,466	0	4	634	21	3,470	655	4,125
ID	6	68	0	0	6	0	71	3	74
IL	45	72,823	28	0	52	390	72,850	443	73,292
IN	38	23,815	11	11,722	39,517	2,799	54,742	23,122	77,864
IA	16	21,384	99	0	229	3	21,483	233	21,716
KS	18	4,671	67	14	4,091	2	4,754	4,090	8,845
KY	27	205,560	48	0	195	1,657	205,609	1,852	207,461
LA	64	96,730	446	739	33,818	216	97,437	34,512	131,949
ME	8	33	1	0	11	219	34	230	264
MD	16	44	1	0	0	312	45	312	357
MA	12	280	0	0	122	47	280	169	449
MI	30	9,951	232	0	2,769	481	10,186	3,247	13,433
MN	7	1,307	33	0	13	0	1,340	13	1,353
MS	18	22,881	513	0	8,802	758	23,584	9,370	32,954
MO	27	24,395	5	0	0	350	24,400	350	24,750
MT	6	4,160	34	0	4	15	4,170	42	4,213
NE	4	217	0	0	210	0	217	210	427
NV	21	2,275	0	0	1,710	1,066	2,337	2,714	5,051
NH	7	32	2	0	5	0	34	5	39
NJ	15	5,537	334	0	8	23,454	5,871	23,462	29,333
NM	12	1,337	0	4	13	1,714	1,354	1,714	3,068
NY	29	2,593	28	0	12	38	2,627	43	2,670
NC	19	495	10	0	542	500	495	1,052	1,547
ND	5	3,010	2	5	3	0	3,020	0	3,020
OH	56	45,258	53	0	31,716	1,634	60,303	18,359	78,662
OK	16	21,869	44	0	0	0	21,913	0	21,913
OR	8	417	1	0	1,285	0	1,702	1	1,703

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Table 5-2. Releases to the Environment from Facilities that Produce, Process, or Use Naphthalene^a

State ^c	RF ^d	Reported amounts released in pounds per year ^b					Total release		
		Air ^e	Water ^f	UI ^g	Land ^h	Other ⁱ	On-site ^j	Off-site ^k	On- and off-site
PA	39	26,284	120	0	1,001	509	26,516	1,398	27,914
RI	5	21	1	0	0	97	22	97	119
SC	19	39,179	1	0	501	94	39,179	596	39,775
SD	1	26	0	0	0	0	26	0	26
TN	26	20,276	3	0	134	0	20,276	137	20,414
TX	180	138,897	1,155	390,485	70,312	29,889	561,194	69,544	630,739
UT	16	2,502	105	0	2,759	206	2,525	3,047	5,572
VA	28	43,826	1,012	0	18	1,248	44,838	1,265	46,103
WA	24	3,240	8	0	313,212	311	316,312	458	316,770
WV	16	25,379	0	3	803	84	25,380	889	26,269
WI	17	4,358	0	0	1,453	801	4,364	2,248	6,613
WY	11	756	0	0	59	15	798	32	830
GU	6	1,363	0	0	0	0	1,363	0	1,363
MP	2	24	0	0	0	0	24	0	24
PR	21	1,028	1	0	0	33	1,029	33	1,062
VI	4	514	28	0	14	0	553	2	556
Total	1,202	1,318,765	4,727	402,976	2,180,478	71,465	3,725,104	253,307	3,978,411

^aThe TRI data should be used with caution since only certain types of facilities are required to report. This is not an exhaustive list. Data are rounded to nearest whole number.

^bData in TRI are maximum amounts released by each facility.

^cPost office state abbreviations are used.

^dNumber of reporting facilities.

^eThe sum of fugitive and point source releases are included in releases to air by a given facility.

^fSurface water discharges, wastewater treatment (metals only), and publicly owned treatment works (POTWs) (metal and metal compounds).

^gClass I wells, Class II-V wells, and underground injection.

^hResource Conservation and Recovery Act (RCRA) subtitle C landfills; other onsite landfills, land treatment, surface impoundments, other land disposal, other landfills.

ⁱStorage only, solidification/stabilization (metals only), other off-site management, transfers to waste broker for disposal, unknown.

^jThe sum of all releases of the chemical to air, land, water, and underground injection wells.

^kTotal amount of chemical transferred off-site, including to POTWs.

RF = reporting facilities; UI = underground injection

Source: TRI21 2023 (Data are from 2021)

Nearly all naphthalene entering the environment is released directly to the air. The largest source of emission is expected to be through inadvertent releases due to combustion of wood and fossil fuels (EPA 2017b). Naphthalene emissions from unvented kerosene space heaters have been reported (Traynor et al.

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1990). Releases to indoor air include tobacco smoking, use of moth repellents containing naphthalene, and proximity to motor vehicles (Jia and Batterman 2011). Methylnaphthalenes may be released to air from fuel and wood combustion and from tobacco smoke (EPA 2017b; Schmeltz et al. 1978).

Naphthalene may also enter the atmosphere during coal-tar production and distillation processes, through volatilization processes (aeration) in publicly owned treatment works (POTWs), from the use of naphthalene in the manufacture of phthalic anhydride, during the production and use of naphthalene, from forest fires, and from tobacco smoke. Off-gassing of treated wood was shown to release <10 tons of naphthalene/year at the Denver Koopers, Inc., facility in Colorado (Morgan et al. 2015). The facility is also permitted to emit 8,160 kg/year volatile naphthalene from the wastewater treatment effluent tank and 59 kg/year volatile naphthalene from the creosote storage tank (Morgan et al. 2015). Naphthalene may also be released from formulations containing naphthalene such as printer ink (Arı 2020). Relatively small emissions of naphthalene occur through the combustion of fireworks, even during heavy holiday usage on the 4th of July (Jia et al. 2020).

Naphthalene has been detected in the emissions from motor vehicles. A gasoline-powered vehicle equipped with a catalytic converter reportedly emits 1,600 µg naphthalene per mile, and heavy-duty diesel vehicles emit between 10.2 and 505 µg naphthalene per mile, depending on whether the vehicle is idling or driving (Jia and Batterman 2011; Schauer et al. 2002). A gasoline-powered vehicle equipped with a catalytic converter emits approximately 800 µg 1-methylnaphthalene per mile and 1,600 µg 2-methylnaphthalene per mile (Schauer et al. 2002). Average concentrations of 137–1714, 92–1,458, and 154–2,129 ng/m³ of naphthalene, 1-methylnaphthalene, and 2-methylnaphthalene, respectively, were detected during various flight related and ground-support activities of C-130H aircraft at an Air National Guard base (Childers et al. 2000).

Naphthalene was previously detected in ash from municipal refuse and hazardous waste incinerators (EPA 1989b; Shane et al. 1990). More recent monitoring studies were not located. More than 960,000 pounds of naphthalene and 260,000 pounds of 2-methylnaphthalene were estimated to be released by waste disposal in 2017 (EPA 2020). In a lab-scale incineration experiment with municipal solid waste, emission factors determined for naphthalene were 287 ng/g for gas, 30.4 ng/g for airborne particles (diameter not reported), 24.9 ng/g for fine particles (0.4–10 µm diameter), and 36.7 ng/g for bottom ash emissions (Li et al. 2019).

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Smoking tobacco products or using electronic cigarettes releases naphthalene and methylnaphthalenes to the air; about 46, 30, and 32 µg/cigarette was released for naphthalene, 1-methylnaphthalene, and 2-methylnaphthalene, respectively (Schmeltz et al. 1976). Cigarette butts littered to the environment can continue to emit naphthalene (Poppendieck et al. 2020). In the aerosol from electronic cigarettes, naphthalene was detected at 61.5–92.2 pg/puff (Dusautoir et al. 2021).

The National Emissions Inventory (NEI) reports air emissions estimates sector for criteria pollutants and precursors and hazardous air pollutants. The estimates are created over a 3-year period; the estimates for 2017 are reported in Table 5-3.

Table 5-3. National Emission Inventory (NEI) Total National Emissions (pounds) for Naphthalene and Methylnaphthalenes Estimated by Sector 2017

Sector	Naphthalene emissions	1-Methylnaphthalene emissions	2-Methylnaphthalene emissions
Agriculture; livestock waste	0.09	–	49,582.19
Bulk gasoline terminals	8,296.77	27.20	57.61
Commercial cooking	201,519.72	–	–
Dust; construction dust	1	–	–
Fires; prescribed fires	37,374,454.72	–	–
Fires; wildfires	85,672,702.66	–	–
Fuel combustion; commercial/institutional; biomass	17,321.75	684.33	970.29
Fuel combustion; commercial/institutional; coal	1,919.78	–	–
Fuel combustion; commercial/institutional; natural gas	4,125.92	–	89.52
Fuel combustion; commercial/institutional; oil	2,151.99	–	0.01
Fuel combustion; commercial/institutional; other	1,334.69	–	0.20
Fuel combustion; electric generation; biomass	10,656.77	–	7.70
Fuel combustion; electric generation; coal	3,765.66	–	61.15
Fuel combustion; electric generation; natural gas	10,376.81	–	38.28
Fuel combustion; electric generation; oil	6,931.90	–	0.69
Fuel combustion; electric generation; other	594.78	–	3.37
Fuel combustion; industrial boilers, ICEs; biomass	174,452.84	6,206.78	8,816.91

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Table 5-3. National Emission Inventory (NEI) Total National Emissions (pounds) for Naphthalene and Methylnaphthalenes Estimated by Sector 2017

Sector	Naphthalene emissions	1-Methylnaphthalene emissions	2-Methylnaphthalene emissions
Fuel combustion; industrial boilers, ICEs; Coal	4,127.96	–	0.28
Fuel combustion; industrial boilers, ICEs; Natural Gas	54,973.81	0.19	15,611.25
Fuel combustion; industrial boilers, ICEs; Oil	18,861.43	–	20.62
Fuel combustion; industrial boilers, ICEs; Other	767,535.55	–	70.27
Fuel combustion; residential; natural gas	2,733.93	–	0.60
Fuel combustion; residential; oil	3,663.43	–	–
Fuel combustion; residential; other	276.16	–	–
Fuel combustion; residential; wood	5,172,159.62	–	–
Gas stations	29,234.43	0.009	4.44
Industrial processes; cement manufacturing	51,356.07	–	76.30
Industrial processes; Chemical Manufacturing	185,758.64	0.01	61.09
Industrial processes; Ferrous Metals	54,204.35	998.75	474.88
Industrial processes; Mining	583.79	–	–
Industrial processes; NEC	439,728.82	0.002	4,579.67
Industrial processes; non-ferrous metals	18,671.10	–	1.86
Industrial processes; oil and gas production	210,055.59	–	0.35
Industrial processes; petroleum refineries	168,207.30	229.73	447.11
Industrial processes; pulp and paper	141,694.13	57.37	2,190.82
Industrial processes; storage and transfer	128,486.79	102.34	502.77
Miscellaneous non-industrial NEC	23,494.82	–	604.42
Mobile; aircraft	1,231,718.57	3,317.82	207,506.43
Mobile; commercial marine vessels	236,093.00	–	–
Mobile; locomotives	147,855.37	–	–
Mobile; non-road equipment; diesel	574,528.59	–	–
Mobile; non-road equipment; gasoline	3,065,367.09	–	–
Mobile; non-road equipment; other	3,291.00	82.63	1,155.69
Mobile; on-road diesel heavy duty vehicles	2,112,775.51	–	–
Mobile; on-road diesel light duty vehicles	742,174.26	–	–

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Table 5-3. National Emission Inventory (NEI) Total National Emissions (pounds) for Naphthalene and Methylnaphthalenes Estimated by Sector 2017

Sector	Naphthalene emissions	1-Methylnaphthalene emissions	2-Methylnaphthalene emissions
Mobile; on-road non-diesel heavy duty vehicles	79,914.05	—	—
Mobile; on-road non-diesel light duty vehicles	4,249,210.65	—	—
Solvent; consumer and commercial solvent use	7,901,059.66	—	—
Solvent; degreasing	20,442.35	—	—
Solvent; dry cleaning	15.45	—	—
Solvent; graphic arts	16,150.25	—	18.88
Solvent; industrial surface coating and solvent use	227,385.95	9.736	20.34
Solvent; non-industrial surface coating	307,872.48	—	—
Waste disposal	963,730.65	—	260,507.89

ICE = internal combustion engine; NEC = not elsewhere classified

Source: EPA 2017b

5.3.2 Water

Estimated releases of 4,727 pounds (~2.1 metric tons) of naphthalene to surface water from 1,202 domestic manufacturing and processing facilities in 2021, accounted for <1% of the estimated total environmental releases from facilities required to report to the TRI (TRI21 2023). This estimate includes releases to wastewater treatment and publicly owned treatment works (POTWs) (TRI21 2023). These releases are summarized in Table 5-2. There is no information on releases of 1- or 2-methylnaphthalene to surface water from manufacturing and processing facilities because these releases are not required to be reported (EPA 2022).

Most of the naphthalene released to water is attributable to coal-tar production and distillation processes. Some naphthalene from these sources is discharged directly to surface waters; the remainder is distributed to POTWs. The effluent and oil-spills from the wood-preserving industry is the only other source of consequence that releases naphthalene into the nation's waterways (EPA 1982).

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Naphthalene was below the limits of quantification ($<0.094\text{--}259$ ng/L) in 99 wastewater treatment plant effluent samples collected by the State of Oregon Department of Environmental Quality between 2010 and 2013 (WQP 2023). More robust effluent monitoring data were not located.

The detection of naphthalene and methylnaphthalenes in groundwater in the vicinity of industrial facilities and landfills (see Section 5.5.2) (Masoner et al. 2014) indicates that these chemicals are released to water from these sources. Methylnaphthalenes have also been detected in effluents from industrial sources.

1-Methylnaphthalene and 2-methylnaphthalene were reported in process sewage and production water samples from coal gasification plants at concentrations of 78–278 and 66–960 $\mu\text{g/L}$, respectively (GDCH 1992).

5.3.3 Soil

Estimated releases of 2,180,478 pounds (~ 989 metric tons) of naphthalene to soil from 1,202 domestic manufacturing and processing facilities in 2021, accounted for about 55% of the estimated total environmental releases from facilities required to report to the TRI (TRI21 2023). An additional 402,976 pounds (~ 183 metric tons), constituting about 10% of the total environmental emissions, were released via underground injection (TRI21 2023). These releases are summarized in Table 5-2. There is no information on releases of 1- or 2-methylnaphthalene to the soil from manufacturing and processing facilities because these releases are not required to be reported (EPA 2022).

Sources of naphthalene emissions to soil include coal-tar production and minor contributions from naphthalene production, POTW sludge disposal, the use of organic chemicals that include naphthalene, and landfill disposal of municipal waste (EPA 1982).

The residuals produced in gas production by coal carbonization, carbureted water gas production, or oil gas production at manufactured gas plants (MGPs) included PAHs (naphthalene, anthracene, phenanthrene, and benzo[1]pyrene). These residuals were deposited on site in tar wells, sewers, nearby pits, or streams resulting in widespread soil and groundwater contamination (Luthy et al. 1994).

Discarded cigarette butts, particularly in large amounts as in urban environments, may contribute to local contamination with naphthalene (Dobaradaran et al. 2019).

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5.4 ENVIRONMENTAL FATE**5.4.1 Transport and Partitioning**

Air. Naphthalene released to the atmosphere may be transported to surface water and/or soil by wet or dry deposition. Since most airborne naphthalene and methylnaphthalenes will be in the vapor phase based on their vapor pressures, deposition is expected to be very slow (about 0.04–0.06 cm/second). It has been estimated that about 2–3% of naphthalene emitted to air is transported to other environmental media, mostly by dry deposition (EPA 1982). Atmospheric transportation and partitioning data for the methylnaphthalenes were not located.

Water. Naphthalene in surface water may volatilize to the atmosphere. With a vapor pressure of 0.085 mm Hg, a water solubility of 31 mg/L at 20 °C, and a Henry's law constant of 4.4×10^{-4} atm-m³/mol (NLM 2023a), it is likely that volatilization will be an important route of naphthalene loss from water. The rate of volatilization also depends upon several environmental conditions, including temperature, wind velocity, and mixing rates of the air and water columns (EPA 1982). The highest measured volatilization flux of naphthalene from Gulf of Mexico sites of the Deepwater Horizon oil spill were 52,200 and 27,500 ng/m²/day (Tidwell et al. 2016). The half-life of naphthalene in the Rhine River was 2.3 days, based on monitoring data (Zoeteman et al. 1980). In an experiment using a mesocosm, that simulated Narragansett Bay, the half-life in water was 12 days during winter, with loss primarily due to volatilization (Wakeham et al. 1983).

Limited data were located on transport and partitioning of methylnaphthalenes in the environment. The respective vapor pressures (0.067 and 0.055 mm Hg), water solubilities (25.8 and 24.6 mg/L), and Henry's law constants (5.14×10^{-4} and 5.18×10^{-4} atm-m³/mol) for 1- and 2-methylnaphthalene are of similar magnitude to these properties for naphthalene (NLM 2023a). Thus, it is likely that loss of methylnaphthalenes from ambient water occurs by volatilization. In a mesocosm experiment, that simulated Narragansett Bay, the half-life of 2-methylnaphthalene in water was 13 days in winter, with loss primarily due to volatilization (Wakeham et al. 1983).

The log octanol/water partition coefficient (K_{ow}) for naphthalene is 3.30 and the log organic carbon coefficients (K_{oc}) range from 2.05 to 3.97 (NLM 2023b, 2023c). Based on the magnitude of these values, it is expected that a moderate fraction of naphthalene in typical surface water would be associated with

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particulate matter. Thus, some naphthalene discharged to surface waters would remain in solution, with some quantity removed by sorption to suspended solids and benthic sediments.

Based on the magnitude of log K_{ow} values for 1- and 2-methylnaphthalene (3.87 and 3.86, respectively) (NLM 2023b, 2023c) and the experimental log K_{oc} values of 3.36 and 3.64 for 1-methylnaphthalene and 3.00–5.96 for 2-methylnaphthalene (NLM 2023b, 2023c), these chemicals may partition similarly to naphthalene in environmental media and may be removed from the water column by sorption to solids.

Sediment and Soil. Naphthalene is easily volatilized from aerated soils (Park et al. 1990) and is adsorbed to a moderate extent (10%) (Karickhoff 1981; Schwarzenbach and Westall 1981). The extent of sorption depends on the organic carbon content of the soil, with rapid movement expected through sandy soils (Howard 1989). The estimated soil adsorption coefficient for naphthalene in a soil with <0.6% organic carbon is 1.8 (Klecka et al. 1990). In soils with 0.4, 1.7, and 0.1% organic carbon, naphthalene had calculated partition coefficients of 0.0034, 0.18, and 0.13 L/kg, respectively (Stagge et al. 2016). Because it adsorbs to aquifer material (Ehrlich et al. 1982), naphthalene's passage through groundwater will be somewhat retarded. Nevertheless, naphthalene frequently appears in effluent drainage from disposal sites (Rittman et al. 1980; Roberts et al. 1980; Schwarzenbach et al. 1983). However, sorption of naphthalene to aquifer materials with low organic carbon content (<0.03%) may be enhanced by the presence of nonionic low-polarity organics, such as tetrachloroethene, commonly found at hazardous waste sites (Brusseau 1991). Similarly, the presence of solvents such as cetylpyridinium chloride may affect sorption capacity of the soils, increasing sorptive capacities for low organic carbon and cation exchange capacity (CEC) soils or decreasing capacity for higher organic carbon and CEC soils (Stagge et al. 2016).

Based on the magnitude of log K_{ow} values for 1- and 2-methylnaphthalene (3.87 and 3.86, respectively) (NLM 2023b, 2023c) and the experimental log K_{oc} values of 3.36 and 3.64 for 1-methylnaphthalene and 3.00–5.96 for 2-methylnaphthalene (NLM 2023b, 2023c), these chemicals may partition similarly to naphthalene in environmental media and are expected to be slightly mobile to immobile in soils.

Other Media. Bioconcentration factors (BCFs) for naphthalene have been measured and calculated from the K_{ow} , K_{oc} , or water solubility. BCFs of 36.5–168 have been measured in carp (NITE 2010a), and 692 and 714 wet-weight (9,230 and 10,307 lipid-weight adjusted) were measured in Sheepshead minnows (Jonsson et al. 2004). Previous studies reported BCFs ranging from about 40 to 1,000 (Banerjee and Baughman 1991; Bysshe 1982; Geyer et al. 1982; Kenaga 1980; Southworth et al. 1978; Veith et al.

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1979). Based on the magnitude of the K_{ow} , bioaccumulation in the food chain is not expected to occur (Thomann 1989). However, naphthalene exposure of cows and chickens could lead to the presence of naphthalene in milk and eggs (Eisele 1985).

In an Organisation for Economic Cooperation and Development (OECD) guideline terrestrial plant bioaccumulation study, BCFs in lettuce (*Lactuca sativa*) via simulated uptake through atmospheric deposition were 184.62 for naphthalene, 77.00 for 1-methylnaphthalene, and 120.26 for 2-methylnaphthalene (Teke et al. 2020).

BCFs for 1- and 2-methylnaphthalene in oysters ranged from about 500 to 12,590 (GDCH 1992). Methylnaphthalenes are also metabolized and excreted rapidly by fish and shellfish when they are removed from polluted waters (Breger et al. 1981; GDCH 1992). In Sheepshead minnows, BCFs of 2,800 and 2,900 (wet-weight), and 37,00 and 44,000 (lipid-weight adjusted) were determined kinetically for 2-methylnaphthalene, with elimination occurring in 2–8 days (Jonsson et al. 2004).

In landfill leachate, a partition coefficient (K_{DOC}) of 22,000 mL/g dissolved organic carbon (DOC) was determined for naphthalene, which correlated with the substance's high water solubility, and supports the possibility for leaching from landfills and other waste sites (Kalmykova et al. 2013). Most of the naphthalene was dissolved in the aqueous phase rather than bound to the dissolved organics in the leachate.

5.4.2 Transformation and Degradation

Air. The most important atmospheric removal process for naphthalene is reaction with photochemically produced hydroxyl radicals (Howard 1989). The rate constant for this reaction is $2.17\text{--}2.39 \times 10^{-11}$ cm³/molecule-second (Atkinson et al. 1987; Phoussongphouang and Arey 2002) and the atmospheric half-life for naphthalene based on this reaction is 5.8 hours < 1 day. The major products are 1- and 2-naphthol and 1- and 2-nitronaphthalene (Atkinson et al. 1987). Atmospheric oxidation with other species such as nitrate radicals and ozone, occurs at a slower rate. Naphthalene reacts with N₂O₅, with an experimentally determined rate constant of 1.4×10^{-17} cm³/molecule-second (Atkinson et al. 1987). Using an ambient 12-hour nighttime concentration for N₂O₅ of 2×10^{10} molecules/cm³, an estimated half-life of approximately 29 days was calculated. Naphthalene also reacts with nighttime nitrate radicals, with an estimated atmospheric half-life of about 60 hours calculated from its experimentally determined rate constant of 6.4×10^{-15} cm³/molecule-second and a nitrate radical concentration of 5×10^8 molecules/cm³.

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(Atkinson 1984). The reaction of naphthalene with ozone is insignificant as compared to its reaction with hydroxyl radicals. Direct photolysis is expected to occur, although no experimental data were located (Howard 1989).

Methylnaphthalenes react with hydroxyl radicals. The reported rate constants are 5.30×10^{-11} and $5.23 \times 10^{-11} \text{ cm}^3/\text{molecule-second}$ for 1- and 2-methylnaphthalene, respectively (NLM 2023b, 2023c). Based on an atmospheric hydroxyl radical concentration of $1.5 \times 10^6/\text{cm}^3$, the corresponding atmospheric half-lives are 2.4 and 2.5 hours. Reactions of 1- and 2-methylnaphthalene with N_2O_5 radicals have half-lives of 24 and 19 days, respectively (GDCH 1992). These chemicals also react with atmospheric ozone and nitrate radicals. In a rural setting, where the concentration of nitrate radicals is lower, calculated atmospheric lifetimes for monosubstituted naphthalenes based on reactions with nitrate radicals range from 2.5 to 3.6 years; in urban and polluted environments, where the concentration of nitrate radicals is higher, the calculated lifetimes range from 22 to 31 hours (Phousongphouang and Arey 2003).

Water. Naphthalene and methylnaphthalenes are degraded in water by photolysis and biological processes. The half-life for direct photolysis of naphthalene in surface water is estimated to be about 71 hours, but the half-life in deeper water (5 m) is estimated at 550 days (Zepp and Schlotzhauer 1979). The half-lives for photolysis of 1- and 2-methylnaphthalene were estimated at 22 and 54 hours, respectively (GDCH 1992). Reduced indirect photolytic rates for naphthalene were observed with increasing salinity, an important consideration when estimating fate in marine environments after oil spills (Jing et al. 2014). Ions in seawater such as Br^- , CO_3^{2-} , and HCO_3^- act as scavengers of hydroxyl radicals, reducing indirect photolysis of naphthalene and methylnaphthalenes.

Biodegradation of naphthalene may be sufficiently rapid for it to be a significant fate process in aquatic systems when acclimated organisms are present. Data on biodegradation of naphthalene in biodegradability tests and natural systems suggest that biodegradation occurs after a relatively short period of acclimation (half-life of about 7 days in oil-polluted water) and the biodegradation rate increases with the naphthalene concentration. Biodegradation occurs slowly (half-lives up to 1,700 days) in unpolluted water (Herbes 1981; Herbes and Schwall 1978; Herbes et al. 1980; Howard 1989; Kappeler and Wuhrmann 1978). Reported biodegradation half-lives range from 3 to 1,700 days in various water systems, occurring more rapidly in PAH- and oil-polluted environments (Howard 1989). In a static-flask-screening test, naphthalene showed rapid acclimation and 100% loss from the test medium in 7 days (Tabak et al. 1981). In another flask-screening test with unacclimated organisms, negligible loss (2%) was observed (NITE 2010b). In an experiment with Narragansett Bay seawater, the half-life of

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naphthalene in late summer was reported at 0.8 days, mainly due to biodegradation (Wakeham et al. 1983). The half-life of 2-methylnaphthalene was 0.7 days in the same experiment.

Methylnaphthalenes are biodegraded under aerobic conditions after adaptation. The highest degradation rates were reported in water constantly polluted with petroleum (GDCH 1992).

Sediment and Soil. Biodegradation is expected to proceed more rapidly in sediments with acclimated organisms. Half-lives reported in sediment include 4.9 hours and >88 days in oil-contaminated and uncontaminated sediment, respectively (Herbes and Schwall 1978), 9 days in sediment near a coal-coking discharge (Herbes 1981), 3, 5, and >2,000 hours in sediments with high, medium, and low PAH levels, respectively (Herbes et al. 1980), and ranging from 2.4 weeks in sediments exposed to petroleum hydrocarbons to 4.4 weeks in sediments from a pristine environment (Howard 1989). Methyl-naphthalenes biodegrade more slowly. Reported half-lives in sediments were 46 weeks for 1-methylnaphthalene and ranged from 14 to 50 weeks for 2-methylnaphthalene (GDCH 1992).

Biodegradation potential is important to biological remediation of soil. Studies on biodegradation of PAHs suggest that adsorption to the organic matter significantly reduces the bioavailability for microorganisms, and thus the biodegradability, of PAHs, including naphthalene (Heitzer et al. 1992; Weissenfels et al. 1992). There is considerable variability in reported naphthalene soil half-lives. The estimated half-life of naphthalene reported for a solid waste site was 3.6 months (Howard 1989). In soils with 0.2–0.6% organic carbon and 92–94% sand, the half-lives were 11–18 days (Klecka et al. 1990). In another study, sandy loams with 0.5–1% organic carbon had naphthalene half-lives of 2–3 days (Park et al. 1990). The half-life in an unimpacted soil with 0.78% organic matter was 34.7 days (Agarry and Oghenejoboh 2015). Biodegradation is accomplished through the action of aerobic microorganisms and declines precipitously when soil conditions become anaerobic (Klecka et al. 1990). Studies indicate that naphthalene biodegrades to carbon dioxide in aerobic soils, with salicylate as an intermediate product (Heitzer et al. 1992).

Abiotic degradation of naphthalene seldom occurs in soils. In one study, only about 10% of the naphthalene added to two soil samples treated with mercuric chloride to kill microorganisms was degraded over a 105- or 196-day period (Park et al. 1990).

In contaminated subsurface soils often found at former MGP sites, naphthalene is present as a component in coal tar, a dense nonaqueous-phase liquid (DNAPL). It may exist in the subsurface in the form of

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trapped pools of organic liquid or as immobilized macroporous ganglia. Slow partitioning of naphthalene and other PAHs from DNAPLs into the aqueous phase causes them to be unavailable to the microorganism, thus resulting in the partitioning of the PAHs being the rate-limiting step in their biodegradation (Thomas et al. 1986). Using phenanthrene as a test substance, Birman and Alexander (1996) showed that the viscosity of the nonaqueous-phase liquid (NAPL) may reflect a slower diffusion of the aromatic substrate in the more viscous NAPLs and its subsequent slower mass transfer to water. Ghoshal and Luthy (1996) demonstrated that a very large fraction of naphthalene can be biodegraded from an accessible coal-tar-NAPL (free flowing) by microorganisms in bioslurry systems. Metabolically active microflora were detected beneath the water table at former MGP sites from 2.6 to 30.8 m below the ground surface. The subsurface microflora appeared to be acclimated to the presence of PAHs and were found to mineralize naphthalene (8–55%) in sediment-water microcosms under aerobic conditions. Naphthalene biodegradation half-lives ranged from 18 to 480 days (Durant et al. 1994).

Partitioning to soil organic matter may also limit biodegradation in uncontaminated soils. Naphthalene remaining in soil for extended periods of time was shown to become less available to bacteria and earthworms (Kelsey and Alexander 1997).

Other Media. Naphthalene is reported to be rapidly eliminated from invertebrates when the organisms are placed in pollutant-free water (Eastmond et al. 1984; Tarshis 1981). Naphthalene is readily metabolized in fish (Howard 1989), and was eliminated within 2–8 days when placed in pollutant-free water (Jonsson et al. 2004).

5.5 LEVELS IN THE ENVIRONMENT

Reliable evaluation of the potential for human exposure to naphthalene, 1-methylnaphthalene, and 2-methylnaphthalene depends, in part, on the reliability of supporting analytical data from environmental samples and biological specimens. Concentrations of naphthalene, 1-methylnaphthalene, and 2-methylnaphthalene in unpolluted atmospheres and in pristine surface waters are often so low as to be near the limits of current analytical methods. In reviewing data on naphthalene, 1-methylnaphthalene, and 2-methylnaphthalene levels monitored or estimated in the environment, it should also be noted that the amount of chemical identified analytically is not necessarily equivalent to the amount that is bioavailable.

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Table 5-4 shows the lowest limits of detection that are achieved by analytical analysis in environmental media. An overview summary of the range of concentrations detected in ambient environmental media sampled from a variety of site types (e.g., rural, urban) is presented in Table 5-5.

Table 5-4. Lowest Limit of Detection Based on Standards for Naphthalene, 1-Methylnaphthalene, and 2-Methylnaphthalene^a

Media	Detection limit ^b	Reference
Air	4.40 ng/m ³	Jia et al. 2020
Drinking water	0.012 µg/L	EPA 2009a
Surface water and groundwater	0.03 µg/L	USGS 2006
Surface water	0.00014–0.027 µg/L 0.000056 (1-methylnaphthalene) 0.0001 (2-methylnaphthalene)	USGS 2018, 2019
Soil	4 µg/kg	USGS 2004
Sediment (pore water)	4 µg/kg 5.7 mg/mL 2.4 ng/mL (1- and 2-methylnaphthalene)	USGS 2004 EPA 2007a
Whole blood	0.0758 ng/g	Hao et al. 2020

^aDetection limits are based on using appropriate preparation and analytics. These limits may not be possible in all situations.

^bAll detection limits are for naphthalene unless otherwise noted.

Table 5-5. Summary of Environmental Levels of Naphthalene, 1-Methylnaphthalene, and 2-Methylnaphthalene

Media	Naphthalene		1-Methyl naphthalene		2-Methyl naphthalene		For more information
	Low	High	Low	High	Low	High	
Outdoor air (ppbv)	0.0025	22.1	0.036	0.0908	0.000574	0.132	Section 5.5.1
Indoor air (ppbv)	0.034	1.9	–	–	–	–	Section 5.5.1
Surface water (ppb)	0.00018	0.52	0.00034	0.2	0.00054	0.2	Section 5.5.2
Ground water (ppb)	>0.2	4,070	0.01	19	36.1	431	Section 5.5.2
Drinking water (ppb)	–	>0.2	–	–	–	–	Section 5.5.2
Food (ppb)	<0.61	561.4	<0.4	306.0	<0.36	286.9	Section 5.5.4
Soil (ppb)	2.0	25,900	2.2	4,400	1.3	11,500	Section 5.5.3

Concentration (ppbv) = 24.45 x concentration (µg/m³) ÷ molecular weight; ppb = µg/L = µg/kg

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Detections of naphthalene, 1-methylnaphthalene, and 2-methylnaphthalene in air, water, and soil at NPL sites are summarized in Table 5-6.

Table 5-6. Naphthalene and Methylnaphthalene Levels in Water, Soil, and Air of National Priorities List (NPL) Sites

Medium	Median ^a	Geometric mean ^a	Geometric standard deviation ^a	Number of quantitative measurements	NPL sites
Naphthalene					
Water (ppb)	59.5	124	58.1	168	110
Soil (ppb)	32,000	38,100	43.2	272	174
Air (ppbv)	2.48	2.14	20.0	43	30
1-Methylnaphthalene					
Water (ppb)	0.0245	1.07	1,230	6	3
Soil (ppb)	63,000	19,000	32.8	12	4
Air (ppbv)	No data	No data	No data	No data	No data
2-Methylnaphthalene					
Water (ppb)	21	32.4	56.8	57	41
Soil (ppb)	15,000	14,000	32.2	191	118
Air (ppbv)	0.0258	0.130	46.5	7	6
Methylnaphthalene					
Water (ppb)	6	6	1	2	1
Soil (ppb)	5,300	11,900	18.0	7	5
Air (ppbv)	No data	No data	No data	No data	No data

^aConcentrations found in ATSDR site documents from 1981 to 2022 for 1,868 NPL sites (ATSDR 2022a). Maximum concentrations were abstracted for types of environmental media for which exposure is likely. Pathways do not necessarily involve exposure or levels of concern.

5.5.1 Air

Naphthalene and methylnaphthalenes have been reported in ambient air at several locations in the United States. While concentrations of naphthalene in air in the United States have been well-studied, more limited data are available on the methylnaphthalenes. The Air Quality System (AQS) reports that the average naphthalene concentration from 2018 to 2021 has remained constant between 0.4 and 0.5 µg/m³, with maximum concentrations reported in 2018, dropping over time. Data on methylnaphthalenes are too limited to observe any longitudinal trends in concentration (EPA 2022b). These data are summarized in Table 5-7.

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Table 5-7. Summary of Annual Concentrations of Naphthalene and Methylnaphthalenes ($\mu\text{g}/\text{m}^3$) Measured in Ambient Air at Locations Across the United States^{a,b}

Year	Number of monitoring locations	Number of samples	Average	Maximum
Naphthalene				
2018	32	1,739	0.04	2.66
2019	36	1,776	0.04	2.21
2020	34	1,801	0.06	1.7
2021	43	2,032	0.04	1.16
2022 ^c	32	720	0.02	0.66
1-Methylnaphthalene				
2018	—	—	—	—
2019	—	—	—	—
2020	1	130	0.0023	0.00581
2021	1	65	0.0026	0.0108
2022 ^c	—	—	—	—
2-Methylnaphthalene				
2018	1	71	0	0
2019	—	—	—	—
2020	1	130	0.0040	0.00843
2021	1	63	0.0039	0.00922
2022 ^c	—	—	—	—

^aValues were originally reported in parts per billion carbon (ppbC) or ng/m^3 and converted to $\mu\text{g}/\text{m}^3$.

^b24-hour sampling period.

^cAs of October 14th, 2022.

Source: EPA 2022b

A Norfolk Southern train derailed near East Palestine, Ohio, on February 3, 2023, with hazardous material being released to the local environment (NTSB 2023). Air monitoring and sampling data have been reported by the EPA (EPA 2023b). Data collected from February 4 to August 18, 2023 resulted in 1,444 samples analyzed for naphthalene (EPA 2023b). A maximum value of 4.58 ppbv was detected on February 28, 2023 (EPA 2023b).

Naphthalene concentrations in air can vary widely depending on the uses of the site, the site's proximity to sources of naphthalene, and atmospheric conditions. A summary of studies monitoring naphthalene and methylnaphthalenes in outdoor air is provided in Table 5-8. During atmospheric stagnation periods in January and July, 2009, ambient air samples were collected from mobile samplers in neighborhoods

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adjacent to three fixed air toxic sites in Tacoma, Washington. Pollutant sources were identified as traffic-related or wood smoke-related. Wood-burning sources had calculated overall means of $16.5 \mu\text{g}/\text{m}^3$ in summer and $10.6 \mu\text{g}/\text{m}^3$ in winter; traffic sources had calculated overall means of $69.5 \mu\text{g}/\text{m}^3$ in summer and $16.1 \mu\text{g}/\text{m}^3$ in winter (Davey et al. 2014).

Table 5-8. Summary of Naphthalene and Methylnaphthalenes ($\mu\text{g}/\text{m}^3$) Measured in Outdoor Air

Date	Location	Average ^a	Range	Percent detected ^b	Notes	Source
Naphthalene						
2001–2003	Riverside, California	0.259	0.013–0.767	–	Urban air	Lu et al. 2005
	San Dimas, California	0.265	0.041–0.652	–		
	Mira Loma, California	0.249	0.027–1.035	–		
	Upland, California	0.207	0.026–0.306	–		
	Long Beach, California	0.091	0.046–0.178	–		
	Los Angeles, California	0.697	0.094–2.543	–		
January 2009; July 2009	Tacoma, Washington	10.6; 16.5	8.44–13.1; 7.18–22.6	–	Wood-burning sources during two air stagnation events	Davey et al. 2014
		16.1; 69.5	12.1–20.3; 31.8–116	–	Traffic sources during two air stagnation events	
1990–2014	United States	0.178	NS–9.092	–	Urban air	Liu et al. 2017
		0.135	NS–1.309	–	Rural air	
June 2013–June 2015	Mille Lacs Band of Ojibwe Land	0.012±0.006	–	–	Rural air	Ellickson et al. 2017
	Minneapolis, Minnesota	0.075±0.016	–	–	Urban air	
August, 2018	Eugene, Oregon	0.08 ^{c,d}	0.005 (LOD)–0.3 ^d	50%	Air during wildfire	Messier et al. 2019
1-Methylnaphthalene						
August, 2018	Eugene, Oregon	0.009 ^{c,d}	0.0009 (LOD)–0.03 ^d	52%	Air during wildfire	Messier et al. 2019
2-Methylnaphthalene						
June 2013–June 2015	Mille Lacs Band of Ojibwe Land	0.00334±0.00165	–	–	Rural air	Ellickson et al. 2017
	Minneapolis, Minnesota	0.0339±0.00784	–	–	Urban air	

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Table 5-8. Summary of Naphthalene and Methylnaphthalenes ($\mu\text{g}/\text{m}^3$) Measured in Outdoor Air

Date	Location	Average ^a	Range	Percent detected ^b	Notes	Source
August, 2018	Eugene, Oregon	0.01 ^{b,d}	0.001 (LOD) –0.08 ^d	55%	Air during wildfire	Messier et al. 2019

^aValue is an average unless otherwise noted.

^bPercent detection on a per sample basis.

^cValue is reported as the median of values above the limit of detection (LOD).

^dValues estimated from a figure and should be treated as approximates.

NS = not specified

Urban air may have higher concentrations of naphthalene and methylnaphthalenes. Rural and urban air monitoring was conducted between June 2013 and June 2015 on the Mille Lacs Band of Ojibwe Land and in south Minneapolis, respectively. Naphthalene was detected at $0.012 \mu\text{g}/\text{m}^3$ in Mille Lacs and at $0.075 \mu\text{g}/\text{m}^3$ in Minneapolis; 2-methylnaphthalene was detected at $0.00334 \mu\text{g}/\text{m}^3$ in Mille Lacs and at $0.0339 \mu\text{g}/\text{m}^3$ in Minneapolis (Ellickson et al. 2017). The highest naphthalene concentrations were observed at a site near a foundry and asphalt production facility. Average air concentrations between 2001 and 2003 in cities in California were between 0.091 and $0.697 \mu\text{g}/\text{m}^3$ for cities in California (Lu et al. 2005). Mean long-term trends analyzed from AQS data between 1990 and 2014 were $0.178 \mu\text{g}/\text{m}^3$ naphthalene in urban air and $0.135 \mu\text{g}/\text{m}^3$ naphthalene in rural air (Liu et al. 2017).

Naphthalene concentrations in indoor air may be higher than outdoor air, depending on ventilation, tobacco use, and use of naphthalene releasing products or burning wood or fuel. Concentrations of naphthalene detected in indoor and outdoor air measured in 24 low-income homes in North Carolina were 0.33 – 9.7 and 0.57 – $1.82 \mu\text{g}/\text{m}^3$ respectively (Chuang et al. 1999). In urban and suburban homes in Southeast Michigan, Syracuse, New York, and Chicago, Illinois, median concentrations of naphthalene detected were 0.84 , 2.84 , and $0.18 \mu\text{g}/\text{m}^3$, respectively (Jia and Batterman 2011). For rural homes in Missoula, Montana, the median naphthalene concentration detected was $0.3 \mu\text{g}/\text{m}^3$. Indoor air concentrations of naphthalene of residences in Ottawa, Canada, ranged from 0.68 to $1.83 \mu\text{g}/\text{m}^3$ (Wheeler et al. 2014). In homes with smokers, indoor and outdoor air concentrations were measured to be 2.2 and $0.3 \mu\text{g}/\text{m}^3$, respectively. Comparable values in homes without smokers were 1.0 and $0.1 \mu\text{g}/\text{m}^3$, respectively (EPA 1991; Gold et al. 1993). Vapor intrusion is not expected to be a source of indoor air naphthalene pollution. Naphthalene was detected in indoor air at 2.6 and $49 \mu\text{g}/\text{m}^3$, in soil gas at $0.5 \mu\text{g}/\text{m}^3$, and in outdoor air at $6.3 \mu\text{g}/\text{m}^3$ at a daycare investigated for vapor intrusion by ATSDR (2007b); a consumer product was reported as a more likely source of the indoor pollution. Naphthalene

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was detected at a maximum of $9.7 \mu\text{g}/\text{m}^3$ in apartments investigated for vapor intrusion, however soil gas samples were not reported (ATSDR 2008). Indoor air concentrations may also be impacted by wildfires; the median indoor air concentration of naphthalene was approximately $0.1 \mu\text{g}/\text{m}^3$ in comparison to $0.08 \mu\text{g}/\text{m}^3$ for outdoor air, and indoor air ranged higher and had a higher percent detection (detected in 79% of indoor air samples) (Messier et al. 2019). Similar trends were observed for the methylnaphthalenes, and median indoor air concentrations of approximately $0.06 \mu\text{g}/\text{m}^3$ 1-methylnaphthalene and $0.09 \mu\text{g}/\text{m}^3$ 2-methylnaphthalene were reported (detected in 67 and 64% of samples, respectively).

Limited recent data reporting naphthalene concentrations at industrial and hazardous waste sites were located. Naphthalene was detected in the air of a wood creosote-treatment facility at $1.50 \mu\text{g}/\text{m}^3$ (Morgan et al. 2015). At sites near another wood creosote-treatment facility, naphthalene ranged from 0.4 to $12.9 \mu\text{g}/\text{m}^3$, 1-methylnaphthalene ranged from 0.2 to $2.3 \mu\text{g}/\text{m}^3$, and 2-methylnaphthalene ranged from 0.2 to $5.7 \mu\text{g}/\text{m}^3$, during 24-hour sampling periods (ATSDR 2007a). Sampling periods of 1–3 hours had larger maximum concentrations: 25.6, 7.2, and $19.4 \mu\text{g}/\text{m}^3$, respectively. Based on use and reported emissions of naphthalene, detections at sites producing or using naphthalene would be expected.

Limited monitoring data were available for methylnaphthalenes. 1-Methylnaphthalene and 2-methylnaphthalene have been reported in ambient air at average concentrations of 0.21 and $0.37 \mu\text{g}/\text{m}^3$, respectively (EPA 2022b).

5.5.2 Water

The EPA maintains a Water Quality Portal (WQP) database that aggregates environmental monitoring data from the National Water Information System (NWIS) and STORage and RETrieval (STORET) system, providing ample data for assessment of current conditions and trends in naphthalene and methylnaphthalene concentrations in waters of the United States. A summary of the data for ambient surface and groundwater from recent years are reported in Table 5-9 (WQP 2023). Naphthalene and methylnaphthalenes have been detected in surface water and groundwater in the United States.

Detections were generally infrequent and at trace levels, although limited sampling was conducted for the methylnaphthalenes. Concentrations present in groundwater were generally higher than surface water, where volatilization may occur.

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Table 5-9. Summary of Concentrations of Naphthalene and Methylnaphthalenes (µg/L) Measured in Surface and Groundwater Across the United States

Year	Average	Maximum	Number of samples	Percent detected
Surface water				
Naphthalene				
2018	0.06	0.3	930	2.2%
2019	0.02	0.02	709	1.0%
2020	0.05	0.15	242	2.1%
2021	0.04	0.16	184	5.4%
2022	0.04	0.52	90	44%
2023 ^a	0.04	0.06	22	41%
1-Methylnaphthalene				
2018	0.03	0.2	182	13%
2019	0.02	0.1	176	7.4%
2020	0.02	0.02	56	1.8%
2021	0.01	0.01	72	4.2%
2022	0.03	0.03	23	4.3%
2023 ^a	—	—	4	0%
2-Methylnaphthalene				
2018	0.05	0.2	431	4.4%
2019	0.04	0.2	348	2.3%
2020	0.04	0.04	93	1.1%
2021	0.01	0.01	74	4.1%
2022	0.03	0.03	23	4.3%
2023 ^a	—	—	4	0%
Groundwater				
Naphthalene				
2018	36.1	365	1,286	1.8%
2019	51.2	522	1,648	1.8%
2020	94.1	700	1,275	3.8%
2021	109	4,070	1,821	9.4%
2022	105	980	2,823	9.4%
2023 ^a	115	740	716	10%
1-Methylnaphthalene				
2018	0.02	0.028	38	7.9%
2019	0.01	0.01	19	5.2%
2020	—	—	39	0%
2021	4.67	19	59	25%
2022	0.077	0.077	22	4.5%
2023 ^a	—	—	—	—

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Table 5-9. Summary of Concentrations of Naphthalene and Methylnaphthalenes (µg/L) Measured in Surface and Groundwater Across the United States

Year	Average	Maximum	Number of samples	Percent detected
2-Methylnaphthalene				
2018	20.1	66	68	8.8%
2019	42.4	379	53	26%
2020	41.4	200	119	16%
2021	36.1	431	216	31%
2022	63.6	1,830	184	35%
2023 ^a	55.2	91.5	36	25%

^aAs of August, 2023.

Source: WQP 2023

In a study of surface water in Southern Lake Powell, recreational waters in Arizona and Utah, naphthalene concentrations ranged from 0.00065 to 0.0029 µg/L in summer 2016 and were below the detection limits (0.022 and 0.027 µg/L, respectively, which were an order of magnitude higher than detection limits for other sampling campaigns) for spring and summer 2017 (USGS 2018, 2019).

1-Methylnaphthalene was detected at concentrations of 0.00058–0.0024, 0.00034–0.0017, and 0.00071–0.0011 µg/L for summer 2016, spring 2017, and summer 2017, respectively; 2-methylnaphthalene was detected at 0.0009–0.0035, 0.00054–0.0019, and 0.00088–0.0021 µg/L for summer 2016, spring 2017, and summer 2017, respectively (USGS 2019).

In a study of contaminants of an urban watershed of Chesapeake Bay, naphthalene was detected in the northeast and northwest branches of Anacostia River (an urban watershed of Chesapeake Bay) at a concentration range of 0.00018–0.0216 µg/L. 2-Methylnaphthalene was also detected at a concentration of 0.00057–0.0627 µg/L (Foster et al. 2000).

Naphthalene is rarely detected in drinking water. In a large-scale monitoring study of principal aquifers in the United States between 1991 to 2010, naphthalene was detected at >0.2 µg/L in 7 of the 40 aquifer areas used for drinking water (USGS 2015). For these aquifers, percent detections ranged from only 0.22 to 5.26%. Current data regarding the presence of methylnaphthalenes in drinking water were not located.

Concentrations of naphthalene and methylnaphthalenes in groundwater are expected to be higher near industrial sites using naphthalene and landfills. In a landfill leachate sampling campaign collected in

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2011, naphthalene, 1-methylnaphthalene, and 2-methylnaphthalene were detected in leachate at median concentrations of 5.05, 1.70, and 1.92 µg/L, respectively, from landfills across the United States (Masoner et al. 2014). Detections in leachate and groundwater plumes have been reported previously from industrial and municipal landfills and waste disposal sites (Barbee 1994; Brown and Donnelly 1988; Kinman et al. 1995). Naphthalene and 2-methylnaphthalene were detected in groundwater at five wood treatment facilities (Rosenfeld and Plumb 1991). Naphthalene was reported in 35% of samples at all five sites at an average concentration of 3,312 µg/L. 2-Methylnaphthalene was reported in 27% of samples at four sites at an average concentration of 563 µg/L. Naphthalene, 1-methylnaphthalene, and 2-methylnaphthalene have been detected in groundwater at Gas Works Park, Seattle, Washington, in the range of 20–12,000, 20–1,100, and 30–1,400 µg/L, respectively (Turney and Goerlitz 1990). Gas Works Park is located on the site of a coal and oil gasification plant that ceased operation in 1956. Naphthalene and 2-methylnaphthalene were detected in the groundwater of a former petroleum bulk plant at 147 and 1,420 µg naphthalene/L and 392 µg 2-methylnaphthalene/L (ATSDR 2006). Naphthalene was below the ATSDR child and adult intermediate environmental media evaluation guide (EMEG) values; EMEGs were not available for 2-methylnaphthalene. Naphthalene and 2-methylnaphthalene were detected in groundwater at the Superfund Portland Harbor Site at an average of 1,150 µg/L (n=644, 71% detected) and 69.3 µg/L (n=438, 77% detected), respectively, between 2004 and 2007 (WQP 2023). Detections in surface water were much lower, with averages of 45.2 and 0.03 µg/L, respectively (percent detections around 13–27%). Naphthalene was not detected in groundwater at the Palermo Wellfield Superfund site between 2018 and 2020 (WQP 2023).

Limited data are available for marine environments. Naphthalene has been reported at a mean concentration of 0.0063 µg/L in seawater in the south Atlantic Ocean (Cripps 1992).

5.5.3 Sediment and Soil

Naphthalene and methylnaphthalenes were generally commonly detected in soil/sediment samples, at average concentrations typically between 100 and 200 µg/kg (WQP 2023). A summary of the data for ambient soil/sediment monitoring is reported in Table 5-10. Samples were not specified as sediment or soil.

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Table 5-10. Summary Naphthalene and Methylnaphthalenes (µg/kg) Measured in Soil/Sediment Across the United States, Reported in the Water Quality Portal

Year	Average	Maximum	Number of samples	Percent detected
Naphthalene				
2018	361	25,900	694	56%
2019	80.0	707	372	27%
2020	139	2,600	214	19%
2021	141	5,900	176	51%
2022	4.08	69	108	56%
2023 ^a	—	—	—	—
1-Methylnaphthalene				
2018	87.8	1,010	277	48%
2019	108	1,360	237	32%
2020	—	—	142	0%
2021	8.72	214.8	118	43%
2022	1.22	5	55	38%
2023 ^a	—	—	—	—
2-Methylnaphthalene				
2018	170	11,500	500	63%
2019	144	2,990	314	30%
2020	216	1,600	193	7.7%
2021	79.7	4,400	152	45%
2022	5.96	140	80	48%
2023 ^a	—	—	—	—

^aAs of August, 2023.

Source: WQP 2023

Naphthalene concentrations have been well characterized in urban soils. The results of several soil and sediment monitoring studies are provided in Table 5-11. In samples taken across Manhattan from 2005 to 2006, median concentrations of naphthalene, 1-methylnaphthalene, and 2-methylnaphthalene in surface soils were 23, 16, and 17 µg/kg, respectively (Azzolina et al. 2016). Concentrations were decreased in subsurface soils. Soils collected from small cities in Florida had approximate median naphthalene concentrations of 75–100 µg/kg (Gao et al. 2019). PAH sources were hypothesized to be from biomass, coal and coke combustion, and vehicle emissions. Naphthalene and methylnaphthalene analysis was conducted for surface and subsurface soil samples that were collected from parks in Milwaukee, Wisconsin, where the only expected pollutant source was atmospheric deposition. In 0–7 cm soil, the

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mean concentrations were 69 µg/kg naphthalene, 37.3 µg/kg 1-methylnaphthalene, and 39.7 µg/kg 2-methylnaphthalene (Siemering and Thiboldeaux 2021). Subsurface concentrations decreased.

Table 5-11. Summary of Naphthalene and Methylnaphthalenes (µg/kg) Measured in Ambient Soil and Sediment

Date	Location	Average ^a	Range	Percent detected	Notes	Source
Naphthalene						
2005–2006	Manhattan, New York	23 ^b	2.4–210	100	Urban surface soil, 0–5 cm	Azzolina et al. 2016
		17 ^b	2.0–22,000	100	Urban subsurface soil, >15 cm	
2017	Milwaukee, Wisconsin	69	20.6–190	5	Soil from parks, 0–7 cm	Siemering and Thiboldeaux 2021
		–	–	0%	Soil from parks, 15–30 cm	
2018	Clay County, Florida	75 ^b	–	–	Soil from small cities	Gao et al. 2019
	Ocala, Florida	83 ^b	–	–		
	Pensacola, Florida	95 ^b	–	–		
	West Palm Beach, Florida	100 ^b	–	–		
1992–1995	United States	–	NS–4,900	7%	496 streambeds sampled	Lopes and Furlong 2001
–	Richardson Bay, California	–	–	–	Decreased from 33 to 2.1 with increasing depth (0–148 cm)	Pereira et al. 1999
–	San Pablo Bay, California	–	–	–	Decreased from 18 to 4.1 with increasing depth (0–239 cm)	
2012–2016	Northern Colorado Plateau, Colorado	–	61	4%	Sediment from bodies of water in and near national parks; detected at 2 of 18 sites	Weissinger et al. 2018
2017	Great Lakes tributaries in Minnesota, Wisconsin, Indiana,	7.04	NS–1,340	100%	Streambeds of tributaries to the Great Lakes	Baldwin et al. 2022

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Table 5-11. Summary of Naphthalene and Methylnaphthalenes (µg/kg) Measured in Ambient Soil and Sediment

Date	Location	Average ^a	Range	Percent detected	Notes	Source
1-Methylnaphthalene						
2005–2006	Ohio, and Manhattan, New York	16 ^b	1.4–150	100%	Urban surface soil, 0–5 cm	Azzolina et al. 2016
		13 ^b	2.2–4,400	100%	Urban subsurface soil, >15 cm	
2017	Milwaukee, Wisconsin	37.3	2.7–233	11%	Soil from parks, 0–7 cm	Siemering and Thiboldeaux 2021
		18.6	14.5–22.4	15%	Soil from parks, 15–30 cm	
2012–2016	Northern Colorado Plateau, Colorado	–	41	8%	Sediment from bodies of water in and near national parks; Detected at 2 of 18 sites	Weissinger et al. 2018
2017	Great Lakes tributaries in Minnesota, Wisconsin, Indiana, Ohio, and New York	11.0	NS–3,050	60%	Streambeds of tributaries to the Great Lakes	Baldwin et al. 2022
2-Methylnaphthalene						
2005–2006	Manhattan, New York	17 ^b	1.3–130	100%	Urban surface soil, 0–5 cm	Azzolina et al. 2016
		11 ^b	1.8–5,500	96%	Urban subsurface soil, >15 cm	
2017	Milwaukee, Wisconsin	39.7	2.3–281	13%	Soil from parks, 0–7 cm	Siemering and Thiboldeaux 2021
		21.8	17.3–24.9	12%	Soil from parks, 15–30 cm	
2012–2016	Northern Colorado Plateau, Colorado	–	62	7%	Sediment from bodies of water in and near national parks; detected at 2 of 18 sites	Weissinger et al. 2018
2017	Great Lakes tributaries in Minnesota, Wisconsin,	18.0	NS–2,460	60%	Streambeds of tributaries to the Great Lakes	Baldwin et al. 2022

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Table 5-11. Summary of Naphthalene and Methylnaphthalenes (µg/kg) Measured in Ambient Soil and Sediment

Date	Location	Average ^a	Range	Percent detected	Notes	Source
	Indiana, Ohio, and New York					

^aValue is an average unless otherwise noted.

^bValue is the median.

Streambed sediments collected from Great Lakes tributaries in several states in the summer of 2017 had median concentrations of 7.04 µg/kg naphthalene, 11.0 µg/kg 1-methylnaphthalene, and 18.0 µg/kg 2-methylnaphthalene detected (Baldwin et al. 2022). Surface sediment samples were collected between 2012 and 2016 from locations in and near national parks on the northern Colorado Plateau for naphthalene analysis. Naphthalene and methylnaphthalenes were detected in 2 of the 18 sites, with maximum concentrations of 61, 41, and 62 µg/kg, for naphthalene, 1-methylnaphthalene, and 2-methylnaphthalene, respectively (Weissinger et al. 2018). Naphthalene was detected in 7% of 496 streambed sediment sites across the United States tested for the presence of semi-volatile organic compounds; the maximum concentration was 4,900 µg/kg dry weight (Lopes and Furlong 2001). Like soil, concentrations of naphthalene have been observed to decrease with depth in sediments. Concentrations of naphthalene decreased from 33 to 2.1 µg/kg dry weight with increasing depth (0–148 cm) in the sediment core in Richardson Bay and from 18 to 4.1 µg/kg dry weight with increasing depth (0–239 cm) in the sediment core in San Pablo Bay (Pereira et al. 1999). These bays are located in the San Francisco Bay, which is the largest urbanized estuary on the west coast of the United States.

Naphthalene and methylnaphthalenes have been reported at higher concentrations near or within sources of contamination, although recent data were not located. Previously, reported naphthalene concentrations in contaminated soils included 6,100 µg/kg in coal-tar contaminated soil (Yu et al. 1990), 16,700 µg/kg in soil from a former tar-oil refinery (Weissenfels et al. 1992), and up to 66 µg/kg in sludge-treated soils (Wild et al. 1990). Methylnaphthalenes (isomer not specified) were reported at a concentration of 2,900 µg/kg in coal-tar contaminated soil (Yu et al. 1990). Hawthorne et al. (2001) reported the concentration of naphthalene to be 48,000 µg/kg in the soil from an unspecified MGP in the midwestern United States. Naphthalene and 2-methylnaphthalene were detected in soil samples collected from a former petroleum bulk plant at 46,700 and 68,600 µg naphthalene/kg and 13,400 µg 2-methylnaphthalene/kg (ATSDR 2006). These pollutants were not reported in soil gas samples, and naphthalene

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was below the ATSDR child and adult reference media evaluation guide (RMEG) values; RMEGs were not available for 2-methylnaphthalene. The mean concentration of naphthalene found in the sediment samples taken from 31 freshwater and estuarine sites adjacent to, nearby, or downstream from potential pollutant sources in Florida was 33,000 µg/kg (Miles and Delfino 1999).

No studies evaluating indoor or residential dust concentrations of naphthalene or methylnaphthalenes in the United States were located. Naphthalene was detected in dusts collected from inside 20 homes in Greece (Stamatelopoulou et al. 2021) and 31 homes in China (Liu et al. 2021). Mean concentrations of naphthalene were 0.339 and 1.984 µg/kg, respectively. Stamatelopoulou et al. (2021) included analyses for 1- and 2-methylnaphthalene and reported mean concentrations of 0.126 and 0.242 µg/kg, respectively. Van Metre et al. (2009) measured PAHs including naphthalene in pavement dust from sealcoated and unsealcoated parking lots in six cities across the United States. The study authors presented the results as the sum of 12 PAHs; results for naphthalene alone were not reported. The summed concentrations of PAHs were substantially higher (on the order of 100-fold) in dust from parking lots that had been sealcoated than those that had not been, indicating that coal tar-sealcoating mixture was likely an important source of PAHs in the dust (Van Metre et al. 2009).

5.5.4 Other Media

Naphthalene and methylnaphthalenes have been detected in trace amounts in fish and unspecified bivalves and polychaetas, although sample sizes were not very large. Most detections were <100 µg/kg. A summary of the available data reported by the WQP is presented in Table 5-12. Data for other taxa groups were not located, although naphthalene has been previously detected in shellfish. Reported naphthalene concentrations were 5–176 µg/kg in oysters, 4–10 µg/kg in mussels, and <1–10 µg/kg in clams from U.S. waters (Bender and Huggett 1989). In shore crabs collected from the San Francisco Bay area, average naphthalene concentrations were 7.4 µg/kg (Miles and Roster 1999). Naphthalene and methylnaphthalene (isomer not specified) were also detected in the muscle (1.5–3.1 µg/kg wet weight), kidney (1.4–4.3 µg/kg wet weight), liver (1.4–4.7 µg/kg wet weight), and blubber (8.3–23.5 µg/kg wet weight) of harp seals caught in southern Labrador on the eastern coast of Canada (Zitko et al. 1998).

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Table 5-12. Summary of Concentrations of Naphthalene and Methylnaphthalenes (µg/kg) Measured in Biota Samples Across the United States

Year	Species	Mean	Maximum	Number of samples	Percent detected
Naphthalene					
2018		3.2	79	140	99%
	<i>Ambloplites rupestris</i>	1.1	2.1	25	100%
	<i>Ameiurus nebulosus</i>	1.1	2.5	30	100%
	<i>Cyprinus carpio</i>	10	79	29	100%
	<i>Micropterus salmoides</i>	2	7.6	22	100%
Other species sampled with n<10: <i>Lepomis gibbosus</i> , <i>Lepomis macrochirus</i> , <i>Lutjanus kasmira</i> , <i>Micropterus dolomieu</i> , <i>Oncorhynchus mykiss</i> , <i>Perca flavescens</i> , <i>Selar crumenophthalmus</i>					
2019		2.7	4.83	19	42%
	<i>L. kasmira</i>	2.4	4.1	6	33%
	<i>Salvelinus namaycush</i>	3.3	4.83	5	100
	<i>S. crumenophthalmus</i>	0.7	0.66	6	17%
Not detected in: <i>Bivalvia</i> , <i>Polycheta</i>					
2020		8.8	73.7	27	59%
	<i>C. carpio</i>	13.9	73.7	9	89%
	<i>L. kasmira</i>	1.7	2.1	6	50%
	<i>M. salmoides</i>	9.9	15.6	2	100%
	<i>S. crumenophthalmus</i>	1.7	2	6	50%
Not detected in: <i>Onchorhynchus tshawytscha</i>					
2021		25.8	240	27	70%
	<i>Ameiurus natalis</i>	20.4	38.7	3	67%
	<i>Bivalvia</i>	16.4	18	5	100%
	<i>Castomus commersonii</i>	4.8	4.77	2	50%
	<i>Polycheta</i>	3.4	3.41	1	100%
	<i>S. crumenophthalmus</i>	91.3	240	3	100%
	<i>Vertebrata</i>	21.3	57.8	3	100%
Not detected in: <i>M. dolomieu</i> , <i>Semotilus atromaculatus</i>					
2022		3.19	12.643	57	91%
	<i>Catostomus latipinnis</i>	5.58	12.643	9	100%
	<i>Pantosteus discobolus</i>	4.82	6.467	7	100%
	<i>C. commersonii</i>	3.87	5.014	4	100%
	<i>O. mykiss</i>	4.74	5.608	6	100%
	<i>C. commersonii</i> x <i>C. latipinnis</i>	4.3	4.792	2	100%
	<i>Salmo trutta</i>	2.8	2.895	2	100%
	<i>C. commersonii</i> x <i>Catostomus discobolus</i>	4.3	4.306	1	100%
	<i>Macoma nasuta</i>	0.621	0.77	10	100%
	<i>S. crumenophthalmus</i>	1.73	2.3	3	100%

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Table 5-12. Summary of Concentrations of Naphthalene and Methylnaphthalenes (µg/kg) Measured in Biota Samples Across the United States

Year	Species	Mean	Maximum	Number of samples	Percent detected
	<i>Alitta virens</i>	0.6	0.76	10	50%
	<i>L. kasmira</i>	1.63	2.4	3	100%
2023 ^a	No data				
1-Methylnaphthalene					
2018		4.5	9.23	6	100%
	<i>O. mykiss</i>	4.5	8.23	6	100%
2019		1.3	2.09	7	71%
	<i>S. namaycush</i>	1.3	2.09	5	100%
Not detected in: <i>Bivalvia</i> , <i>Polycheta</i>					
2020		15.8	95.8	15	60%
	<i>C. carpio</i>	17.4	95.8	9	89%
	<i>O. tshawytscha</i>	3.54	3.54	4	25%
Not detected in: <i>M. salmoides</i>					
2021		9.9	55	22	68%
	<i>A. natalis</i>	24.7	24.7	3	33%
	<i>Bivalvia</i>	4.8	5.4	5	100%
	<i>C. commersonii</i>	5.4	5.44	3	33%
	<i>Polychaeta</i>	23.3	55	3	100%
	<i>S. atromaculatus</i>	14.2	14.2	3	33%
	<i>Vertebrata</i>	2.6	5.771	4	100%
Not detected in: <i>M. dolomieu</i>					
2022		3.63	11.09	31	97%
	<i>C. commersonii</i>	2.48	3.054	4	75%
	<i>C. latipinnis</i>	4.67	11.09	9	100%
	<i>P. discobolus</i>	4.02	5.517	7	100%
	<i>C. commersonii</i> x <i>C. discobolus</i>	4.12	4.123	1	100%
	<i>O. mykiss</i>	3.04	3.754	6	100%
	<i>C. commersonii</i> x <i>C. latipinnis</i>	2.59	2.847	2	100%
	<i>S. trutta</i>	1.94	2.309	2	100%
2023 ^a	No data				
2-Methylnaphthalene					
2018		3.6	28	128	100%
	<i>A. rupestris</i>	1.7	3.5	25	100%
	<i>A. nebulosus</i>	1.1	3.1	30	100%
	<i>C. carpio</i>	7.4	28	29	100%
	<i>M. salmoides</i>	4.5	23	22	100%
Other species sampled with n<10: <i>L. gibbosus</i> , <i>L. macrochirus</i> , <i>M. dolomieu</i> , <i>O. mykiss</i> , <i>P. flavesceus</i>					
2019		1.8	2.65	7	71%

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Table 5-12. Summary of Concentrations of Naphthalene and Methylnaphthalenes (µg/kg) Measured in Biota Samples Across the United States

Year	Species	Mean	Maximum	Number of samples	Percent detected
	<i>S. namaycush</i>	1.8	2.65	5	100%
Not detected in: <i>Bivalvia</i> , <i>Polycheta</i>					
2020		7.8	41	15	80%
	<i>C. carpio</i>	9.6	41	9	100%
	<i>O. tshawytscha</i>	2.7	6.22	4	75%
Not detected in: <i>M. salmoides</i>					
2021		14.6	84	22	73%
	<i>A. natalis</i>	41.7	41.7	3	33%
	<i>Bivalvia</i>	6.86	7.3	5	100%
	<i>C. commersonii</i>	5.25	8.05	3	67%
	<i>Polychaeta</i>	38	84	3	100%
	<i>S. atromaculatus</i>	19.8	19.8	3	33%
	<i>Vertebrata</i>	3.197	5.784	4	100%
Not detected in: <i>M. dolomieu</i>					
2022		3.36	7.361	51	84%
	<i>C. latipinnis</i>	5.2	6.726	9	100%
	<i>C. commersonii</i> x <i>C. discobolus</i>	4.91	4.906	1	100%
	<i>C. commersonii</i>	3.59	4.271	4	75%
	<i>O. mykiss</i>	4.32	4.792	6	100%
	<i>P. discobolus</i>	5.27	7.361	7	100%
	<i>C. commersonii</i> x <i>C. latipinnis</i>	3.45	3.521	2	100%
	<i>S. trutta</i>	2.78	3.76	2	100%
	<i>M. nasuta</i>	0.525	0.64	10	100%
	<i>A. virens</i>	0.507	0.68	10	30%
2023 ^a	No data				

^aAs of August, 2023.

Source: WQP 2023

Higher concentrations of naphthalene and 1- and 2-methylnaphthalene in biota are expected to be caused by nearby pollution. Naphthalene and methylnaphthalenes (isomer not specified) were detected at concentrations of 7.15 and 65.11 µg/kg of salmon tissue, respectively, and at 12.9 and 17.3 µg/kg of mussels, respectively. Both the salmon and mussels were caught in Exxon Valdez spill affected Snug Harbor in the Prince William Sound (Neff and Burns 1996). Methylnaphthalenes have occasionally been detected in fish from polluted waters. 2-Methylnaphthalene was reported at concentrations ranging from

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0.4 to 320 µg/kg in fish from Ohio waters, but neither isomer of methylnaphthalene was detected in liver or muscle tissue of fish from polluted areas of Puget Sound (GDCH 1992).

Table 5-13 presents a summary of naphthalene, 1-methylnaphthalene, and 2-methylnaphthalene concentrations in food, beverages, and supplements. Naphthalene was reported to be below the limit of quantification in oil extracted from menhaden fish, a source of commercial fish oil, caught off the coasts of New Jersey, Delaware, and Louisiana (Chopra et al. 2019). Naphthalene and methylnaphthalenes were detected in commercial coffee beans at 8.2–561.4 µg/kg for naphthalene, 24.0–306.0 µg/kg for 1-methylnaphthalene, and 7.2–286.9 µg/kg for 2-methylnaphthalene (Jimenez et al. 2014). Higher concentrations were associated with darker roasts, due to contamination likely occurring during the roasting process. Other current data regarding naphthalene contamination of food in the United States were not located. Naphthalene was not included in the Food and Drug Administration (FDA) Total Diet Study between 2003 to 2017 (FDA 2022a). Naphthalene may contaminate food from atmospheric deposition of naphthalene in air, or partitioning from soil and water. Previously, naphthalene was detected in 2 of 13,980 samples of foods analyzed in six states (Minyard and Roberts 1991). In a Lower Rio Grande Valley environmental study, naphthalene (median concentration, 2.159 µg/kg body weight) was detected in five of the nine duplicate-diet samples (Berry et al. 1997). Naphthalene (1–7 µg/kg) was also detected in fresh tree-ripened apricots, plums, and their interspecific hybrids (Gomez et al. 1993).

Table 5-13. Summary of Naphthalene and Methylnaphthalenes Measured in Food, Beverages, and Supplements

Location	Product	Average	Range	Notes	Source
Naphthalene					
Coasts of New Jersey, Delaware, and Louisiana	Oil from Menhaden fish	<3 µg/kg	–	Not detected	Chopra et al. 2019
United States	Instant coffee beans	<0.61 µg/kg	–	Not detected in 2 of 2 products	Jimenez et al. 2014
	Espresso coffee beans	<0.61 µg/kg; 22.8 µg/kg	–	Not detected in 1 of 2 products	
	Light blend coffee beans	8.2 µg/kg; 13.4 µg/kg	–		
	Medium blend coffee beans	27.9 µg/kg; 79.1 µg/kg	–		
	Dark blend decaffeinated beans	101.7 µg/kg	–		
	Dark blend coffee beans	–	27.8–561.4 µg/kg	4 products analyzed	

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Table 5-13. Summary of Naphthalene and Methylnaphthalenes Measured in Food, Beverages, and Supplements

Location	Product	Average	Range	Notes	Source
United States; 10 states	–	–	–	Detected in 2 of 13,980 food samples	Minyard and Roberts 1991
–	Apricots, plums, and their hybrids	–	1–7 µg/kg		Gomez et al. 1993
Spain	Cereal-based foodstuffs; cookies, breakfast cereal, flour, pasta, rice, bread	–	0.013–5.500 µg/kg	22 foods analyzed	Sampaio et al. 2021
Spain	Beer	–	0.340–1.500 µg/L		Sampaio et al. 2021
	Wine	–	0.075–3.600 µg/L		
	Juice	–	0.00029– 0.0036 µg/L		
Canada	Farmed salmon	1.98 µg/kg	–		Easton et al. 2002
Pacific coast	Wild salmon	2.15 µg/kg	–		
1-Methylnaphthalene					
United States	Instant coffee beans	<0.4 µg/kg	–	Not detected in 2 of 2 products	Jimenez et al. 2014
	Espresso coffee beans	<0.47 µg/kg; 24.0 µg/kg	–	Not detected in 1 of 2 products	
	Light blend coffee beans	<0.47 µg/kg	–	Not detected in 2 of 2 products	
	Medium blend coffee beans	28.1 µg/kg; 39.7 µg/kg	–		
	Dark blend decaffeinated beans	97.6 µg/kg	–		
	Dark blend coffee beans	–	27.2–306.0 µg/kg	4 products analyzed	
Canada	Farmed salmon	0.96 µg/kg	–		Easton et al. 2002
Pacific cost	Wild salmon	1.53 µg/kg	–		
Poland	Unsmoked cheese	10.5 µg/kg	8.8–12.3 µg/kg	5 products analyzed	Polak- Śliwińska et al. 2022
	Smoked cheese	5.0 µg/kg	1.5–11.3 µg/kg	10 products analyzed	
2-Methylnaphthalene					
United States	Instant coffee beans	<0.36 µg/kg	–	Not detected in 2 of 2 products	Jimenez et al. 2014
	Espresso coffee beans	9.9 µg/kg; <0.36 µg/kg	–	Not detected in 1 of 2 products	
	Light blend coffee beans	<0.36 µg/kg; 28.2 µg/kg	–	Not detected in 1 of 2 products	

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Table 5-13. Summary of Naphthalene and Methylnaphthalenes Measured in Food, Beverages, and Supplements

Location	Product	Average	Range	Notes	Source
	Medium blend coffee beans	<0.36 µg/kg	–	Not detected in 2 of 2 products	
	Dark blend decaffeinated beans	7.2 µg/kg	–		
	Dark blend coffee beans	–	10.5–286.9 µg/kg	4 products analyzed	
Canada	Farmed salmon	1.98 µg/kg	–		Easton et al. 2002
Pacific coast	Wild salmon	2.93 µg/kg	–		

Outside of the United States, naphthalene was detected in 22 cereal-based foodstuffs, such as flour, pasta, rice, and bread, at 0.013–5.5 µg/kg (Sampaio et al. 2021). Naphthalene was detected at 0.340–1.500 µg/L in beer, 0.075–3.600 µg/L in wine, and 0.00029–0.0026 µg/L in juice (Sampaio et al. 2021).

Food grown near sources of naphthalene may have higher concentrations. Naphthalene was detected in all leafy vegetable samples (e.g., garden egg leaves and Chinese cabbage) grown in the city center of Accra, Ghana (Sampaio et al. 2021). Vegetables grown in an industrial area of Thessaloniki, Greece had naphthalene concentrations measured to be 0.37–15 µg/kg dry weight in cabbage; 8.9–30 µg/kg dry weight in carrots; 6.3–35 µg/kg dry weight in leeks; 4.9–53 µg/kg dry weight in lettuce; and 27–63 µg/kg dry weight in endive (Kipopoulou et al. 1999). Naphthalene was among the volatile organic compounds (VOCs) identified in whole and ground sorghum (Seitz et al. 1999).

Naphthalene, 1-methylnaphthalene, and 2-methylnaphthalene were detected at mean concentrations of 1.98, 0.96, and 1.98 µg/kg, respectively, in whole gutted farmed salmon and at 2.15, 1.53, and 2.93 µg/kg, respectively, in whole gutted wild salmon from the Pacific coast (Easton et al. 2002).

Naphthalene may contaminate food if cooked by a source that releases naphthalene. Naphthalene was detected in the gas phase (5,860 µg emitted per kg of meat cooked) as well as the particle phase (1,440–1,690 µg emitted per kg of meat cooked) in the emissions from the process of charbroiling hamburger meat over a natural gas grill (Schauer et al. 1999). Measurements in the meat were not conducted in this study. Naphthalene was detected in traditionally smoked cheeses (5.0 µg/kg), but at higher average concentrations in unsmoked cheeses (10.5 µg/kg) (Polak-Śliwińska et al. 2022). Naphthalene has also been detected in smoked salmon (Zelinkova and Wenzl 2015).

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Studies conducted in the 1990s suggested that naphthalene contamination could also occur from food packaging. Naphthalene levels in sterilized milk drinks contained in low-density polyethylene (LDPE) bottles were shown to be low (20 µg/L) at the time of purchase, increasing to 100 µg/L 30 days later, and averaging 250 µg/L at the expiration date of the milk (Lau et al. 1994). Residual naphthalene present in the LDPE packaging was hypothesized to be the contamination source. A later study by the same study authors observed that the level of naphthalene in LDPE milk bottle material had been reduced to 100–400 µg/kg due to the use of new packaging material (Lau et al. 1995). More recent data on naphthalene leaching from food packaging were not located.

Naphthalene has been detected in a variety of other consumer products. Table 5-14 reproduced from a report by the Danish Environmental Protection Agency, reports naphthalene concentrations detected in products available commercially in Denmark (Danish EPA 2015). Similar analysis of products sold in the United States were not located.

Table 5-14. Summary of Naphthalene Measured in Consumer Products

Product	Value	Notes
Window glass colors	5.7–11 mg/kg	Red paint
Toothbrush	0.04–0.53 mg/kg	0.0053 mg/toothbrush
Incense smoke	403 µg/m ³	
Printed matter	0.122–0.389 mg/kg; 18–90 µg/m ³ emitted	
Textiles	0.04–2.4 mg/kg	
Bathing shoes	0.2–0.5 mg/kg	
Bicycle tires	0.5–1.0 mg/kg	
Rubber figurine	0.2–0.5 mg/kg	
Balloons	0.2–0.5 mg/kg	
Toy car	0.2–0.5 mg/kg	
Tattoo ink	0.8–81 mg/kg 1.9–2.8 mg/kg 1.6 mg/kg 1.3 mg/kg	Black ink Blue ink Red ink Orange ink
Wood tar	510 mg/kg	
Silicone based pacifiers	>0.1 mg/kg	
Products with <0.2 mg/kg: rubber shoes, bracelet, scooter and bicycle handles, eraser, doll, teething ring, swimming equipment, bib, bags, alarm horn, and pen		

Source: Danish EPA 2015

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Naphthalene was detected at a concentration of 227 mg/kg of wood burned from the fireplace combustion of pine wood. 1-Methylnaphthalene was detected at concentrations of 10.6, 6.39, and 4.31 mg/kg of wood burned from the combustion of pine, oak, and eucalyptus wood respectively (Schauer et al. 2001). 2-Methylnaphthalene was detected at concentrations of 15.0, 9.31, and 5.69 mg/kg of wood burned from combustion of pine, oak, and eucalyptus wood, respectively. Naphthalene was not measured from the oak and eucalyptus fires (Schauer et al. 2001). In another study, the respective median concentrations of naphthalene, 1-methylnaphthalene, and 2-methylnaphthalene were determined to be 22.57, 4.14, and 4.76 mg/kg of burned Ponderosa pine in the fireplace; 60.86, 12.71, and 15.55 mg/kg for mixed hardwoods in the fireplace; and 34.96, 5.23 and 6.32 mg/kg for mixed hardwoods burned in a woodstove (McDonald et al. 2000).

Naphthalene and methylnaphthalene detections in tobacco products are reported in Table 5-15.

Naphthalene was not detected in main-stream smoke from filtered “low nicotine” research cigarettes, but was emitted at a rate of 18.11 ug/cigarette into sidestream smoke (Charles et al. 2007). In a study from 1978, reported levels of naphthalene, 1-methylnaphthalene, and 2-methylnaphthalene in the smoke from U.S. commercial unfiltered cigarettes were 3, 1, and 1 µg, respectively (Schmeltz et al. 1978). Levels in sidestream smoke were found to be higher: 46, 30, and 32 µg/cigarette, respectively (Schmeltz et al. 1976). In the emissions from electronic cigarettes, naphthalene was detected at 6.15×10^{-5} – 9.22×10^{-5} µg/puff, significantly lower than 3,598.6 µg/puff in a reference conventional cigarette (Dusautoir et al. 2021). Naphthalene and the methylnaphthalenes have been detected at approximately between 10 and 100 µg/kg dry weight in smokeless tobacco products (McAdam et al. 2013).

Table 5-15. Summary of Naphthalene and Methylnaphthalenes Measured in Tobacco Products

Product	Naphthalene	1-Methylnaphthalene	2-Methylnaphthalene	Source
Smoke of unfiltered cigarettes	3 µg/cigarette	1 µg/cigarette	1 µg/cigarette	Schmeltz et al. 1978
Sidestream smoke of unfiltered cigarettes	46 µg/cigarette	30 µg/cigarette	32 µg/cigarette	
Smoke of filtered “low nicotine” research cigarettes	Below detection limit	–	–	Charles et al. 2007
Sidestream smoke of filtered “low	18.11 µg/cigarette	–	–	

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Table 5-15. Summary of Naphthalene and Methylnaphthalenes Measured in Tobacco Products

Product	Naphthalene	1-Methylnaphthalene	2-Methylnaphthalene	Source
nicotine” research cigarettes				
Electronic cigarette	6.15x10 ⁻⁵ – 9.22x10 ⁻⁵ µg/puff	–	–	Dusautoir et al. 2021
Reference conventional cigarette	3,598.6 µg/puff	–	–	
Chewing tobacco	54.0 µg/kg dw	20.1 µg/kg dw	10.4 µg/kg dw	McAdam et al. 2013
Dry snuff	84.9 µg/kg dw	75.2 µg/kg dw	60.0 µg/kg dw	
Hard pellet	69.7 µg/kg dw	19.2 µg/kg dw	10.5 µg/kg dw	
Soft pellet	76.5 µg/kg dw	74.2 µg/kg dw	65.6 µg/kg dw	
Moist snuff	110 µg/kg dw	62.0 µg/kg dw	46.9 µg/kg dw	
Plug products	53.4 µg/kg dw	18.3 µg/kg dw	9.51 µg/kg dw	

dw = dry weight

Naphthalene, 1-methylnaphthalene, and 2-methylnaphthalene were among the chemicals detected in air in Lower Manhattan in the aftermath of the destruction of the World Trade Center, New York City, New York on September 11, 2001. Concentration of naphthalene ranged from 699 ng/m³ on September 26–27, 2001, to 42 ng/m³ on October 21–22, 2001. The concentration of 1-methylnaphthalene ranged from 178 to 100 ng/m³ and that of 2-methylnaphthylene ranged from 267 to 165 ng/m³ for the same days (Swartz et al. 2003).

5.6 GENERAL POPULATION EXPOSURE

The general population is most likely to be exposed to naphthalene by inhalation of ambient and indoor air. The use of naphthalene-containing moth repellents and smoke from cigarettes are the main sources of naphthalene in indoor air. Other indoor sources include kerosene heaters, wood burning, and formulations containing naphthalene, such as printer ink (Arı 2020).

Based on an urban/suburban average air concentration of 0.04 µg/m³ (8.0x10⁻⁶ ppmv) (EPA 2022b) and an inhalation rate of 20 m³/day, it has been estimated that the average daily intake from ambient air is 0.8 µg (Howard 1989). Intake from indoor air may be higher, depending on the presence of indoor sources. The estimated average daily intakes from ambient air may be about 4.2 µg for 1-methylnaphthalene and 7.4 µg for 2-methylnaphthalene. These estimates are based on ambient air samples taken

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from an average air concentration of $0.21 \mu\text{g}/\text{m}^3$ (0.036 ppmv) 1-methylnaphthalene, $0.37 \mu\text{g}/\text{m}^3$ (0.064 ppmv) 2-methylnaphthalene (EPA 2022b), and an assumed human daily intake of 20 m^3 .

Inhalation exposure is a major source of exposure in both adults and children, particularly in homes where repellents and deodorant blocks containing naphthalene are used or tobacco is smoked in the home. Under experimental conditions, a box of moth balls placed in a closet had naphthalene emissions between 8 and 12 mg/hour, decreasing over time to ~ 5 mg/hour (Guerrero and Corsi 2012). Naphthalene was one of the PAHs detected in an eight-home pilot study that was conducted in Columbus, Ohio to measure the PAH concentration profiles in house dust. The average concentration of naphthalene was found to be dependent upon the method of extraction ($2.8 \text{ mg}/\text{m}^3$ by Soxhlet extraction and $1.8 \text{ mg}/\text{m}^3$ by sonication extraction) (Chuang et al. 1995). Concentrations of naphthalene detected in the indoor and outdoor air measured in 24 low-income homes in North Carolina were 0.33–9.7 and $0.57\text{--}1.82 \mu\text{g}/\text{m}^3$, respectively (Chuang et al. 1999). In a study reporting the concentrations of VOCs in a wide range of environments (i.e., homes, offices, restaurants, pubs, department stores, train and bus stations, heavily trafficked roadside locations, buses, trains and automobiles) in Birmingham, United Kingdom, naphthalene concentrations were found to range from $0.1 \mu\text{g}/\text{m}^3$ (laboratories) to $12.1 \mu\text{g}/\text{m}^3$ (heavily trafficked roadside) (Kim et al. 2001). A mean concentration of naphthalene was found to be $2.3 \mu\text{g}/\text{m}^3$ in a German environmental survey that monitored 113 adults aged 25–69 years, selected at random, for personal exposure to VOCs including naphthalene (Hoffmann et al. 2000). Low levels of naphthalene (average concentration, $0.44 \mu\text{g}/\text{m}^3$) and 1-methylnaphthalene (average concentration, $0.08 \mu\text{g}/\text{m}^3$) were found in the indoor air of 92% of single-family homes and 81% of apartments monitored (Kostianen 1995). Naphthalene has been detected in the smoke from charbroiling meat (Schauer et al. 1999) and from the smoke from domestic fireplaces and wood-burning stoves (McDonald et al. 2000; Schauer et al. 2001).

Exposure to naphthalene may occur from ingestion of drinking water and/or food, but these exposures are expected to be much less than inhalation exposures for the general population. Estimated exposure from drinking water, assuming a worst-case water concentration of about $0.2 \mu\text{g}/\text{L}$ (USGS 2015), is $0.4 \mu\text{g}/\text{day}$ (Howard 1989). However, naphthalene was rarely detected in drinking water. No recent dietary exposure estimates were available.

Dermal exposure to naphthalene may occur from handling or wearing clothing stored in naphthalene-containing moth repellents. However, no data were located concerning the level of human exposure to naphthalene, 1-methylnaphthalene, or 2-methylnaphthalene via this exposure route. Experimental studies

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have shown that naphthalene can be dermally absorbed and systemically metabolized in rats (Turkall et al. 1994).

The Centers for Disease Control and Prevention (CDC) creates ongoing assessments on Human Exposure to Environmental Chemicals that were derived from data obtained from NHANES. The biomonitoring data report urinary levels of two metabolites of naphthalene, 1-hydroxynaphthalene (or 1-naphthol) and 2-hydroxynaphthalene (2-naphthol), from a sample of people who represent the noninstitutionalized, civilian U.S. population during 2-year study periods. The data for the most recent study period (2015–2016) are summarized in Table 5-16. In studies on worker exposures, naphthalene air concentrations were correlated with 1- and 2-hydroxynaphthalene; 1-hydroxynaphthalene, may also be a metabolite of the insecticide carbaryl (CDC 2017). Urinary levels reflect recent exposure, and higher levels are typically found in smokers and workers who are in industries that expose them to naphthalene. Table 5-17 provides the urinary levels of 1- and 2-hydroxynaphthalene in U.S. adult (≥ 18 years old) smokers, who had means higher than adult (≥ 20 years old) nonsmokers.

Table 5-16. Geometric Mean of the Urine Concentration ($\mu\text{g/L}$) of 1- and 2-Hydroxynaphthalene in the U.S. Population (2015–2016)

Population group	Geometric mean	95% CL	Sample size
1-Hydroxynaphthalene			
Total population	1.36	1.29–1.43	2,926
Age 3–5 years	0.83	0.78–1.01	471
Age 6–11 years	0.88	0.78–1.00	373
Age 12–19 years	0.95	0.85–1.07	392
Age 20+ years	1.86	1.72–2.01	1,690
Males	1.53	1.42–1.65	1,463
Females	1.20	1.11–1.30	1,463
Mexican Americans	1.07	0.96–1.20	556
Non-Hispanic Blacks	1.96	1.75–2.19	640
Non-Hispanic Whites	1.48	1.32–1.64	879
2-Hydroxynaphthalene			
Total population	5.23	5.02–5.45	2,926
Age 3–5 years	4.02	3.95–4.95	471
Age 6–11 years	4.42	3.95–4.96	373
Age 12–19 years	5.57	5.01–6.19	392
Age 20+ years	5.74	5.44–6.07	1,690
Males	5.36	5.06–5.66	1,463
Females	5.07	4.78–5.38	1,463

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Table 5-16. Geometric Mean of the Urine Concentration ($\mu\text{g/L}$) of 1- and 2-Hydroxynaphthalene in the U.S. Population (2015–2016)

Population group	Geometric mean	95% CL	Sample size
Mexican Americans	7.21	6.62–7.85	556
Non-Hispanic Blacks	7.13	6.59–7.71	640
Non-Hispanic Whites	4.03	3.73–4.36	879

CL = confidence limit

Source: CDC 2023

Table 5-17. Geometric Mean of the Urine Concentration ($\mu\text{g/L}$) of 1-Hydroxynaphthalene and 2-Hydroxynaphthalene in the U.S. Adult Smoking Population (2015–2016)

Population group	Geometric mean	95% CL	Sample size
1-Hydroxynaphthalene			
Total population	2.73	2.57–2.90	3,010
Males	3.17	2.89–3.48	1,114
Females	2.32	2.08–2.58	1,079
Mexican Americans	1.64	1.40–1.93	335
Non-Hispanic Blacks	4.61	4.05–5.23	504
Non-Hispanic Whites	3.23	2.82–3.71	743
2-Hydroxynaphthalene			
Total population	7.10	6.81–7.39	3,010
Males	7.48	7.01–7.98	1,114
Females	6.62	6.17–7.10	1,079
Mexican Americans	8.74	7.87–9.70	335
Non-Hispanic Blacks	10.43	9.63–11.29	504
Non-Hispanic Whites	6.04	5.52–6.61	743

CL = confidence limit

Source: CDC 2023

Naphthalene was detected in 40% of human adipose tissue samples at concentrations ranging from <9 to 63 $\mu\text{g/kg}$ in a National Human Adipose Tissue Survey (NHATS) (EPA 1986b). More recent large-scale biomonitoring studies were not available. Naphthalene was detected between 0.618 and 5.14 ng/g in 10 whole blood samples obtained from a blood donation center in the San Francisco Bay area (Hao et al. 2020). In a study of 52 women in Ottawa, Canada, naphthalene was detected in breastmilk, with a median concentration of 7.55 ng/g lipid (range, 3.86–79.36 ng/g lipid) (Wheeler et al. 2014). The study authors also concluded that urinary concentrations of naphthalene metabolites tended to be similar to

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(1-naphthol) or lower (2-naphthol) than those reported in another Canadian survey of women of reproductive age and only urinary metabolite 1-naphthol and naphthalene levels in breast milk were correlated.

A personal air monitoring study of 17 pregnant women in their third trimester, conducted in the McAllen-Edinburg-Mission area of Texas, utilized both air-sampler backpacks and passive-sampler silicone wristbands to measure methylnaphthalene exposure across 3 nonconsecutive days. The backpack reported exposure to 57.26 ng/m³ 1-methylnaphthalene and the wristband reported exposure to 139.93 ng/m³ 1-methylnaphthalene; 93.50 ng/m³ 2-methylnaphthalene and 174.78 ng/m³ 2-methylnaphthalene were reported by the backpack and wristband samplers, respectively (Mendoza-Sanchez et al. 2022). Personal air monitoring of pregnant women in Ottawa, Canada, reported median naphthalene concentrations of 0.73 and 0.79 µg/m³ during pregnancy on weekdays and weekends, respectively, and 1.74 µg/m³ 2–3 months after birth (Wheeler et al. 2014). Air samples were collected from a sampler attached to the collar.

Children are likely to be exposed to naphthalene via the same routes that affect adults, such as inhalation of contaminated air, ingestion of contaminated drinking water or contaminated food, and dermal contact with contaminated soils or products treated with the compound. Small children are more likely than adults to come into intimate contact with yard dirt, lawns, and dust from carpets. Dislodgeable pesticide residues in carpets or on uncovered floors may present a relatively important exposure route for infants and toddlers through dermal contact and oral ingestion. The tendency of young children to ingest soil, either intentionally through pica or unintentionally through hand-to-mouth activity, is well documented. These behavioral traits can result in ingestion of naphthalene present in soil and dust. Naphthalene has been detected in the house-dust in an eight-home pilot study (Chuang et al. 1995).

Accidental ingestion of household products containing naphthalene such as mothballs or deodorant blocks frequently occurs in children. In 2020, 527 cases of accidental naphthalene moth repellent ingestion were reported to Poison Control Centers in the United States (Gummin et al. 2021). About 50% of these cases occurred in children under 5 years of age.

Naphthalene was among the chemicals detected at nine day care centers in Durham, Raleigh, and Chapel Hill, North Carolina (Wilson et al. 1999). Indoor and outdoor air was found to contain naphthalene at concentrations of 205 and 89.6 ng/m³, respectively. The concentrations were 0.011 ppm in soil, 0.008 ppm in dust, 0.94 ppb in liquid food, and 0.25 ppb in solid food samples. The differences in PAH

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concentrations between daycare centers serving low-income clients and those serving middle-income clients were found to be small.

Naphthalene (mothballs) is commonly used as a moth repellent in clothes during storage and as a deodorizer in diaper pails. Acute hemolysis was reported in 21 children following a period of inhalation exposure of naphthalene. The source of naphthalene was woolen clothes and blankets that had been stored with mothballs over the summer (Valaes et al. 1963).

A potential source of exposure in infants is from the presence of naphthalene in breast milk or formula. Naphthalene was detected (concentrations not reported) in six of eight breast milk samples from women in four U.S. cities (Pellizzari et al. 1982). Children may also be exposed to naphthalene from milk drinks that have been stored in LDPE bottles (Lau et al. 1994).

Naphthalene may volatilize from water; thus, there is potential for inhalation exposure during showering and bathing. ATSDR's three-compartment Shower and Household-Use Exposure (SHOWER) model predicts air concentrations in the shower stall, bathroom, and main house throughout the day by estimating the contribution from showering or bathing and the contribution from other water sources in the house, such as the dishwasher, clothes washer, and faucets. This information, along with human activity patterns, is used to calculate a daily TWA exposure concentration via inhalation exposure and from dermal uptake from skin contact. ATSDR's SHOWER model is available by sending a request to showermodel@cdc.gov. Using representative values from drinking water aquifers as discussed in Section 5.5.2 and representative outdoor air levels discussed in Section 5.5.1, Reasonable Maximum Exposure (RME) levels for naphthalene were calculated for different exposure groups (see Table 5-18). Data regarding methylnaphthalene concentrations in drinking water sources were not available, and estimates could therefore not be calculated.

Table 5-18. Reasonable Maximum Estimate of Naphthalene Daily Inhalation and Dermal Doses from Showering by Exposure Group

Exposure group	Inhalation ($\mu\text{g}/\text{m}^3$)	Dermal ($\mu\text{g}/\text{kg}/\text{day}$)
Birth–<1 year	0.096	0.0063
1–<2 years	0.096	0.0058
2–<6 years	0.096	0.0050
6–<11 years	0.096	0.0041
11–<16 years	0.096	0.0033
16–<21 years	0.096	0.0030
Adult	0.096	0.0030

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Table 5-18. Reasonable Maximum Estimate of Naphthalene Daily Inhalation and Dermal Doses from Showering by Exposure Group

Exposure group	Inhalation ($\mu\text{g}/\text{m}^3$)	Dermal ($\mu\text{g}/\text{kg}/\text{day}$)
Pregnant and breastfeeding women	0.096	0.0030

Source: ATSDR 2022b

5.7 POPULATIONS WITH POTENTIALLY HIGH EXPOSURES

Naphthalene concentrations can vary widely based on the site conditions, source of naphthalene, and proximity to the source, resulting in large variations in the levels of exposure, even for populations with expected high exposures. Members of the general population most likely to have high levels of exposure to naphthalene are users of naphthalene-containing moth repellents (including infants exposed to blankets or clothing stored in naphthalene-containing mothballs), smokers, and those in proximity to smokers. Workers in naphthalene-producing or naphthalene-using industries, and workers exposed to burning wood or coal, and fuels, could be subject to heightened exposure. Individuals living or working near hazardous waste sites at which naphthalene has been detected could also be exposed to higher naphthalene concentrations if they came into contact with contaminated media. Potentially high exposure to naphthalene and other PAHs are possible for people working with or using coal tar or coal tar creosote products.

NIOSH (2009) evaluated environmental tobacco smoke exposure in Las Vegas casino dealers, including measurements of naphthalene concentrations in personal breathing zone samples and area samples. The geometric mean concentration naphthalene in personal breathing zone samples across three casinos was $0.78 \mu\text{g}/\text{m}^3$, with a range of $0.21\text{--}1.4 \mu\text{g}/\text{m}^3$. In area samples, the concentrations were similar, with a geometric mean concentration of $0.729 \mu\text{g}/\text{m}^3$ (range $0.19\text{--}1.6 \mu\text{g}/\text{m}^3$).

In a personal monitoring study collecting dermal wipes primarily from the lower arms, hands, and neck, U.S. Air Force fuel-cell maintenance workers had an average estimate whole body dermal exposure of $2,020 \text{ ng}/\text{m}^2$ (range, $100\text{--}4.88 \times 10^6 \text{ ng}/\text{m}^2$) to naphthalene (Chao et al. 2005). The highest dermal exposures were seen in workers who entered fuel tanks (to perform cleaning or maintenance tasks); those whose work did not involve entry into the tanks had lower dermal exposure levels (Chao et al. 2005).

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People living near industrial sites may have increased exposure to naphthalene and methylnaphthalenes. Naphthalene has also been detected in household dust, at $0.083 \mu\text{g}/\text{m}^2$ from wipes collected in 25 homes in Houston, Texas, near an oil refinery. (Horney et al. 2018).

Firefighters may be exposed to naphthalene and methylnaphthalenes when around the combustion of wood. Naphthalene was detected at $<4\text{--}21,439 \text{ ng}/\text{m}^3$ via personal air monitoring during wildfire and prescribed burning events (Navarro et al. 2017). During overhaul events, naphthalene was detected in air at up to $89.91 \mu\text{g}/\text{m}^3$ (Baxter et al. 2014), and at an average of $0.010 \mu\text{g}/\text{m}^3$ in the air during a wildfire (Simms et al. 2021). Another personal air monitoring study reported $7,460\text{--}344,000 \mu\text{g}/\text{m}^3$ naphthalene detected from monitors outside the firefighter's jackets and from less than the limit of detection to $6,250 \mu\text{g}/\text{m}^3$ naphthalene detected within the firefighters' jackets (Mayer et al. 2022) suggesting that firefighters may have higher dermal exposure to naphthalene than the general population. In addition, firefighters or other workers exposed to naphthalene may carry it home or elsewhere with them on their clothing. Naphthalene was detected at 9.24 and $9.22 \mu\text{g}/\text{m}^3$ in the kitchen and truck bay (respectively) of one firehouse but was below the quantification limit in the same areas of another firehouse (Baxter et al. 2014). Skin wipes of firefighters on their hands and jaw/throat showed an increase in naphthalene post shift: $3.27\text{--}4.24 \text{ ng}/\text{wipe}$ for hands and $3.89\text{--}5.16 \text{ ng}/\text{wipe}$ of the jaw/throat area (Cherry et al. 2021).

The highest naphthalene exposure is anticipated to be in naphthalene-producing industries and naphthalene-using industries such as wood preserving, tanning, and ink and dye production; however, no current American workplace monitoring studies for these specific industries were located. Liu and Jia (2015) compared PAH exposures across different occupations using urinary metabolite levels from NHANES surveys between 2001 and 2008. Urinary levels of naphthalene metabolites in the study population of 4,162 adults were highest among individuals whose jobs were categorized as "extractive, construction, and repair" occupations (Liu and Jia 2015). The weighted geometric mean urinary naphthalene metabolite concentration for this group was ~40% higher than the corresponding value in the group categorized as "management" (the reference group). In a study of German and Austrian abrasive manufacturing sites, personal air measurements of naphthalene were measured for workers over the course of a 4–5.5-hour shift. The measurement for workers with direct naphthalene exposure by mixing or sieving was $8.0\pm 3.0 \text{ mg}/\text{m}^3$, and the measurement for workers with direct naphthalene exposure by pressing or moulding was $4.9\pm 3.7 \text{ mg}/\text{m}^3$ (Weiss et al. 2020). Bystander exposure from post-pressing or finishing was $0.6\pm 0.2 \text{ mg}/\text{m}^3$ naphthalene. Naphthalene was still detected during shifts of spatially separated workers who were finishing or packing, or working in an office, at $0.2\pm 0.1 \text{ mg}/\text{m}^3$ (Weiss et al. 2020). In coke plants in Poland between 2005 and 2010, naphthalene was measured by personal air

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monitoring at medians of 86.0 $\mu\text{g}/\text{m}^3$ for coke-oven workers, 175.5 $\mu\text{g}/\text{m}^3$ for coke byproduct workers, and 73.5 $\mu\text{g}/\text{m}^3$ for total area workers (Bieniek and Łusiak 2012). In 2003, personal air monitoring of road construction workers in the Milan and Lodi provinces of Italy was conducted during the first part of the work shift (about 4 hours). Naphthalene exposure for asphalt workers was reported to be 426 ng/m^3 , and exposure for road construction workers was reported to be 371 ng/m^3 (Buratti et al. 2007).

McCormick et al. (2022) evaluated exposure to PAHs including naphthalene in a group of 21 workers using refined coal tar sealant to seal asphalt. The exposure measures included area and personal air samples, wipe samples of the hand and neck, and analysis of pre- and post-shift urine samples for urinary metabolites. The median personal air concentration was 61.81 $\mu\text{g}/\text{m}^3$, the median post-shift hand wipe exposure was 0.28 $\mu\text{g}/\text{cm}^2$, and the median post-shift neck wipe exposure was 1.10 $\mu\text{g}/\text{sample}$ (McCormick et al. 2022). The median post-shift urinary 1- and 2-naphthol concentrations were 14.75 and 18.27 $\mu\text{g}/\text{g}$ creatinine (McCormick et al. 2022). A 1980 National Institute for Occupational Safety and Health (NIOSH 1980) survey of worker exposures to PAHs at a petroleum refinery in Tulsa, Oklahoma reported average air concentrations of naphthalene as high as 10.18 $\mu\text{g}/\text{m}^3$ in an area sample and 19.27 $\mu\text{g}/\text{m}^3$ for a personal sample, measured over a day shift. For the methylnaphthalenes, 16.4 and 17.56 $\mu\text{g}/\text{m}^3$ were the maximum average area concentrations reported for 1-methylnaphthalene and 2-methylnaphthalene, respectively, and the highest average concentrations in personal samples over a shift detected were 17.81 and 31.9 $\mu\text{g}/\text{m}^3$ for 1-methylnaphthalene and 2-methylnaphthalene, respectively. The workers at greatest risk of exposure included mining machine operators, aircraft engine mechanics, and miscellaneous machine operators.

Recent estimates of the number of workers exposed to naphthalene during its manufacture and subsequent use are 250–500 in the United Kingdom and 1,500–2,000 in the European Union (EU). These estimates do not include operators handling creosote treated lumber or brush applicators, or users of tar paints/membranes (EU 2003).