6. POTENTIAL FOR HUMAN EXPOSURE

6.1 OVERVIEW

Carbon monoxide is a colorless, odorless, and tasteless gas that is ubiquitous in the atmosphere (George 2001). It arises from both natural and anthropogenic (human-made) sources. It is produced as a primary pollutant during the incomplete combustion of fossil fuels and biomass, including internal combustion engines, wildfires, and controlled burns. Carbon monoxide is also produced indirectly from the photochemical oxidation of methane and other VOCs in the atmosphere. Vegetation can emit carbon monoxide into the atmosphere as a metabolic byproduct. Photooxidation of organic matter in surface waters (lakes, streams, rivers, oceans) and surface soils also results in the formation of carbon monoxide. Volcanic activity is another natural source of carbon monoxide in the atmosphere. Carbon monoxide is also produced endogenously in humans during the normal catabolism of hemoglobin (Hb). The amount of anthropogenic carbon monoxide emissions versus that from natural sources is difficult to quantify since both sources of carbon monoxide vary over time. The EPA estimated that 84% of all carbon monoxide emissions in 2005 arose as a result of human activity, with biogenic emissions accounting for 16% of the total emissions (EPA 2012). However, an analysis of the carbon monoxide budget over North America concluded that during the summer months, when natural sources of carbon monoxide precursors such as biogenic VOCs and forest fires are high, natural sources of carbon monoxide in the atmosphere are far greater than anthropogenic contributions (Miller et al. 2008). Data from the EPA National Emissions Inventory (NEI) suggest that as much as 75% of the total point and non-point emissions of carbon monoxide are historically associated with on-road automobile use (EPA 2010).

The background levels of carbon monoxide have changed significantly in the past several decades. Concentrations have decreased appreciably due to reduced emissions from automobiles as a consequence of advancements in automotive design. The development of catalytic converters for passenger vehicles, beginning in the 1970s, resulted in a substantial decrease in carbon monoxide emissions, despite large increases in miles traveled (George 2001). In the early 1980s, automakers equipped vehicles with more sophisticated catalytic converters and added on-board computers and O_2 sensors in order to help optimize the efficiency of the converter. The end result is that modern passenger automobiles emit about 90% less carbon monoxide over their lifetimes as compared to vehicles designed in previous decades (George 2001).

The annual average outdoor carbon monoxide concentrations are roughly 0.12 parts per million by volume (ppmv) in the Northern Hemisphere and about 0.04 ppmv in the Southern Hemisphere (EPA

2000). These levels are variable throughout the course of the year, with seasonal maximum levels occurring during late winter in both hemispheres when inversion conditions (in which air pollutants are trapped near the ground beneath a layer of warm air) are more frequent. Minimum levels are generally observed during late summer. Carbon monoxide concentrations are reported to range from a minimum of about 0.03 ppmv during summer in the Southern Hemisphere to about 0.20 ppmv at high latitudes in the Northern Hemisphere during winter (EPA 2000). Urban locations with high automobile usage or a high volume of stationary emission sources, such as refineries or power plants, typically have greater atmospheric levels of carbon monoxide as compared to rural or remote sites. In metropolitan areas in the United States, as much as 95% of all carbon monoxide emissions result from on-road vehicle exhaust (EPA 2008). The majority of these on-road emissions are derived from gasoline-powered vehicles, since diesel vehicles emit less carbon monoxide. There is also a diurnal pattern of atmospheric carbon monoxide concentrations in urban areas, with the highest levels occurring during hours with heavy vehicular usage (rush hours) and the lowest levels occurring at times that correlate with lower commuting activity (Campbell et al. 1995; EPA 2000). Maximum carbon monoxide levels frequently exceed 5 ppmv at these locations during the high commute hours.

Carbon monoxide levels in indoor air are greatly dependent upon the presence of combustion-based appliances and whether occupants smoke tobacco products. Unvented kerosene and gas space heaters; leaking chimneys and furnaces; back-drafting from furnaces, gas water heaters, wood stoves, and fireplaces; gas stoves, generators, and other gasoline-powered equipment; automobile exhaust from attached garages; and tobacco smoke all contribute to indoor air levels of carbon monoxide (EPA 2009a). Average levels in homes without gas stoves vary from 0.5 to 5 ppmv. Levels near properly adjusted gas stoves are often 5–15 ppmv, and those near poorly adjusted stoves may be ≥30 ppmv (EPA 2009a). Dangerous levels of carbon monoxide can occur inside boat cabins, partially enclosed cockpits, and beneath swim platforms or other enclosed areas (USCG 2008). Most new boats are equipped with carbon monoxide monitors; however, the U.S. Coast Guard advises owners of boats built prior to 1998 to have the monitors inspected or replaced (USCG 2008).

The primary degradation pathway of carbon monoxide in the environment occurs through its reaction with photochemically-produced hydroxyl radicals. (It should be noted that the production of hydroxyl radicals requires ultraviolet [UV] radiation that does not penetrate windows and therefore, photooxidation is likely negligible indoors.) In addition, soils and coastal waters may also act as a sink for carbon monoxide, since various forms of microorganisms are capable of utilizing carbon monoxide as an energy source (Tolli et al. 2006).

Exposure of the general population to carbon monoxide occurs through inhalation. Populations living in urban areas with heavy vehicular traffic or stationary sources such as petroleum refineries, gas and coal burning power plants, petrochemical plants, and coke oven plants are more likely to be exposed to higher levels of carbon monoxide from ambient outdoor air. Employees in these refineries and plants and workers who are subject to high levels of vehicular exhaust (such as taxi cab drivers and toll booth workers) may be occupationally exposed to higher levels of carbon monoxide. Members of the public who smoke or work in smoke-filled environments such as restaurants, bars, and casinos where smoking is allowed are exposed to higher levels of carbon monoxide than members of the population who do not smoke and are not frequently exposed to second-hand tobacco smoke.

6.2 RELEASES TO THE ENVIRONMENT

6.2.1 Air

Title I of the Clean Air Act of 1970 establishes carbon monoxide as one of six criteria pollutants and sets national air quality standards for carbon monoxide and the other criteria pollutants (EPA 2000). Two databases developed by the EPA are particularly useful for monitoring carbon monoxide levels and emissions throughout the United States. EPA's National Emission Inventory (NEI) database contains detailed information about sources that emit criteria air pollutants and their precursors and hazardous air pollutants for the 50 United States, Washington DC, Puerto Rico, and the U.S. Virgin Islands. The Air Quality System (AQS) database is EPA's repository of criteria air pollutant monitoring data since the 1970s. Table 6-1 contains data for carbon monoxide emissions from 1970 to 2008 from the NEI database for 13 major emission categories. Detailed carbon monoxide emissions from these sources for individual years are available as zipped Microsoft Access® database files that may be accessed directly from the EPA website; however, these data are subject to occasional revisions by EPA as emission estimates for a specific time period are amended. As indicated in Table 6-1, on-road vehicle use has historically accounted for the largest percentage of emissions in the United States as compared to the other emission sources; however, the quantity of carbon monoxide emitted from automobiles has been declining significantly over the past 4 decades due to the use of emission control devices and catalytic converters.

Indoor air levels of carbon monoxide are highly dependent upon the smoking habits, the types of appliances and heating units that are used in the home or building, and whether or not the home or building has an attached garage for automobiles. Carbon monoxide levels from the use of appliances will

Table 6-1. Anthropogenic Carbon Monoxide Emissions (Thousands of Short Tons) from 1970 to 2008

	Emissions by category[a]													
Year[b]	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
1970	237	770	3,625	3,397	3,644	2,179	620	NA	NA	7,059	163,231	11,371	7,909	204,042
1975	276	763	3,441	2,204	2,496	2,211	630	NA	NA	3,230	153,555	14,329	5,263	188,398
1980	322	750	6,230	2,151	2,246	1,723	830	NA	NA	2,300	143,827	16,685	8,344	185,408
1985	291	670	7,525	1,845	2,223	462	694	2	49	1,941	134,187	19,029	7,927	176,845
1990	363	879	4,269	1,183	2,640	333	537	5	76	1,079	110,255	21,447	11,122	154,188
1991	349	920	4,587	1,127	2,571	345	548	5	28	1,116	104,980	21,934	8,618	147,128
1992	350	955	4,849	1,112	2,496	371	544	5	17	1,138	99,705	22,419	6,934	140,895
1993	363	1,043	4,181	1,093	2,536	371	594	5	51	1,248	94,431	22,904	7,082	135,902
1994	370	1,041	4,108	1,171	2,475	338	600	5	24	1,225	89,156	23,389	9,656	133,558
1995	372	1,056	4,506	1,223	2,380	348	624	6	25	1,185	83,881	23,874	7,298	126,778
1996	408	1,188	2,741	1,053	1,599	354	561	1	70	2,904	78,606	24,358	15,016	128,859
1997	423	1,162	2,742	1,071	1,710	367	582	2	71	2,948	75,849	23,668	7,316	117,911
1998	451	1,151	2,727	1,081	1,702	366	590	2	72	3,121	73,244	23,689	7,184	115,380
1999	496	1,213	3,829	350	1,255	159	571	52	163	3,019	68,708	23,316	11,410	114,541
2000	484	1,219	3,081	361	1,295	161	592	51	169	1,849	68,061	24,178	12,964	114,465
2001	485	1,253	3,088	372	1,380	162	615	50	178	1,851	63,476	24,677	8,676	106,263
2002	657	1,267	3,550	284	987	357	490	2	118	1,594	60,596	22,662	18,493	111,057
2003	652	1,229	3,477	259	934	355	504	2	114	1,580	56,579	21,999	17,364	105,078
2004	647	1,190	3,404	233	882	353	519	2	111	1,567	52,562	21,336	16,235	99,041
2005	643	1,152	3,331	208	829	351	534	2	107	1,554	48,544	20,672	15,106	93,034
2006	661	1,173	3,343	227	869	352	522	2	110	1,564	45,318	19,793	13,981	87,915
2007	680	1,195	3,352	246	908	353	511	2	113	1,574	42,092	18,915	12,856	82,801
2008	699	1,216	3,369	265	947	355	500	2	115	1,584	38,866	18,036	11,731	77,685

[a]Categories
1. Fuel combustion electric utilities
2. Fuel combustion industrial utilities
3. Fuel combustion other
4. Chemical allied manufacturing
5. Metal processing
6. Petroleum and related categories
7. Other industrial processes
8. Solvent utilization
9. Storage and transport
10. Waste disposal and recycling
11. Highway vehicles
12. Off-highway
13. Miscellaneous

[b]Emission estimates are subject to updates for subsequent revised versions of the National Emissions Inventory (NEI) database. These numbers may be different than values published for previous versions of the data and may also be different than values for subsequent revisions of the data as generated by the Environmental Protection Agency.

NA = not available

Source: EPA 2009h

depend on several factors, such as the type of fuel used, ventilation, appliance design, fuel consumption rate, use pattern, and operating condition (EPA 1991, 2000, 2010). As reported in the EPA Air Quality Criteria Reports (1991, 2000), carbon monoxide emissions from ranges, ovens, and pilot lights using natural gas were typically greater under yellow tipping flame conditions (characteristic of an improper air-fuel ratio) than blue tipping flame conditions (characteristic of properly adjusted stoves). The average emission rate (mass of carbon monoxide emitted per energy unit produced) for top burning ovens and broilers was 11.9–87.7 micrograms per kilojoule (μg/kJ) under blue flame conditions, as opposed to 53.5–156.6 μg/kJ for improperly adjusted ovens and broilers. In separate tests using three different gas ranges deliberately adjusted to produce blue tipping or yellow tipping flames, the average emission rate ranged from 34.3–70.9 μg/kJ under properly adjusted operation to 108.4–196.9 μg/kJ under improperly adjusted conditions (EPA 1991, 2000).

Quantitative estimates have been made regarding emissions of carbon monoxide from wood-burning stoves and fireplaces under normal operating conditions (Houck et al. 2006). Carbon monoxide emission factor data were based on 277 tests on 70 fireplace models. The mean emission factor was 64.1 g carbon monoxide emitted per kg dry wood (SD of 40.7 g/kg dry wood) (Houck et al. 2006). It has been reported that emission rates of carbon monoxide for well-tuned unvented gas appliances range from 0.15 to 3.2 g/hour, while rates for poorly tuned unvented ones range from 1.5 to 22 g/hour (Dutton et al. 2001).

6.2.2 Water

Direct anthropogenic releases of carbon monoxide to water are not expected; however, natural processes occur that result in carbon monoxide formation in waters. The photodegradation of dissolved organic matter is primarily responsible for producing carbon monoxide in sunlit surface waters (Tolli et al. 2006). Emissions from oceans are a minor source of carbon monoxide with estimated ranges from about 10 to 100 teragrams (Tg) annually (EPA 2000; Liss and Slater 1974).

6.2.3 Soil

The formation of carbon monoxide in soils appears to occur by abiotic processes, such as thermal decomposition or photodecomposition of organic matter. In general, warm and moist conditions found in most soils favor carbon monoxide uptake, whereas hot and dry conditions as found in deserts and some savannas favor the release of carbon monoxide from soil to the atmosphere with estimated annual emissions of about 30 Tg per year (EPA 2000).

6.3 ENVIRONMENTAL FATE

6.3.1 Transport and Partitioning

Carbon monoxide is a gas that will partition to the atmosphere and is distributed globally by the horizontal movement of the wind. Wind direction determines the horizontal transport of carbon monoxide and what impact emissions from one location will have upon another site (EPA 1991). Carbon monoxide levels may be high around local sources, and locations downwind from the source may also be elevated. The transport of carbon monoxide in urban locations is complex and can be influenced by the geometry of street canyons, topography around roadways, and presence of noise barriers, vegetation, and buildings, as well as local meteorological factors. A field study was designed to characterize the air quality and flow of pollutants near a highway with and without noise barriers (Baldauf et al. 2008). The site also contained an open field and a residential neighborhood with mature vegetation. Time-series carbon monoxide levels were collected in an open field with no barrier and an area behind the noise barrier. Levels of carbon monoxide were reduced as much as 50% behind the noise barrier as compared to measurements taken at the open field, depending upon the direction of the wind. However, when wind direction was directly toward the road, carbon monoxide levels behind the barrier were slightly higher than in the open field indicating that pollutants can be trapped behind noise barriers depending upon meteorological conditions (Baldauf et al. 2008).

In most urban areas during the winter months, there is often enhanced stability in the atmospheric boundary layer, which reduces the vertical mixing of emissions from the ground. This effectively traps carbon monoxide at street levels during these periods. Unreacted carbon monoxide in the troposphere is slowly transported to the mesosphere and stratosphere, where it reacts with atomic oxygen generated by the photodissociation of O_2 (Fabian et al. 1979; Pressman and Warneck 1970).

The surface waters of the world's oceans are saturated with carbon monoxide with respect to the atmosphere and are therefore a net source of atmospheric carbon monoxide. Using a mean atmospheric carbon monoxide concentration over the ocean surface of 0.13 ppmv and a surface water concentration of $6x10^{-8}$ cm^3 carbon monoxide per cm^3 water, the total annual flux of carbon monoxide to the atmosphere from seawater was estimated at approximately $4.3x10^{13}$ g/year (43 teragrams (Tg)) (Liss and Slater 1974). Other reported estimates based on computed carbon monoxide concentrations in surface waters were reported to range from 13 to 165 Tg/year (Ohta 1997). Differences in microbial activity in surface water account for the variations in surface water levels and the flux into the atmosphere (Conrad and Seiler 1988).

6.3.2 Transformation and Degradation

6.3.2.1 Air

Carbon monoxide is generally stable under environmental conditions. Reactions with molecular oxygen (O_2) or water vapor are very slow at ambient temperatures and pressure. Carbon monoxide reacts with ground-state triplet oxygen atoms, $O(^3P)$, produced by the atmospheric photodegradation of nitrogen dioxide and ozone, or atomic oxygen, formed by the photodissociation of molecular O_2 in the stratosphere, to form CO_2 (NRC 1977). However, the primary degradation pathway of carbon monoxide in the troposphere is through its reaction with photochemically-produced hydroxyl radicals. This results in the formation of CO_2 and atomic hydrogen, which rapidly reacts with O_2 to form peroxy radicals (EPA 2000, 2010). The second-order rate constant for the gas-phase reaction of carbon monoxide with hydroxyl radicals at atmospheric pressure has been measured as $2.4x10^{-13}$ cm^3/molecule-second (EPA 1991). This corresponds to an estimated tropospheric half-life of approximately 22–67 days, assuming a hydroxyl radical concentration of $5.0x10^5$–$1.5x10^6$ hydroxyl radicals per cm^3 air. No estimates of the half-life of carbon monoxide in indoor air were located. Hydroxyl radicals are formed photochemically by sunlight; therefore, their levels in indoor air will be negligible.

6.3.2.2 Water

Although oceans and other water bodies are considered a net source of carbon monoxide in the environment, evidence suggests that various microorganisms may degrade carbon monoxide in the water (Conrad and Seiler 1988). Taxonomically diverse microorganisms isolated from surface waters collected off the New England coast readily oxidized carbon monoxide (Tolli et al. 2006). Microbial oxidation rate constants for carbon monoxide in coastal waters were reported to range from 0.01 to 0.11 $hours^{-1}$, corresponding to half-lives on the order of several hours (Tolli et al. 2006). These rates were reported to be approximately an order of magnitude greater than in oligotrophic environments, suggesting the presence of an active carbon monoxide oxidizing microbial community near shore.

6.3.2.3 Sediment and Soil

Soils may act as a source or a sink for carbon monoxide, depending on soil moisture, intensity of sunlight reaching the soil surface, and soil temperature (Conrad and Seiler 1985). In general, warm and moist conditions found in most soils favor uptake, whereas hot and dry conditions as found in deserts and some

savannas favor the release of carbon monoxide (EPA 2000). Global estimates of carbon monoxide consumption by soil microorganisms ranged from 15 to 640 Tg (from $1.5x10^{13}$ to $6.4x10^{14}$ g) per year (King 1999a). Carbon monoxide oxidation to CO_2 has been demonstrated for both aerobic and anaerobic microorganisms.

6.4 LEVELS MONITORED OR ESTIMATED IN THE ENVIRONMENT

Reliable evaluation of the potential for human exposure to carbon monoxide depends in part on the reliability of supporting analytical data from environmental samples and biological specimens. Concentrations of carbon monoxide 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 monoxide 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. The analytical methods available for monitoring carbon monoxide in a variety of environmental media are detailed in Chapter 7.

6.4.1 Air

The concentration of carbon monoxide in air can be represented using various concentration units. Air monitoring data for carbon monoxide are usually expressed or reported as either parts per million by volume (ppmv) or parts per billion by volume (ppbv). A concentration of 1 ppmv implies that for every million molecules of gas in the measured volume, one of them is a carbon monoxide molecule. In order to express these concentrations in mass units, the following conversion factors may be used: 1.00 ppmv=1.16 mg/m^3 (1.00 mg/m^3=0.86 ppmv) and 1.00 ppbv=1.16 $\mu g/m^3$ at 20 °C.

Annual average outdoor carbon monoxide concentrations are about 0.12 ppmv in the Northern Hemisphere and about 0.04 ppmv in the Southern Hemisphere (EPA 2000). In general, the concentration of carbon monoxide decreases with altitude in the Northern Hemisphere, but this vertical gradient may be reversed in the Southern Hemisphere due to the transport of carbon monoxide from the Northern to the Southern Hemisphere (EPA 1991). Annual 24-hour average carbon monoxide concentrations obtained at monitoring locations at rural sites in the United States are typically about 0.2 ppmv, compared with an annual 24-hour average of 1.2 ppmv across all monitoring sites (EPA 2000). Carbon monoxide levels (1- and 8-hour maximum levels) from various cities in the United States for 2008 are provided in Table 6-2. These data are derived from measurements submitted to the EPA AQS database, which collects data from EPA, state, local, and tribal air pollution control agencies. As indicated by the data presented in the table, only one measurement exceeded the EPA 8-hour carbon monoxide level of 9 ppm,

Table 6-2. 1-Hour and 8-Hour Maximum Carbon Monoxide Levels at Monitoring Stations Throughout the United States

	1-Hour carbon monoxide level			8-Hour carbon monoxide level				
Number of measure-ments	First maximum (ppmv)	Second maximum (ppmv)	Number exceeding average	First maximum (ppmv)	Second maximum (ppmv)	Number exceeding average	City	State[a]
2,169	8.1	6.7	0	3.6	3.5	0	Fairbanks	AK
2,176	6.1	6	0	4.1	3.8	0	Anchorage	AK
1,988	5.1	4.5	0	2.5	2.3	0	Not provided	AK
2,176	5.6	5.5	0	3.1	2.8	0	Anchorage	AK
2,173	5.7	4.5	0	3.3	2.2	0	Fairbanks	AK
2,173	8.3	8	0	4.8	4.7	0	Anchorage	AK
7,500	19.6	15.9	0	10.7	8.1	1	Birmingham	AL
7,563	8	6.1	0	2.3	2.2	0	Fairfield	AL
8,012	3.4	3	0	2.4	2.3	0	Birmingham	AL
8,750	6.8	2.5	0	1.8	1.5	0	North Little Rock	AR
5,049	1.5	1.4	0	1	1	0	Surprise	AZ
4,584	0.7	0.7	0	0.5	0.5	0	Not provided	AZ
7,947	3.1	3.1	0	2.5	2.4	0	Phoenix	AZ
8,720	2.2	1.8	0	1.3	1	0	Tucson	AZ
8,736	2.6	2.1	0	1.1	1.1	0	Tucson	AZ
8,696	2.9	2.5	0	1.4	1.3	0	Tucson	AZ
4,369	2.5	2.5	0	1.9	1.5	0	Tucson	AZ
8,157	1.5	1.3	0	1	0.9	0	Tucson	AZ
4,315	2	1.8	0	1.3	1.2	0	Tucson	AZ
5,027	2.4	2.3	0	1.8	1.4	0	Tempe	AZ
5,043	1.8	1.7	0	1.4	1.4	0	Chandler	AZ
5,057	3.7	3.2	0	2.2	2	0	Phoenix	AZ
8,654	3	3	0	2.7	2.4	0	Phoenix	AZ
4,933	2	2	0	1.5	1.4	0	Scottsdale	AZ
5,060	2.1	2	0	1.6	1.5	0	Glendale	AZ
5,038	2.1	2	0	1.3	1.3	0	Phoenix	AZ
5,012	1.7	1.7	0	1.4	1.3	0	Mesa	AZ
8,575	4.7	4.5	0	3.1	3	0	Phoenix	AZ
8,307	3.9	3.6	0	2.8	2.8	0	Phoenix	AZ
8,397	3.6	3.5	0	2.6	2.2	0	Phoenix	AZ
6,905	2.1	1.9	0	1.1	1	0	Lompoc	CA
6,893	1.4	1.2	0	0.6	0.6	0	Goleta	CA
6,097	1.6	1.3	0	0.7	0.6	0	Vandenberg Air Force Base	CA
6,177	3.3	3	0	2.1	1.9	0	San Jose	CA
7,046	7.6	3.7	0	1.3	1.1	0	Davenport	CA
6,230	2.7	2.5	0	1.9	1.7	0	Vallejo	CA

Table 6-2. 1-Hour and 8-Hour Maximum Carbon Monoxide Levels at Monitoring Stations Throughout the United States

	1-Hour carbon monoxide level			8-Hour carbon monoxide level				
Number of measure-ments	First maximum (ppmv)	Second maximum (ppmv)	Number exceeding average	First maximum (ppmv)	Second maximum (ppmv)	Number exceeding average	City	State[a]
6,251	0.9	0.9	0	0.7	0.6	0	Benicia	CA
6,244	3.5	1.9	0	1.3	1.1	0	Santa Rosa	CA
5,550	2.8	2.3	0	1.8	1.7	0	Modesto	CA
6,035	1.9	1.9	0	1.2	1.2	0	Turlock	CA
6,270	2.2	2.2	0	1.4	1.4	0	Livermore	CA
6,227	2.9	2.4	0	1.6	1.4	0	Oakland	CA
6,202	1.9	1.8	0	1.3	1.3	0	Fremont (Centerville)	CA
6,175	2.1	2	0	1.5	1.5	0	Berkeley	CA
5,576	3.1	3	0	2.4	2.1	0	Chico	CA
6,240	1.5	1.5	0	1	1	0	Concord	CA
6,274	1	0.9	0	0.8	0.8	0	Bethel Island	CA
6,225	2.5	2.1	0	1.3	0.9	0	San Pablo	CA
6,266	2.8	2.2	0	1.4	1.3	0	Pittsburg	CA
5,430	2.6	2.6	0	1.8	1.7	0	Fresno	CA
5,563	3.1	2.8	0	2.3	2.1	0	Fresno	CA
5,519	1.6	1.5	0	1	1	0	Fresno	CA
4,785	2.3	2.2	0	1.5	1.3	0	Clovis	CA
5,768	1.9	1.9	0	1.6	1.4	0	Eureka	CA
5,543	8.2	7	0	5.3	4.1	0	Calexico	CA
5,262	7.3	6.8	0	3.2	3.1	0	Calexico	CA
6,270	2.5	2.3	0	1.7	1.7	0	El Centro	CA
4,139	3.5	2.7	0	2.2	2.1	0	Bakersfield	CA
5,554	2.3	2.1	0	1.4	1.3	0	Azusa	CA
5,552	2.7	2.3	0	1.8	1.7	0	West Los Angeles	CA
5,555	3	2.8	0	2.5	2	0	Burbank	CA
5,560	2.9	2.8	0	2	1.9	0	Los Angeles	CA
5,594	3.4	3.3	0	2.3	2.1	0	Reseda	CA
5,579	5.8	5.7	0	4.3	4.1	0	Lynwood	CA
5,281	2.9	2.5	0	1.9	1.8	0	Pico Rivera	CA
5,557	2.6	2.6	0	1.7	1.7	0	Pomona	CA
5,550	2.4	2.4	0	2	1.9	0	Pasadena	CA
5,567	3.3	3	0	2.5	2.4	0	Long Beach	CA
5,315	3.1	2.6	0	1.9	1.8	0	Los Angeles	CA
5,495	1.6	1.5	0	0.9	0.8	0	Santa Clarita	CA
5,538	2.2	1.7	0	0.9	0.8	0	Lancaster	CA
6,208	1.7	1.7	0	1	1	0	San Rafael	CA

Table 6-2. 1-Hour and 8-Hour Maximum Carbon Monoxide Levels at Monitoring Stations Throughout the United States

	1-Hour carbon monoxide level			8-Hour carbon monoxide level				
Number of measure-ments	First maximum (ppmv)	Second maximum (ppmv)	Number exceeding average	First maximum (ppmv)	Second maximum (ppmv)	Number exceeding average	City	State[a]
7,224	4.5	3.9	0	3.4	3.3	0	Ukiah	CA
3,282	1.5	1.4	0	1	0.9	0	Willits	CA
7,177	2.2	1.6	0	0.9	0.8	0	Salinas	CA
6,255	3.2	3.1	0	1.8	1.6	0	Napa	CA
5,560	3.3	3	0	2.4	2.1	0	Anaheim	CA
5,571	3	2.8	0	2	2	0	Costa Mesa	CA
5,524	1.5	1.5	0	1.1	1	0	Mission Viejo	CA
5,567	4.7	4.6	0	2.5	2.4	0	La Habra	CA
5,605	4.7	4.5	0	1.9	1.9	0	Riverside	CA
5,574	1	0.9	0	0.5	0.5	0	Palm Springs	CA
5,546	2.7	2.5	0	1.9	1.7	0	Rubidoux (West Riverside)	CA
5,564	1.1	1.1	0	0.8	0.8	0	Lake Elsinore	CA
6,390	2.3	2.3	0	1.8	1.8	0	North Highlands	CA
7,292	2.9	2.7	0	2.5	1.8	0	Sacramento	CA
8,036	3.1	3.1	0	2.8	2.4	0	Sacramento	CA
4,812	2.7	2.5	0	1.8	1.7	0	Sacramento	CA
5,519	1.4	1.3	0	1.2	1.1	0	Barstow	CA
5,587	1.4	1.4	0	0.9	0.9	0	Victorville	CA
5,491	2.1	1.9	0	1.4	1.2	0	Upland	CA
1,388	1.3	1.1	0	0.8	0.8	0	Fontana	CA
5,556	2.2	2.1	0	1.4	1.4	0	San Bernardino	CA
6,212	2	2	0	1.5	1.5	0	Chula Vista	CA
706	2.4	2.2	0	1.8	1.5	0	San Diego	CA
6,006	4.6	4	0	2.8	2.5	0	Escondido	CA
6,130	3.1	3.1	0	2.5	2.5	0	San Diego	CA
5,119	4.3	3.9	0	2.7	2.5	0	Otay Mesa	CA
6,247	2.1	1.9	0	1.5	1.4	0	San Francisco	CA
5,546	2.6	2.5	0	1.6	1.6	0	Stockton	CA
6,214	4.3	3.8	0	1.9	1.8	0	Redwood City	CA
4,811	5.2	3.4	0	1.2	1.2	0	Santa Barbara	CA
5,462	1.5	1.5	0	0.8	0.8	0	Santa Maria	CA
6,182	3.5	2.5	0	1.7	0.9	0	Capitan	CA
6,190	3.1	3.1	0	2.4	1.7	0	Welby	CO
6,505	3.5	3.3	0	2.7	2.4	0	Longmont	CO

Table 6-2. 1-Hour and 8-Hour Maximum Carbon Monoxide Levels at Monitoring Stations Throughout the United States

	1-Hour carbon monoxide level			8-Hour carbon monoxide level				
Number of measure-ments	First maximum (ppmv)	Second maximum (ppmv)	Number exceeding average	First maximum (ppmv)	Second maximum (ppmv)	Number exceeding average	City	State[a]
6,507	3.4	3.2	0	2.3	2.2	0	Greeley	CO
6,481	2.2	2.1	0	1.4	1.3	0	Grand Junction	CO
6,487	5.1	4.6	0	3	2.2	0	Fort Collins	CO
4,249	0.8	0.8	0	0.7	0.7	0	Not provided	CO
6,420	4	3.5	0	2.6	2.3	0	Colorado Springs	CO
6,203	7.1	7	0	3.1	2.3	0	Denver	CO
6,488	4.8	4.5	0	2.4	1.9	0	Denver	CO
6,499	6	5.9	0	3.7	3.1	0	Hartford	CT
6,319	1.6	1.6	0	1.4	1.1	0	Westport	CT
6,305	3.3	3.2	0	2.2	2	0	Bridgeport	CT
6,491	1.2	1.1	0	0.9	0.9	0	Thomaston	CT
6,511	1.8	1.6	0	1.3	1.2	0	East Hartford	CT
3,314	2.2	2.1	0	1.9	1.6	0	New Haven	CT
6,525	6	4	0	2.6	1.8	0	Washington	DC
6,513	3	2.7	0	2.6	2.1	0	Washington	DC
7,030	1.4	1	0	0.9	0.8	0	Not provided	DE
7,171	2	2	0	1.3	1.1	0	Wilmington	DE
6,500	2.1	2	0	1.6	1.6	0	Fort Lauderdale	FL
6,513	1.6	1.5	0	1	0.9	0	Clearwater	FL
6,499	2.4	2.1	0	1.6	1.5	0	Hollywood	FL
6,269	8.7	6.2	0	3.3	2.8	0	Jacksonville	FL
6,318	2.5	2.1	0	1.4	1.2	0	Jacksonville	FL
6,250	2.3	2.2	0	1.1	1.1	0	Jacksonville	FL
6,551	2.6	2.5	0	2	1.8	0	Tampa	FL
6,511	1.2	1	0	0.5	0.4	0	Plant City	FL
6,506	2.2	2	0	1.2	1.1	0	Miami	FL
6,515	2.4	2	0	1.7	1.4	0	Not provided	FL
6,329	3.9	3.9	0	2.4	2.1	0	Miami	FL
6,550	2.8	2.6	0	2.1	1.6	0	Miami	FL
6,449	1.1	1	0	1	1	0	Winter Park	FL
2,167	1.5	1.4	0	1.1	1.1	0	Palm Beach	FL
6,280	1.5	1.4	0	1.2	1.1	0	Pompano Beach	FL
5,747	2.8	2.1	0	1.8	1.8	0	Decatur	GA
6,435	0.5	0.5	0	0.5	0.5	0	Not provided	GA
5,918	2.2	2.1	0	1.4	1.2	0	Atlanta	GA

Table 6-2. 1-Hour and 8-Hour Maximum Carbon Monoxide Levels at Monitoring Stations Throughout the United States

	1-Hour carbon monoxide level			8-Hour carbon monoxide level				
Number of measure-ments	First maximum (ppmv)	Second maximum (ppmv)	Number exceeding average	First maximum (ppmv)	Second maximum (ppmv)	Number exceeding average	City	State[a]
6,554	2.1	1.7	0	1	1	0	Honolulu	HI
5,268	1.7	1.3	0	0.7	0.7	0	Ewa Beach	HI
2,050	1.5	1.1	0	0.7	0.6	0	Cedar Rapids	IA
5,017	1.6	1.5	0	1.3	1.2	0	Cedar Rapids	IA
7,396	1.9	1.6	0	1	1	0	Des Moines	IA
8,199	1.2	1.2	0	0.7	0.7	0	Davenport	IA
4,609	4.1	3.6	0	1.6	1.5	0	Boise	ID
7,797	2.9	2.7	0	2.3	2.2	0	East Saint Louis	IL
7,977	2.5	2.2	0	1.5	1.3	0	Springfield	IL
7,965	5.6	3	0	1.9	1.7	0	Rockford	IL
7,917	3.6	3.2	0	2.9	2.1	0	Peoria	IL
7,960	2.5	2.5	0	2.3	2.2	0	Maywood	IL
8,007	1.9	1.3	0	1.2	0.9	0	Northbrook	IL
7,926	2.4	2.3	0	1.7	1.5	0	Cicero	IL
7,783	2.3	2	0	1.8	1.5	0	Schiller Park	IL
7,982	7.3	4.4	0	2	1.5	0	Chicago	IL
6,380	1.9	1.7	0	1.2	1.2	0	Indianapolis (Remainder)	IN
5,972	2	1.8	0	1.5	1.1	0	Evansville	IN
6,538	9.1	7.1	0	3.3	3	0	East Chicago	IN
3,984	0.8	0.8	0	0.7	0.7	0	Pittsboro	IN
6,445	3.9	3.8	0	2.9	2.3	0	Fort Wayne	IN
8,710	3.6	3.5	0	3.2	2.1	0	Indianapolis	IN
6,520	2.8	2.7	0	2	1.2	0	Wichita	KS
6,394	2.7	2.4	0	1.6	1.5	0	Wichita	KS
6,389	2.2	2.2	0	1.8	1.4	0	Kansas City	KS
7,113	6.9	3.4	0	2.8	2.2	0	Louisville	KY
6,937	3.1	3.1	0	2.7	2.1	0	Louisville	KY
7,723	2.9	2.5	0	1.9	1.8	0	Baton Rouge	LA
5,769	0.9	0.7	0	0.4	0.4	0	Lynn	MA
6,586	3.4	3.4	0	3	2.5	0	Springfield	MA
6,835	3.7	3.2	0	2.6	2.1	0	Lowell	MA
6,830	1.7	1.6	0	1.3	1	0	Boston	MA
6,875	1.5	1.5	0	1.1	0.9	0	Boston	MA
6,831	2.8	2.7	0	1.7	1.3	0	Worcester	MA
6,022	2.6	2.4	0	1.6	1.5	0	Essex	MD
6,407	0.4	0.4	0	0.3	0.3	0	Not provided	MD

Table 6-2. 1-Hour and 8-Hour Maximum Carbon Monoxide Levels at Monitoring Stations Throughout the United States

	1-Hour carbon monoxide level			8-Hour carbon monoxide level				
Number of measure-ments	First maximum (ppmv)	Second maximum (ppmv)	Number exceeding average	First maximum (ppmv)	Second maximum (ppmv)	Number exceeding average	City	State[a]
6,104	2.4	2.2	0	2.1	2	0	Baltimore	MD
6,439	1.4	1	0	0.9	0.8	0	Beltsville	MD
1,211	0.6	0.6	0	0.4	0.4	0	Presque Isle	ME
5,816	1.6	1.4	0	1.3	1	0	Portland	ME
6,351	0.4	0.4	0	0.4	0.3	0	Not provided	ME
4,569	2	1.6	0	1.2	1.1	0	Allen Park	MI
4,218	2	1.8	0	1.1	1	0	Grand Rapids	MI
7,278	2	2	0	0.8	0.7	0	Minneapolis	MN
7,262	0.5	0.5	0	0.3	0.3	0	Inver Grove Heights	MN
5,712	0.6	0.6	0	0.4	0.3	0	Rosemount	MN
2,169	1.8	1.5	0	1.2	1.2	0	Fridley	MN
7,022	3.2	3.1	0	2.4	2.4	0	St. Paul	MN
6,975	1.8	1.7	0	1.2	1.2	0	St. Cloud	MN
7,122	4.1	2.2	0	1.8	1.5	0	Duluth	MN
6,533	1.1	1	0	0.7	0.7	0	Sunset Hills	MO
6,536	1.9	1.8	0	1.2	1	0	Springfield	MO
6,528	3.3	2.9	0	2.2	1.6	0	St. Louis	MO
6,469	2.4	2.1	0	1.8	1.4	0	St. Louis	MO
2,083	3.4	3.4	0	2.9	2.7	0	Missoula	MT
2,104	2	1.9	0	0.7	0.7	0	Not provided	MT
6,916	6.7	5.7	0	2.4	2.2	0	West Yellowstone	MT
1,542	6.1	4.2	0	1.6	1.1	0	Not provided	MT
7,130	4.8	3.7	0	2.3	2	0	Billings	MT
7,244	7.7	3	0	1.8	1.5	0	Great Falls	MT
5,578	7.2	3.4	0	2.4	1.9	0	Kalispell	MT
2,819	1.5	1.5	0	1.3	1.1	0	Not provided	NC
7,811	1.9	1.8	0	1.5	1.4	0	Charlotte	NC
3,664	3.5	3.1	0	2.2	2.2	0	Raleigh	NC
7,081	4	2.8	0	2.4	1.8	0	Raleigh	NC
7,384	1.6	1.5	0	0.9	0.7	0	Rockwell	NC
2,044	2.2	2.2	0	1.7	1.7	0	Fayetteville	NC
7,927	2.3	2.1	0	1.9	1.6	0	Charlotte	NC
1,985	1.9	1.9	0	1.6	1.5	0	Greensboro	NC
6,531	2.7	2.5	0	2.3	1.9	0	Winston-Salem	NC
2,754	1.9	1.9	0	1.5	1.2	0	Durham	NC
7,930	6.5	1.7	0	1.2	0.7	0	Not provided	ND

Table 6-2. 1-Hour and 8-Hour Maximum Carbon Monoxide Levels at Monitoring Stations Throughout the United States

	1-Hour carbon monoxide level			8-Hour carbon monoxide level				
Number of measure-ments	First maximum (ppmv)	Second maximum (ppmv)	Number exceeding average	First maximum (ppmv)	Second maximum (ppmv)	Number exceeding average	City	State[a]
6,365	3.1	2.9	0	2.5	2	0	Omaha	NE
7,252	6.5	4.5	0	1.8	1.8	0	Lincoln	NE
6,464	9.4	6	0	4.4	3.5	0	Manchester	NH
6,285	1.5	1.4	0	1.1	1.1	0	Fort Lee	NJ
2,188	1.8	1.6	0	1.1	1	0	Elizabeth	NJ
6,544	2.3	1.9	0	1.5	1.3	0	Morristown	NJ
6,508	3.4	3.4	0	2	1.6	0	Freehold	NJ
6,373	2.2	2.1	0	1.2	1.2	0	Camden	NJ
6,522	1	0.9	0	0.7	0.6	0	Not provided	NJ
6,498	2.1	2.1	0	1.7	1.5	0	Jersey City	NJ
6,318	2	1.6	0	1.2	0.9	0	Perth Amboy	NJ
6,484	2.2	2.2	0	1.8	1.6	0	Hackensack	NJ
6,326	3.7	2.7	0	1.8	1.4	0	Burlington	NJ
3,065	3.6	2.8	0	1.8	1.5	0	Albuquerque	NM
6,140	2.6	2.2	0	1.7	1.1	0	Albuquerque	NM
3,130	2.6	2.5	0	1.8	1.7	0	Albuquerque	NM
5,792	6.5	3	0	2.4	2.3	0	Albuquerque	NM
3,057	4.9	3.7	0	1.6	1.3	0	Albuquerque	NM
806	2.4	2.4	0	1.9	1.8	0	South Valley	NM
6,377	4.2	3.9	0	2.1	2	0	Sparks	NV
6,463	2.2	1.9	0	1.5	1.5	0	Lemmon Valley-Golden Valley	NV
4,243	2.9	2.7	0	2.2	1.7	0	Carson City	NV
5,033	3.5	2.9	0	2.3	2.1	0	Las Vegas	NV
6,217	5.1	4.7	0	4.2	3.7	0	Las Vegas	NV
6,275	4.1	3.9	0	3.1	2.8	0	Las Vegas	NV
6,190	3.2	2.9	0	2.1	2.1	0	Las Vegas	NV
6,271	4.2	3.6	0	2.5	2.4	0	Las Vegas	NV
6,178	5.8	5.3	0	2.6	2.4	0	Stateline	NV
6,476	2.1	2.1	0	1.5	1.5	0	Reno	NV
6,515	1.8	1.7	0	1.3	1.3	0	Reno	NV
6,400	3	2.9	0	2.3	2.2	0	Reno	NV
6,512	1.8	1.7	0	0.8	0.8	0	Reno	NV
6,466	1.8	1.8	0	1.2	0.9	0	Holtsville	NY
7,922	3	2.7	0	1.8	1.8	0	Schenectady	NY
7,445	8.6	2.3	0	1.7	1.6	0	New York	NY
7,956	2	1.9	0	1.7	1.4	0	Syracuse	NY

Table 6-2. 1-Hour and 8-Hour Maximum Carbon Monoxide Levels at Monitoring Stations Throughout the United States

	1-Hour carbon monoxide level			8-Hour carbon monoxide level				
Number of measure-ments	First maximum (ppmv)	Second maximum (ppmv)	Number exceeding average	First maximum (ppmv)	Second maximum (ppmv)	Number exceeding average	City	State[a]
7,957	1.4	1.3	0	1.2	1	0	Niagara Falls	NY
7,769	1.5	1.2	0	1	0.9	0	Albany	NY
4,245	1.6	1.5	0	1.2	1.2	0	New York	NY
7,429	1.3	1.2	0	1.1	1	0	Rochester	NY
5,757	1.3	1	0	0.7	0.7	0	Tonawanda	NY
7,452	1.6	1.6	0	1.1	1	0	Buffalo	NY
7,962	2.3	2.1	0	1.8	1.7	0	New York	NY
3,419	1.7	1.6	0	1.3	1.2	0	New York	NY
6,967	4.8	4.8	0	2.1	1.5	0	Cleveland	OH
7,023	7.8	6.3	0	3.3	2.4	0	Cleveland	OH
6,948	2	1.5	0	0.9	0.8	0	Akron	OH
7,003	1.7	1.6	0	1.3	1.1	0	Akron	OH
6,158	2.9	2.9	0	2.6	2.5	0	Canton	OH
8,739	2.3	2.3	0	1.6	1.5	0	Dayton	OH
8,720	1.5	1.4	0	1.1	1	0	Dayton	OH
7,259	2.6	2.6	0	2.6	2.3	0	Mentor	OH
6,358	5.9	5.1	0	3.6	2.7	0	Cincinnati	OH
7,183	2.7	2.3	0	1.6	1.4	0	Columbus	OH
7,232	2	1.8	0	1.5	1.3	0	Cleveland	OH
7,252	2	2	0	1.2	1.2	0	Cleveland	OH
7,752	2.5	2.1	0	1.1	1.1	0	Oklahoma City	OK
1,382	0.4	0.4	0	0.3	0.3	0	Cherry Tree	OK
3,185	1.7	0.5	0	0.4	0.3	0	Park Hill	OK
4,625	1.7	0.3	0	0.5	0.3	0	Not provided	OK
2,278	1.7	1.6	0	1.4	1.3	0	Tulsa	OK
7,991	2.1	1.9	0	1.3	1.2	0	Tulsa	OK
5,933	2.7	2.6	0	2.3	2.2	0	Portland	OR
6,541	2.7	2.7	0	1.8	1.6	0	Portland	OR
6,437	3.4	3.4	0	2.6	2.2	0	Medford	OR
6,530	2.2	2.1	0	1.7	1.6	0	Eugene	OR
5,023	0.8	0.8	0	0.5	0.4	0	Not provided	PA
7,048	1.9	1.8	0	1.6	1.5	0	Pittsburgh	PA
7,243	2	2	0	1.3	1.2	0	York	PA
7,211	1.4	1	0	0.8	0.5	0	Greensburg	PA
6,517	1.6	1.6	0	1.3	1.1	0	Pittsburgh	PA
6,523	2.3	2.1	0	1.7	1.4	0	Pittsburgh	PA
7,054	2.6	2	0	1.6	1.3	0	Beaver Falls	PA

Table 6-2. 1-Hour and 8-Hour Maximum Carbon Monoxide Levels at Monitoring Stations Throughout the United States

	1-Hour carbon monoxide level			8-Hour carbon monoxide level				
Number of measure-ments	First maximum (ppmv)	Second maximum (ppmv)	Number exceeding average	First maximum (ppmv)	Second maximum (ppmv)	Number exceeding average	City	State[a]
7,197	1.5	1.3	0	0.9	0.9	0	Not provided	PA
7,206	1.4	1.2	0	0.8	0.7	0	Altoona	PA
7,009	4.3	2.9	0	2	1.9	0	Bristol	PA
7,215	1.7	1.4	0	1.2	1.1	0	Johnstown	PA
7,174	1.4	1.4	0	1.1	1.1	0	Harrisburg	PA
7,152	2.8	1.6	0	1	1	0	Erie	PA
4,958	0.5	0.5	0	0.3	0.3	0	Not provided	PA
7,212	1.8	1.4	0	1.2	1	0	Scranton	PA
6,694	2.6	1.9	0	1.6	1.4	0	Lancaster	PA
7,162	1.2	1.2	0	0.7	0.7	0	New Castle	PA
7,200	2.6	2.4	0	1.9	1.5	0	Wilkes-Barre	PA
7,306	1.1	1.1	0	0.8	0.8	0	Norristown	PA
7,308	2.1	2	0	1.6	1.6	0	Freemansburg	PA
6,160	3.7	2.7	0	1.7	1.3	0	Philadelphia	PA
1,764	1.3	1.1	0	0.7	0.7	0	Philadelphia	PA
7,094	1.3	1.2	0	1.2	1.1	0	Charleroi	PA
3,795	4.2	2.8	0	2.3	2.3	0	Bayamon	PR
5,854	3.8	3.7	0	2.4	2.3	0	San Juan	PR
6,421	3.9	3.3	0	1.7	1.4	0	San Juan	PR
6,420	1.5	1.4	0	1	0.9	0	East Providence	RI
8,714	2.3	2	0	1.4	1.3	0	Greenville	SC
8,561	0.9	0.8	0	0.5	0.5	0	Not provided	SC
8,747	3.2	3.2	0	2.4	1.9	0	Nashville	TN
6,248	1.7	1.5	0	1	1	0	Kingsport	TN
8,514	3.2	2.5	0	1.5	1.4	0	Memphis	TN
6,824	1.6	1.5	0	0.8	0.7	0	Brownsville	TX
5,201	1.7	1.7	0	1.4	1.3	0	Dallas	TX
7,170	7	6.1	0	4.9	3.2	0	El Paso	TX
6,895	2.9	2.7	0	1.5	1.5	0	El Paso	TX
7,198	5	4.8	0	3	1.8	0	El Paso	TX
6,712	7.3	6	0	4.2	2.4	0	El Paso	TX
7,202	6.7	6.6	0	4.8	3.9	0	El Paso	TX
6,985	4.3	4	0	3	2.8	0	El Paso	TX
7,040	3.5	3.4	0	1.7	1.7	0	Laredo	TX
7,176	2.5	2.1	0	1.4	1.3	0	El Paso	TX
6,875	2.9	2.7	0	1.7	1.5	0	Not provided	TX
6,310	3.8	3.7	0	2.7	2.3	0	Houston	TX

Table 6-2. 1-Hour and 8-Hour Maximum Carbon Monoxide Levels at Monitoring Stations Throughout the United States

	1-Hour carbon monoxide level			8-Hour carbon monoxide level				
Number of measure-ments	First maximum (ppmv)	Second maximum (ppmv)	Number exceeding average	First maximum (ppmv)	Second maximum (ppmv)	Number exceeding average	City	State[a]
6,258	2.1	1.9	0	1.6	1.3	0	Houston	TX
6,322	8.9	8.1	0	5.9	5.2	0	Houston	TX
5,662	1.4	1.4	0	1	0.8	0	Houston	TX
6,863	1.7	1.5	0	0.9	0.6	0	Deer Park	TX
5,594	1.8	1.7	0	1	0.7	0	Nederland	TX
7,105	0.8	0.3	0	0.3	0.3	0	Waco	TX
7,080	1.7	1.7	0	1.1	1	0	Fort Worth	TX
7,205	1.8	1.4	0	1	0.9	0	Arlington	TX
7,241	0.7	0.6	0	0.4	0.4	0	Austin	TX
6,942	3.2	2.9	0	1.4	1.3	0	Laredo	TX
6,154	0.9	0.9	0	0.5	0.5	0	Not provided	TX
6,309	2.5	2.4	0	1.9	1.4	0	San Antonio	TX
7,199	7.8	4.7	0	2.7	2.6	0	San Antonio	TX
7,235	3.2	2.9	0	1.6	1.6	0	Socorro	TX
6,469	3	2.9	0	2.2	2.1	0	Not provided	UT
6,297	4.1	3.6	0	2.4	2.3	0	Salt Lake City	UT
5,776	27.9	24.2	0	8.8	6.4	0	Ogden	UT
6,333	5	3.9	0	1.6	1.5	0	Provo	UT
5,744	3.3	3.3	0	2	2	0	Ogden	UT
2,125	3.7	3.3	0	1.8	1.8	0	West Valley	UT
5,996	1.1	1	0	0.9	0.8	0	Annandale	VA
6,479	1.3	1.2	0	1	0.8	0	Richmond	VA
6,469	1.7	1.6	0	1.2	1.1	0	Not provided	VA
7,175	1.4	1.4	0	1.2	1	0	Not provided	VA
7,133	1.9	1.9	0	1.9	1.8	0	Franconia	VA
6,489	2	2	0	1.5	1.4	0	Roanoke	VA
7,097	2	2	0	1.5	1.5	0	Mclean	VA
6,365	1.9	1.9	0	1.2	1.2	0	Alexandria	VA
6,439	4.2	4.1	0	1.6	1.3	0	Hampton	VA
6,487	4.7	4.5	0	2.2	1.9	0	Norfolk	VA
6,218	3.1	2.7	0	2.1	1.8	0	Rutland	VT
6,194	1.9	1.8	0	1.2	1.1	0	Burlington	VT
7,232	3.4	3.1	0	2.3	1.9	0	Bellevue	WA
5,468	0.3	0.3	0	0.3	0.3	0	Not provided	WA
6,885	1.4	1.2	0	0.9	0.9	0	Seattle	WA
7,140	4.3	4.1	0	2.4	2.4	0	Spokane	WA
7,674	0.5	0.5	0	0.4	0.4	0	Not provided	WI

Table 6-2. 1-Hour and 8-Hour Maximum Carbon Monoxide Levels at Monitoring Stations Throughout the United States

	1-Hour carbon monoxide level			8-Hour carbon monoxide level				
Number of measure-ments	First maximum (ppmv)	Second maximum (ppmv)	Number exceeding average	First maximum (ppmv)	Second maximum (ppmv)	Number exceeding average	City	State[a]
6,541	3.9	3.5	0	2.3	2.2	0	Weirton	WV
6,532	2.7	2.7	0	1.8	1.7	0	Weirton	WV
6,449	4.5	4.3	0	2.9	2.3	0	Weirton	WV
6,984	0.9	0.8	0	0.6	0.4	0	Not provided	WY
6,361	0.9	0.9	0	0.7	0.7	0	Not provided	WY

[a]Post office state abbreviations are used.

Source: EPA 2009i

and no measurements exceeded the 1-hour average level of 35 ppm at the 365 different monitoring sites. Using data from this nationwide network of monitoring sites, EPA estimated that there has been a 75% decrease in the ambient levels of carbon monoxide in the United States from 1980 to 2006 (EPA 2008).

The EPA Integrated Science Assessment (ISA) on carbon monoxide (2010), used monitoring data from 2005 to 2007 at 12 remote locations in the United States to estimate policy-relevant background (PRB) concentrations of carbon monoxide. These concentrations are defined as levels that would be expected to occur in the United States in the absence of anthropogenic emissions in continental North America. These remote-site baseline measurements were obtained from The National Oceanic and Atmospheric Administration's (NOAA) Earth System Research Laboratory (ESRL), Global Monitoring Division (GMD). The 3-year average carbon monoxide PRBs at remote locations outside the continental United States (OCONUS) were 0.13 ppmv (Alaska sites) and 0.0992 ppmv (Hawaii sites). Over the continental United States (CONUS) region, the 3-year average carbon monoxide PRB concentration was 0.132 ppmv (EPA 2010). The seasonal variability of carbon monoxide levels was observed at each monitoring location with minima achieved during the summer and fall months and maxima observed during the winter and spring seasons.

Urban areas with heavy vehicular traffic congestion tend to have high levels of carbon monoxide in ambient air. These levels follow a predictable diurnal pattern, which reaches maximum concentrations at times of heavy commuting and then decreases during periods of low vehicular traffic. The apex of these profiles corresponds to the morning and evening rush hour commutes when vehicle density is at its highest. For many locations, the morning peak yields higher carbon monoxide levels than the evening peak, because the height of the mixed layer is much lower during the morning, thereby inhibiting vertical mixing that helps dissipate the carbon monoxide. In the late afternoon and into early evening, increased atmospheric turbulence resulting from solar activity raises the height of the mixed layer, resulting in generally lower carbon monoxide concentrations compared with those of the morning (EPA 2000). A study conducted by the Toronto (Canada) Public Health Department examined the level of carbon monoxide at four sites in Toronto as a function of traffic density (Campbell et al. 1995). The four areas of the study were categorized as low, medium, or high in terms of traffic density. Mean hourly carbon monoxide levels ranged from 0.63 ppmv at a low traffic density site (average daily vehicle count of 2,000 vehicles) to 1.54 ppmv at a site in which the vehicular count was about 45,000 per day (Campbell et al. 1995). Chen et al. (2008) measured carbon monoxide levels at 10 roadside pollution monitoring sites in the city of Leicester, England. A diurnal carbon monoxide concentration pattern was observed in this study; however, the carbon monoxide levels during the evening rush hour period generally exceeded the

levels than the morning commute. Maximum carbon monoxide levels at these sites ranged from 0.8 to 3.1 ppmv during the morning commute, while maximum levels were 1.0–4.0 ppmv during the evening rush hour (Chen et al. 2008).

High levels of carbon monoxide inside vehicles and other transportation sources that use gasoline powered engines are frequently observed. Duci et al. (2003) studied the concentration of carbon monoxide in vehicles along heavy traffic routes in Athens, Greece. The mean carbon monoxide exposure level for trips greater than 30 minutes in duration were 21.4 ppmv for private car versus 10.4, 9.6, 4, and 11.5 ppmv for bus, trolley, electric train, and pedestrians, respectively, during the winter season (Duci et al. 2003). Besides the mode of transportation, the route travelled, the monitoring period, and the season of year had significant influences on the measured carbon monoxide concentrations. In-vehicle carbon monoxide levels were monitored in a passenger vehicle driven along a heavily traveled route of a commercial/residential area of Beirut, Lebanon under several ventilation modes (Abi Esper et al. 2007a). Trips were conducted during morning rush hours in spring and summer months. The highest mean carbon monoxide levels were observed within vehicles driven with the windows and vents closed (37.4 ppmv) and windows closed and air conditioning on recirculation ventilation settings (30.8 ppmv) (Abi Esper et al. 2007a). Opening a window or setting the air conditioning unit to fresh air intake generally resulted in a reduction of carbon monoxide levels within the vehicle.

Indoor air levels of carbon monoxide are greatly dependent upon the presence of indoor combustion sources such as wood burning stoves, fireplaces, gas space heaters, and gas stoves, as well as the operating condition and usage patterns of these appliances or whether the occupants smoke. Dutton et al. (2001) studied carbon monoxide levels in two residences located in Boulder, Colorado using unvented natural gas fireplaces. Time-averaged carbon monoxide levels were1.5–78 ppmv at one residence and 1.6–30 ppmv at the other residence while the fireplace operated uninterrupted; however, levels >100 ppm were observed at one of the residences on several occasions. Background carbon monoxide levels were 0–7 ppmv in the homes when the fireplaces were not operating. Attached garages may also be a significant source of carbon monoxide to the indoor air of residences. The net increase of carbon monoxide levels in 16 homes with attached garages ranged from <1 to 30 ppmv following the cold start of an automobile enclosed within the attached garage (Graham et al. 2004).

6.4.2 Water

The levels of carbon monoxide in the surface waters of the world's oceans are supersaturated with respect to the partial pressure of carbon monoxide in the atmosphere and are subject to diurnal cycling. Levels have been reported to vary from $2x10^{-8}$ to $1.3x10^{-7}$ cm^3 carbon monoxide per cm^3 of water (20–130 nanoliters per liter [nL/L]) based on measurements in the Pacific Ocean and from $2x10^{-8}$ to $1x10^{-7}$ cm^3 carbon monoxide per cm^3 of water (20–100 nL/L) in the North Atlantic (Liss and Slater 1974). Carbon monoxide concentrations in seawater measured in the upwelling region of the equatorial Pacific Ocean were reported to range from 42 to 173 nL/L on two consecutive sampling dates and reached a maximum value of 246 nL/L on subsequent sampling at a later date (Ohta 1997). These levels showed a marked diurnal variation with a maximum and minimum occurring early in the afternoon and morning, respectively. The concentrations in the water column decreased as a function of depth from the water surface to approximately 10 nL/L at a depth of 70 meters. Tolli et al. (2006) reported a carbon monoxide level of 12 nanomoles/L at a coastal sampling location in Vineyard Sound, Massachusetts.

6.4.3 Sediment and Soil

In-situ soil-gas carbon monoxide levels were studied in a pine forest soil and cultivated soil as a function of depth from the surface (King 1999b). In the pine forest soil, the carbon monoxide concentrations remained elevated (250–320 ppbv) and greater than the atmospheric levels through the upper surface soil (O-horizon, 0–2 cm depth), but declined to values less than the atmospheric level in the lower depths of the soil (A-horizon 2–10 cm depth). In the cultivated soil, carbon monoxide levels decreased rapidly from approximately 250 ppbv in the upper 1 cm of the O-horizon to approximately 50 ppbv at a depth of 3 cm, which was roughly 5-fold less than ambient atmospheric levels.

6.4.4 Other Environmental Media

Carbon monoxide is released from tobacco smoke; however, the amount released is a function of the type of tobacco product (e.g., cigarette, cigar) and the degree to which tobacco is actively smoked. Moir et al. (2008) examined the emissions of carbon monoxide and other compounds under two smoking conditions from marijuana and tobacco cigarettes using a mechanical rotary smoking machine. The standard conditions employed a puff volume of 35 mL, puff duration of 2 seconds, and a puff interval of 60 seconds. Conditions more consistent with marijuana smoking employed a puff volume of 70 mL, puff duration of 2 seconds, and a 30-second interval between puffs. These conditions were referred to as extreme conditions. Under standard conditions, the average±standard deviation (SD) emission of carbon

monoxide in mainstream smoke (n=20) was 20.8±1.9 mg carbon monoxide per tobacco cigarette and 13.4±1.6 mg carbon monoxide per marijuana cigarette. Under extreme smoking conditions, the levels were 41.5±4.0 mg carbon monoxide per tobacco cigarette and 35.3±2.9 mg carbon monoxide per marijuana cigarette. These results predict that typical use of marijuana (70 mL puff volume) would result in more carbon monoxide being inhaled than during typical cigarette smoking (30 mL puff volume). The carbon monoxide emissions in sidestream smoke were 61.7±2.0 and 54.0±3.7 mg carbon monoxide per tobacco cigarette and marijuana cigarette, respectively, using the standard conditions. Under extreme smoking conditions, the levels were 61.6±2.9 and 50.6±3.9 mg carbon monoxide per cigarette for tobacco and marijuana cigarettes, respectively.

Emissions from plants and biomass burning are reported to contribute approximately $1x10^{14}$ g/year to the global environment (Khalil and Rasmussen 1990). The direct emission of carbon monoxide from living plants increases as a function of solar irradiance. The source of the carbon monoxide likely occurs as a result of direct photooxidation of the plant material followed by transport to the stomata; however, the exact mechanism is not fully understood (Sanderson 2002).

6.5 GENERAL POPULATION AND OCCUPATIONAL EXPOSURE

The general population is exposed to carbon monoxide through the inhalation of indoor and outdoor air. Since carbon monoxide is ubiquitous in the environment, all humans are exposed to some level of carbon monoxide. The CDC estimated that during 2004–2006, an estimated average of 20,636 emergency room visits occurred for nonfatal, unintentional, non-fire-related carbon monoxide exposures annually (CDC 2008). Approximately 73% of these exposures occurred in residences, 13% occurred in workplace settings, and the rest were in other or unknown settings. The greatest number of incidences (8,538 incidences representing approximately 41% of the cases) occurred during the winter months of December through February. Nearly 70% of the incidences were diagnosed as carbon monoxide poisoning. Table 6-3 displays the estimated number of exposure cases categorized by age and gender.

Weather-related disasters in which large segments of the population have lost power for extended periods of time often result in carbon monoxide-related accidents through the improper use of gasoline-powered devices. Two major hurricanes struck the Gulf Coast of the United States in 2005 (hurricanes Katrina and Rita) resulting in sustained power outages for many residents of the affected states. Multiple carbon monoxide poisonings were reported over the period of disrupted power, primarily due to the use of improperly vented generators (CDC 2006). Twenty-seven separate incidents of carbon monoxide

Table 6-3. Average Annual Estimated Non-Fatal Carbon Monoxide Exposure Cases in the United States Emergency Room Visits (2004–2006)

Age (years)	Number of cases[a]	Percentage of the total
0–4	2,344	11.4
5–9	1,407	6.8
10–14	1,577	7.6
15–24	3,341	16.2
25–34	4,183	20.3
35–44	2,775	13.5
45–54	2,229	10.8
55–64	1,444	7.0
≥65	1,328	6.4
Gender		
Male	9,770	47.3
Female	10,866	52.7

[a]Age data were unavailable for eight cases.

Source: CDC 2008

poisoning were reported during the dates of August 29–October 19, 2005, in Texas and Alabama, resulting in 78 nonfatal cases and 10 deaths. A portable generator was involved in 25 (93%) of the 27 incidents. Regarding the other two incidents, one involved a fixed generator and one involved a portable gas stove (CDC 2006).

Recreational water craft are a source of accidental carbon monoxide exposures (USCG 2008). A study conducted by the National Institute for Occupational Safety and Health (NIOSH) confirmed 176 acute boating-related carbon monoxide poisonings over a 15-year period at a lake on the Arizona/Utah border (CDC 2005). The findings of this study indicated that occupancy near carbon monoxide sources, failed carbon monoxide detectors, water level exhaust from generators on houseboats or cabin cruisers, and carbon monoxide from generators or propulsion engines within the airspace formed by an extended rear houseboat deck contributed to these accidents (CDC 2005).

NIOSH (1996) issued a report describing carbon monoxide poisonings that occurred through the use of small gasoline-powered engines and tools such as pressure washers, gas-powered saws, and compressors. In many cases, dangerous levels of carbon monoxide built up rapidly when using these tools, even in relatively open spaces with some ventilation like parking garages or open barns.

Blood carboxyhemoglobin (COHb) levels were measured on a cross-sectional national probability sample of persons representative of the civilian population in the United States aged 3–74 years in the second National Health and Nutrition Examination Survey (NHANES II) conducted from February 1976 to February 1980 (Radford and Drizd 1982). The statistical analysis of COHb levels in blood of the population based on smoking status and age is provided in Table 6-4. Four principal inhalation exposure routes were examined (outdoor air, indoor air, occupational exposure, and smoking). Of these four exposure routes, it was concluded that COHb levels in the population were most influenced by smoking status. Close examination of the data also indicated that COHb levels in the population tended to be greater during the winter months as opposed to the summer months, presumably due to the amount of time spent indoors where carbon monoxide levels are assumed to be higher than outdoor air. A slightly higher proportion of ex-smokers had COHb levels over 2% versus people who never smoked (5.5% versus 3.6%). This accounts for the higher mean and standard deviation for ex-smokers than for never-smokers, because the two medians are nearly identical (0.77% COHb versus 0.74% COHb, respectively). This difference may be accounted for in part or wholly by the inclusion in the ex-smoking group of people who incorrectly reported a history of having stopped smoking (Radford and Drizd 1982).

Table 6-4. Carboxyhemoglobin (COHb) Levels in the U.S. Population Based Upon Smoking Status

Age (years)	N[2a]	N[3b]	Mean COHb percent	Standard deviation	Standard error	50th percentile	75th percentile	90th percentile	95th percentile
All smoking status									
3–74	9,365	195,877	1.93	2.236	0.037	0.91	2.38	5.49	6.83
3–11	2,055	30,066	0.73	0.502	0.019	0.67	0.87	1.12	1.42
12–74	7,310	165,812	2.14	2.358	0.044	1.01	3.17	5.79	7.05
Never smoked[c]									
3–74	5,459	106,042	0.83	0.671	0.021	0.72	0.97	1.33	1.65
3–11	2,055	30,066	0.73	0.502	0.019	0.67	0.87	1.12	1.42
12–74	3,404	75,976	0.87	0.726	0.025	0.74	1.01	1.38	1.77
Ex-smokers[c]									
12–74	1,366	28,655	0.97	0.999	0.031	0.77	1.04	1.58	2.08
Current smokers[c]									
12–74	2,533	61.015	4.30	2.533	0.072	4.15	5.89	7.56	8.68

[a]N^2 = unweighted population size
[b]N^3 = population estimate in thousands
[c]Never-smokers were defined as persons who self-reported that they had smoked fewer than 100 cigarettes in their lifetimes and were not current smokers. Ex-smokers were persons who reported that they had smoked more than 100 cigarettes but were not current smokers. Current smokers were persons reporting that they were current cigarette, cigar, or pipe smokers.

Source: Radford and Drizd 1982

Additional studies have shown that COHb levels do not differ in ex-smokers versus those who never smoked (Yasuda et al. 2004).

Carbon monoxide exposure to European populations residing in five cities have been investigated through the EXPOLIS research project conducted from 1996 to 1998, and the results of this study have been summarized in several publications (Bruinen de Bruin et al. 2004a, 2004b; Hanninen et al. 2004). The geometric mean 48-hour exposure levels of nonsmoking subjects were 1.68, 0.82, 0.45, 2.17, and 1.50 mg/m^3 (1.45, 0.71, 0.39, 1.87, and 1.29 ppmv) in Athens, Basle, Helsinki, Milan, and Prague, respectively (Hanninen et al. 2004). Bruinen de Bruin et al. (2004a) used data for 50 office workers residing in Milan, Italy over a 1-year period to assess the contribution of local sources to exposure and microenvironment concentrations. This study examined the time that the subjects spent in 11 different microenvironments and three exposure-influencing activities: gas cooking, smoking, and commuting. The results of this study indicated that exposures from indoor environments contributed approximately 82% of the total carbon monoxide exposures, because this is where the study population spent over 90% of their time; however, approximately 16% of the total exposure to carbon monoxide occurred from commuting activities, even though these activities only accounted for about 7.5% of the population's time.

Occupations such as toll both workers, gas station attendants, taxi drivers, and traffic or bicycle police are potentially exposed to high levels of carbon monoxide due to emissions from automobile exhaust. Carbon monoxide levels were monitored continuously during both morning (9 AM–12 PM) and afternoon (2–4 PM) hours at seven gas stations located in New York, New Jersey, and Connecticut (API 1994). Mean (arithmetic) concentrations of carbon monoxide at the pumping islands ranged from 1.15 to 5.44 ppmv, with a maximum 1-minute level of 144 ppmv observed at one station. Firefighters and rescue/response personnel are potentially exposed to carbon monoxide levels near or exceeding recommended occupational exposure limits. A study conducted from 1986 to 1989 in northern California was performed to estimate the level of carbon monoxide that wildland firefighters are exposed to during various job tasks associated with that profession (Materna et al. 1992). Following a series of prescribed burns, the instantaneous fireline carbon monoxide levels ranged from 3 to 80 ppmv; however, firefighters who tended gasoline powered pumping engines were exposed to levels as high as 300 ppmv. The mean time-weighted average (TWA) exposure level obtained from 46 personal measurements was 14.4 ppmv, but one employee had a TWA exposure of 38 ppmv and five firefighters had TWAs >25 ppmv. Industrial or in-home use of methylene chloride paint strippers in poorly ventilated areas can lead to high levels of carbon monoxide in blood, since carbon monoxide is a metabolic byproduct of methylene chloride.

6.6 EXPOSURES OF CHILDREN

This section focuses on exposures from conception to maturity at 18 years in humans. Differences from adults in susceptibility to hazardous substances are discussed in Section 3.7, Children's Susceptibility.

Children are not small adults. A child's exposure may differ from an adult's exposure in many ways. Children drink more fluids, eat more food, breathe more air per kilogram of body weight, and have a larger skin surface in proportion to their body volume. A child's diet often differs from that of adults. The developing human's source of nutrition changes with age: from placental nourishment to breast milk or formula to the diet of older children who eat more of certain types of foods than adults. A child's behavior and lifestyle also influence exposure. Children crawl on the floor, put things in their mouths, sometimes eat inappropriate things (such as dirt or paint chips), and spend more time outdoors. Children also are closer to the ground, and they do not use the judgment of adults to avoid hazards (NRC 1993).

As with adults, children are exposed to carbon monoxide through the inhalation of indoor and outdoor air. The NHANES II survey (see Table 6-4) includes COHb levels of children. Several activities may influence the levels of carbon monoxide to which children or infants are exposed. Time spent indoors versus outdoors, riding in automobiles, and exposure to second-hand tobacco smoke influence the total carbon monoxide exposure that children receive. COHb levels in children were significantly greater when measured during the winter months of November–March, as opposed to levels obtained in May–September. The average COHb level for all children in the NHANES study aged 3–11 years was 0.87% for samples collected during the winter months and 0.58% during the summer months. The location where the children in the population resided also influenced the COHb levels observed in the study. Children residing in central cities with populations over 1 million tended to have the highest mean COHb levels (1.01% in winter months and 0.77% in summer months), while children living in rural areas had mean COHb levels of 0.79% in the winter months and 0.49% during the summer months (Radford and Drizd 1982).

Pregnant females who smoke potentially expose their unborn fetus to carbon monoxide, and the health consequences of this activity have been discussed in Chapter 3. Carbon monoxide crosses the placenta and can accumulate in the fetus to a greater extent than in the mother.

6.7 POPULATIONS WITH POTENTIALLY HIGH EXPOSURES

Populations that are exposed to high levels of vehicular traffic are expected to have greater exposure to carbon monoxide, as compared to individuals in low traffic density areas. As discussed in Section 6.5, certain occupations such as toll workers, gas station attendants, firefighters, and other professions exposed to combustion sources may have high levels of exposure.

Members of the general population who smoke or live with smokers are exposed to higher levels of carbon monoxide than nonsmoking members of the general population. COHb levels typically average about 5% in regular smokers, but may be as high as 10% in heavy smokers (Benowitz 2003). Data from the NHANES II study indicate that mean COHb levels in the blood of smokers are approximately 4 times greater than levels for members of the nonsmoking population (Radford and Drizd 1982). More recent data support these conclusions. In a study of 11,403 men aged 35–64 years, the mean COHb level for nonsmokers was 0.79%, but rose to 6.54% for those who smoked >40 cigarettes/day (Law et al. 1997). COHb levels were measured as part of pulmonary function testing in 100 subjects in one pulmonary laboratory located in a Virginia hospital outpatient setting (Mahoney et al. 2007). COHb levels for the entire group averaged 1.9%, with a range of 1–8%. The average COHb level for nonsmokers (n=85) was 1.6%, while the level for smokers (n=15) was 3.5%. COHb levels were measured for smokers versus nonsmokers at four commercial establishments where cigarette smoking was not prohibited and COHb levels were also obtained in a control group of 50 college students and professors in a well-ventilated, nonsmoking environment (Light et al. 2007). The average COHb concentration of 33 smokers from the commercial establishments was 5.04%, while the average value for the 27 nonsmokers was 2.49%. COHb levels ranged from 1 to 6% in the nonsmokers and from 1 to 14% in the smoking group. The COHb levels in the control group were 1%.

6.8 ADEQUACY OF THE DATABASE

Section 104(i)(5)(A) of CERCLA, as amended, directs the Administrator of ATSDR (in consultation with the Administrator of EPA and agencies and programs of the Public Health Service) to assess whether adequate information on the health effects of carbon monoxide is available. Where adequate information is not available, ATSDR, in conjunction with National Institute of Environmental Health Sciences (NIEHS), is required to assure the initiation of a program of research designed to determine the health effects (and techniques for developing methods to determine such health effects) of carbon monoxide.

The following categories of possible data needs have been identified by a joint team of scientists from ATSDR, NTP, and EPA. They are defined as substance-specific informational needs that if met would reduce the uncertainties of human health assessment. This definition should not be interpreted to mean that all data needs discussed in this section must be filled. In the future, the identified data needs will be evaluated and prioritized, and a substance-specific research agenda will be proposed.

6.8.1 Identification of Data Needs

Physical and Chemical Properties. Information is available on the physical and chemical properties of carbon monoxide (George 2001; Lide 2008; O'Neil et al. 2006; Verschueren 2001). These data are captured in Chapter 4. No data needs are identified.

Production, Import/Export, Use, Release, and Disposal. According to the Emergency Planning and Community Right-to-Know Act of 1986, 42 U.S.C. Section 11023, industries are required to submit substance release and off-site transfer information to the EPA. The TRI, which contains this information for 2007, became available in February of 2009. This database is updated yearly and should provide a list of industrial production facilities and emissions. Adequate information on the production and use of carbon monoxide was located (George 2001); no information on the import/export of carbon monoxide was found, but these volumes are assumed to be low. Since carbon monoxide is not required to be reported under the TRI, the production and emissions from U.S. industrial facilities is not reported to the EPA. The EPA continuously updates the NEI database, which contains detailed information about sources that emit carbon monoxide. No data needs are identified.

Environmental Fate. The environmental fate of carbon monoxide is well understood. When released to the atmosphere, carbon monoxide eventually reacts with photochemically produced hydroxyl radicals and is oxidized to CO_2 (EPA 2000, 2010). Microorganisms have also been shown to oxidize carbon monoxide to CO_2 (Tolli et al. 2006). Data on the half-life of carbon monoxide in indoor environments would be desirable.

Bioavailability from Environmental Media. Carbon monoxide is a gas and is not considered bioavailable from environmental media other than air. No data needs are identified.

Food Chain Bioaccumulation. Carbon monoxide is a gas and does not bioaccumulate in the food chain. No data needs are identified.

Exposure Levels in Environmental Media. Reliable monitoring data for the levels of carbon monoxide in contaminated media at hazardous waste sites are needed so that the information obtained on levels of carbon monoxide in the environment can be used in combination with the known body burden of carbon monoxide to assess the potential risk of adverse health effects in populations living in the vicinity of hazardous waste sites.

The EPA continuously monitors carbon monoxide levels throughout the United States. The EPA's NEI database contains detailed information about sources that emit criteria air pollutants, including carbon monoxide for the 50 United States, Washington DC, Puerto Rico, and the U.S. Virgin Islands. The AQS database is EPA's repository of criteria air pollutant monitoring data since the 1970s. These databases are updated regularly.

Exposure Levels in Humans. All humans are exposed to carbon monoxide through the inhalation of ambient air. Indoor air levels of carbon monoxide are highly variable and depend upon the type, condition, and venting procedures of appliances. The NHANES II survey, conducted from February 1976 to February 1980, provided an analysis of COHb levels in blood of the population based on smoking status, age, race, and other factors (Radford and Drizd 1982). These data are not current; therefore, a data need exists to update these data with new monitoring results.

This information is necessary for assessing the need to conduct health studies on these populations.

Exposures of Children. Children are exposed to carbon monoxide by the same pathway as adults (inhalation of air). While the levels of COHb in children's blood from the NHANES II study is comprehensive, these surveys are over 2 decades old. Therefore, a data need exists to update this study with new monitoring results.

Child health data needs relating to susceptibility are discussed in Section 3.12.2, Identification of Data Needs: Children's Susceptibility.

Exposure Registries. No exposure registries for carbon monoxide were located. This substance is not currently one of the compounds for which a sub-registry has been established in the National Exposure Registry. The substance will be considered in the future when chemical selection is made for sub-registries to be established. The information that is amassed in the National Exposure Registry

facilitates the epidemiological research needed to assess adverse health outcomes that may be related to exposure to this substance.

6.8.2 Ongoing Studies

The Federal Research in Progress (FEDRIP 2009) database provides additional information obtainable from a few ongoing studies that may fill in some of the data needs identified in Section 6.8.1. A study being conducted by Ohio State University (Ross Kauffman, principal investigator) seeks to study tobacco use in two Ohio prisons. One objective of this study is to examine the influence of an indoor tobacco ban on smoking behaviors among low-security prisoners. A second objective is to provide prison administrators with the information needed to develop successful policies by gathering information on prisoner attitudes toward tobacco control policies and cessation programs in correctional settings. The study is also intended to lay the groundwork for future studies of tobacco use in prison facilities. It is anticipated that this study will address COHb levels in the prison facilities.