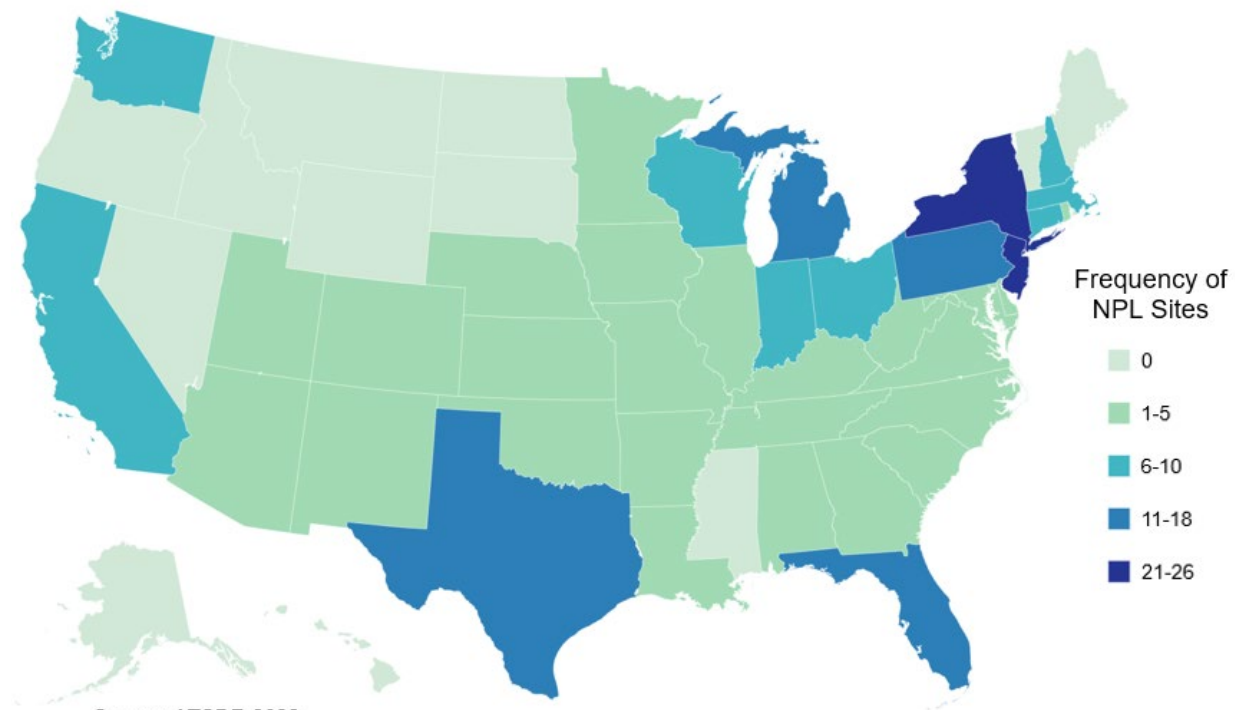


CHAPTER 5. POTENTIAL FOR HUMAN EXPOSURE

5.1 OVERVIEW

Carbon disulfide has been identified in at least 246 of the 1,868 hazardous waste sites that have been proposed for inclusion on the EPA National Priorities List (NPL) (ATSDR 2022). However, the number of sites in which carbon disulfide has been evaluated is not known. The number of sites in each state is shown in Figure 5-1. Of these sites, 243 are located within the United States, 1 is located in the Virgin Islands, and 2 are located in Puerto Rico (not shown).

Figure 5-1. Number of NPL Sites with Carbon Disulfide Contamination



Source: ATSDR 2022

- The main route of carbon disulfide exposure for the general population would be through inhalation of ambient air; however, atmospheric concentrations of carbon disulfide are usually low.
- Inhalation exposure under occupational settings is the most prominent route of human exposure. Workers involved in the manufacture of carbon disulfide, and production of products using this compound such as viscose rayon fibers, are exposed to much higher levels than the general population. Dermal exposure is also possible in workplace settings.

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- Carbon disulfide is released to the environment in emissions from manufacturing and use facilities and is also emitted through natural processes such as composting, and volcanic and geothermal activity. Oceans, marshes, and coastal areas are important biogenic sources of carbon disulfide.
- Carbon disulfide is expected to partition mainly to the air. In air, carbon disulfide will react with photochemically generated hydroxyl radicals and has an estimated half-life of 5.5 days.
- Carbon disulfide released to water can hydrolyze slowly; however, the overwhelming portion will volatilize to air. The potential for carbon disulfide to bioconcentrate in aquatic organisms is low. Similarly, carbon disulfide released to soil will quickly volatilize to the atmosphere, but a small portion may leach into groundwater since it is mobile in soil surfaces.

Carbon disulfide has both natural and anthropogenic sources (WHO 2002). Although there is a great deal of uncertainty in the estimates, globally, at least 40%, and perhaps as much as 80%, of releases are due to natural sources (EC/HC 2000; WHO 2002). The primary anthropological disposition of carbon disulfide in the environment is related to its use as an industrial solvent and chemical intermediate. Releases from industrial processes are almost exclusively to the atmosphere. Releases of the compound to surface waters and soils are expected to partition rapidly to the atmosphere through volatilization. Hydrolysis and biodegradation do not appear to be important processes in determining the environmental fate of carbon disulfide. It has been detected at generally low levels in ambient air, surface water, groundwater, and human milk. Concentrations in environmental media are greatest near source areas (e.g., industrial point sources, oceans and marshes, volcanoes).

Inhalation of carbon disulfide in workplace air is generally the main route of human exposure to the compound, with skin exposure also important when the solvent is handled manually.

5.2 PRODUCTION, IMPORT/EXPORT, USE, AND DISPOSAL

5.2.1 Production

Carbon disulfide was first manufactured commercially around 1880 (Timmerman 1978). Carbon disulfide is commercially manufactured by the reaction of sulfur with charcoal or methane (Lay et al. 2012). Ethane, propane, and propene have also been used, but to a much lower extent as compared to methane. Since the methane process was first introduced in the early 1950s, it has surpassed the older charcoal process in the production of carbon disulfide, which is no longer used in the United States, Europe, or Japan (Lay et al. 2012). In areas where natural gas or methane is not readily available or when the plant size is small, the charcoal process may still be used in the production of carbon disulfide to meet

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viscose rayon requirements. Carbon disulfide is normally available both in technical and reagent grades with >99% purity (Lay et al. 2012).

Historical trends in carbon disulfide production closely paralleled those of the viscose rayon industry, one of its largest users (Timmerman 1978; WHO 1981). Production increased by nearly 50% between 1941 and 1969, from 242,000 to 362,000 metric tons. This increase was partly due to a sudden rise in demand for carbon tetrachloride, an intermediate in the production of fluorocarbon propellants and refrigerants; carbon disulfide is used in the production of carbon tetrachloride. The 1969 production level remained relatively stable until about 1974 when it declined sharply to the 1975 level of 217,000 metric tons (Timmerman 1978). National aggregate production volumes reported in more recent years, 2016–2019, for carbon disulfide were between 250 million and <500 million pounds annually (~113,000–<227,000 metric tons) for 10 reporting companies (3M [two locations]; Arkema Delaware Inc. [two locations]; Chemtrade Holdco US Inc.; Equilon Enterprises LLC; Nouryon Chemicals LLC; Nouryon Functional Chemicals LLC; Tessenderlo Kerley, Inc; Viscofan USA); more precise information is not available based on confidential business information (CBI) (EPA 2022c).

Table 5-1 summarizes information on companies that reported the production, import, or use of carbon disulfide for the Toxics Release Inventory (TRI) in 2022 (TRI22 2024). TRI data should be used with caution since only certain types of industrial facilities are required to report. This is not an exhaustive list.

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

State ^a	Number of facilities	Minimum amount on site in pounds ^b	Maximum amount on site in pounds ^b	Activities and uses ^c
AL	6	100	49,999,999	1, 3, 4, 5, 6, 12, 13, 14
AR	2	1,000	999,999	2, 3, 9, 10, 12
CA	12	0	999,999	1, 3, 5, 6, 12, 13, 14
CT	1	10,000	99,999	6
DE	1	1,000,000	9,999,999	1, 3, 6
FL	1	0	99	1, 13
GA	1	100,000	999,999	6
ID	1	1,000,000	9,999,999	2, 3, 6
IL	8	0	999,999	1, 3, 5, 6, 12, 13, 14
IN	4	0	9,999	1, 5, 6, 12, 13, 14
KS	5	0	999,999	1, 5, 10, 14
KY	3	100	999,999	1, 5, 6, 14

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

State ^a	Number of facilities	Minimum amount on site in pounds ^b	Maximum amount on site in pounds ^b	Activities and uses ^c
LA	18	0	9,999,999	1, 3, 5, 6, 12, 13, 14
MI	1	1,000	9,999	1, 5
MN	2	0	9,999	1, 2, 3, 5, 6, 9, 10, 13
MO	2	100,000	999,999	6, 12
MS	1	100	999	1, 5, 6
MT	3	0	999	1, 2, 5, 6, 13, 14
ND	3	0	999,999	1, 5, 13
NM	1	0	99	1, 5
NY	1	100,000	999,999	1, 3, 5, 6
OH	11	0	99,999	1, 5, 6, 12, 14
OK	6	0	999,999	1, 5, 7, 8, 14
PA	3	10,000	999,999	1, 5, 10, 13
TN	4	1,000	999,999	1, 5, 6, 10
TX	37	0	9,999,999	1, 2, 3, 4, 5, 6, 7, 10, 11, 12, 13, 14
UT	3	0	999	1, 5, 14
WA	4	0	9,999,999	1, 2, 3, 5, 6, 13, 14
WY	1	1,000	9,999	1, 5, 6

^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: TRI22 2024 (Data are from 2022)

5.2.2 Import/Export

Viscofan USA Inc. and Chemtrade Holdco US Inc. reported that 3,033,548 and 1,378,950 pounds of carbon disulfide were imported in 2018, and 2019, respectively (EPA 2022c). Five other manufacturers declared this information as CBI and three manufacturers declared no imports. Nine of the domestic chemical companies reporting to the CDR declared zero exports or that information as CBI in 2019. Nouryon Functional Chemicals LLC reported exports of 41,000,000 pounds of carbon disulfide for 2019 (EPA 2022c).

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5.2.3 Use

Carbon disulfide has been an important industrial chemical since the 1800s because of its many useful properties, including its ability to solubilize fats, rubbers, phosphorus, sulfur, and other elements (Sine 1989; Timmerman 1978; Windholz 1983). Because of its ability to dissolve phosphorus, it was once widely used to produce matches but was later replaced by another chemical. Carbon disulfide's fat solvent properties also made it indispensable in preparing fats, lacquers, and camphor; refining petroleum jelly and paraffin; and extracting oil from bones, palmstones, olives, and rags. It was also used in processing India rubber sap from tropical trees. In all these extraction processes, however, carbon disulfide has been replaced by other solvents (Davidson and Feinleib 1972).

Its fat, rubber, and metal solvent properties have made carbon disulfide highly suitable for a variety of other continuing industrial applications including the following: vulcanization and manufacture of rubber and rubber accessories; production of resins, xanthates, thiocyanates, plywood adhesives, and flotation agents; solvent and spinning-solution applications primarily in the manufacture of rayon; polymerization inhibition of vinyl chloride; conversion and processing of hydrocarbons; petroleum-well cleaning; brightening of precious metals in electroplating; thin film deposition of nickel; as an agent to increase corrosion and wear-resistance in metals; rust removal from metals; and removal and recovery of metals and other elements from wastewater and other media (Davidson and Feinleib 1972; EPA 1978; Sine 1989; WHO 1981; Windholz 1983). It has also been used in industry as a means to promote sulfation in the synthesis of rare earth sulfides used in semiconductors, as a regenerator for transition metal sulfide catalysts, as a development restrainer in photography and lithography, and as a solvent to remove printing on recycled plastics (Timmerman 1978).

Carbon disulfide's most important industrial use, however, has been in the manufacture of regenerated cellulose rayon by the viscose process (viscose rayon) (Davidson and Feinleib 1972; EPA 1978; NIOSH 1977; Timmerman 1978; WHO 1981). In the United States, the approximate end uses of carbon disulfide are rayon production (44%); agriculture and other chemicals (35%); rubber chemicals (18%); and cellophane and other regenerated cellulose products such as sponges (3%) (Smith and Timmerman 2003). Carbon disulfide is also used in the production of dithiocarbamate pesticides (Campanale et al. 2023; Lay et al. 2012).

Another historic industrial use for carbon disulfide has been as a feedstock for carbon tetrachloride production (NIOSH 1977; Timmerman 1978). While only 10% of U.S. carbon disulfide production was

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used to produce carbon tetrachloride in 1960, this increased to 32% in 1974, largely because of a rapid increase in the demand for carbon tetrachloride for the production of fluorocarbon propellants and refrigerants (Timmerman 1978). Environmental and toxicity concerns related to the manufacture and use of carbon tetrachloride have led to a decrease in demand for carbon disulfide for this purpose. In 1991, the last remaining carbon tetrachloride plant in the United States that employed the carbon disulfide synthetic route was closed permanently (Smith and Timmerman 2003).

In agriculture, carbon disulfide was previously used as a fumigant to control insects in stored grain, normally mixed with carbon tetrachloride to reduce the fire hazard (Sine 1989; Worthing 1987). It was also previously used to remove botfly larva infestations from the stomachs of horses and ectoparasites from swine (Rossoff 1974). However, use of carbon disulfide as a grain fumigant was voluntarily cancelled after 1985 (EPA 1985). Carbon disulfide is not currently registered for use as a pesticide in the United States (EPA 2023a).

An intensive specialty use is to desorb charcoal sampling tubes in National Institute for Occupational Safety and Health (NIOSH) methods for airborne organics (NIOSH 1984b). Carbon disulfide is used extensively in research laboratory chemical synthetics methods (Dunn and Rudolf 1989).

5.2.4 Disposal

Carbon disulfide is a very flammable liquid that burns to produce carbon dioxide and sulfur dioxide. Therefore, it is a good candidate for controlled incineration, provided that a sulfur dioxide scrubber is used. Some methods proposed by the EPA (1981b) include liquid injection incineration at a temperature range of 650–1,600°C, rotary kiln incineration at a temperature range of 820–1,600°C, and fluidized bed incineration at a temperature range of 450–980°C. Adsorption to activated coal with hydrogen sulfide in the absence of free oxygen yields a process that can regenerate large percentages of sulfur for reuse (UNEP 1985). It is not recommended that landfills be used as a disposal method because of the high flammability of this compound (UNEP 1985). No information was found on quantities and locations of disposal. The EPA Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) guideline for reportable quantities is 100 pounds (EPA 2022a).

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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 2022d). 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 2022d).

5.3.1 Air

Estimated releases of 8,231,727 pounds (~3,734 metric tons) of carbon disulfide to the atmosphere from 144 domestic manufacturing and processing facilities in 2022, accounted for about 97% of the estimated total environmental releases from facilities required to report to the TRI (TRI22 2024). These releases are summarized in Table 5-2.

Table 5-2. Releases to the Environment from Facilities that Produce, Process, or Use Carbon Disulfide^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
AL	6	90,894	617	0	1	0	91,511	1	91,512
AR	2	1,203,439	382	0	2	0	1,203,821	2	1,203,823
CA	11	13,863	1,163	0	19	3,721	13,864	4,902	18,766
CT	1	781	0	0	0	0	781	0	781
DE	1	1,453	0	0	0	0	1,453	0	1,453
FL	1	61	0	0	0	0	61	0	61
GA	1	1,302	0	0	0	0	1,302	0	1,302
ID	1	962	0	0	0	0	962	0	962
IL	8	3,114,718	75,275	0	3	0	3,114,733	75,263	3,189,995
IN	4	2,488	4	0	1	0	2,492	1	2,493
KS	5	827,041	23,756	0	0	0	850,797	0	850,797
KY	3	1,312	0	0	0	0	1,312	0	1,312
LA	18	336,061	90	0	24	0	336,151	24	336,175
MI	1	107	3	0	0	0	107	3	110
MN	2	3,865	0	0	0	0	3,865	0	3,865

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Table 5-2. Releases to the Environment from Facilities that Produce, Process, or Use Carbon Disulfide^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- and off-site
							On-site ^j	Off-site ^k	
MO	2	405	0	0	0	0	405	0	405
MS	1	2,300	50	0	112	0	2,350	112	2,462
MT	3	946	0	0	0	0	946	0	946
ND	2	3,516	4	6	0	0	3,526	0	3,526
NM	1	8,200	0	1	0	0	8,201	0	8,201
NY	1	280,000	827	0	491	0	280,000	1,318	281,318
OH	11	32,480	4	0	1	0	32,480	5	32,485
OK	6	10,577	5	3,825	0	0	10,582	3,825	14,407
PA	3	88,691	0	0	0	0	88,691	0	88,691
TN	4	2,081,741	108,000	0	0	0	2,081,741	108,000	2,189,741
TX	37	117,783	37	3,900	19	0	121,720	19	121,739
UT	3	766	22	0	9	0	766	31	797
WA	4	5,683	12	0	0	0	5,695	0	5,695
WY	1	291	0	0	0	0	291	0	291
Total	144	8,231,727	210,250	7,732	682	3,721	8,260,607	193,506	8,454,112

^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: TRI22 2024 (Data are from 2022)

EPA's National Emission Inventory (NEI) database contains information regarding sources that emit criteria air pollutants (CAPs) and their precursors, and hazardous air pollutants (HAPs) for the 50 United States, Washington DC, Puerto Rico, and the U.S. Virgin Islands. Emissions are estimated from multiple sources, including state and local environmental agencies; the TRI database; computer models for on- and off-road emissions; and databases related to EPA's Maximum Achievable Control Technology (MACT)

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programs to reduce emissions of HAPs. Carbon disulfide emissions estimated from the 2017 inventory are summarized in Table 5-3 (EPA 2023b).

Table 5-3. Carbon Disulfide Emissions to the Air Based on 2017 National Emissions Inventory

Emission sector	Pounds emitted
Agriculture, livestock waste	279,572
Bulk gasoline terminals	4
Fuel combustion, commercial/institutional, biomass	338
Fuel combustion, commercial/institutional, coal	167
Fuel combustion, commercial/institutional, other	73
Fuel combustion, electric generation, coal	24,634
Fuel combustion, electric generation, natural gas	88
Fuel combustion, electric generation, oil	0
Fuel combustion, electric generation, other	301
Fuel combustion, industrial boilers, internal combustion engines, biomass	11,047
Fuel combustion, industrial boilers, internal combustion engines, coal	4,175
Fuel combustion, industrial boilers, internal combustion engines, natural gas	52,388
Fuel combustion, industrial boilers, internal combustion engines, oil	99
Fuel combustion, industrial boilers, internal combustion engines, other	16,665
Fuel combustion, residential, other	0
Gas stations	1
Industrial processes, cement manufacturing	2,258
Industrial processes, chemical manufacturing	4,285,453
Industrial processes, ferrous metals	2,563
Industrial processes, mining	4
Industrial processes, not elsewhere classified	4,017,826
Industrial Processes, non-ferrous Metals	32,882
Industrial processes, oil and gas production	588
Industrial processes, petroleum refineries	61,271
Industrial processes, pulp and paper	148,782
Industrial processes, storage and transfer	79,144
Solvent, degreasing	34
Solvent, industrial surface coating and solvent use	21,759
Waste disposal	58,158

Source: EPA 2023b

The largest single source of anthropogenic release of carbon disulfide has been in the viscose rayon industry. Zumkehr et al. (2017) reported emissions of carbon disulfide from rayon production as 23 ± 12 Gg S per year (gigagrams sulfur per year). However, additional anthropogenic sources of carbon

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disulfide release have been reported. Small amounts of carbon disulfide have also been detected in a landfill simulator (Vogt and Walsh 1985) and in the odoriferous emissions from a sewage treatment plant (Ruby et al. 1987). Carbon disulfide emissions were measured in the combustion of 15 barbecue charcoal products from five countries (6 in Korea, 4 in China, 3 in Indonesia, 1 in Malaysia, and 1 in the United States) at rates of 0.22–125 $\mu\text{g}/\text{m}^3$ (mean of 12 $\mu\text{g}/\text{m}^3$); the highest level was measured in Korean products while the lowest level was measured in the product from the United States (Mahmudur Rahman and Kim 2012).

Additional sources of anthropogenic release of carbon disulfide may include environmental breakdown of dithiocarbamate pesticides in the environment (Campanale et al. 2023). For example, usage of metab potassium, dazomet, and thiram in the United States in 2018 were approximately 50 million tons, <1 million tons, and <0.2 million tons, respectively (USGS 2018a, 2018b, 2018c). However, no estimates of the amount of carbon disulfide released into the atmosphere from these pesticide usages were available.

Carbon disulfide was one of seven sulfur-gas emission rates assessed from problem drywall installed in U.S. homes (LBNL 2011). Historically, carbon disulfide was used in the processing of rubber, but changing technology made the old practices outmoded. Nevertheless, carbon disulfide was measured as 6.88, 3.37, 29.72, and 1.69% of the volatile emissions in mixing, shaping, vulcanization, and storage, respectively, in the production of rubber products (Huang et al. 2022). Automotive tire wear has been suggested as a potential source of atmospheric carbon disulfide. The emission of carbon disulfide from pyrolysis of scrap tires decreased with increasing temperature (650–1,050°C) and decreased with an increase in oxygen supply (Fullana et al. 2000).

There are several known natural sources of carbon disulfide, including wetlands (Hines et al. 1993), oceans (Chin and Davis 1993), plant roots (Piluk et al. 1998), and microbial activity in soils (Banwart and Bremner 1975; Kanda et al. 1995). Emissions of carbon disulfide in aerobic and anaerobic/aerobic composting were measured as 0.4 and <0.1 g/ton of compost (Smet et al. 1999). Estimates from the 1980s suggested that natural sources of carbon disulfide were 4–5 times greater than anthropogenic releases; however, later modeling results suggest that the major source of carbon disulfide derives from industrial emissions (58%), while the oceans contribute about 34%, and the remainder comes from terrestrial sources (EC/HC 2000). Lennartz et al. (2021) produced monthly resolved modelled oceanic emissions of carbonyl sulfide and carbon disulfide over the period of 2000–2019, reported in terms of their sulfur content. Maximum monthly mean concentrations of carbon disulfide were shown to vary the most in the summer months in the northern temperate regions (23–66°N) from 4.3 Gg S per month

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(gigagrams sulfur per month) in June 2011 and 6.0 Gg S per month in June 2018 but show less variability in the winter months (e.g., between 0.8 and 1.2 Gg S per month in December).

During analytical measurements of sulfur compounds at five wetland areas in Florida, carbon disulfide was often not detected, while large amounts of dimethylsulfide were found (Cooper et al. 1987). However, low levels of carbon disulfide were consistently detected in samples collected from the same area using a slightly modified procedure (Hines et al. 1993). Based on their measurements and assumptions in the study of sulfur emissions from a North Carolina salt marsh, Aneja et al. (1980) estimated that carbon disulfide produced by marshes (0.022 g sulfur/m² per year) contributes <0.07% of biogenic sulfur and <8% to the stratospheric aerosol layer. DeMello et al. (1987) speculated that carbon disulfide generation from coastal areas in Florida was related to the concentration of organic matter in the sediment. Staubes et al. (1987) found that humic soils were stronger sources for biogenic sulfur than soils with lower organic content; however, a low humic content coupled with high moisture favors the production of carbon disulfide over dimethylsulfide.

5.3.2 Water

Estimated releases of 210,250 pounds (~95.37 metric tons) of carbon disulfide to surface water from 144 domestic manufacturing and processing facilities in 2022, accounted for about 2.5% of the estimated total environmental releases from facilities required to report to the TRI (TRI22 2024). This estimate includes releases to wastewater treatment and publicly owned treatment works (POTWs) (TRI22 2024). These releases are summarized in Table 5-2.

Carbon disulfide is widely found in coastal and ocean waters and extensive study has been done to determine levels over the different types of water bodies. The measurements of Carroll (1985) show that the ocean appears to be a source of carbon disulfide, possibly via anaerobic microorganisms.

Concentrations of <10 nmol/L have been found in a sulfide-rich lake in Spain (Sirnó et al. 1993). Carbon disulfide has also been detected in the vent fluids and sediment surface waters of undersea hydrothermal sites (Marchand et al. 1994).

Lennartz et al. (2021) estimated the globally integrated annual emissions of carbonyl sulfide and carbon disulfide from the world's oceans from 2000 to 2019, reported in terms of their sulfur content. The results for carbon disulfide are shown in Table 5-4.

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Table 5-4. Global Annual Emissions of Carbon Disulfide from Oceans

Year	Emissions (Gg S) ^a
2000	160.8
2001	160.0
2002	161.2
2003	160.3
2004	172.0
2005	169.1
2006	175.3
2007	173.4
2008	175.0
2009	179.7
2010	189.2
2011	179.5
2012	181.2
2013	181.3
2014	170.1
2015	175.0
2016	181.5
2017	189.7
2018	187.8
2019	177.3
Mean (standard deviation)	174.97 (9.3)

^aCarbon disulfide emissions were reported in terms of their sulfur content (Gg S). 1 Gg (Gigagram) =1,000 metric tons.

Source: Lennartz et al. 2021

5.3.3 Soil

Estimated releases of 682 pounds (~0.31 metric tons) of carbon disulfide to soil from 144 domestic manufacturing and processing facilities in 2022, accounted for <1% of the estimated total environmental releases from facilities required to report to the TRI (TRI22 2024). An additional 7,732 pounds (~3.51 metric tons), constituting <1% of the total environmental emissions, were released via underground injection (TRI22 2024). These releases are summarized in Table 5-2.

Emissions of carbon disulfide from soil and plant material occurs naturally due to the metabolism of organic substances from soil bacteria and plants during the growing season (EC/HC 2000). Increases in soil moisture, temperature, organic content, and light increase the rate of carbon disulfide production from

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soil. The Canadian government estimated that 35,000 metric tons of carbon disulfide are released to the Canadian environment from its production in soil (EC/HC 2000). Fain et al. (1987) reported 0.9 mg/L carbon disulfide (dry weight basis) in a typical refinery oily waste applied to a land treatment unit.

5.4 ENVIRONMENTAL FATE

5.4.1 Transport and Partitioning

Air. Releases of carbon disulfide to the environment as a result of industrial activity are expected to be primarily to the atmosphere. Any carbon disulfide released to surface waters in effluent streams is expected to partition rapidly to the atmosphere as a result of the high ratio of vapor pressure to the solubility (Henry's law constant= 1.33×10^{-2} atm m³/mol) of the compound. Hydrolysis is not a significant removal mechanism since the evaporation half-life from a saturated solution is estimated to be 11 minutes (EPA 1978).

Water. Although no information was found evaluating the partitioning of carbon disulfide from water onto sediments, it is not expected to be removed significantly from the aquatic phase through adsorption. The low K_{oc} value, determined from a log K_{ow} of 1.94 and a regression-derived equation, is 48 (EPA 2012). This indicates high soil mobility, but carbon disulfide will probably be less mobile in soils of high organic content.

Sediment and Soil. Although Roy and Griffin (1985) did not conduct adsorption studies, they classified carbon disulfide as a mobile solvent exhibiting a low tendency to be retained by soils. Carbon disulfide released to soils in spills should rapidly volatilize to the atmosphere, but a portion of the compound remaining on soil surfaces could be available for transport into groundwater since it does not have much affinity for soil particles. Farwell et al. (1979) indicated that carbon disulfide volatilizes from a variety of soils, although rates were not provided.

Other Media. The bioconcentration of carbon disulfide was measured in carp (*Cyprinus carpio*); at starting concentrations of 50 and 5 µg/L, the respective bioconcentration factors (BCFs) were <6.1 and <60 (NITE 1988). Estimated BCF and bioaccumulation factors were 8.9 and 6.6, respectively (EPA 2012). These values indicate that carbon disulfide is not expected to bioaccumulate in aquatic organisms.

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5.4.2 Transformation and Degradation

Air. Carbon disulfide reacts with hydroxyl radicals in the troposphere to produce carbonyl sulfide. The lifetime of carbon disulfide in the troposphere, assuming a reaction rate constant of 4.3×10^{-13} cm³/molecule-second, is 73 days (Cox and Sheppard 1980). The half-life for this same reaction is estimated to be 5.5 days, calculated from an experimental rate constant of 2.9×10^{-12} cm³/molecule-second (Arnts et al. 1989).

The photo-oxidation products of carbon disulfide in the laboratory were identified as carbon monoxide, carbonyl sulfide, sulfur dioxide, and a polymer that adhered to the sides of the reaction vessel (Heicklen et al. 1971). Although carbon disulfide absorbs light at wavelengths of 280–350 nm, dissociation does not occur under environmental conditions because of low molar absorptivity (Atkinson et al. 1978; Wood and Heicklen 1971) and direct photolysis of carbon disulfide in the atmosphere does not appear to be significant. EPA (1978) stated that the information available indicated that carbon disulfide is relatively persistent in the atmosphere. For the atmospheric oxidation of carbon disulfide to sulfur dioxide, carbonyl sulfide, and carbon monoxide, the half-life was estimated to be about 12 days.

According to Wine et al. (1981), electronically excited carbon disulfide is rapidly produced in the troposphere from absorption of solar photons. This excited carbon disulfide reacts with oxygen on a time scale of 1–2 weeks to yield carbonyl sulfide, the predominant sulfur-containing compound in the troposphere.

The lifetime of carbon disulfide in the atmosphere has been estimated to be 12 days, too short a time to reach the stratosphere. Removal was suggested to occur by a hydroxyl radical reaction or an oxygen atom reaction, but not by dissociation (Khalil and Rasmussen 1984).

Based on the estimates of a lifetime in the troposphere for carbon disulfide on the order of weeks and the troposphere to stratosphere turnover time on the order of years, very little tropospheric carbon disulfide is expected to be transported to the stratosphere (EPA 1986).

Water. Carbon disulfide is stable to hydrolysis in the pH region of environmental concern (pH 4–10). At pH 13, carbon disulfide has a hydrolysis half-life at of about 1 hour at 25°C; by extrapolation, at pH 9, carbon disulfide has a half-life of 1.1 years (EPA 1978). In oxygenated seawater, carbon disulfide was found to be stable for >10 days (Lovelock 1974). The volatilization half-life from a saturated water

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solution has been estimated to be 11 minutes (EPA 1978). The compound apparently does not undergo biodegradation at rates that are competitive with its volatilization from surface waters.

Sediment and Soil. No data were found in the available literature on the biodegradation of carbon disulfide in soil. However, since the chemical is rapidly volatilized (high Henry's law constant) and probably highly mobile in soil (low K_{oc}), it is unlikely that it remains in the soil long enough to be significantly biodegraded.

Microbial degradation of large amounts of carbon disulfide in soil would not be expected to be significant since this compound is a soil disinfectant and toxic to bacteria. Hydrolysis of carbon disulfide on wet soil surfaces is also unlikely (EPA 1986). Oxidation of carbon disulfide by a *Thiobacillus* species isolated from soil has been observed (Plas et al. 1993).

5.5 LEVELS IN THE ENVIRONMENT

Reliable evaluation of the potential for human exposure to carbon disulfide depends, in part, on the reliability of supporting analytical data from environmental samples and biological specimens.

Concentrations of carbon disulfide 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 carbon disulfide 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.

Table 5-5 shows the lowest limit of detections that are achieved by analytical analysis in environmental media. An overview summary of the range of concentrations detected in environmental media is presented in Table 5-6.

Table 5-5. Lowest Limit of Detection Based on Standards

Media	Detection limit ^{a,b}	Reference
Air	0.002 ppbv (0.006 µg/m ³)	Pandey and Kim 2009
Drinking water	0.026 µg/L	NEMI (2023)
Surface water and groundwater	0.026 µg/L	NEMI (2023)
Soil	0.11 µg/kg	WQP (2023)

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Table 5-5. Lowest Limit of Detection Based on Standards

Media	Detection limit ^{a,b}	Reference
Sediment	1.0 µg/kg	WQP (2023)
Urine ^c	11.2 µg/L	CDC (2022)

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

^bUnit conversion: ppb = µg/L (aqueous); = µg/kg (sediment and soil); ppbv = 24.45 concentration µg/m³/76.14 g/mol (air).

^cMetabolite: 2-thiothiazolidine-4-carboxylic acid (TTCA).

Table 5-6. Summary of Environmental Levels of Carbon Disulfide^a

Media	Low	High	For more information
Outdoor air (ppbv)	0.005	22	Section 5.5.1
Indoor air, nonoccupational (ppbv)	0.0048	1.4	Section 5.5.1
Surface water (µg/L)	<0.05	<0.76	Section 5.5.2
Groundwater (µg/L)	<0.05	68.8	Section 5.5.2
Soil (µg/kg)	<0.11	<67.6	Section 5.5.3
Sediment (µg/kg)	<1.0	32.9	Section 5.5.3

^aUnit conversion: ppb = µg/L (aqueous); = µg/kg (sediment and soil); ppbv = 24.45 concentration µg/m³/76.14 g/mol (air). Summary values represent most recent ambient data available. Ranges do not reflect values below the limit of detection.

Detections of carbon disulfide in air, water, and soil at NPL sites are summarized in Table 5-7.

Table 5-7. Carbon Disulfide 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
Water (µg/L)	19	29.3	65.7	37	26
Soil (µg/kg)	21.5	30.8	23.6	30	23
Air (ppbv)	2.81	4.92	10.4	17	12

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

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5.5.1 Air

Data for 2018–2022 obtained from EPA’s Air Quality System (AQS) database are presented in Table 5-8 (EPA 2023c). Data for 2022 show average concentrations of carbon disulfide at various monitoring stations ranging from 0.0 to 2.17 $\mu\text{g}/\text{m}^3$ (0.694 ppbv), with maximum values of 12.2 $\mu\text{g}/\text{m}^3$ (3.90 ppbv). Data obtained for 2020 show similar average concentrations for carbon disulfide, ranging from 0.0 to 2.19 $\mu\text{g}/\text{m}^3$ but with a higher maximum value of 68.5 $\mu\text{g}/\text{m}^3$ (21.9 ppbv). Higher average concentrations of 0.0–5.56 $\mu\text{g}/\text{m}^3$ (1.77 ppbv) with a similar maximum value of 61.9 $\mu\text{g}/\text{m}^3$ (19.8 ppbv) were found for 2018 (EPA 2023c). Logue et al. (2010, 2011) studied air pollutant concentrations at four sites in Pennsylvania from 2006 to 2008 and found carbon disulfide arithmetic mean concentrations of 0.07–0.14 $\mu\text{g}/\text{m}^3$ (0.02–0.045 ppbv); 81% of the samples did not contain carbon disulfide. Carbon disulfide contributed 4.2% of volatile organic compounds (VOCs) measured in the atmosphere at one of five urban sites in Texas (Conley et al. 2005). Analysis of outdoor air at 74 residential homes in Ottawa Canada during 2002–2003 found carbon disulfide in 22% of all samples at a concentration range of 0.015–0.38 $\mu\text{g}/\text{m}^3$ (0.0048–0.12 ppbv) and an arithmetic mean of 0.04 $\mu\text{g}/\text{m}^3$ (0.01 ppbv) (Zhu et al. 2005). The estimated global background level of carbon disulfide has been reported as 1.2 $\mu\text{g}/\text{m}^3$ (0.38 ppbv) (Rosenbaum et al. 1999). Fresh and aged smoke from western U.S. wildfires contained low levels of carbon disulfide (<0.01 $\mu\text{g}/\text{m}^3$) (O’Dell et al. 2020).

Table 5-8. Summary of Annual Concentration of Carbon Disulfide ($\mu\text{g}/\text{m}^3$) Measured in Ambient Air at Locations Across the United States^{a,b}

Year	Number of monitoring locations	Number of samples	Lowest arithmetic mean at all locations	Average arithmetic mean at all locations	Highest arithmetic mean at all locations	Maximum concentration
2018	87	4,697	0	0.472	5.56	61.9
2019	63	3,316	0	0.429	3.49	20.7
2020	65	3,195	0	0.249	2.19	68.5
2021	68	5,719	0	0.145	2.36	10.9
2022	60	1,532	0	0.199	2.17	12.2

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

^b24-hour sampling period.

Source: EPA 2023c

In a study of indoor air in suburban and rural homes in New Jersey between December 2003 and April 2006, carbon disulfide was detected in 3 of 100 samples at a 95th percentile of <1.6 $\mu\text{g}/\text{m}^3$ and maximum of 4.4 $\mu\text{g}/\text{m}^3$ (1.4 ppbv) (Weisel et al. 2008). Analysis of indoor air at 75 residential homes in Ottawa

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Canada during 2002–2003 detected carbon disulfide in 67% of all samples at a concentration range of 0.015–3.29 $\mu\text{g}/\text{m}^3$ (0.0048–1.05 ppbv) and an arithmetic mean of 0.34 $\mu\text{g}/\text{m}^3$ (0.11 ppbv) (Zhu et al. 2005).

Air levels in occupational exposure settings are much higher than ambient exposure levels. Historical occupational exposure levels in viscose rayon factories were typically >10 ppm (Wägar et al. 1981), with brief exposures as high as 254.4 ppm reported for specific jobs (Liss and Finkelstein 1996). However, improvements in working conditions, processes, and other technical improvements have reduced occupational air levels. For example, occupational exposure to carbon disulfide in a viscose rayon factory was reduced by nearly 50% between 1992 and 2009, with median (95th percentile) exposure levels of 4.15 (12.5) ppm in 1992 and 2.48 (6.74) ppm in 2009 (Göen et al. 2014). Additional exposure level details for different departments in this factory can be found in Section 5.7.

In a similar study, Bulat et al. (2002) measured carbon disulfide air concentrations before and after technical improvements in a viscose rayon factory. Exposure was reduced up to 95% for employees with the highest initial exposure levels (see Table 5-9).

Table 5-9. Personal Air Exposure Measurements by Job Type Before and After Technical Improvements^a

Job title	Viscose preparator	Spinner	First spinner
Before improvement, inside mask	14.7 (9.2–20.2) mg/m^3 4.72 (2.9–6.49) ppm	NR	NR
Before improvement, outside mask	90.2 (62.8–139.5) mg/m^3 28.0 (20.2–44.8) ppm	111.5 (93.8–132.6) mg/m^3 35.8 (30.1–42.58) ppm	100.9 (75.3–185.3) mg/m^3 32.4 (24.2–59.5) ppm
After improvement, inside mask	10.1 (6.0–17.0) mg/m^3 3.24 (1.93–5.46) ppm	5.4 (3.95–7.37) mg/m^3 1.7 (1.28–2.37) ppm	6.3 (3.3–11.9) mg/m^3 2.0 (1.1–3.82) ppm
After improvement, outside mask	20.8 (1.3–34.44) mg/m^3 6.68 (0.42–11.06) ppm	8.11 (5.71–11.53) mg/m^3 2.6 (1.83–3.7) ppm	40.27 ^b mg/m^3 12.93 ppm

^aGeometric means and 95% confidence intervals. Unit conversion: ppm = 24.45 concentration $\text{mg}/\text{m}^3/76.14 \text{ g/mol}$.

^bOnly one measurement available.

NR = not reported

Source: Bulat et al. 2002

5.5.2 Water

Reported average concentrations of carbon disulfide levels in ocean water collected from various locations were 15.7 picomoles/L (0.0012 $\mu\text{g}/\text{L}$) (Lennartz et al. 2020) and 18 picomoles/L (0.0014 $\mu\text{g}/\text{L}$)

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(Lennartz et al. 2020, 2021). Using data from the National Water-Quality Assessment project (NAWQA) and the U.S. Geological Survey (USGS), Bexfield et al. (2022) conducted a national study of VOC concentrations in 1537 wells sampled in 23 principal aquifer surveys over the span of 2013–2019. Carbon disulfide was found at less than the detection limit (0.05–0.8613 µg/L) in 1,324 wells, at estimated levels of 0.05–5.844 µg/L in 185 wells, and at measured concentrations of 0.062–4.236 µg/L in 25 wells (Bexfield et al. 2022). Thirty-eight U.S. streams were monitored from 2012 to 2014 for 719 compounds; carbon disulfide was found in 14 streams at ~30 ng/L (Bradley et al. 2017). Carbon disulfide was found at a maximum concentration of <0.76 µg/L in a stratified lake in Connecticut; the highest levels were at the deepest level (Hu et al. 2007). Carbon disulfide was detected in about 40% of the 95 monitoring wells in the Glassboro study area of New Jersey; it was not detected in 30 public supply wells (Stackelberg et al. 2001).

According to the Water Quality Portal (WQP) database, from 2015 to 2023, carbon disulfide has been detected in 29% of 41 surface water samples at average concentrations of 0.135–0.201 µg/L (WQP 2023). For groundwater sample data, carbon disulfide was found in ~51% of 1,541 samples for the years 2015–2023; the average concentration was reported as 0.98–1.79 µg/L (WQP 2023) (see Table 5-10).

Table 5-10. Summary of Concentrations of Carbon Disulfide (µg/L) Measured in Surface and Groundwater Across the United States

Year range	Average	Maximum	Number of Samples	Percent detected
Surface water				
2015–2017	0.135	0.17	8	25
2018–2020	0.201	0.51	14	50
2021–2023 ^a	0.173	0.32	19	15.8
Groundwater				
2015–2017	0.98	56	701	54.4
2018–2020	1.79	76	507	43.4
2021–2023 ^a	1.23	68.8	333	54.7

^aAs of April 14, 2023.

Source: WQP 2023

Miermans et al. (2000) studied Dutch surface water of the Rhine River, Meuse River, Northern Delta Area of the Rhine-Meuse-Scheldt Rivers, and Westerscheldt Estuary; carbon disulfide was found at 0.9, 4.5, 0.1, and 0.1 µg/L, respectively.

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5.5.3 Sediment and Soil

WQP (2023) data show reported soil samples for 2012 (4 samples) and 2015 (14 samples); however, all results were less than the detection limit range of 0.11–67.6 µg/kg. No data were reported for soil samples for any other years up to 2023. Carbon disulfide was reported in soil gas samples from the Palermo Wellfield Superfund Site at less than the quantitation limit (WQP 2023). Sediment data available for the last 10 years from WQP (2023) reported 13 of 155 samples containing carbon disulfide at 1.6–32.9 µg/kg. No other sediment data were located.

5.5.4 Other Media

Carbon disulfide's previous use as a fumigant resulted in residues on grains, legumes, and other fruit and vegetable products (Daft 1987; Heikes 1987; Lovegren et al. 1979). Current studies of carbon disulfide concentrations in food products were not located. Carbon disulfide concentrations were 1,500 ppm in the root of Oriental ginseng (*Panax ginseng*) and 0.19 ppm in the stem of kohlrabi (*Brassica oleracea*) and in the fruit of shiitake (*Lentinus edodes*) (NLM 2023). Carbon disulfide was found in *Charybdis feriatus* crabs at 217.2, 203.9, and 29.8 µg/kg in the leg, body, and carapace, respectively (Chung 1999).

5.6 GENERAL POPULATION EXPOSURE

The general population may be exposed to low levels of carbon disulfide in ambient air. Absorption through the skin is a much less important route than inhalation, and oral exposure is negligible. Accurate, current estimates of the daily intake of carbon disulfide are not available, or possible, due to the lack of appropriate current monitoring data. Ambient air levels across the United States in 2022 ranged from 2.17 to 12.2 µg/m³ (0.694–3.90 ppbv) (EPA 2023c). In 2021, median ambient annual average concentrations across New York, New Jersey, and Connecticut reported in U.S. EPA's National Air Toxic Assessment (NATA) database were 0.00566 µg/m³ (0.00182 ppbv) (Li et al. 2021). Data on ambient indoor air levels of carbon disulfide that are not obtained under occupational settings are scarce, but levels ranging from 0.015 to 4.4 µg/m³ (0.005–1.4 ppbv) have been reported in North America (Weisel et al. 2008; Zhu et al. 2005).

Carbon disulfide 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

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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 time weighted average 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 air and water levels discussed in Section 5.5.1 and 5.5.2, Reasonable Maximum Exposure (RME) levels for carbon disulfide were calculated for different exposure groups (Table 5-11).

Table 5-11. Reasonable Maximum Exposure of Carbon Disulfide for Daily Inhalation Dose and Administered Dermal Dose in $\mu\text{g}/\text{kg}/\text{day}$ for the Target Person

Exposure group	Inhalation	Dermal
Birth-<1 year	2.6	0.0089
1-<2 years	2.8	0.0082
2-<6 years	1.8	0.0070
6-<11 years	0.97	0.0057
11-<16 years	0.65	0.0047
16-<21 years	0.49	0.0043
Adult	0.44	0.0042
Pregnant and breastfeeding women	0.63	0.0042

Source: ATSDR 2023

5.7 POPULATIONS WITH POTENTIALLY HIGH EXPOSURES

Human exposure to carbon disulfide is expected to be highest among certain occupational groups (e.g., workers involved in the production of viscose rayon). While historical occupational exposure levels were high (>10 ppmv in workplace air), current exposure levels are lower. Occupational monitoring data obtained since the year 2000 report central estimates (medians or means) ranging from 1.86 to 5.96 ppmv in 2009 (Göen et al. 2014; Guo et al. 2016; Jhun et al. 2007, 2009; Yoshioka et al. 2017). While lower than historical values, this exposure is still approximately 2–3 orders of magnitude above ambient exposure levels (see Section 5.6). While carbon disulfide is the predominant chemical exposure at viscose rayon factories, co-exposure to other chemicals frequently occurs (NIOSH 1977). The most common is hydrogen sulfide, generally found at concentrations approximately 1/10th of carbon disulfide exposure levels (Hernberg et al. 1970). Other potential exposures include tin oxide, zinc oxide and sulfate, sodium hydroxide, sulfuric acid, and lead, but these exposures are considered minimal compared to carbon disulfide (Johnson et al. 1983). Other occupations with potential for exposure to carbon

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disulfide include chemical manufacturing workers using carbon disulfide in producing thiocarbamates or other end products, cellophane manufacturing, viscose sponge production, and laboratory specialty workers (e.g., researchers using carbon disulfide).

Nursing infants of women occupationally exposed to carbon disulfide may also be at increased risk of exposure, as carbon disulfide is excreted in breast milk, and can be detected for up to a month or more following exposure (Cai and Bao 1981; Pellizzari et al. 1982).

Persons living in certain source-dominated areas may be at risk for higher than background exposures to carbon disulfide. These may include persons living near industries and facilities that manufacture and use carbon disulfide (e.g., viscose rayon plants, sponge manufacturers). For example, measured carbon disulfide levels outside 10 residences within 1 mile of the Nylonge sponge manufacturing facility in Elyria, Ohio over a 20-day period in September to October of 1998 ranged from <1.1 to 290 ppb (ATSDR 1999). Participants were instructed to collect samples when they perceived odors to be “significant;” some of the descriptors used for the odor included rotten eggs, sulfur, burning, sewer gas, and pungent. Of particular concern would be a worker with occupational exposure to carbon disulfide who also lives close enough to the plant to be exposed to elevated levels at home as well. Elevated biomarkers of exposure (e.g., urinary concentrations of carbon disulfide or its metabolites) have been reported in children who live close (15 km) to a factory emitting carbon disulfide into the atmosphere, compared to children living 400 km away (Helasova 1969).

In addition, members of the general population living in the vicinity of industrial point emission sources are exposed to higher than background levels of carbon disulfide. The compound has been detected in both ambient air and water in low concentrations, with somewhat higher concentrations in localized areas around industrial and disposal sites. For example, ambient air levels of carbon disulfide from October 2020 to September 2021 ranged from 1.6 to 7.4 ppbv in various community locations in Kalamazoo, Michigan near Graphic Packaging International, LLC, and the Kalamazoo Water Reclamation Plant (MDHHS 2023). The exposure levels in the upper range for these communities are more than twice the upper range exposure levels reported in ambient air across the United States in 2022 (Section 5.6). In 2008, predicted vapor intrusion for buildings near the former Industrial Chemical Supply Company (ICSC) hazardous water properties in Tampa, Florida from wells contaminated with carbon disulfide ranged from 0.16 to 0.3 ppbv; well concentrations were not reported (ATSDR 2008). No information was found regarding the number of people potentially exposed in the vicinity of hazardous waste sites.

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However, since carbon disulfide has been found near hazardous waste sites, people living near them may be exposed to higher than background levels.

Göen et al. (2014) studied workplace air levels of carbon disulfide and creatinine concentrations of the carbon disulfide metabolite, TTCA, in urine of factory workers of a viscose rayon manufacturing facility located in Germany. Cross-sectional studies were conducted in 1992 and 2009 and supplemented with company internal data. The results comparing personal air monitoring of carbon disulfide exposure and urinary TTCA levels from 1992 versus 2009 in different departments (job function and location) of the facility are shown in Tables 5-12 and 5-13, respectively. Personal carbon disulfide air monitoring data were significantly correlated with urinary TTCA levels in 2009; correlation analysis was not conducted for 1992 data. The study authors concluded that exposures to carbon disulfide have decreased over this time period as engineering controls and other safety measures have reduced air levels in these settings; however, the study authors noted that the data do not show a linear trend over the temporal period.

Table 5-12. Carbon Disulfide Personal Air Monitoring (ppm) in a Rayon Factory in 1992 and 2009

Department	Number of measurements	Median	95 th percentile	Range
1992				
Spinning of textile rayon	109	2.95	7.23	0.52–19.3
Spinning of technical rayon	95	5.54	15.4	0.87–18.3
Washing of textile rayon spools	37	8.86	28.1	1.11–65.7
Post-treatment	95	3.83	7.07	<0.20–16.9
Rayon ageing and filter cleaning	16	1.70	–	<0.20–5.11
All exposed workers	352	4.15	15.4	<0.20–65.7
2009				
Spinning of textile rayon	52	3.36	6.46	0.480–13.2
Spinning of technical rayon	63	2.97	11.5	0.195–20.9
Washing of textile rayon spools	23	2.01	3.86	<0.20–5.65
Post-treatment	56	1.86	6.15	0.460–11.4
Rayon ageing and filter cleaning	12	2.60	3.62	1.36–3.92
All exposed workers	209	2.48	6.71	<0.20–20.9

Source Göen et al. (2014)

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Table 5-13. 2-Thiothiazolidine-4-carboxylic Acid (mg/g Creatinine) Concentration in Urine of Workers in a Rayon Factory in 1992 and 2009

Department	Number of measurements	Median	95 th percentile	Range
1992				
Spinning of textile rayon	112	1.31	3.29	0.03–6.37
Spinning of technical rayon	97	2.76	7.43	0.04–11.0
Washing of textile rayon spools	40	3.72	7.96	0.40–11.6
Post-treatment	96	1.49	4.26	0.05–6.72
Rayon ageing and filter cleaning	17	0.65	2.23	0.23–2.23
All exposed workers	362	1.63	5.57	0.03–11.6
2009				
Spinning of textile rayon	53	0.97	2.12	0.08–4.68
Spinning of technical rayon	65	1.02	2.78	0.09–5.27
Washing of textile rayon spools	22	0.46	1.81	0.06–2.20
Post-treatment	54	0.58	2.47	0.04–3.50
Rayon ageing and filter cleaning	12	0.80	1.54	0.48–5.27
All exposed workers	209	0.86	0.86	0.04–5.27

Source Göen et al. (2014)

In a similar study, Vermeulen et al. (2005) reported urine TTCA levels in rubber workers from nine factories (three rubber tire, five general rubber goods, and one retreading company) based on departments using biomonitoring data collected from January to July 1997; results are presented in Table 5-14.

Table 5-14. Weekday Urinary Levels of 2-Thiothiazolidine-4-carboxylic Acid in Rubber Workers by Department

Department	Number of subjects	Number of measurements	Arithmetic mean in $\mu\text{mol/mol}$ creatinine (mg/g creatinine) ^a	Geometric mean in $\mu\text{mol/mol}$ creatinine (mg/g creatinine) ^a
Mixing	10	30	15 (0.022)	7 (0.01)
Pre-treating	14	41	16 (0.023)	8 (0.01)
Molding	27	76	34 (0.049)	11 (0.016) ^b
Curing	24	67	27 (0.039)	16 (0.023) ^b
Finishing	9	25	42 (0.061)	13 (0.019)

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Table 5-14. Weekday Urinary Levels of 2-Thiothiazolidine-4-carboxylic Acid in Rubber Workers by Department

Department	Number of subjects	Number of measurements	Arithmetic mean in $\mu\text{mol/mol}$ creatinine (mg/g creatinine) ^a	Geometric mean in $\mu\text{mol/mol}$ creatinine (mg/g creatinine) ^a
Shipping	3	8	15 (0.022)	14 (0.020)
Engineer service	14	38	17 (0.025)	7 (0.01)

^aTo facilitate comparison across studies, urinary levels reported in $\mu\text{mol/mol}$ creatinine were converted to mg/g creatinine based on the molecular weights of 2-thiothiazolidine-4-carboxylic acid (163.2 g/mol = 0.1632 mg/ μmol ; NLM 2024a) and creatinine (113.12 g/mol; NLM 2024b). 1 μmol 2-thiothiazolidine-4-carboxylic acid/1 mol creatinine = 0.1632 mg 2-thiothiazolidine-4-carboxylic acid/113.12 g creatinine = 0.001443 mg 2-thiothiazolidine-4-carboxylic acid/g creatine. Example calculation: 15 $\mu\text{mol/mol}$ creatinine \times 0.001443 = 0.022 mg/g creatinine.

^bMean weekday urinary biomarker levels of subjects in a department significantly higher than Sunday urinary biomarker levels (paired *t*-test); $p < 0.05$.

Source: Vermeulen et al. 2005

Levels of the carbon disulfide metabolite, TTCA, were measured in the urine of individuals after completing their shift in a rayon factory (Chang et al. 2002). Levels of TTCA were excreted about 34% within the first 2 hours after exposure; the mean half-life for excretion was 8.7 hours, with total elimination by 22–24 hours.