CARBON MONOXIDE EXPOSURE IN NEW YORK CITY: A HISTORICAL OVERVIEW*

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On a worldwide basis, natural sources of carbon monoxide, such as the oceans, have been estimated to produce more than 35×10^9 metric tons per year, while man-made sources are approximately 3.6×10^7 metric tons per year.[1,2] However, natural sources are diffused and do not result in exposures as high as those associated with human activity.

Carbon monoxide asphyxiation resulting from burning fossil fuels in poorly ventilated spaces has been documented from early times. Many such examples are cited by Lewin in his study of the history of carbon monoxide poisoning.[3] He mentions that in ancient Rome the use of coal and wood fumes for execution, suicide, and even mass execution was not uncommon. Accidental poisoning was also frequent because of the way homes and public baths were heated. Seneca, for example, committed suicide by shutting himself in a bath heated with coal; Hannibal killed the inhabitants of Nuceria by suffocating them in a bath. The emperor Julian the Apostate was almost killed when coal was used to heat his room in Paris. In 1902 Emile Zola lost his life by CO asphyxiation due to a faulty flue.[4] The lethal effects of coal fumes, first referred to by Aristotle, were not attributed to CO until the beginning of the 19th Century.

HISTORICAL CO TRENDS IN NEW YORK CITY AND OTHER URBAN AREAS

Measurements of CO in community air did not begin until the first quarter of this century and were then conducted only in a few surveys of short duration. Continuous measurements were not started until the 1960s.

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TABLE I. CARBON MONOXIDE MEASUREMENTS IN NEW YORK FROM 1922 TO 1979

Year	*CO concentration (ppm.)*	*Sampling condition*	*Reference*
1922	100; range, 10-290	Moderate-heavy traffic	5
1932	Range, 2-129; average, 32	Heavy traffic (average: 1900 cars per hour)	6
1966	Peak hourly average range, 19-95; average, 32	In-traffic sample, very heavy traffic	7
1967	Hourly average range, 1-17; average, 8	45th St. and Park Ave., continuous samples, heavy traffic flow (1,000 to 3,400 vehicles per hour)	8
1969	2-hour average concentration, 12 ppm.	110 E. 45th St., 600 vehicles/hour 6 m. above street level	9
1979 (period ending 9/30/79)	Max. 8-hour running average 17.0 ppm.; max. 1-hour, 41.8 ppm.	45th St., continuous 24-hour monitoring	11

In New York City, measurements of CO in ambient air were reported as early as 1922. Table I summarizes reported measurements made at heavy traffic streets between 1922 and 1969.[5-9] According to these data, CO concentrations near busy thoroughfares and intersections in New York City did not increase during that time and, as previously reported,[10] may actually have decreased.

In 1968 New York City began to maintain a continuous record of CO and other pollutant concentrations measured at 12 different sites. These stations were distributed throughout the city and, for the purpose of CO monitoring, are classified as either "traffic" or "background" sites. Seven stations are currently operational. There are only two street-level monitors, 45th Street and Canal Street, and five background rooftop sites. Figure 1 shows their relative locations.

Mean annual CO concentrations at the two high traffic density stations and the Brooklyn Library site are plotted in Figure 2.[11] The library station is located in an area of old, large apartment houses and commercial buildings, and was selected as representative of the residential areas of the city, away from heavy vehicular traffic. For comparison, the annual CO average concentrations for Mamaroneck, a suburban site outside of New York City, are also shown.[12] It is evident that the annual CO average concentrations have decreased substantially since 1968 at all these sta-

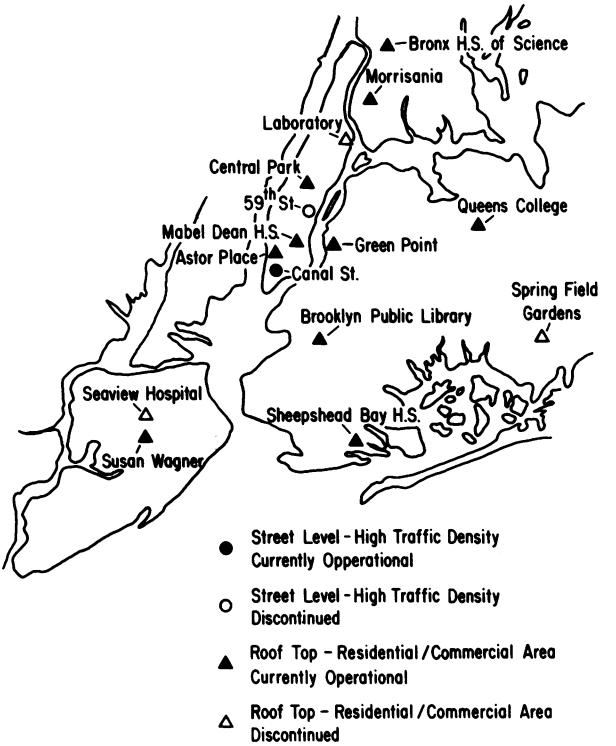

Fig. 1. New York City aerometric network location of CO monitoring sites

tions. It should be noted that prior to 1975 the 45th Street mean annual CO concentrations were overestimated by as much as 4 to 5 ppm. due to a systematic error that was subsequently corrected.[13]

The hourly maximum concentrations at the two traffic sites have also decreased, from more than 60 parts per million during the late 1960s to about 35 ppm. by 1978, a value currently exceeded only once or twice a year (Figure 3).[11] Background stations have also experienced a decline in the maximum one-hour peak value. The 9 ppm. 8-hour secondary Environmental Protection Agency standard is occasionally violated at some of the background stations and, more frequently, at traffic sites. Data prior to 1974 are not fully comparable to values recorded after that year because eight-hour running averages are used now on a continuous basis instead of the 7 A.M. to 3 P.M. values used previously. However, at both traffic sites the number of days in which the eight-hour average concentration exceeds the standard has decreased. At Canal Street this index of air quality has

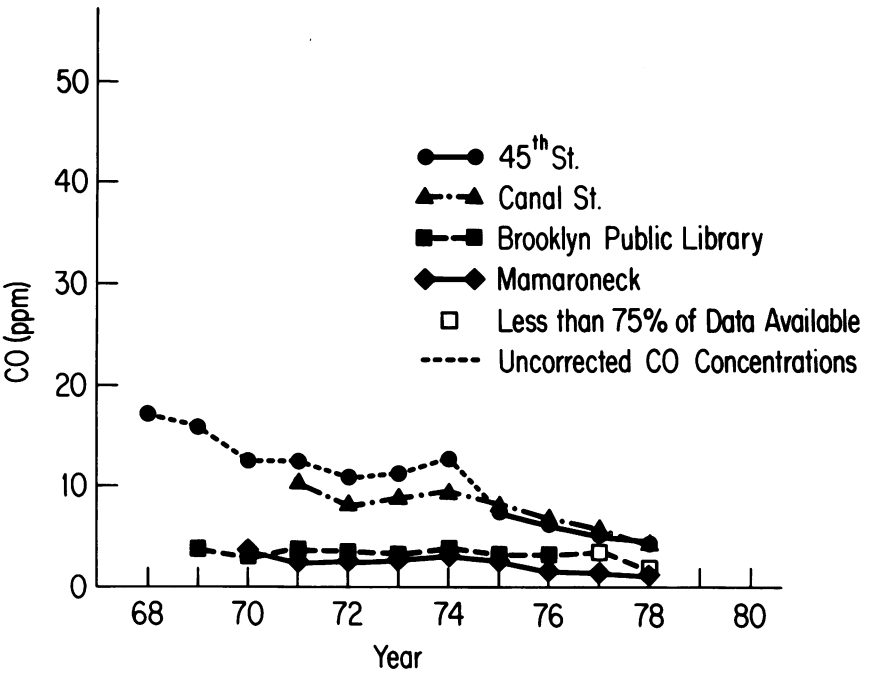

Fig. 2. CO annual arithmetic means at selected air quality Region II sites

dropped from 182 days in 1971 to 32 days during 1978. At the 45th Street site the reduction has not been as dramatic (286 in 1971 versus 154 during 1978). The Brooklyn Library background station has also experienced a decline, from four to zero days.[11] These improvements could have been more pronounced had eight-hour running averages been used prior to 1974.

High CO concentrations in city atmospheres were not unique to New York City in past times. In 1928 Bloomfield made a survey of CO concentrations in 14 large United States cities, and reported values ranging from 20 to 170 ppm.[14] Connolly et al. reported that the average CO concentration in the city of Chicago was 31 ppm. in 1928; 36.5% of the collected air samples contained between 30 and 100 ppm.[15] Clayton et al. reported concentrations of CO as high as 100 ppm. in downtown Detroit during 1956 and 1957, with a median of 9 ppm. during a 21-week period; maxima of 100 ppm. were recorded in a neighborhood shopping area (median of 10 ppm. during a 58-week period).[16] In contrast, of approximately 2.41×10^6 hourly CO measurements reported nationwide in 1976, only 16 exceeded 35 ppm. The highest value recorded during that year

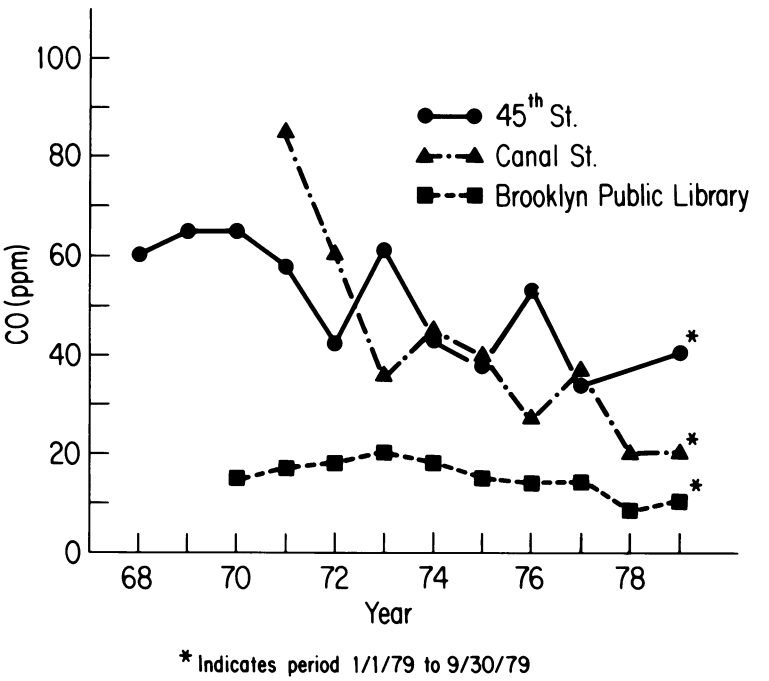

Fig. 3. New York City aerometric network maximum one hour CO concentration at selected sites

was 55.4 ppm. at Joliet, Ill.[17]

High concentrations of CO in community air have also been reported in foreign cities in the past. In 1930 Keeser et al. measured concentrations ranging from 0 to 270 ppm. in Berlin.[18] Similar results were reported by Froboese in 1931[19] and Boedicker in 1932.[20] In contrast, by 1974 Kampf reported maximum concentrations of only 10 ppm. during a six-year period on a Berlin street with average traffic density.[21] Cambier and Marcy reported CO ambient levels ranging from 40 to 60 ppm. in the streets of Paris in 1928,[22] comparable to values as high as 60 ppm. recorded in 1966 at heavy traffic intersections.[23] Table II summarizes some of these data.

Castrop in 1955[24] and later Wilkins in 1956[25] observed that since the 1920s, in spite of large increases in the total gasoline consumption in London, the CO concentration in city streets seemed to have decreased. This is similar to the trend observed in New York City, and may be partially related to vehicular traffic saturation of the central business

TABLE II. PAST AND PRESENT CO CONCENTRATIONS IN SELECTED URBAN AREAS

Year	*City*	*Concentration (ppm.)*	*Ref.*
1928	Survey of 14 U.S. cities	20-170 ppm. 700-5,400 cars/hour	14
1928	Chicago	Av. 31 ppm. Max. 100 ppm.	15
1976	Chicago	21.4 ppm. Max. obsv. (1976)	17
1956-57	Detroit	100 ppm. Max. obsv.	16
1976	Detroit	24.8 ppm. Max. obsv. (1976)	17
1920	Paris	40-60 ppm.	22
1966	Paris	60.1 ppm. Max. obsv.	23
1930	Berlin	0-270 ppm.	18
1974	Berlin	10 ppm. Max. obsv.	21

districts of large urban areas early in this century. Many of the earlier measurements had been made in streets already heavily congested, which could scarcely accommodate any more traffic; thus, CO concentrations in those areas did not increase. However, this explanation is not sufficient fully to account for the observed decreases in CO concentrations. Other possible factors in this decrease could be that the internal combustion engines produced more CO in earlier years and that the use of coal and manufactured gas for space heating, cooking, and illumination were important sources now eliminated.

SOURCES OF CO IN OUTDOOR AIR

It is, in fact, recognized that the automobile engine produced more carbon monoxide per gallon of gasoline consumed during the first half of the century. In 1930 Sayers and Davenport estimated that the exhaust from automobiles was approximately 7.0% CO by volume.[26] In the mid-1960s, prior to the adoption of federal emissions guidelines, the average concentration was estimated to be 3.8%.[27] With implementation of the Clean Air Act, substantial further reductions began to take place, and at present it is estimated that the average concentration is 0.5%. When the present fleet is replaced by cars that meet the 1982 clean air standard, the concentration will be further reduced to 0.1%.

TABLE III. CONSUMPTION OF THE PRINCIPAL FOSSIL FUELS IN NEW YORK CITY FOR THE YEARS 1934, 1965 AND 1975

Fuel	*1934*	*1965*	*1975**
Coal ($\times 10^6$ tons)			
Anthracite	10.6	0.72	0.3
Bituminous	9.1	5.4	0
Fuel oil ($\times 10^6$ gal.)	611	4,086	3,387
Natural gas ($\times 10^9$ cu. ft.)	0	167	98
Manufactured gas ($\times 10^9$ cu. ft.)	54	0	0
Gasoline ($\times 10^6$ gal.)	$\approx$ 500	1,250 $\times 10^6$ (1954)	1453

*Estimated residential and electric generation use.

Another factor in reduction of CO pollution, probably more important than heavy traffic in residential urban areas, was elimination of coal as a fuel for space heating of homes and public buildings. Table III shows some of the changes in New York City since the 1930s.[10,28,29] Use of coal for space heating has been virtually eliminated, and power plants currently use only gas and oil for electric and steam generation. It has been estimated that CO emissions from residential heating units may have amounted to 400,000 tons of CO during 1934.[10] The total CO emissions in New York City from motor vehicles during 1975, the last year with an available emission inventory, were approximately 1.06×10^6 tons, which represents slightly over 94% of the total CO emissions during that year.[28] Thus, the estimated 1934 space heating emissions may be equivalent to 40% of the 1975 vehicular emissions.

Burning of refuse in apartment dwelling incinerators is another source that has also been greatly reduced. During 1964 1.65×10^5 tons of refuse were burned in domestic incinerators in New York City, which produced an estimated 7.6×10^4 tons of CO, more than the combined emissions of all sources except automobiles during 1975.[29] Emissions from these sources seem to have been substantial. It should be noted, however, that these emissions were above street level and, particularly in the case of space heating, were relatively diffuse compared to those in heavily trafficked areas.

It is difficult to assess CO emissions from automobiles in New York City during past years. Previous studies indicate that consumption of gasoline between the years 1935 and 1937 was approximately 500×10^6

gallons. By 1954 gasoline consumption had more than doubled to 1,250 × 10^6 gallons.[30] During 1975 approximately 1,450 × 10^6 gallons were consumed, only 14% above the 1954 figure.[31] However, this is probably an overestimate, because it is based on the assumption that daily fuel use on weekends is similar to that of a work·day. Assuming that gasoline use on a weekend day equals 50% of the weekday consumption, the total gasoline use during 1975 could be estimated to have been 1,246 × 10^6 gallons. Whereas in-city gasoline use increased approximately by less than a factor of three since 1935, consumption of gasoline in the tristate region, including New York City, increased from 525 × 10^6 gallons in 1934 to 2.1 × 10^9 gallons during 1969.[10] As would be expected, increases in gasoline consumption in the tristate region have been relatively greater in suburban areas; thus, the impact of increased vehicular emissions may not have been as significant in the city. Unfortunately, there is a lack of data with which CO exposure trends in suburban residential areas can be described.

Sources of Indoor Exposure

Human habitations have been polluted by CO ever since prehistoric man first learned to use fire in caves. Indoor exposures to CO must have been significantly higher in the past than at present. In more primitive societies, open burning of charcoal or wood for cooking or heating in poorly ventilated areas may result in high levels of CO. Cleary and Blackburn reported peak CO concentrations of 150 ppm. inside native huts in the highlands of New Guinea.[32] In 1955 Fumio Komatsu reported studies in the community of Kinasa, where tatami mats were manufactured indoors in a room heated by an open charcoal fire. He reported CO exposures ranging from 2,000 to 3,000 ppm. and workers' CoHb levels as high as 30%.[33] Levels of Benz-a-pyrene (BaP), another pollutant resulting from fuel combustion, have been reported to be as high as 166 ng./m.^{3} in the native huts of the mountain region of Kenya.[34] For comparison, New York City air contains 1 to 5 ng./m.^{3} of BaP.[35] Such high levels of BaP in Kenya could indicate possible high CO exposure. Further studies are necessary for the determination of CO and other pollutant exposures in these environments.

Except for occupational exposures in industry, very few data have been

reported on past indoor CO exposures in urban dwellings. Bloomfield, for example, reported a concentration of 40 ppm. on the fourth floor of a building located on a street where the CO ambient level was 30 ppm.[14] These levels possibly resulted from unvented heaters and leakage of illuminating gas containing as much as 25% CO, which were significant sources of indoor CO in New York City.[36] This is emphasized by the fact that the number of CO-related accidental deaths due to use of illuminating gas reached 611 in 1927.[36] In contrast, during the six-year period from 1973 through 1978, only 43 accidental CO-related deaths occurred, 35 as a result of motor vehicle exhausts, and eight from incomplete combustion sources.[37] Thus, the number of CO-related deaths has significantly decreased as a result of elimination of the use of illuminating gas. For every fatality, a great many sublethal exposures can be assumed. In addition, in private residences heated by coal, it was a common experience for flue dampers to close unexpectedly at night, causing "coal gas" to flood the house.

Current indoor CO exposures, although undoubtedly lower than in the past, can sometimes surpass outdoor values, and on occasion even exceed outdoor environmental standards.[38,39] The main sources of indoor CO have been identified as gas-fired cooking appliances, attached garages, and faulty furnaces. These exposures are of some concern, particularly as houses become more airtight for energy conservation reasons.

An important source of indoor CO is cigarette smoking, not only in homes but also in places of public gathering. Bridge et al. measured average CO concentrations of 9 ppm. at a party where 50 cigarettes and 17 cigars were smoked over a period of 1.5 hours.[40] CO levels at public arenas have been reported as high as 25 ppm. during an eight-hour period under conditions of inadequate ventilation and no smoking regulations.[41] These unnecessary exposures can be controlled by such measures.

The use of fuel-propelled engines in enclosed areas may also result in unnecessary exposure to the general public. Johnson et al. measured CO levels as high as 304 ppm. in ice skating rinks after the use of propane-powered ice resurfacing machines.[42] More recently, values of 57 ppm. have been reported in ice skating rinks as a result of ice resurfacing machine use.[43] However, these exposures are of more concern for the players in the rink than the public, and were correctable by improvements in the ventilation system.[26]

SUMMARY

CO concentrations in the downtown areas of large cities have remained stable or decreased since the beginning of the century in spite of increases in total gasoline use. These decreases can be explained by such factors as the improvement of the efficiency of the internal combustion engines, the change in the type of fuel used for space heating and electrical generation, and replacement of manufactured by natural gas. Indoor exposures have decreased also, as indicated by the large reduction in accidental CO poisoning deaths.

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