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**Description of Facilities
and Employee Exposure to Carbon Monoxide
at
Four Different Bridge and Tunnel Toll Authorities
in the United States**

**Final Report
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16. Abstract (Limit: 200 words) Carbon-monoxide (630080) exposures were investigated at bridge and tunnel toll authorities, including the Port Authority of New York and New Jersey, Maryland Transportation Authority, Massachusetts Port Authority, and Massachusetts Turnpike Authority. A description of each of the facilities operated by each authority, a history of operations and changes that could affect exposure to motor vehicle exhaust, a description of the job duties performed by the workers, and a description of the present and past exposures to carbon-monoxide and other agents in motor vehicle exhaust were provided. Available information indicated that current exposures were about one third lower than exposures that occurred prior to 1970. Vehicle emissions had been reduced, and improved toll booth designs allowed better natural air circulation. In some cases, forced mechanical ventilation had been installed. Exposure criteria were lower than in the past. For most workers in tunnels and toll booths, full shift average exposures were below the OSHA permissible exposure limit of 35 parts per million. At one authority, tunnel observation booths have been replaced by remote video cameras.			
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Abstract

In 1988, NIOSH reported the results of a retrospective cohort mortality study of employees working at toll bridges and tunnels operated by the Triborough Bridge and Tunnel Authority in New York City. The results indicated a significantly increased risk of heart disease mortality. A larger study was undertaken in an attempt to repeat in another population the evaluation of risk of heart disease. The larger study included toll facility employees at the Port Authority of New York & New Jersey, Maryland Transportation Authority (Baltimore), Massachusetts Port Authority and Massachusetts Turnpike Authority (Boston). A total of ten bridges and five tunnels were included.

This report provides a description of each of the facilities operated by each authority, a history of operations and changes that could affect exposure to motor vehicle exhaust, a description of the job duties performed by the employees, and a description of the present and past exposure to carbon monoxide, exposure variability, and potential exposure to other agents in motor vehicle exhaust. Current exposures were determined by NIOSH by performing extent of exposure surveys during the winter and summer seasons at six bridges and four tunnels.

Although past exposure data are scant and details are lacking which would allow direct comparison of the data to present conditions, available information indicates that present exposures are about one-third lower than exposures that occurred prior to 1970 (assuming similar traffic and engineering design conditions). Reductions in vehicle emissions are primarily responsible for the reduction in employee exposures at the toll booths, although improved toll booth designs which allow better natural air circulation, and in some cases forced mechanical ventilation, have also contributed to this improvement in air quality. Employees working within tunnels have also benefited from lower vehicle emissions and adoption of exposure criteria that are lower than in the past. Specifically, the maximum acceptable concentration of CO in tunnels prior to 1970 was generally 250 ppm, whereas current practice is to maintain the tunnel concentration below 125 ppm, or lower. Using data collected during NIOSH surveys, it is known that most tunnel officers do not currently experience short-term (1-minute) CO concentrations above 100 ppm during the course of a work shift. Nearly all full-shift average exposures, for both employees stationed in tunnels as well as toll booths, are below the NIOSH and Occupational Safety and Health Administration (OSHA) designated level of 35 ppm. At one authority, tunnel observation booths have been abandoned in place of remote video cameras, therefore removing these employees from exposure when not responding to an emergency situation.

Due to the lack of extensive detailed data on past exposures and the variables which contribute to those exposures, a sophisticated mathematical modelling of exposures could not be performed. Instead, a simple descriptive compilation of the exposure data is presented.

The results from the epidemiological portion of this study are reported in a separate report.

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Introduction and Methods

In 1988, NIOSH reported the results of a retrospective cohort mortality study on the health effects of chronic carbon monoxide (CO) exposure in 5,529 New York City bridge and tunnel officers. The study included employees working between January 1, 1952, and February 10, 1981, at any one of nine major water crossings operated by the Triborough Bridge and Tunnel Authority (TBTA) of New York City.¹ The purpose of that study was to determine whether chronic occupational exposure to CO was associated with an increased risk of heart disease deaths, a question proposed in an earlier study.² The results of our study showed that tunnel officers, whose past CO exposures averaged between 50-60 parts per million, were at significantly increased risk of heart disease mortality (Standardized Mortality Ratio (SMR) = 135, 90% Confidence Interval (CI) = 1.09-1.68). The comparison population was residents of the city of New York. The data suggested that two factors contributed to produce the elevated risk of heart disease: the higher levels of CO exposure experienced by tunnel officers, and the movement into a critical higher age group.

Based on these findings and those of other investigators, in 1989 the Occupational Safety and Health Administration (OSHA) revised its CO permissible occupational exposure limit (PEL) downward from a 50 part per million (ppm), 8-hour time-weighted average, to a 35 ppm 8-hour TWA with a 200 ppm ceiling-limit.³ The rationale for these lower limits for CO exposures was to ensure that employee carboxyhemoglobin (COHb) levels be maintained at or below 5 percent in order to protect those workers at greater risk of cardiovascular impairment. In 1989, the American Congress of Governmental Industrial Hygienists (ACGIH) lowered its recommended CO standard to 25 ppm in order to maintain a carboxyhemoglobin (COHb) level at or below 3.5 percent.⁴

The purpose of this investigation was to attempt to replicate the study of CO exposure and heart disease mortality risk in another population that would include other toll facility employees elsewhere. In this expanded study, the Port Authority of New York & New Jersey, Maryland Transportation Authority, Massachusetts Port Authority, and Massachusetts Turnpike Authority were involved. The study protocol (see below) also

provided for an improved analysis of retrospective exposure to CO which was lacking in the first study.

This report provides a description of each on the facilities operated by each authority, a history of operations and changes that could affect exposure to motor vehicle exhaust, a description of the job duties performed by the employees, and a description of the present and past exposure to carbon monoxide and other agents in motor vehicle exhaust. The results from the epidemiological study are reported separately. However, it should be noted that the years of employment studied were between 1960-1990. The number of employees per authority in the study cohort, current number of toll collectors, and years of tolled operation are shown in Table 1.

The protocol for the study entitled "Heart Disease Mortality Among Bridge and Tunnel Officers Exposed to Carbon Monoxide" describes alternative options for estimating past exposures to carbon monoxide (CO). Three approaches which were suggested include: 1) quantitative exposure estimates, which are specific for the job title, work site, and year, 2) estimates by exposure category, in which jobs are classified into ranked exposure categories, and 3) qualitative estimates, in which no numerical values are assigned. This report compiles the best available information that presently is known to exist and that could be used in estimating past exposures to CO at each facility location. The information includes current extent of exposure data on CO that was collected by NIOSH during two site surveys to many of the sites included in the epidemiological study. Because of the large number of sites, similarities between sites and relative importance in the number of employees at each site were considered when determining which sites to survey. Both winter and summer surveys were conducted to account for the seasonal differences in traffic and emissions variation.

References

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4. American Conference of Governmental Industrial Hygienists, Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposures Indices, 1992-1993. Cincinnati, Ohio, 1992.

Table 1
Characteristics of Bridges and Tunnels at Each Authority

NAME OF AUTHORITY ¹	ABBREVIATED NAME OF FACILITY	YEAR FACILITY OPENED	NUMBER OF CURRENT TOLL COLLECTORS (as of 1989)	TOTAL NUMBER OF ALL EMPLOYEES IN COHORT	YEARS TOLLS COLLECTED
MdTA	Balt. Harbor Tun.	1957	152	2722	1957-Present
	Ft. McHenry Tun.	1985	148		1985-Present
	Franc. Scott Key Br.	1977	56		1977-Present
	Harry W. Nice Br.	1940	41		1940-Present
	J.F.Kennedy Hwy.	1963	107		1963-Present
	Thom. J. Hatem Br.	1940	40		1940-Present
	Will. P. Lane Br.	1952	84		1952-Present
MTA	Sumner Tunnel	1932	62	697	1932-Present
	Callahan Tunnel	1964	62		1964-1984
MPA	Tobin Bridge.	1950	43	283	1950-Present
PANYNJ	Holland Tunnel	1927	166	5467	1927-Present
	Lincoln Tunnel	1937	273		1937-Present
	Geo. Wash. Br.	1931	279		1931-Present
	Goethals Bridge	1928	160		1928-Present
	Bayonne Bridge	1931	160		1931-Present
	Outerbridge Cr.	1928	160		1928-Present

A-4

¹ Explanation of table 1 abbreviations

MdTA = Maryland Transportation Authority

MTA = Massachusetts Turnpike Authority

PANYNJ = Port Authority of New York

MPA = Massachusetts Port Authority

Description of Sites and Employee Exposure to Carbon Monoxide at Toll Facilities

Port Authority of New York and New Jersey

Description of Facilities

The Port Authority of New York and New Jersey operates four bridges and two tunnels. Each of these facilities have collected tolls since their inception. Toll collection was originally done in both directions, but since 1971 tolls have been collected in the east-bound direction only. The bridges operated by this authority are the George Washington, the Goethals, the Outerbridge Crossing, and the Bayonne. The two tunnels operated by the PANY&NJ which traverse the Hudson River are the Holland Tunnel and Lincoln Tunnel.

George Washington Bridge

The George Washington Bridge was opened to traffic in 1931 with six lanes. Two additional lanes were added in 1946. In 1962, a lower level was opened to traffic, which increased the bridge's capacity by 75 percent. The bridge is the world's only 14-lane suspension bridge. It is 4,760 feet long between anchorages and 119 feet wide. East-bound access to the bridge is via three toll plazas; Upper and Lower on Interstate 95, and Palisades Interstate Parkway (PIP). The number of booths located in each plaza are 12, 12 and 7, respectively. At night, 5 to 6 booths are closed in the lower and upper plaza while the Palisades Plaza is closed entirely. Historically, the number of booths was certainly less. Reference in one historical report from 1941 indicates five west-bound lanes open, with only two east-bound lanes open at mid-day on a Friday.¹ Current daily traffic volumes in the east-bound direction are about 55,000, 48,000 and 22,000 vehicles per day (48 million per year), respectively. Bridge traffic has increased steadily during its history. Total yearly traffic more than doubled between 1947 and 1953, from 14 million to 31 million. After the lower level was completed in 1963, traffic increased from 47 million to its current level of about 95 million. The toll booths installed at the upper plaza in 1983 are provided with forced fresh air ventilation by a central air supply unit located above the canopy. The toll booths in the other two plazas were never ventilated with forced fresh air.

Goethals Bridge

The Goethals Bridge was opened to traffic in 1928. It spans the Kill van Kull waterway between New Jersey and Staten Island. The toll plaza was originally built with 16 lanes. However, in 1971, one-way tolls were initiated in the east-bound direction only and the number of operating toll lanes was reduced to eight. During the night shift, only four lanes are open. Forced fresh air ventilation is not provided to the toll booths (i.e., natural air ventilation only). Presently, the number of vehicles tolled is about 35,000 per day (12 million annually).

Outerbridge Crossing

The Outerbridge Crossing was also opened to traffic in 1928. It also spans the Kill van Kull waterway between New Jersey and Staten Island. When one-way tolls were initiated in 1971, the number of booths in the toll plaza was reduced from 16 to eight. The number of vehicles tolled in 1986 was 11 million. All of the booths lacked forced air ventilation until 1991.

Bayonne Bridge

The Bayonne Bridge, which spans the Arthur Kill waterway between New Jersey and Staten Island, was completed in 1931. It is one of the longest steel arch bridges in the world. In 1986, 2,680,000 vehicles were tolled in the east-bound direction. Currently, there are four toll lanes at this bridge. Prior to 1971, there were eight toll lanes. Forced fresh air ventilation that is brought in from a remote location is not provided to the toll booths.

Holland Tunnel

The Holland Tunnel originally and presently consists of two tubes running under the Hudson River between New Jersey and Manhattan. These were opened to traffic in November, 1927. Each tube contains two lanes. The tubes are over 8000 feet long. The tubes are ventilated by four ventilation buildings, two on each side of the Hudson River. These buildings house 84 immense vane axial fans (42 air supply and 42 exhaust) that can

provide a complete change of air every 90 seconds. The fresh air duct is below the roadway where it is introduced through slots centered every 10-15 feet. The exhausted air is removed through ceiling slots leading to the main duct at the top of each tube. The carbon monoxide concentrations are monitored continuously at each of seven segments in the tunnel by automated sampling equipment. "Hopcalyte" sensors have been used to monitor CO concentrations since the Holland and Lincoln Tunnels were first operational. Presently, if the CO levels exceed 150 ppm, audible and visual signals alert the tunnel operator to manually adjust the ventilation by increasing fan speeds. However, as recently as the early 1970's, a ceiling concentration of 200 ppm was allowed. Prior to that, 250 ppm was the alarm level and was considered acceptable within vehicular tunnels within the U.S.

Tunnel observation booths are located along a catwalk on one side of each tunnel. These are manned so that a quick response to an emergency situation can occur. Fresh air was introduced in 1978 to the booths via the tunnel supply air duct under the road bed. These booths and the means of transport to and from the booths by employees are further described in the section concerning the Lincoln Tunnel.

The toll plaza is in a relatively open area and at ground level. Prior to 1971, there were six toll lanes on the New York side of the tunnel and six toll lanes on the New Jersey side. The Manhattan Toll Plaza was removed in 1971 when one-way tolls were implemented. There are presently eight toll booths in the east-bound direction. A major construction project at the toll plaza replaced the old booths in 1991 with ventilated booths. East-bound traffic count in 1986 was almost 13 million.

Lincoln Tunnel

The Lincoln Tunnel operation presently includes three tubes north of the Holland Tunnel linking New Jersey with mid-town Manhattan. The Center tube was opened in 1937, the north tube in 1945 and the south tube in 1957. These tunnels are approximately 8000 feet long. There are two lanes in each tunnel. Observation booths are located in each tube and at least one is manned in each tunnel at all times. In 1973, motorized vehicles (catwalk cars) were introduced to transport employees to the booths. Originally, these

vehicles were gasoline operated, and were themselves a potential source of pollution. The added mobility provided by the cars reduced the number of manned booths from five to two during day hours and only one during the night. In 1978, the tunnel booths were ventilated by coupling into the forced fresh air shaft for the tunnel. Battery-operated vehicles were introduced and further reduced exposure to vehicular emissions.

The toll plaza has always been located on the New Jersey side of the Hudson River. The plaza is bordered on three sides by vertical walls that are about 60 feet high. Multi-story buildings are above the top of the wall in some areas. Therefore, the toll plaza is in a location that is generally protected from natural winds. Currently, there are 12 booths (14 lanes) in the plaza which are all open during the daytime hours. At night, the number of operated booths is reduced to five. Forced fresh air ventilation is not provided to any of the booths. The number of vehicles tolled in the east-bound direction is about 110,000 each day or 21 million a year (1986).

The vehicle counts in the east-bound direction of all the above PANY&NJ crossings are graphically presented in the following figure. Although vehicle counts have generally increased at all sites each decade, the rate of increase at some sites has been irregular.

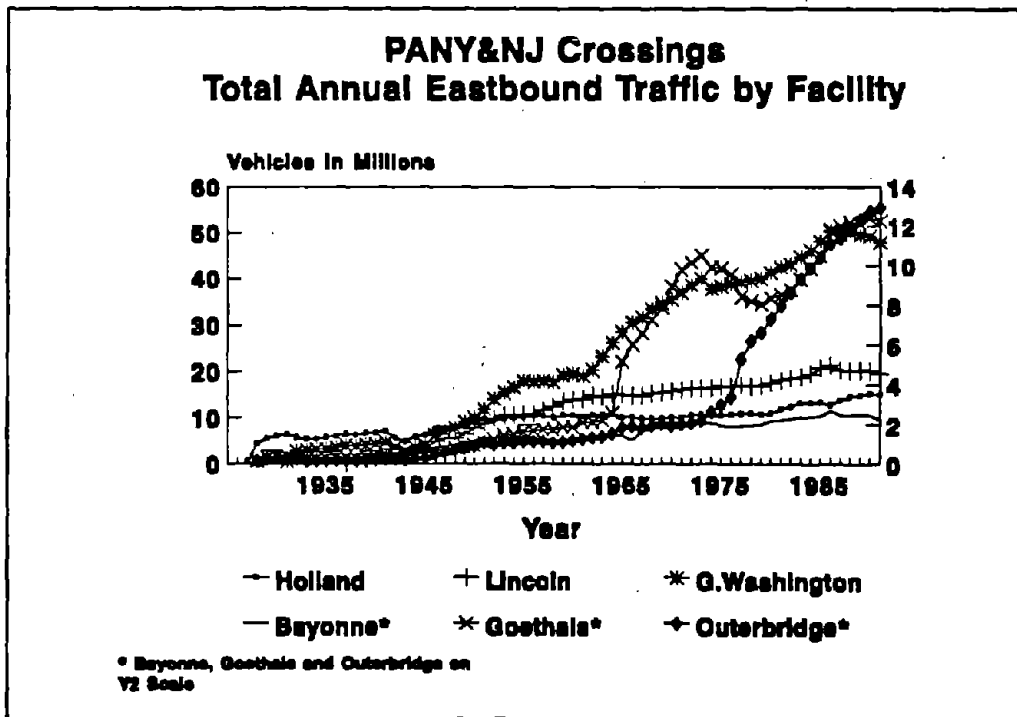


Figure 1 - Historical change in traffic at each facility operated by PANY&NJ

The monthly deviations in traffic count through the east-bound toll plaza of each facility are shown in Figure 2 below, for the year 1992. Overall, traffic volume is less during the winter (-18% in February compared to August).

Seasonal Traffic Counts for Each PANY&NJ Crossing

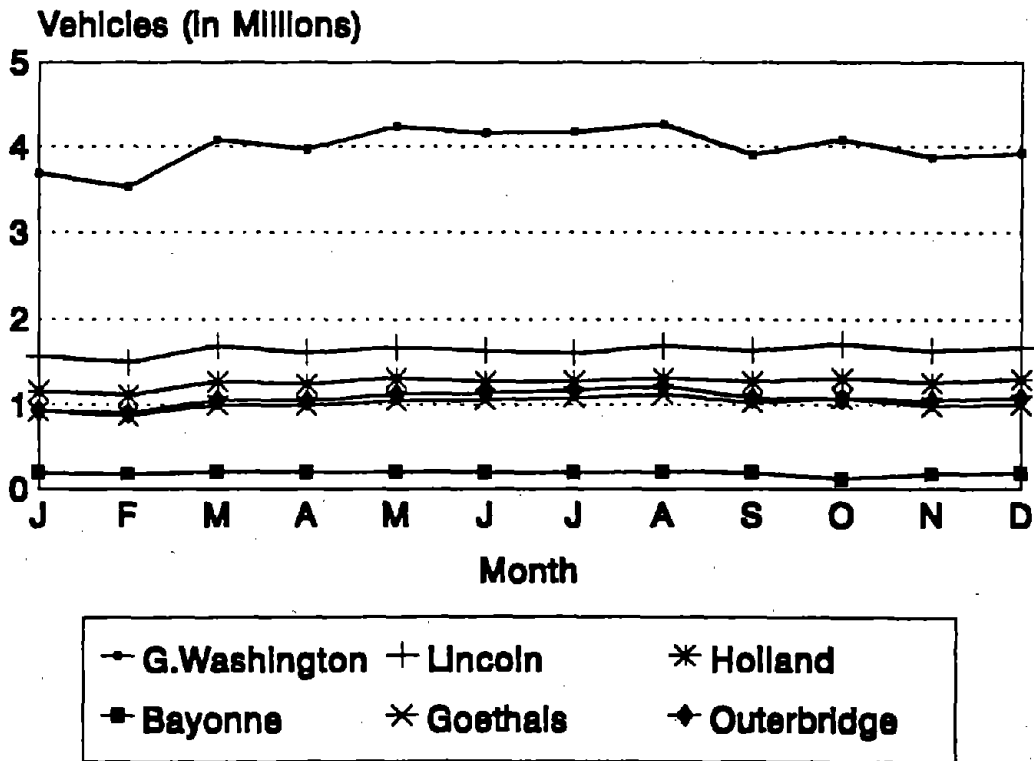


Figure 2 - Seasonal variation in traffic counts is minimal during the year at most of the PANY&NJ bridges and tunnels.

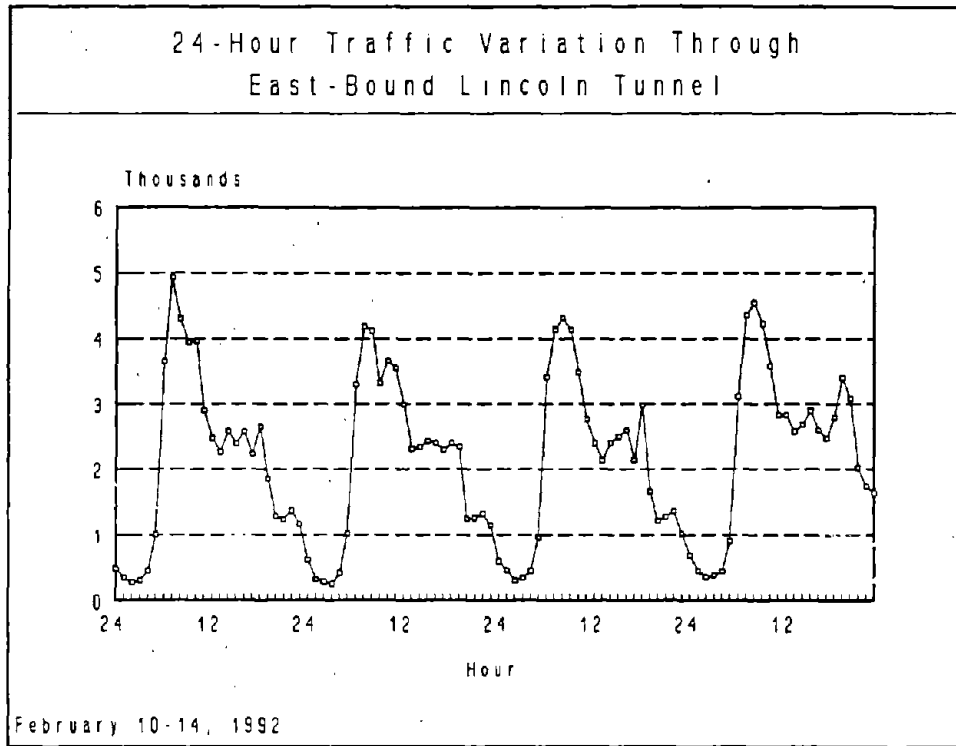


Figure 3 - This figure plots the variation of 24-hour traffic variation during a workweek. A similar pattern is seen to be repeated each day.

The 24-hour traffic variation is graphically shown for the east-bound plaza of the Lincoln tunnel in the figure above. The pattern for the time frame shown is quite regular, showing most of the traffic going east-bound into Manhattan in the morning rush hours.

Employee Exposure to Carbon Monoxide

The air concentrations of CO have been monitored within the Holland and Lincoln tunnels since their inception, and monitoring is performed routinely at the George Washington Bridge Expressway. However, the PANY&NJ has a record retention program which encouraged disposal of any type of hard copy record of the concentration data for more than five years. Therefore, reliance on old reports is the only source of such information.

Holland Tunnel

The earliest known survey of atmospheric contaminant concentrations was performed in 1941 by the U.S. Public Health Service.¹ In that comprehensive report it is stated that "the most important single factor that governs the concentration of carbon monoxide in the air of the tunnel is the number of passenger cars and the number of trucks and buses in any particular section of the tunnel at one time." Intuition and the accompanying figures would support this statement. It could be assumed that the number of vehicles in the toll plaza would also directly affect the CO concentration, although the particular ambient weather conditions could also be a major predictor.

Toll Plazas

Exposure concentrations of CO at the Jersey City Plaza were determined during an evening, June 1, 1941.¹ Traffic conditions were unusually heavy, as it was the end of the Memorial Day weekend. There was little or no wind, although the weather was cool and the sky clear. Six lanes were open to traffic and approximately 2,000 cars an hour passed the toll booths. Table 2 indicates the CO concentrations measured, the carboxyhemoglobin levels found among the six toll collectors, and their smoking habits.

The following air concentrations were determined by using a portable MSA carbon monoxide direct-reading meter. Because of the heavy traffic and lack of wind, it was felt that the above data represent almost the maximal exposure that the collectors were likely to have. At the New York plaza (north tunnel), where there was very little traffic, exposures were clearly lower. Of 14 measurements taken with a MSA portable indicator, eight were below 10 ppm, three were 10 ppm, and three were 20 ppm.

Table 2
Carbon Monoxide Exposure at Holland Tunnel Toll Lanes
During Worst-Case Conditions in 1941

Date & Time	Lane and Carbon Monoxide Concentrations (in PPM)				
	1 ¹	2-3	4-5	6	\bar{X} (st.dev)
June 1, 1941	1 ¹	2-3	4-5	6	\bar{X} (st.dev)
8:25-9:15	-- ²	--	--	--	65 (25)
10:37-10:58	10	50	70	30	40 (25)
11:35-11:54	30	65	60	20	44 (22)

Toll Collector	1	2	3	4	5	6
Smoking Habits ³	NS	NS	+++	NS	+++	++
COHb % Conc.	6	10.9	15.1	10.2	15.2	13.6

¹ Truck and bus lane, other lanes are passenger vehicle lanes.

² No data were provided in report for individual lanes.

³ NS = Nonsmoker; ++ means average use of pipe, cigars, or cigarettes; +++ means greater than average use of whatever form of tobacco.

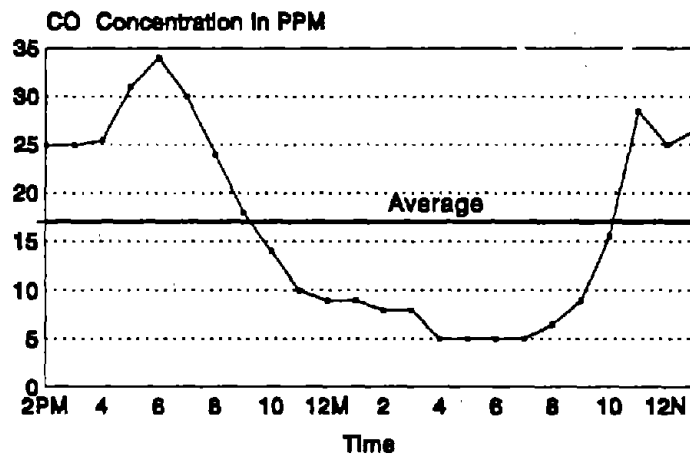
Data from reference 1.

Extended sampling performed by H.W. Frevert at the PANY&NJ during May, 1940 found that the maximal CO concentration was 130 ppm while the average on different days ranged between 10 and 30 ppm around the toll booths (as reported by Sievers, R.F., 1942). In August, 1940, with the use of an automatic CO recorder, the average concentration range at both the New York and New Jersey plazas of the Holland Tunnel and at the George Washington Bridge was between 30 and 40 ppm. The highest recording was 130 ppm.

During the early 1970's (exact date unspecified) PANY&NJ Risk Management personnel detected 15 and 12 ppm as an 8-hour TWA in two booths (lanes 6 & 10) during the first shift (6 a.m. - 2 p.m.) at the New Jersey plaza.

The 8-hour average concentration of CO in the toll booths at the Manhattan plaza in 1973 were found to be 12 and 15 ppm in two samples.² Continuous sampling for 24 hours in two booths provided 1-hour average CO concentrations which are depicted in the following graph.

Average Hourly CO Concentrations In Toll Booths* Holland Tunnel, January 14-16, 1974



*Two booths, Lanes 6 & 10

Figure 4 - This figure indicates an appreciable change in CO concentrations in the toll booths during a 24-hour day which is a reflection of traffic load through the toll plaza.

During 1987-89, stationary monitoring for CO and other airborne contaminants was performed by the Risk and Environmental Programs Division, PANY&NJ. Ecolyzer 211 dosimeters were attached at breathing level near the door opening that the toll collectors used to take tolls. The data was stored in a electronic data logging device. Full-shift samples were taken and sampling occurred over most of the year. The results of that sampling showed that the average CO concentration monitored was 10.9 ppm, range 6.5-20 (n=8).

During September, 1990 and again during February, 1992 NIOSH conducted four-day long sampling surveys for CO at the Holland Tunnel. Personal dosimeters (National Draeger 190) with internal data logging capability were provided to toll collectors to be worn in their shirt pockets during their entire shift. Sampling was continuous over all three work shifts. The results of the first survey were a mean exposure of 6 ppm, range 1-12 (n=46). The second survey found an average exposure of 3.9 ppm, range 0-10 ppm (n=23). The average exposure during each shift was similar, possibly due to the practice of closing some booths during off-peak hours.

Tunnel Officers

The following figures represent the hourly average CO concentrations in the Holland Tunnel in 1941. One part of CO per 10,000 parts is equivalent to 100 ppm. Figure 5 shows the CO concentrations recorded during Easter Sunday, 1941. A record number of vehicles (31,713) passed through the south tube that day and these results therefore probably

HEAVY HOLIDAY TRAFFIC

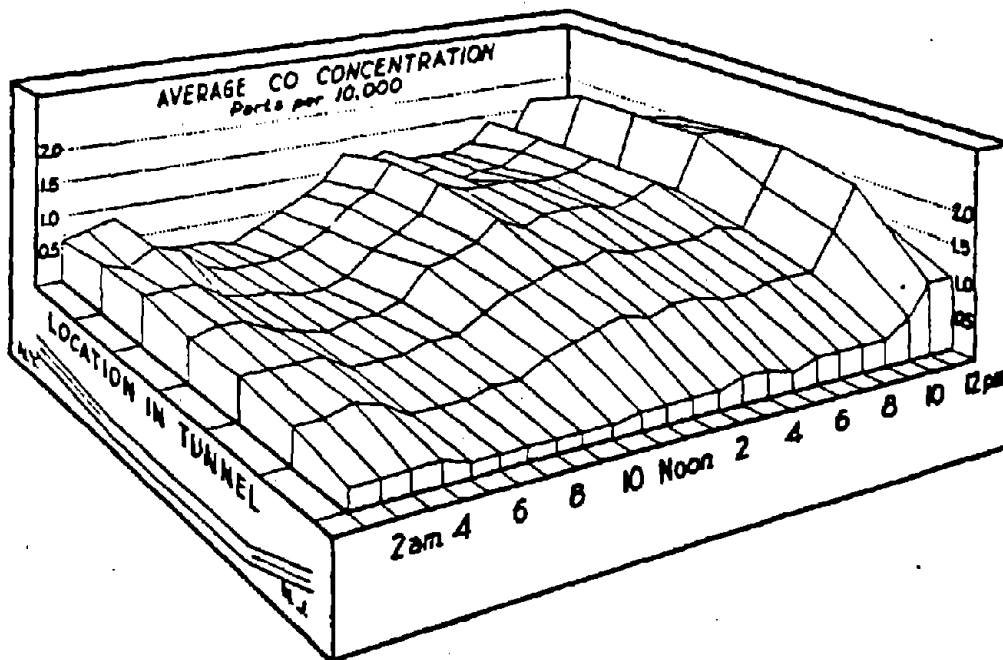


Figure 5
Stereodiagram showing the average hourly CO concentration during each hour of the day within each of seven sections of the south tube of the Holland Tunnel on Easter Sunday, 1941. One part of CO per 10,000 parts of air = 100 ppm.

represent a worst case exposure situation. On the other hand, Figure 6 depicts the concentrations recorded in the exhausted air for each Tuesday, Wednesday, and Thursday of March 1941. These results are entitled "Average Midweek Exposures" and are believed to be more representative of the magnitude of a typical exposure to tunnel officers stationed along the catwalk inside the south tube of the tunnel. Although fresh air is introduced at the roadway and exhausted through the ceiling, measurements conducted by NIOSH in the Brooklyn-Battery Tunnel indicated homogenous concentrations from roadway to ceiling because of the high degree of air mixing provided by the ventilation system and the moving vehicles within the tunnel. Exposures in the north tube are expected to be similar.

AVERAGE MIDWEEK EXPOSURE

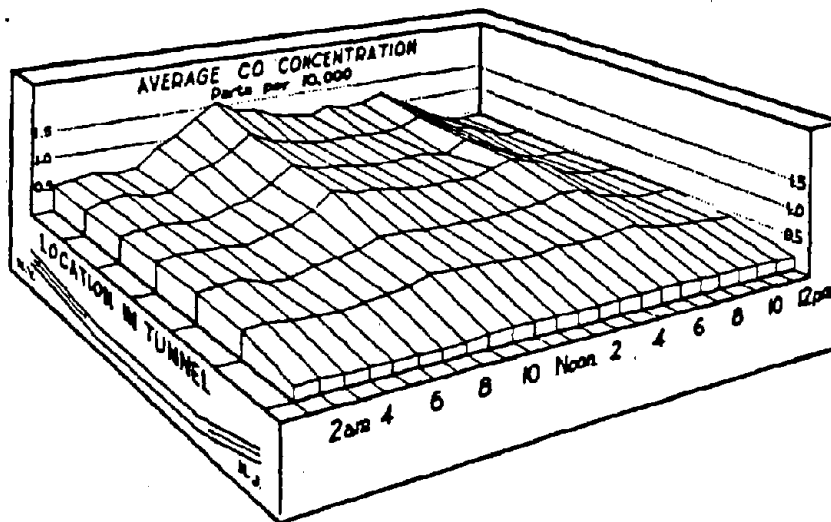


Figure 6
Stereodiagram showing the average atmospheric CO concentration during each hour of the day within each of seven sections of the south tube of the Holland Tunnel in 1941. One part of CO per 10,000 parts air is equivalent to 100 ppm.

It should be noted that the tunnels are a controlled environment. At the time of the above measurements, the "action level" was 250 ppm, at which point audible and visual alarms would alert the tunnel engineer and increased ventilation would be provided to lower the air

concentrations to an acceptable level. During a traffic blockage which would fill the tunnel with vehicles, the traffic count could be reduced substantially. Therefore, tunnel CO concentrations would generally be expected to be only poorly correlated with traffic counts.

The following figure shows the concentration of CO in the incline section of the Holland Tunnel during a two hour period of heavy traffic in 1941.

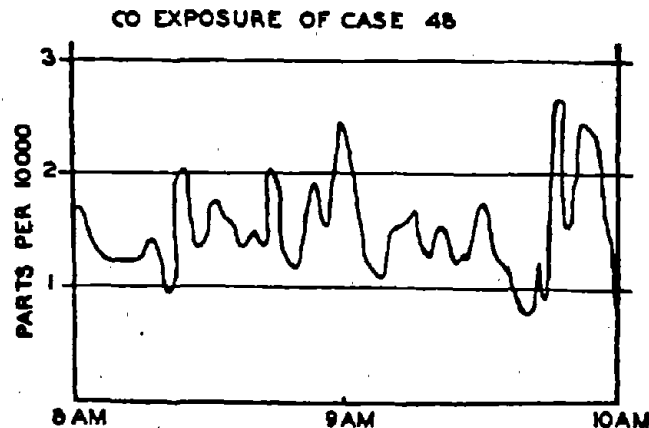


Figure 8
Concentration of CO in inclined section of Holland Tunnel, 1941.

In 1980-81 four full-shift samples were collected inside the Facility Operations Agents (FOA's) observation booth using General Electric portable dosimeters. The average exposure was 35 ppm, range 28.5-42 ppm (memo of H. Pool, March 2, 1981).

Samples collected in 1987-89 by the PANY&NJ near FOA's indicated a mean exposure of 6.1 ppm, range 1.2-15 ppm (n=9). The G.E. dosimeters were worn by PANY&NJ staff from the Environmental Risk Management Division in their breathing zones and these individuals "shadowed" the toll collectors for the duration of their shift.

In September, 1990 and February, 1992 NIOSH conducted four day sampling surveys of CO exposure at the Holland Tunnel. In 1990, the personal sampling results showed an average of 7 ppm, range 4-10 (n=4). During the second survey, an average exposure of 5.2 ppm, range 0-12 ppm (n=27) was determined.

Average Hourly CO Concentrations in Toll Booths* Lincoln Tunnel, November 14-16, 1973

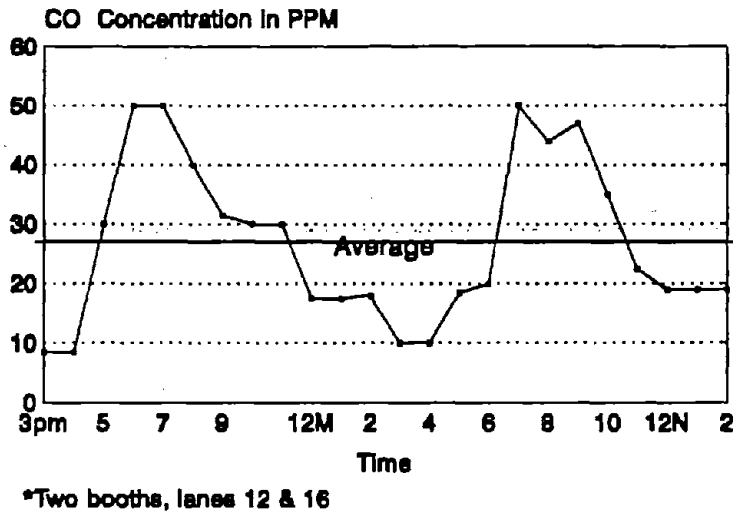


Figure 7 - The hourly average CO concentrations in the Toll booths is seen to change with time of day according to this historical data.

Lincoln Tunnel

Toll Booths

In October, 1973 the PANY&NJ Risk Management Division issued a report on CO readings taken inside toll booths.² Concentrations were taken using a portable Ecolyzer instrument (Energetics, Inc.). Several 8-hour and 24-hour samples were recorded (the toll booths monitored were closed about an hour during each shift change). The hourly readings inside two toll booths were averaged and are shown below in Figure 8. The weather conditions were recorded as mild, clear and with a slight breeze. During daylight hours, average concentrations were 34 ppm.

Full-shift samples were also collected inside the toll booths of the Lincoln Tunnel, presumably during 1971.² Two samples in the west-bound direction, 2nd shift (lanes 16 & 12) averaged 20.6 and 26.3 ppm, respectively. A sample taken in an east-bound lane (lane 6) showed an average of 7.2 ppm.

Full-shift stationary samples collected by PANY&NJ during 1987-89 found a mean concentration of 8.8 ppm, range 6.5-12 ppm (n=7).

During September, 1990 and again during February, 1992 NIOSH conducted four-day sampling surveys for CO at the Lincoln Tunnel. Personal dosimeters (Drager 190) were provided to toll collectors to be worn in their shirt pockets during their entire shift. The results of the first survey determined a mean exposure over all shifts of 9 ppm, range 3-15 ppm (n=55). Wind speeds during this survey were unusually low during the sampling period. During the second survey, a mean exposure of 3.3 ppm was detected, range 0-10 ppm (n=35). Wind conditions during the second survey were slightly lower than normal for this location.

Tunnel Exposures

In 1962, Scott Research Laboratories prepared a report entitled "Chemical Composition of the Lincoln Tunnel".³ Carbon Monoxide air concentrations were reported to be between 55 to 211 ppm, with a mean concentration during peak traffic hours of 152 ppm. Sampling was started in April and continued until September using a direct-reading infrared analyzer of the tunnel exhaust air. Police officers stationed within the tunnel would likely have experienced exposures approximately equal to these concentrations of CO.

In 1974, limited sampling within the Lincoln Tunnel was performed by NIOSH in order to evaluate an air purifier for the observation booths.⁴ The average air concentration in the tunnel was lowest near the opening of the tunnel and highest in the center. Concentrations were about 30-40 at the ends and 80 ppm in the center.

During the fall of 1980 and the spring of 1981, four full-shift samples were taken in the breathing zone of FOA workers inside the ventilated observation booths. The average reading was 24.5 ppm, the range of average exposures was 17-30 ppm.⁵

During 1987-89, samples collected by PANY&NJ found a mean full-shift concentration of 5.7 ppm, range 2.2-9.4 ppm (n=11) among FOA's. The samplers were worn in the breathing zone of a second person who accompanied the FOA during the entire shift.

A sampling survey by NIOSH in September, 1990 found the FOA's average full-shift exposure to CO to be 8 ppm, range 3-16 ppm (n=18). A second survey in February, 1992 found the average exposure to be 2.8 ppm, range 0-7 ppm (n=16).

George Washington Bridge

Sampling of the air for CO was performed mid-day on a Friday, May 31, 1941.¹ Being the beginning of a holiday weekend, traffic conditions were probably unusually heavy. The dial readings of a hand-operated MSA carbon monoxide indicator were recorded at 30-second intervals between 11:30 a.m. and 12:19 p.m. at stations on the traffic islands as close as possible to the toll collectors. A total of 73 readings were recorded. Readings ranged from "zero" to 170 ppm. The average concentration was 58 ppm and the standard deviation of the distribution 46 ppm.

In 1971, direct reading (Ecolyzer) measurements at the Palisades Interstate Parkway Plaza (booth #42) indicated that the concentrations were 35-55 ppm between 6 a.m. and 10 a.m. By 3:30 p.m., the concentrations were 15-30 ppm. At the lower plaza, measurements were "consistently" between 15-30 ppm (Hay & Pool, 1974).

The sampling data obtained from the PANY&NJ for the period 1987-89 indicated a mean CO concentration of 11.7 ppm, range 7-18 ppm (n=8) at the Lower Plaza, and 6.8 ppm, range 5-9 ppm (n=5) at the Palisades Interstate Parkway Plaza. Concentrations measured at the Main Plaza were lower due to the presence of forced fresh air ventilation. At the Main Plaza, the mean concentration was 4.9 ppm, range <2.5-10 ppm (n=6).

In September, 1990 NIOSH surveyed the CO exposure levels at the Main Toll Plaza. Personal full-shift exposures averaged 1.5 ppm, range 0-11 ppm over all three shifts (n=34). During this survey, an additional 18 stationary samplers were attached at about head level just outside the booth window. The personal sampling results were 75% lower than the concentrations measured outside the booth. Had forced fresh air ventilation not been provided to the booths, it is expected that the outside samples, with a mean concentration of 6 ppm, would be representative of personal exposures.

In February, 1992 NIOSH again surveyed the CO exposure levels at the Main Toll Plaza and expanded coverage to include the Lower Plaza. The average full-shift concentration at the Main Plaza was 2 ppm, range 0-5 ppm (n=28). At the Lower Plaza, the average concentration measured was 4 ppm, range 0-12 ppm (n=28). The night-time shift average was 0.4 and 2 ppm on two different days, while the day-time average concentrations ranged from 2-7 ppm.

Staten Island Bridges

During October, 1973 sampling for CO was performed by the PANY&NJ using a direct-reading meter. The 8-hour TWA for the Goethals Bridge was 35-45 ppm; Bayonne, 10-15 ppm; and Outerbridge Crossing, 5-10 ppm (Hay and Pool, 1974).

During the 1987-89 period, stationary samples were collected inside the toll booths by the PANY&NJ. Direct-reading (General Electric) personal dosimeters were used. The mean concentration measured at the Goethals Bridge was 7 ppm, range 4-10 ppm (n=8). The mean concentration at the Bayonne Bridge was 6.6 ppm, range 1-17 ppm (n=5) and at the Outerbridge Crossing the mean was 6.1 ppm, range 1-9 ppm (n=5).

Personal sampling data obtained by NIOSH in September, 1990 at the Goethals Bridge indicated a mean full-shift exposure of 7 ppm over all shifts, range 1-14 ppm (n=17). Exposure during the day shifts were higher, averaging 10 and 9 ppm, than during the night shift which averaged only 4 ppm. Stationary samples mounted outside the booth which were matched to the personal samples on the toll collectors measured concentrations that were essentially the same, indicating that the toll booths provide no discernible protection from exposure to vehicle exhaust gases.

Personal sampling data collected by NIOSH in February, 1992 produced an average exposure level of 4.4 ppm over all shifts, range 1-9 ppm (n=25). The night-time shift exposures were lower, averaging 3.3 ppm, than the day-time shifts, averaging 4.7 and 5.3 ppm.

Summary of Historical Exposures to CO at PANY&NJ River Crossings

The following graphs (Figures 9-12) were prepared to graphically summarize the trends in historical concentrations that have been measured at the PANY&NJ toll facilities. Some of the early measurements lack specific information on the conditions, location of the samples or the technique used to measure CO. Often only a few samples were taken. Under such circumstances, a reliable average exposure value could not be calculated. Therefore, only the range of measurements is presented.

The decline in CO exposures since 1970 corresponds to the decline in vehicle emission levels as determined by EPA (refer to chart on F-3). The decline in CO emissions became most apparent after the late 1970's (See section entitled "Historical Trends in Vehicle Emissions").

Historical Exposures to CO at the Holland Tunnel Showing Range and Means

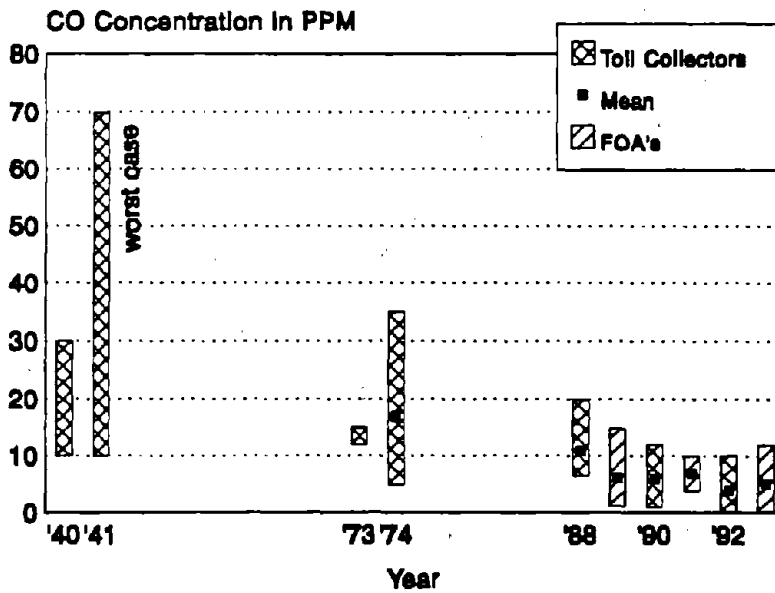


Figure 9

Historical Exposures to CO at the George Washington Bridge

Showing Range and Means at Three Plazas

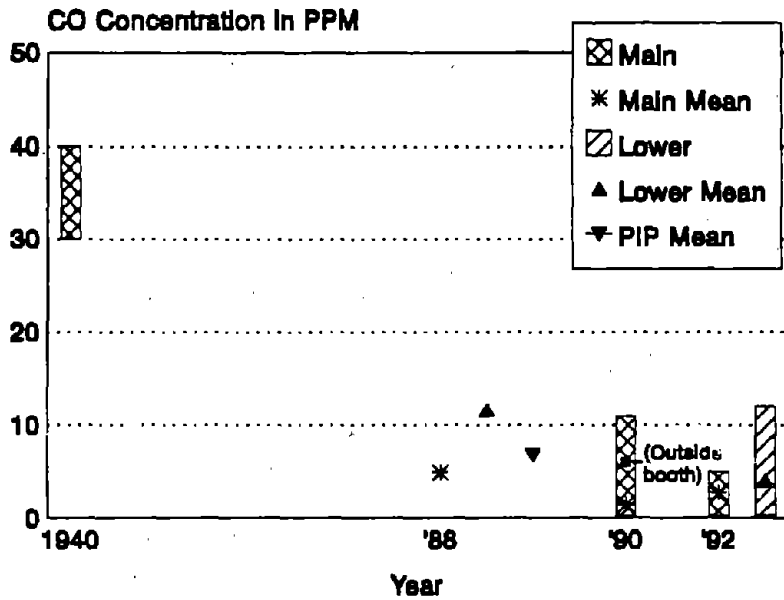


Figure 10

Historical Exposures to CO at the Staten Island Bridges

Showing Range and Means

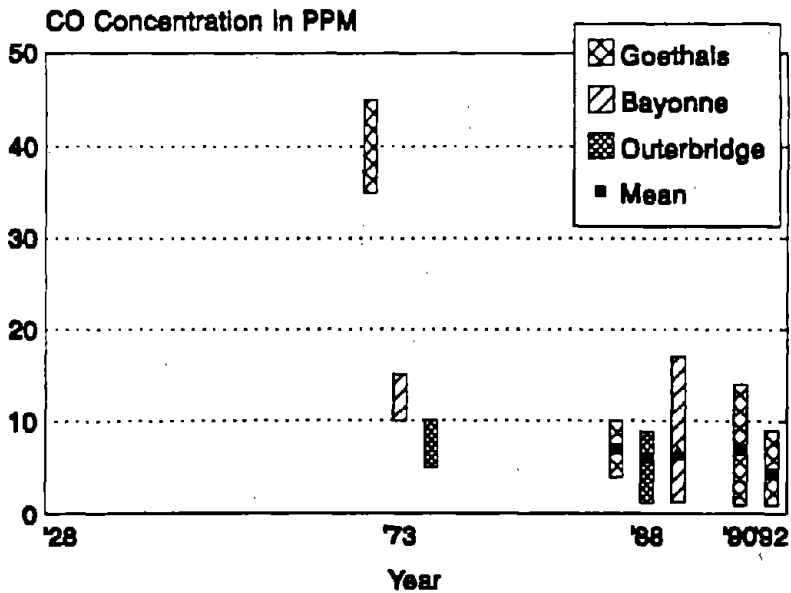
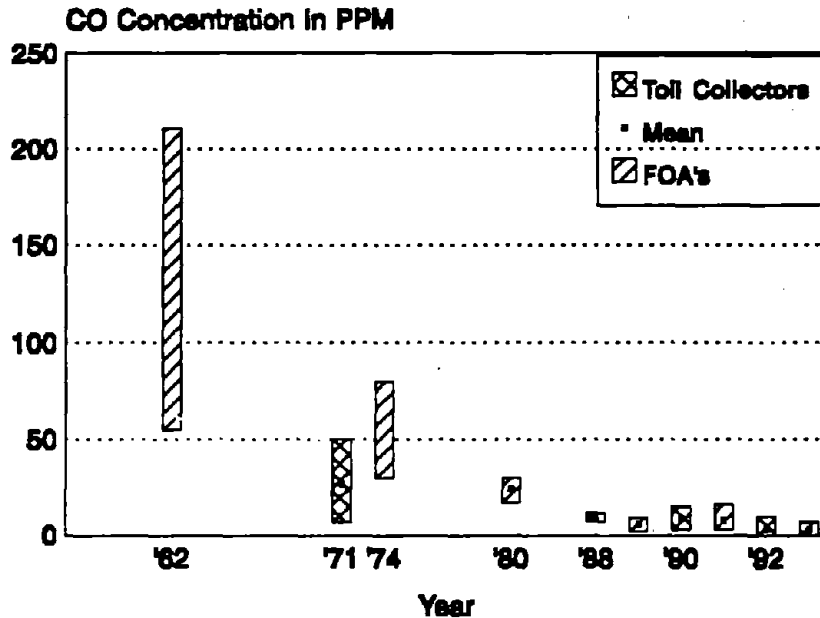


Figure 11

Historical Exposures to CO at the Lincoln Tunnel

Showing Range and Means



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2. Hay, R.A., H.R. Pool, Jr.: Air Sampling for Carbon Monoxide Concentrations in Toll Booths at Tunnels and Bridges Facilities. Prepared by the Port Authority of New York and New Jersey, Comptrollers Department, Risk Management Division, Environmental Sanitation Section, March 1974.
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Massachusetts Turnpike Authority (MTA)

Description of Facility

The MTA owns and operates the Sumner-Callahan Tunnels. The tunnels are directly east of downtown Boston and go under the Inner Boston Harbor to East Boston. The Sumner tunnel was opened in 1934. The tunnel was under the control of the City of Boston till 1958, at which time the MTA took over. The tunnel contained a two lane roadway with toll booths at the Boston portal and East Boston portal. In 1961, the Sumner tunnel was closed for refurbishment, and the parallel Callahan tunnel was opened to handle the increasing traffic (see following figure). The new toll plaza was located in East Boston and contained 14 toll lanes to handle the traffic going through

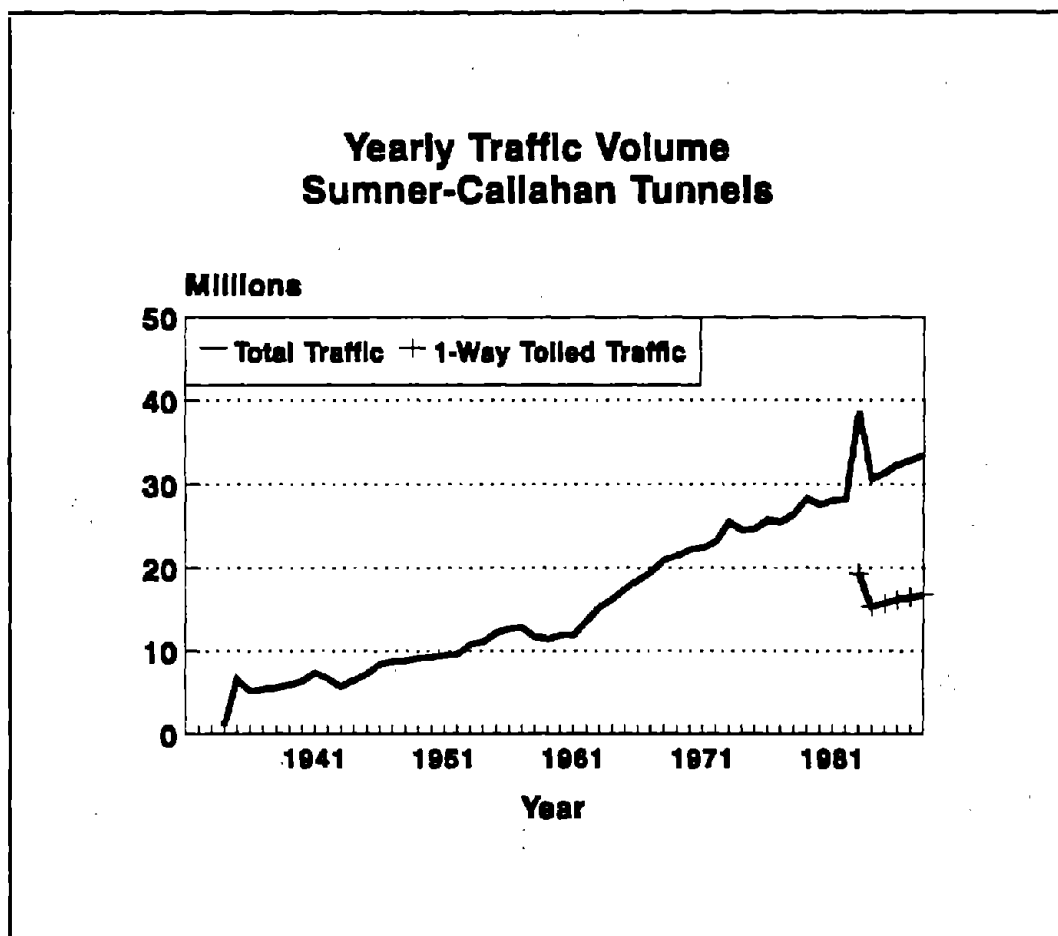


Figure 13

both tunnels. Both the Sumner tunnel and the newer Callahan tunnel collected tolls until May, 1983 after which tolls were only collected going west through the Sumner tunnel. At that time, the toll booths for the Callahan Tunnel were dismantled and removed. Figure 13 depicts the growth in traffic usage by this facility.

The Sumner-Callahan Tunnels are both ventilated to control vehicle emissions. The Callahan tunnel has a total capacity of 1,848,000 CFM which is provided by six 3-speed fans. The Sumner tunnel has the same total capacity which is provided by 14 two-speed centrifugal fans. Presently the fans run at 40-45% of total capacity because of the lower vehicle emissions.

Continuous CO monitoring has always been automatically performed within each tunnel. There are four sampling points in the Sumner Tunnel and two in the Callahan. The monitoring system is calibrated weekly. Strip chart recorders display the CO levels in the Control Room. The present objective is to keep the level of CO below 35 ppm. Adjustment of the ventilation rate when needed is performed manually. In a report dated 1984,¹ it was stated that at that time the ventilation systems were controlled to maintain the CO concentration below 120 ppm.

There are currently eight lanes at the toll plaza and two were automatic toll machines until 1993, when the automatic tolls were converted back to manual lanes. The toll booths have never received fresh air ventilation from a remote source (i.e. received only local ambient air through openings in the booth). The present toll plaza is located at the top of the grade leading from the tunnels. The plaza is at a level that is equivalent to the surrounding residential area which consists of one to three story buildings. Thus, natural air movement is not particularly obstructed, nor is it facilitated by the surroundings.

Three observation booths were originally included in each tunnel. The observation booths were initially designed to receive fresh air from the tunnel ventilation system. The performance of this design has been a function of the rate of air influx (CFM), the amount of leakage into the booth, and the concentration of CO outside the enclosure. The employees must walk into the tunnel along the catwalk to reach their assigned booths.

The present assignment of employees during a day-time shift typically includes eight employees assigned to the toll lanes (three relief + five full duty) and four assigned to one observation booth within each tunnel. The tunnel guards typically spend two two-hour periods during their work shift inside the tunnel, with two two-hour periods at the toll plaza and on breaks. The same pool of employees are used for both job tasks on a rotating basis.

Employee Exposure to Carbon Monoxide

In 1962, Larsen reported sampling results for CO inside the Sumner tunnel. Additional sampling was performed at a toll booth, but was not reported. MSA Hopcalite CO monitors were used to obtain continuous stationary air sampling data. Over a period of one week, the 1-hour average CO concentrations inside the tunnel ranged from 22 ppm to 111 ppm.² In addition, the instantaneous peak concentrations were determined. The concentrations varied with time of day and traffic density. Figure 14 below depicts those results. Employees assigned to the observation booth probably had exposures similar to the levels displayed in this graph.

A survey of police officers' exposures to CO in downtown Boston was performed by Burgess, et.al. during 1970. Sampling was performed during the work-day during all seasons. Although the sampling location was not at the Sumner toll plaza, the police officers were usually located within traffic while directing. This data therefore may serve as a surrogate for toll collectors exposures during this time period. The seasonal average concentrations reported ranged from 7-18 ppm.

In 1973, a large study was performed by Arthur D. Little, Inc. for the MTA to characterize exposure to CO among Sumner-Callahan Tunnel employees working at the toll booths.⁴ Sampling was performed continuously using a non-dispersive infrared analyzer with the inlet attached at head

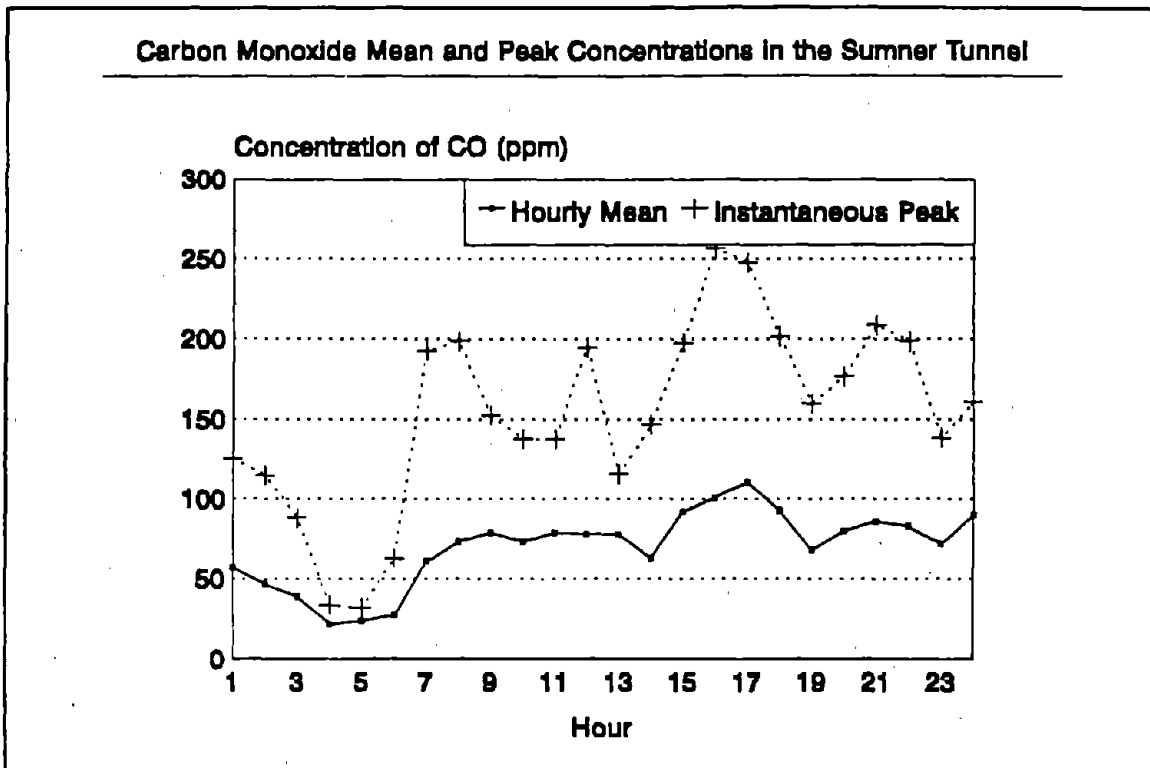


Figure 14 - The monitoring data above was collected in 1962.

level at the window opening on the toll booths. Average exposures to toll collectors are reported in Table 3 below. The data is a summary of several hundred 5-minute average sampling results.

Table 3
**Carbon Monoxide Concentrations (PPM)
 Breathing Zone Exposures at All Toll Lanes**

Shift (Start)	Summer	Winter
1 (00:30)	14	15
2 (08:30)	22	19
3 (16:30)	29	22

An important finding made during the study was that there was very little difference in CO concentration between the different lanes. No lane differed from the plaza average by more than 3 ppm. Therefore, the average plaza level or data from only one toll booth could serve as a accurate indicator of overall exposure. Another conclusion drawn from the data was that there is little or no difference in the CO concentration between the winter and the summer.

The following data (Figure 15), which were also included in the A.D. Little report, show how the CO concentrations change during the day and are affected by traffic volume and wind speed.

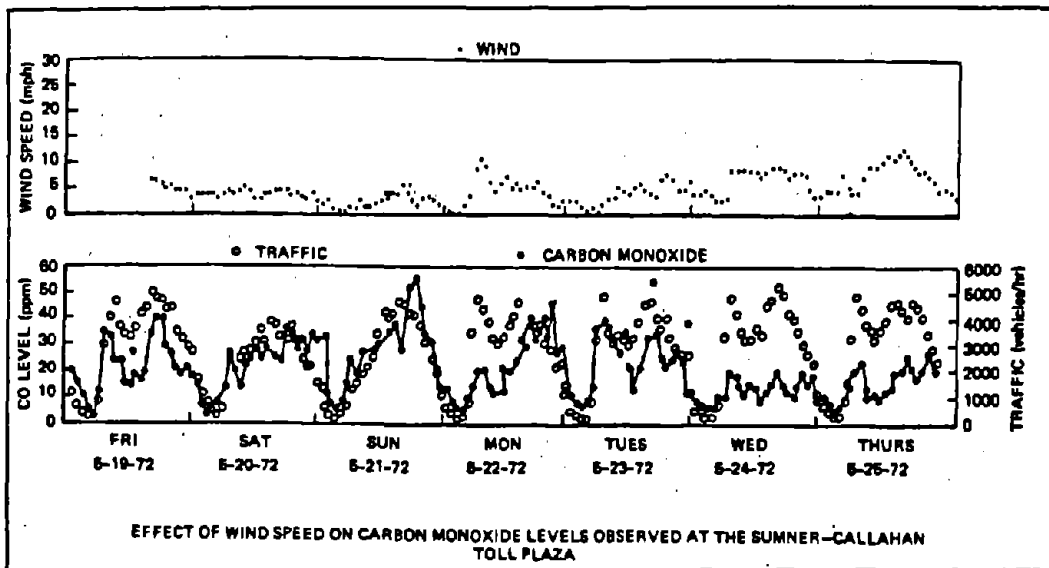


Figure 15 - This data was collected in 1973.

The effect of increasing wind speed is especially prominent during Wednesday and Thursday.

The A.D. Little survey also assessed the exposures to the tunnel guards stationed in the observation booths. Depending on which shift they were monitored, the range of 8-hour time-weighted average exposures ranged from 13-71 ppm and a mean equal to 32 ppm in the Callahan Tunnel, and a range of 16-62 ppm and a mean of 35 ppm in the Sumner Tunnel. These exposures assumed that the shift included two hours plaza duty at 20 ppm CO and two hours on breaks at 10 ppm CO. Additional sampling was performed inside the observation booths and outside the booths so that the difference could be compared. Among three booths in each tunnel, no difference was determined. Overall (all three shifts and three booths in each tunnel), the ratio of inside to outside concentrations in the Callahan Tunnel was 1.03, and was 0.94 in the Sumner Tunnel.

In 1984, an Air Quality Impact Analysis was performed by TRC Environmental Consultants which monitored the CO concentration in the exhaust air from each tunnel. Continuous measurements were taken over four 24-hour periods during low ambient temperature conditions during work week days. The results of that sampling are shown below in Table 4.

Table 4
Carbon Monoxide Concentrations in Exhaust Air From
Sumner and Callahan Tunnels, 1984

Sumner Tunnel			Callahan Tunnel		
Highest 1-Hour Average	Highest 8-Hour Average	24-Hour Average	Highest 1-Hour Average	Highest 8-Hour Average	24-Hour Average
80	58	34	70	42	25

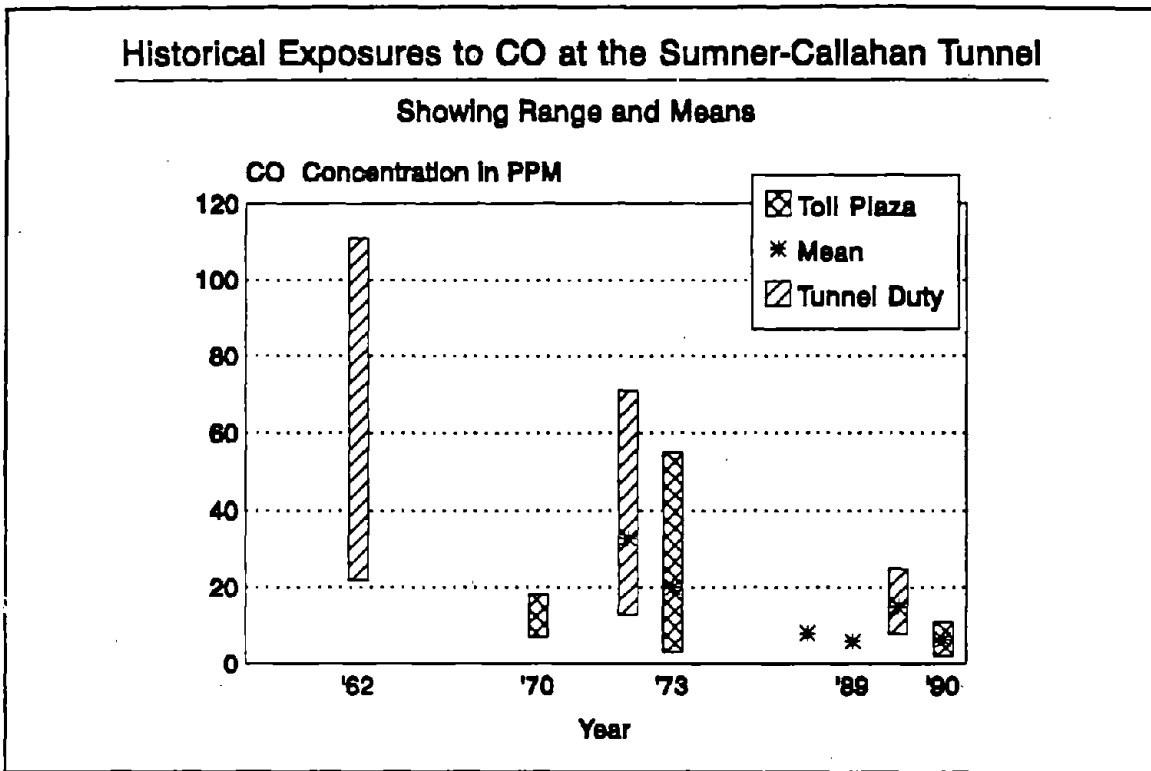


Figure 16

Surveys were performed by NIOSH in November, 1989 and in August, 1990 to characterize the extent of exposure to CO at the toll booths and while on duty inside the observation booths. National Draeger 190 personal dosimeters were worn in the shirt pocket of the employees during all three shifts. The mean exposures to toll collectors during both surveys were 6 and 6.4 ppm, respectively (using only the day shifts for better comparison to the historical data). The range of 8-hour TWA exposures was 2-11 ppm. Employees assigned to the tunnel observation booths were more exposed than if they had been assigned to the toll booths. The mean 8-hour average exposure in the tunnel was 8 ppm during the November survey and 15 ppm during the August survey, range 8-25 ppm.

The results of the current study and all earlier studies are summarized in Figure 16 which depicts all the historical monitoring results that were available.

References

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3. Burgess, W., L. Diberardinis, F.E. Speizer: Exposure to Automobile Exhaust. Arch. Environ. Health 26:325-329, 1973.
4. Arthur D. Little, Inc.: Survey of Air Quality at Facilities of the Massachusetts Turnpike Authority. Final Report to the Massachusetts Turnpike Authority, July 8, 1974.

Massachusetts Port Authority

Tobin Memorial Bridge

Construction on the Tobin Memorial Bridge was completed in 1950. The bridge spans the Mystic River between Charlestown and Chelsea and carries the traffic on U.S. Route 1. Ownership and operation of the bridge was transferred from the City of Boston to the Massachusetts Port Authority in 1959.

The bridge consists of an upper and lower level, each taking one-way traffic. Until 1983, tolls were collected on both levels, at which time the collection of tolls was discontinued on the lower level. Each of the toll plazas consisted of seven toll booths. In 1983, two of the seven upper level booths were converted to automatic stations. None of the booths were ever ventilated by forced air. In 1990, new toll booths were installed on the upper level with supplied forced air ventilation which is temperature controlled. The toll booth location is on the bridge and is at an elevation of approximately 115 feet over the river. With this location as it is, it is commonly noted that the site is affected by windy conditions that prevail most of the year.

After an initial increase in traffic counts during the first decade of operations, traffic has increased more gradually from 1960 until the present. There have been intermittent changes in traffic due to construction projects, both on the bridge itself (decreasing traffic) and at the Sumner-Callahan Tunnel (diverting traffic to the Tobin bridge). Total annual traffic counts are plotted in Figure 17.

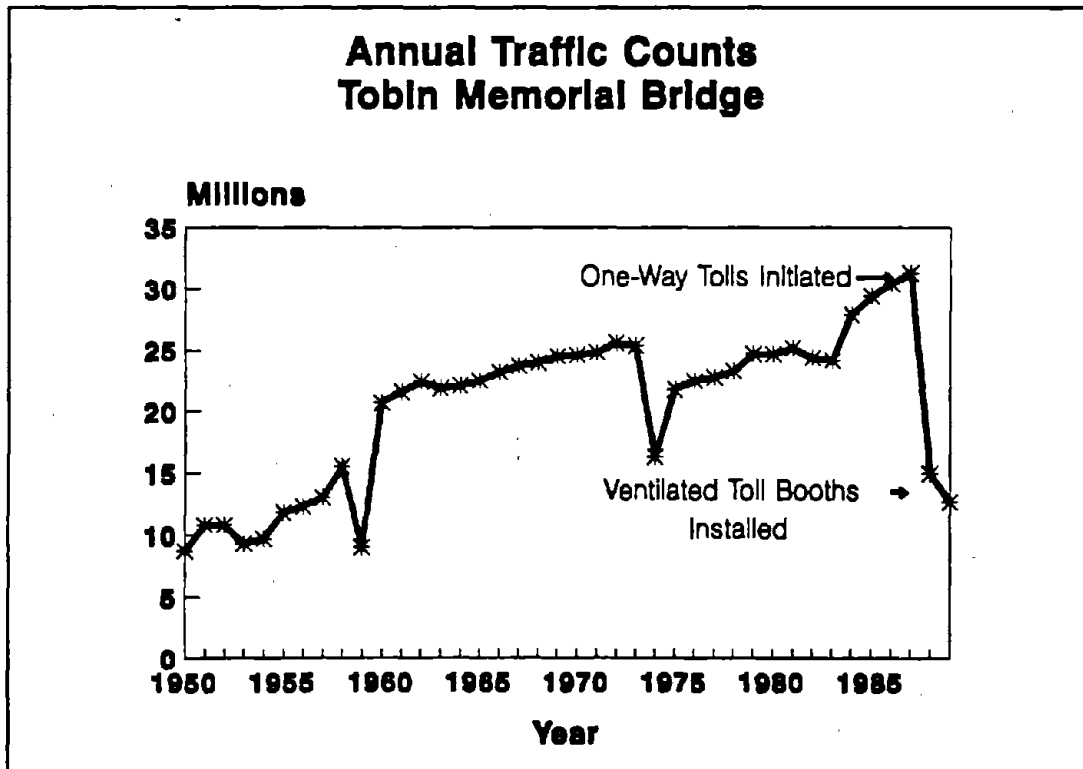


Figure 17

Three shifts are operated each day for toll collectors: 6:00 a.m.-2:00 p.m., 2:00 p.m.-10:00 p.m., and 10:00 p.m.-6:00 a.m. Start and end of shift times are staggered, so there is a slight variation in the exact times employees are on duty. Two twenty-minute breaks and one 30-minute meal break are provided during each shift.

Maintenance workers include mechanics, painters, electricians, and others needed to maintain the integrity and operation of the bridge and associated facilities. They could be exposed to carbon monoxide if their work required that they be around operating vehicles. The maintenance workers are on duty from 6:30 a.m. til 3:00 p.m.

Employee Exposure to Carbon Monoxide

Other than the recent extent of exposure monitoring that was performed by NIOSH, no other environmental exposure surveys are known to have been performed at this location. It has been assumed that because of the elevated location of the toll plaza, ambient breezes remove vehicle exhausts effectively.

During November 6-9, 1989 NIOSH conducted an extent of exposure study for carbon monoxide at the Tobin Bridge. A total of 45 full-shift personal samples were collected on toll collectors and maintenance workers. Samples were collected from toll collectors over all three shifts and on two shifts from maintenance workers. Samples were obtained using National Draeger 190 dosimeters.

In addition to the exposure data, weather data were obtained during the monitoring period. During the survey, the average temperature was 53°F and the average wind speed was 9.2 mph (range 0 - 19 mph). The average historical wind speed during the month of November at the Boston International Airport is 13.0 mph. The average annual wind speed is 12.5 mph. Therefore, it would be unusual for wind speeds to be much lower, on average, than were encountered during this survey. The results of the exposure survey are shown on the following page in Table 5.

Historical exposures are believed to have been higher, despite the lesser traffic volume, because of the greater pollutant emissions per vehicle. This is the pattern at all other toll facilities, except where traffic has increased at least eight to ten-fold since 1970, when emission controls were initially introduced. In addition, exposures at the lower level toll plaza may have been higher than on the upper level toll plaza due to the capping effect of the upper deck over the lower plaza. Since the lower toll plaza has not been used since 1983, this theory could not be tested.

Table 5
 Summary of Personal Exposures to Carbon Monoxide
 Tobin Memorial Bridge Maintenance Workers and Toll Collectors
 November 6-9, 1989

Job	Shift ¹	Number of Samples	Average 8-Hour Conc. (ppm)	Range	Average 1-Minute Concentration	Highest 1-minute Concentration
Maintenance	2	3	2	1-3	45	80
	3	6	6	1-19	264	817
Toll Collectors	1	15	2	1-3	32	136
	2	7	2	1-2	58	79
	3	14	4	2-7	70	154

Footnote:

¹ Shift 1 began approximately 10:30 p.m.; shift 2 began approximately 6:30 a.m.; and shift 3 began approximately 2:30 p.m.

Maryland Transportation Authority

The Maryland Transportation Authority (MdTA) operates several bridge and tunnel toll facilities around the Baltimore metropolitan area. Included in the cohort mortality study are the following facilities: 1) Baltimore Harbor Tunnel, 2) Fort McHenry Tunnel, 3) Francis Scott Key Memorial Bridge, 4) Harry W. Nice Memorial Bridge, 5) John F. Kennedy Memorial Highway, 6) Thomas J. Hatem Memorial Bridge and 7) William Preston Lane Memorial Bridge.

Description of Facilities

Baltimore Harbor (Patapsco) Tunnel

The Baltimore Harbor Tunnel was opened to traffic in 1957. The tunnel consists of separate east-bound and west-bound tubes. The toll plaza is located on the west side of the harbor.

Thirty-two fans provide fresh air through a duct underneath the roadways and exhaust air above the roadway ceiling. The fans are driven by 450 horsepower electric motors. The tunnel is designed for full ventilation to be approximately 6,075,000 cfm total for both tubes. Approximately 1,500,000 cfm is supply air and an equal amount is exhaust air in each of the tubes, providing approximately 476 cfm per linear foot of tube.

There are normally two peak traffic periods Monday through Friday, of approximately three hours each, centered on 8:00 a.m. and 5:00 p.m. Traffic volume is heavier southbound in the morning and heavier northbound in the late afternoon. Heavy vehicle traffic accounts for about 5% of all traffic presently, but the ratio was as high as 15.5% in 1962 and remained above 10% until 1987.

Air in the exhaust ducts is continuously sampled and analyzed for carbon monoxide by four analyzers, two in each ventilation buildings. The results of this analysis are recorded by four strip chart recorders on the headquarters control panel. The recorders are set to alarm if the concentration exceeds 250 ppm, warning the operator that the CO concentration is objectionably high. Tanks of zero and 400 ppm span gas are connected to the analyzers through solenoid valves. The CO analyzers are automatically calibrated every 96 hours.

Police officers are assigned to several locations. Inside the tunnels are eight observation booths. Special tunnel officers were assigned to these posts with two 2-hour periods inside the tunnel and two 2-hour periods either at the truck inspection post outside the entrance to each tube or at the Fairfield or Canton Garages. Although the observation booths are ventilated and reportedly reduced pollutant exposures effectively, the practice during peak traffic hours was for officers to stand outside the booths to direct traffic. Officers at the garages are basically on stand-by, waiting to respond to a vehicle breakdown with a tow-truck. Overall, officers spent the least amount of time stationed inside the tunnels. In 1987, video cameras were fully operational inside the tubes and officers were no longer stationed there.

There have always been 13 toll booths at a single plaza. The current toll collection booths were installed in 1989 and are equipped with forced fresh air ventilation. At the Baltimore Harbor Tunnel, the air intake for the booths is located on the side of the Administration Building away from the tollbooths and traffic. (The Administration Building is located parallel and adjacent to the traffic lanes at all sites.) A forward curved fan provides 13,000 cfm of air to ventilate the Administration Building and tollbooths. For the tollbooths, air moves through the main air supply duct (24" x 36") located in the personnel tunnel beneath the tollbooths. At each booth, an air duct (12" x 12")

branches off from the main duct. This duct again divides into two ducts (12" x 3"), one duct going to each door of the booth. The air exits through a louvered slot (1.75" wide and 33" long with louvers on 0.625" centers) in the lower half of the door jamb. The air velocity at the slot ranged from 200 to 1100 fpm, averaging 600 fpm or 150 cfm. Measurements were made by NIOSH at one booth at each site. The previous booths were equipped in 1973 with air conditioning and a filter "air purifier" installed in the air inlet from the outside. This probably had no effect on exposure to carbon monoxide and other gaseous pollutants. The older booths extended all the way up to the canopy, blocking air flow. The newer booths are only half the height of the canopy and allow greater air circulation.

Fort McHenry Tunnel

The Fort McHenry Tunnel was opened to traffic in 1985. It is the world's largest underwater vehicular tunnel. The opening of this tunnel greatly reduced the traffic going into the Baltimore Harbor Tunnel. At times, traffic used to back up three miles behind the toll plaza. Because only a small fraction of the deceased cohort had ever worked at this facility, this report does not characterize the facility and the extent of exposure to CO among its employees.

Francis Scott Key Memorial Bridge

This bridge was first opened in 1977. Seven new toll booths were installed in 1989 that are provided with forced fresh air ventilation. The air intake is located behind the administration building away from traffic. The ventilation system is similar in design and capacity as the one at the Harbor Tunnel. At the Key Bridge the toll booth air velocities at the slot range from 300 to 640 fpm, averaging 430 fpm or 100 cfm.

Harry W. Nice Memorial Bridge

This bridge was first opened in 1940. It crosses the Potomac River south of Washington, D.C. Current traffic is about 4 million vehicles yearly. Four toll lanes exist on the plaza. In 1985, new ventilated booths were installed on the toll plaza. Heavy commercial traffic accounts for about 11% of all vehicles today but this ratio has been as high as 25.5% in 1958.

John F. Kennedy Memorial Highway

This highway toll plaza was dedicated in 1963. The toll plaza presently collects tolls from over 18 million vehicles each year. There are 14 toll lanes and tolls are collected in each direction. The toll booths are not mechanically ventilated.

Thomas J. Hatem Memorial Bridge

This bridge was originally opened to traffic in 1940. It spans the Susquehanna River. Traffic volume is over 7 million vehicles per year. None of the five toll booths are mechanically ventilated.

William Preston Lane Memorial Bridge

This bridge was originally a two-lane structure and opened to traffic in 1952. It crosses the Chesapeake Bay south of Baltimore and provides ready access during the summer to ocean recreational areas. By 1967, traffic had more than doubled and a second three-lane bridge was added in 1973. Traffic volumes today exceed 16 million vehicles per year. New fresh air ventilated toll booths were installed on the toll plaza in late 1990. At that time one-way tolls were initiated in the east-bound direction. There are 12 toll lanes in the toll plaza. Heavy commercial

vehicles have accounted for about 10% of all vehicles on the William Preston Lane Memorial Bridge since its inception. The amount of traffic received by this bridge during the summer dramatically increases by about 50%.

Toll collectors at each of the above facilities were on a rotating shift schedule prior to 1985. Now almost all toll collectors are on a fixed schedule.

Data on past annual traffic volumes at each of the respective facilities operated by the Maryland Transportation Authority are presented in the following graph.

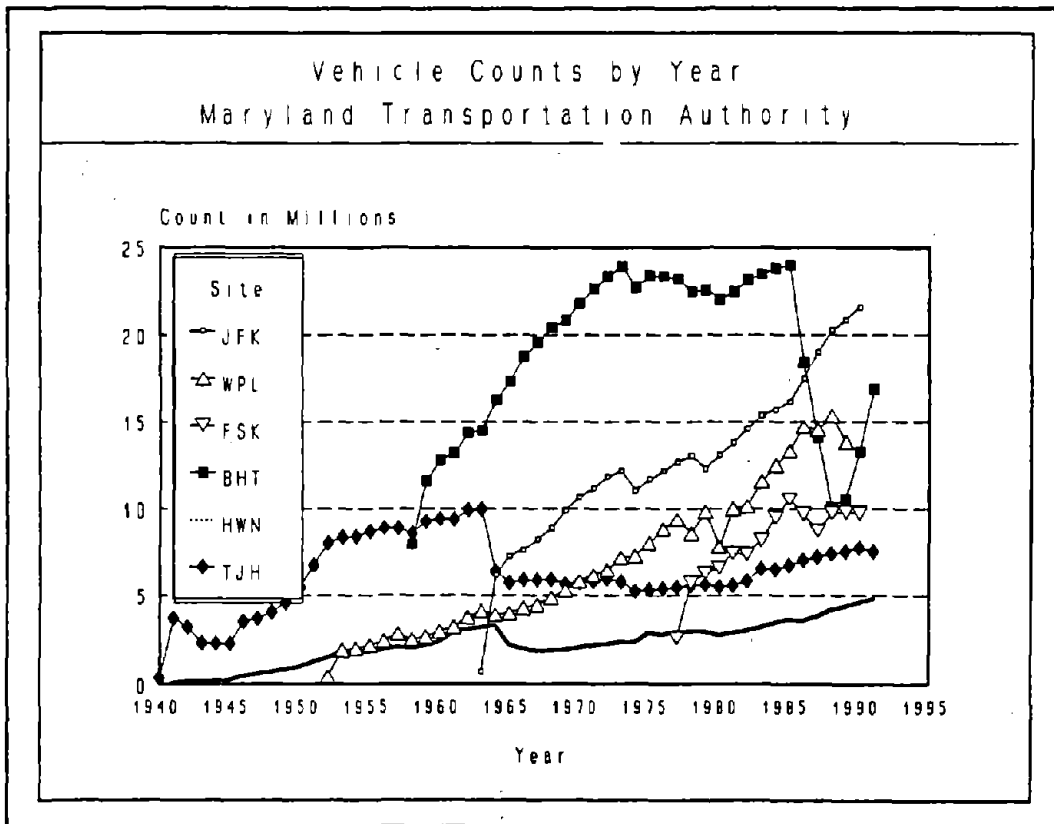


Figure 18 - Abbreviations: JFK = J. F. Kennedy Mem. Hywy.; WPL = Will. Preston Lane Mem. Br.; FSK = Fran. Scott Key Mem. Br.; BHT = Balt. Harbor Tun.; HWN = H. W. Nice Mem. Bridge; TJH = T. J. Hatem Mem. Br.

Description of Employee Exposure to Carbon Monoxide

Very little monitoring of exposures is known to have been performed at these sites. The current extent of exposure data serves as the primary means of comparing exposures here to exposures at other toll collection authorities in this study.

Old (1975) ventilation reports from the Baltimore Harbor Tunnel were retrieved and inspected for the levels of average and peak CO concentrations that were recorded on the strip chart recorders. Regardless of season, average concentrations during most of the day were between 50 to 100 ppm. Short-term concentrations during the day ranged from 30 to 200 ppm. Concentrations were similar in both tubes.

On June 11, 1976, inspectors from the state Department of Licensing and Regulation, Division of Labor and Industry conducted a survey of the Baltimore Harbor Tunnel and support buildings. Inside the tunnel, CO levels averaged for one hour ranged from 211 ppm to 52 ppm (method unspecified). The average one hour TWA was 103 ppm. Conditions of traffic were not specified in the report. At the end of the work shift, breath analysis was performed to ascertain carboxyhemoglobin levels. None of the officers exceeded 10% COHb.

During the above survey, toll collectors were also monitored for six air contaminants. Only the highest 8-hour TWA's were reported which were as follows: carbon monoxide, 32 ppm; lead, 16 mg/m³; acrolein, 0.007 ppm; formaldehyde, 0.04 ppm; nitrogen dioxide, 0.03 ppm; and respiratory dust, 0.18 mg/m³.

In a second survey conducted at the Baltimore Harbor Tunnel by the state Department of Licensing and Regulation, Division of Labor and Industry on November 7, 1986 officers were monitored for exposure to noise, carbon monoxide and asbestos. Peak levels of noise inside the tunnel reached as high as 112 dBA. Carbon monoxide levels were surveyed using two MSA CO dosimeters. Carbon monoxide levels outside one of the booths inside the tunnel ranged from 13-20 ppm while CO levels inside the booth were between 6-8 ppm. The corresponding TWA's were 17 and 7.6 ppm. According to the report, since the officers spent about half of their time in the tubes, their 8-hour TWA exposure was likely to have been about 5 ppm. These results are evidence of the effectiveness of the ventilated booths to reduce exposure. Asbestos sampling results ranged from 0.1 f/cc to less than 0.02 f/cc.

In a third survey conducted during August, 1987 CO exposures at the Ft. McHenry Tunnel and Lane Memorial Bridge toll plazas were monitored. It was suggested that this time of year represented peak traffic conditions and perhaps, less favorable weather (lower wind speeds). Surveys were conducted on Friday evening shifts. Two Ecolyzer CO analyzers were used for the surveys and were attached to Metrosonic Data Loggers[®]. The wind conditions were described as mild. The results are reported in Table 6 below. Included in the table are the highest instantaneous peak concentrations, average 8-hour TWA, and 15-minute short-term exposure level (STEL) measured.

Measured Carbon Monoxide Concentrations (in PPM)
Table 6

Location	Date	Lane #	Peak	Avg.	15-min STEL
Ft. McHenry Tunnel	7-31-87	16	110	6	14
Lane Memorial Bridge	8-7-87	9	108	13	22
Lane Memorial Bridge	8-7-87	10	101	7	20

At the request of the Maryland Department of Transportation, monitoring for carbon monoxide was conducted over a 24-hour period in the west tube of the Baltimore Harbor Tunnel. The study was performed by Aerosol Monitoring & Analysis, Inc. during June 30 through July 1, 1987. Sampling was performed at several of the observation booths using MSA mini CO V monitors and Neotronics Model 40C carbon monoxide monitors. The results of the 24-hour continuous sampling period found average CO concentrations as shown in Table 7.

Table 7

Station G	Average PPM	Station F	Average PPM
8am-6:30pm	22	8am-6:30pm	25
6:30pm-12am	2	8pm-12am	18.5
12am-8am	6	12am-8am	15.7

During four to five day surveys in February, 1991 and August, 1991, NIOSH conducted extent of personal exposure monitoring for CO among toll collectors. Sampling was accomplished using National Draeger 190 dosimeters with data-logging capability and the collected data were transferred into a computer at the end of each work shift. The dosimeters were worn primarily in the breast shirt pocket if they were personal samples, or else on the belt of each employee. In addition to the exposure data, hourly weather information and traffic counts were obtained during the monitoring period. Table 8 summarizes that data.

It can be seen that all current exposures to CO at the sites monitored are low relative to the sites at the other authorities and compared to all established exposure criteria. Ventilated booths at the Baltimore Harbor Tunnel are one factor which contributes to this and low traffic counts through most of the facilities are another. The average wind speeds at these locations are also greater than the average wind speeds near New York City or Boston.

Table 8
Carbon Monoxide Personal Exposures (in PPM) At Baltimore Toll Facilities

Location	Date	Number of Samples	Average 8-Hour TWA	Average 15-Minute Max.	Average 1-Minute Max.	Maximum Peak Exposure	Wind Conditions (mph)	Daily Traffic
FSK Bridge ¹	2/25-27/91	24	1	6	30	88	9.1	25,000
FSK Bridge ¹	8/20-22/91	24	2	12	42	186	6	28,000
JFK Hywy	2/26-3/1/91	32	1	6	23	98	7.8	no data
JFK Hywy	8/20-24/91	61	2	9	33	73	<6	50-90,000
BHT ²	2/26-3/1/91	63	1	5	19	59	7.8	50,000
BHT ²	8/20-24/91	51	2	10	37	109	6	53,000
WPL Bridge	2/27-3/1/91	20	1	8	23	98	6.5	14,000
WPL Bridge	8/23-24/91	21	3	10	49	143	<6	57-90,000

Notes:

1. No effect of the booth ventilation system was determined on exposures.
2. The booth ventilation system reduced exposures by 80%.

Within-Shift Exposure Variation

An employee's daily exposure to CO can be highly variable. Figure 19 displays the 8-hour workshift profile of CO exposures for one toll collector at the Goethals Bridge. The break periods can be seen in the figure as well as the elevation in CO concentrations during the afternoon rush-hour period. The time-weighted average was 6 ppm and the highest peak exposure was 59 ppm. This sample was taken with a Draeger CO monitor 190 during a NIOSH survey in February, 1992.

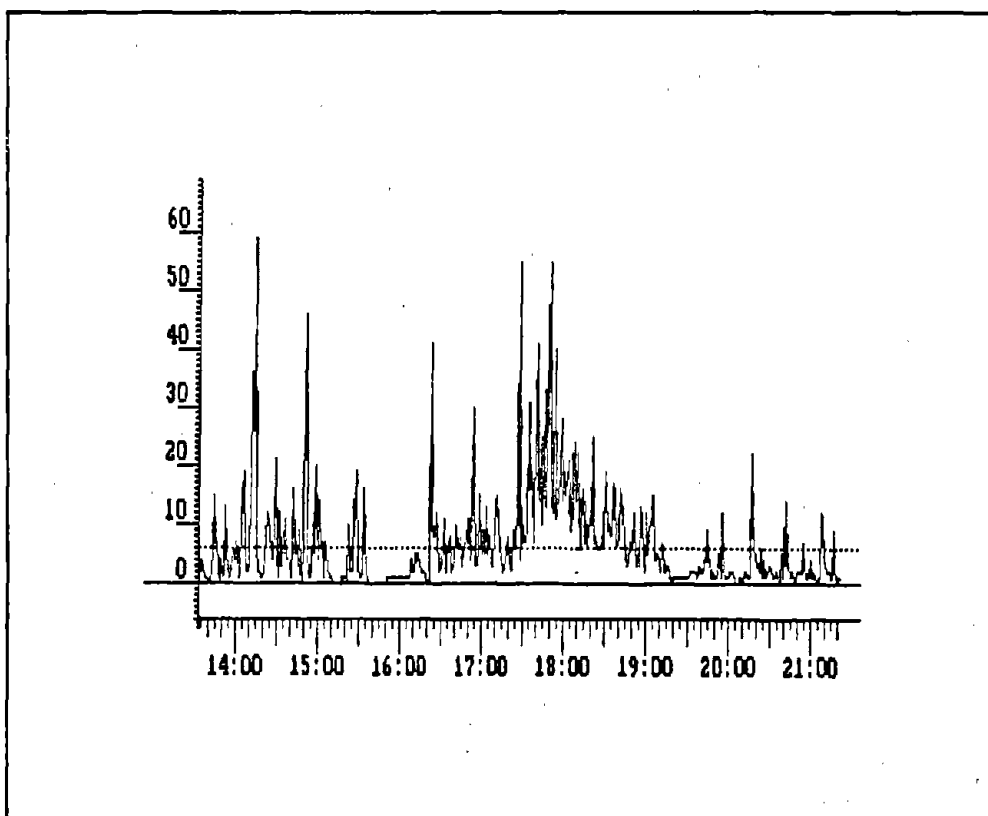


Figure 19 - Carbon Monoxide Exposure of Toll Collector, Goethals Bridge, February 1992

A histogram of the average number of minutes exceeding various concentrations of CO in a random subset of 20 toll collectors at the Lincoln Tunnel are shown in Figure 20. The samples were taken during the summer, 1990 and probably represent some of the highest exposures among the PANY&NJ toll facilities. The distribution of the concentrations is log-normally distributed. All samples used in this subset represent full 8-hour exposures.

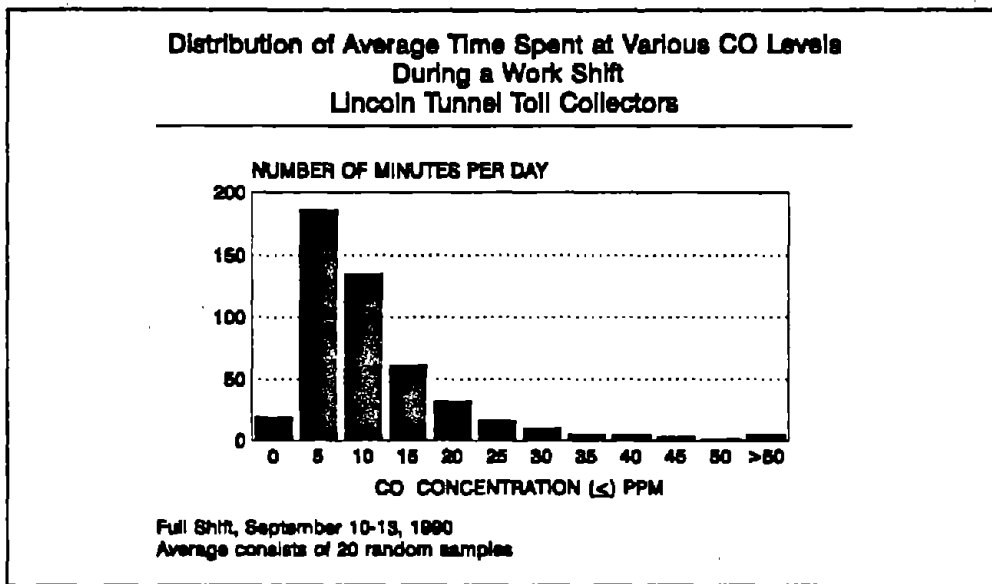


Figure 20

A further analysis of the highest 1-minute exposures in the above subset of 20 toll collectors is presented in figure 21. The mean peak exposure level was 87 ppm and the median was 80 ppm. These exposures are transient and constitute a small proportion of the workday.

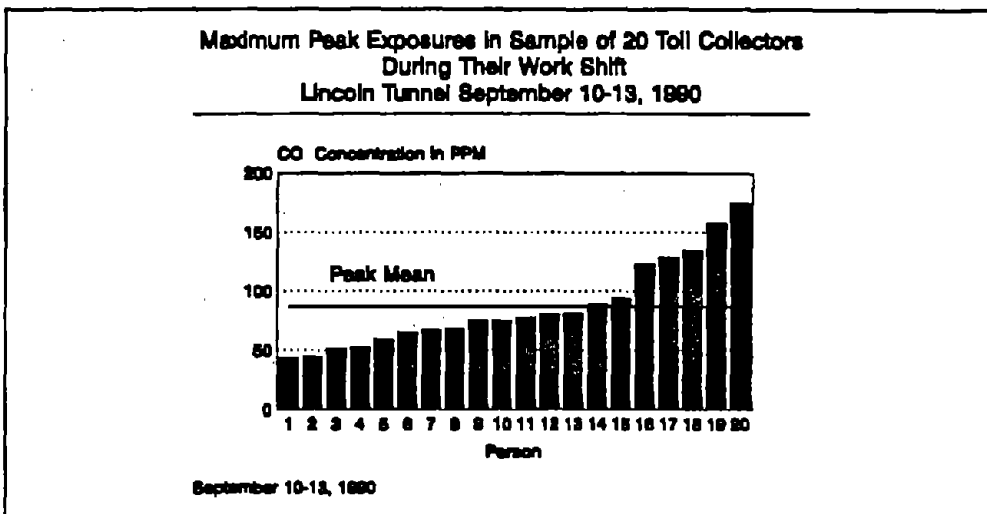
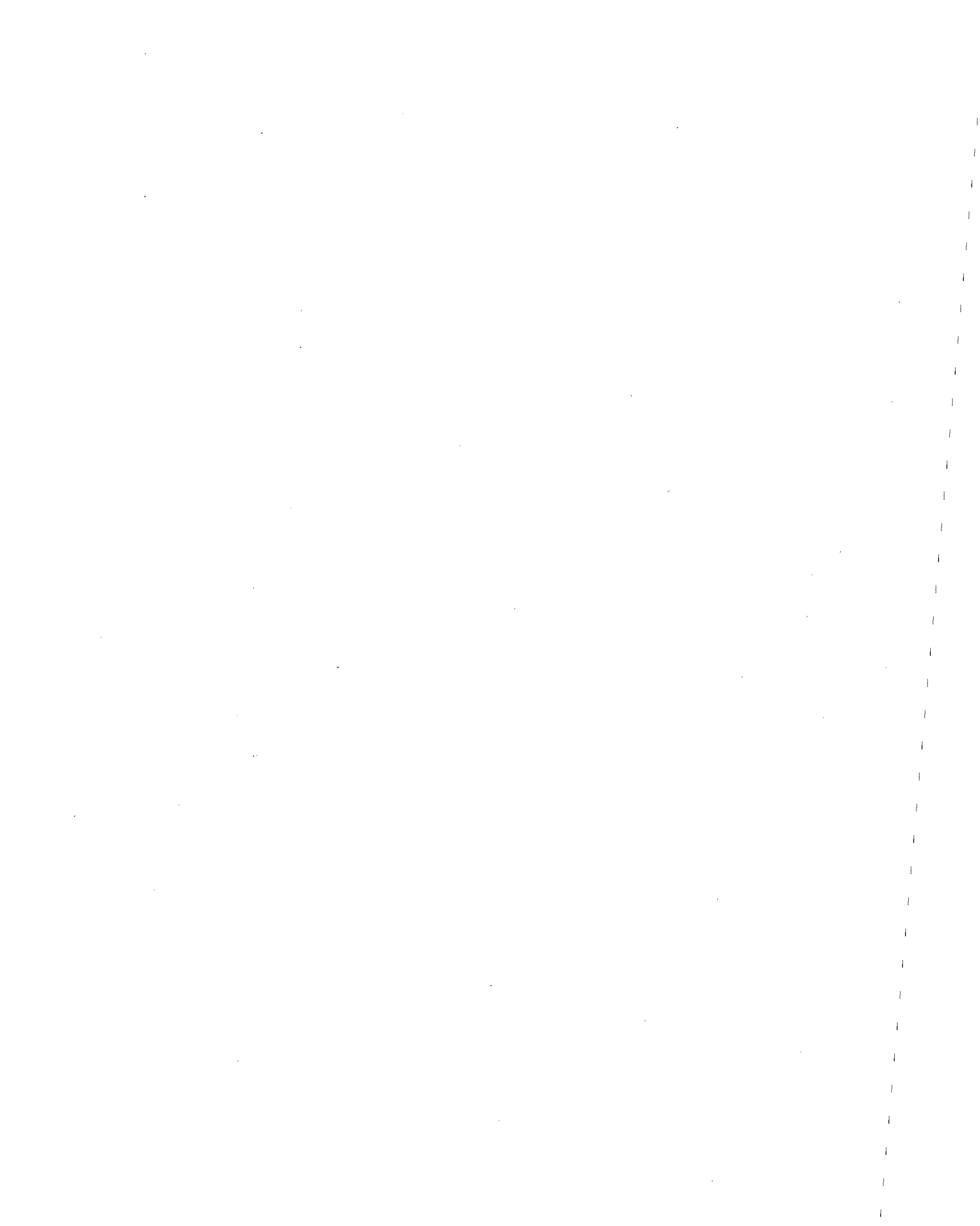


Figure 21

The mean air concentration of CO in the above personal exposure measurements is 8 ppm. As can be seen from the data distribution in Figure 20, most of the time spent by these workers was in air containing a lesser concentration than the current criteria of 35 ppm specified by NIOSH and OSHA. However, transient peak exposures between 50 to more than 150 ppm typically occur during the work shift. Historical 8-hour TWA exposures were known to be much higher, according to the historical sampling results. There is less information on magnitude of short-term exposures among these workers. Information on the distribution of current short-term concentrations may be useful in estimating the historical occurrence of high exposures during a typical workshift when only the mean exposure is known. The occurrence of short-term high level excursions of CO and its relationship to health is discussed in the Discussion section of this report and the epidemiology report.



Other Exposures

The study population is exposed to other environmental pollutants besides CO which may contribute to heart disease and lung cancer. Among the possible contributors to heart disease that have been identified include noise, inorganic lead, ozone and peroxyacetyl nitrate (PAN). In addition to chemical exposures, there are potential ergonomic and mental stresses associated with the continuous collection of tolls. These pollutants were not sampled during the NIOSH exposure surveys and the following information on these exposures is taken from other sources.

Occupational exposure to noise at most of the toll booths associated with this study is between 75-86 dBA on a 8-hour time-weighted average. Within the tunnels, noise levels vary between 75-120 dBA. These measurements have been taken recently and it is not known how well they represent past exposures.¹

Current exposure to inorganic lead is consistently below 0.001 mg/m³ in measurements taken at the toll booths by the PANY&NJ. In the past, before leaded gasoline was phased out of use by the USEPA, air concentrations were higher. In the early 1970's, air concentrations at toll booths in New York City averaged 31 ug/m³ with peaks of about 90 ug/m³.² Currently, NIOSH recommends that lead exposure not exceed 0.1 mg/m³ as an 8-hour TWA.

Strong oxidants, like ozone and peroxyacetyl nitrate have not been detected in tunnel air during peak traffic flow.³

The study population is exposed to air contaminants that may be associated with respiratory cancer. In 1962, Scott Research Laboratories reported formaldehyde concentrations inside the Lincoln Tunnel as high as 0.65 ppm at the catwalk using a chromatographic acid method. The average concentration was about 0.1 ppm. Acrolein was also detected at a level of about 0.035 ppm. Total aldehydes, using a MBTH method, averaged 0.05 ppm, with peak concentrations of 0.16 ppm, inside toll booths in the metropolitan New York City area in 1972.² A survey of the Lincoln Tunnel in 1982 found that the formaldehyde concentration was 1.3% of the total non-methane organic carbon or 0.36% of the carbon monoxide concentration.⁴ NIOSH recommends that formaldehyde exposure not exceed 0.02 ppm as an 8-hour TWA or 0.1 ppm at any time. NIOSH also recommends that acrolein exposure not exceed 0.1 as a 8-hour TWA or 0.3 ppm during any 15-minute period.

Human response to diesel exhaust has been the subject of much research in recent years. In one nested case-control study of lung cancer among truck drivers and mechanics in the Teamsters Union, a statistically significant excess of lung cancer was found in long-distance (diesel) drivers with 35+ years of employment and almost a significantly elevated excess in those with 18+ years of employment.⁵ Extensive extent of exposure monitoring of elemental carbon concentration, which is a fairly specific marker of diesel exhaust, averaged 5.5 ug/m³. Residential background concentrations averaged 1.4 ug/m³ and roadway background levels averaged 3.4 ug/m³.

Limited elemental carbon monitoring was conducted at some of the PANY&NJ facilities and at the Sumner-Callahan Tunnel in Boston. The results of the analysis indicate toll collector's exposures to diesel exhaust summarized in Table 9 are higher

than that of the truck drivers in the Teamsters study. This is not unexpected since up to 12% of all vehicles passing the toll lanes are trucks and buses and the toll collectors experience the exhaust that accompanies the acceleration of these large vehicles as they are driven away from the toll booths. NIOSH has not issued a recommendation of an acceptable exposure limit for elemental carbon.

Stationary sampling was conducted at the Lincoln Tunnel, Holland Tunnel, and George Washington Bridge in New York and at the Sumner-Callahan Tunnel in Boston for elemental and organic carbon analysis. The samplers were placed primarily on those lanes most likely to receive the most truck and bus traffic. The sample media was attached at head level on the side of the open window through which the toll collectors collect tolls. The average elemental carbon concentration is shown in the following table.

Table 9
Average Elemental and Organic Carbon Concentrations
at Toll Plazas
1991-1992

Site	Elemental Carbon (ug/m ³)	Organic Carbon (ug/m ³)	Comment
G.W. Bridge	88.6	69.8	n=4, 8-10% truck traffic
Lincoln Tunnel	29.7	85.5	n=4, 12% truck traffic
Holland Tunnel	12.7	43.3	n=5, 6.5% truck traffic
Sumner-Callahan Tunnel	9.8	52.4	n=11, 2.5% truck traffic
Field Blank	0.0	3	
Field Blank	0.0	4	
Field Blank	0.0	3	
Ambient	2.3	14	Behind Lincoln Admin. Bldg.
Ambient	3.8	30	At hotel near G.W. Bridge
Ambient	0.3	17	At motel in Boston
Ambient	1.0	18	At motel in Boston

The concentration of elemental carbon corresponds to the proportion of diesel truck vehicles which pass through each of the sites that were monitored. The proportion of truck vehicles is reported for the entire facility, which may be less than the proportion actually passing a specific toll booth at which sampling was performed. This is because some lanes receive more truck traffic because of their proximity to the truck lanes that are designated for the roadway. The organic carbon concentration is presented also and is indicative of total nonvolatile organic matter in the air.

References

1. Data based on surveys performed by PANY&NJ and by NIOSH at the TBTA Queens Midtown Tunnel.
2. Ayes, S.M. et.al.:Health Effects of Exposure to High Concentrations of Automotive Emissions: Studies in Bridge and Tunnel Workers in New York City. Arch Environ. Health 27:168-178, 1973.
3. Taylor, F.R., O.P. Hellrich and W.E. Root: Survey of the Chemical Composition of the Atmosphere of the Lincoln Tunnel. Prepared for The Port Authority of New York Authority by Scott Research Laboratories,Inc., 1962.
4. Lonneman, W.A, R.L. Sella, S.A. Meeks:Non-Methane Organic Compositions in the Lincoln Tunnel. Environ. Sci. Technol. 20:790-796, 1986.
5. Steenland, K., D. Silverman, D. Zaebst: Exposure to Diesel Exhaust in the Trucking Industry and Possible Relationships with Lung Cancer. Am. J. Indust. Med. 21:887-890, 1992.

Historical Trends in Vehicle Emissions

Since the creation of the U.S. Environmental Protection Agency and the subsequent passage of the Air Quality Act in 1967, vehicle emissions in new cars have been reduced substantially. The 1970 Clean Air Amendments required that emissions of CO be reduced 90 percent by 1975. In 1973, the EPA Administrator delayed the deadline and set interim standards. The 1977 amendments further delayed the deadline to 1982. As the emission requirements pertain only to new vehicles and it takes time to replace older vehicles in use with these newer vehicles, no immediate impact on air quality associated with mobile vehicles should be expected. In addition, the aging of new vehicles significantly decreases their fuel efficiency and the effectiveness of pollution control devices. Thus, the observed decline in air pollution levels lags by several years the introduction of new low-polluting vehicles to the roadways.

The USEPA has a program which entails road testing of a random sample of all vehicles. This program began in 1970. The results of their testing of tail pipe emissions of idling vehicles, from estimates beginning with 1965 to actual measurements since the inception of that program, are shown in figure 22. The data indicate a reduction of CO emissions only after 1980.

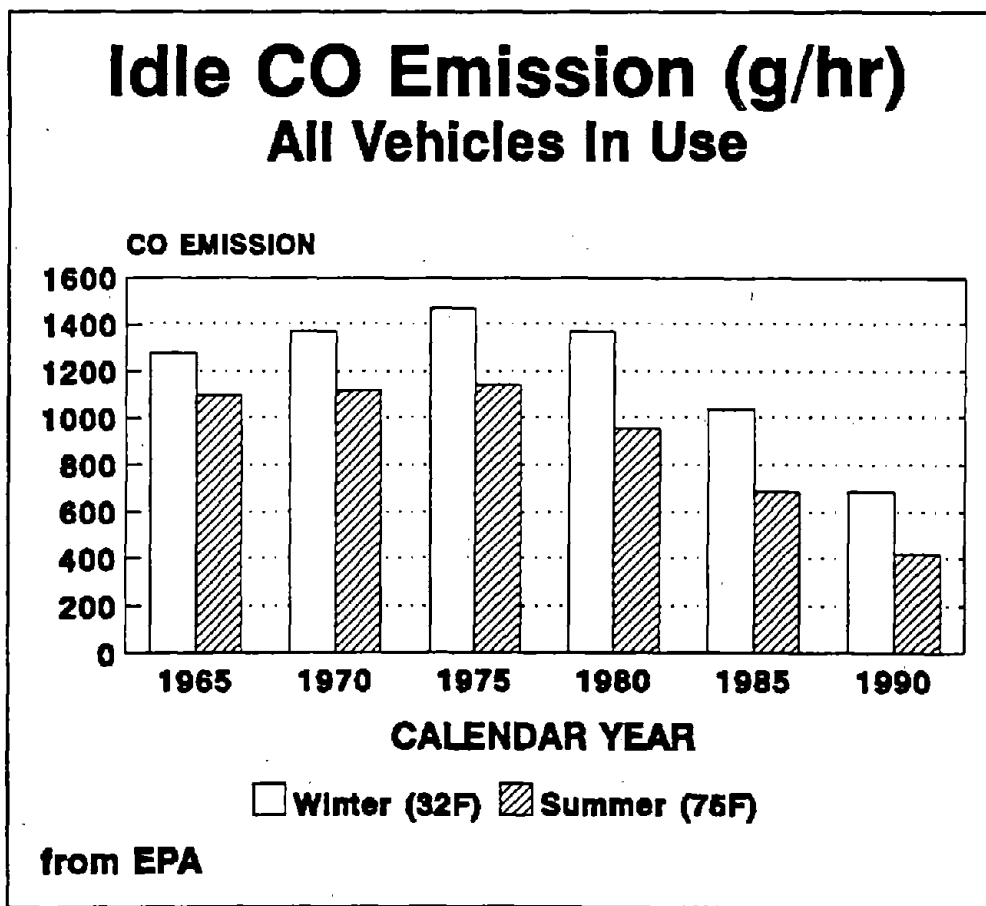


Figure 22

Unfortunately, vehicles stopping at toll plazas also accelerate rapidly once the toll is paid. This complicating factor cannot be addressed with the existing EPA data. The affect of acceleration on CO emissions can be seen in Table 10. The amount of CO produced per linear foot of travel is greatest during acceleration and especially high when the vehicle is accelerating from slow speeds, which best corresponds to acceleration from a toll booth.

Table 10
Carbon Monoxide Generation
CFM x 10⁻⁶ per Foot of Travel, Average Vehicle

Speed (mph)	Downgrade	Level	Acceleration	Upgrade
35	21	29	100	44
30	23	33	116	51
25	26	36	138	58
20	29	40	160	66
15	38	51	210	82
10	54	66	269	114

Data taken from report by F. Roehlich, MSA Research Corporation, Evans City, PA entitled "Development of an Air Purifier for Personal Cubicles", paper presented at 1974 Am. Indust. Hyg. Conf., Miami Beach, FL. Work under contract with NIOSH, Cincinnati, OH.

Dissimilar results to the EPA data comes from the study by Lonneman, which compared the amount of CO measured inside the Lincoln Tunnel in 1970 and 1982.¹ In 1982, the concentration of CO (presented as parts per billion of carbon) inside the tunnel was 24% of the concentration measured in 1970. The authors did not believe that the difference was due to lower traffic densities or to higher exhaust ventilation in the tunnels, although it was unclear from the publication if support for this assumption existed. Instead, the authors attributed most of the decline to reduced vehicle emission rates.

A comparison of the exposure monitoring data from the past (mid-1970's and before) and present suggests that the exposure levels today have declined to about one third the previous levels. A similar trend in the EPA CO emission data is seen, and the magnitude of change is similar (one-third to one-half lower presently).

Reference

1. Lonneman, W.A., R.L. Sella, S.A. Meeks: Non-Methane Organic Compositions in the Lincoln Tunnel. Environ. Sci. Technol. 20:790-796, 1986.

Summary of Historical Trends in CO Exposures and Comparison Between Facilities

Generally, employee exposures to CO have declined over time at the toll facilities studied. This observation is based primarily on survey data from the past and present. However, because exposure is a function of vehicle emission and vehicle number, the latter factor must also be considered when referring to trends in exposure since the use of some of the toll facilities has dramatically increased in some cases, while remaining much the same at other facilities. Numerous examples of each case can be seen in any of the figures within the sections describing the facilities that show the annual traffic counts. Where traffic has increased six-fold since the 1970's or before, current exposure measurements are not appreciably different from past exposures occurring when traffic was much less. A dramatic increase in traffic can effectively cancel any otherwise expected decrease in CO exposures that would have occurred from reduced vehicle emissions. An example of this occurrence would be the increase in traffic using the Outerbridge Crossing in New York (+650%). On the other hand, where traffic has not appreciably changed, exposures in the early 1970's and before are seen to be about three times higher than they are presently. In comparable locations at the Lincoln Tunnel, for example, 8-hour TWA exposures in 1971 were about 23 ppm in the west-bound direction and 7 ppm in the east-bound direction (season unspecified). Presently, the average exposure is about 9 ppm in the summer and 3 ppm in the winter. At the Holland Tunnel toll collection booths (Manhattan Plaza) average CO concentrations of about 15 ppm were measured in 1971, compared to 5 ppm currently in the New Jersey Plaza. Traffic counts at neither of these sites has increased substantially over the last two decades (+22%, Lincoln; +49%, Holland). At the Sumner-Callahan Tunnel, toll lane concentrations have declined from about 20 ppm in 1971 to 6 ppm presently. The traffic counts have increased by about 40%.

There is little information regarding vehicle emissions in vehicles prior to 1965. It has been assumed that emission levels long ago were similar to emission levels during 1965-1970 when the earliest measurements were collected. If this assumption is correct, the only additional factor determining employee exposure to vehicle emissions prior to 1970 would be traffic counts, and possibly work practices and engineering changes (e.g., administrative procedures, ventilation, structural

design). Mathematical modelling of past exposures using these key determining factors is an approach that could assist in estimating past exposures when no historical data is available.

Table 11 lists each facility in the study and the range of exposure measurements collected during the 1970-1974 period. This period of time was most active in terms of monitoring employee exposure due to the promulgation of the Occupational Safety and Health Act of 1970. The table also shows the current levels of exposure from measurements collected during the 1989-1991 period. The table therefore allows a comparison of current exposures between facilities and across time (to a period when historical data is most often available).

Table 11
Average Daily Extent of Exposure in PPM to CO by Site
For Toll Collectors Only

SITE	PAST EXPOSURE (1970-1974) ¹	PRESENT EXPOSURES (1989-91) ²
Maryland T.A.		
BHT	-	2
FMT	-	OPENED 1985
FSK	-	2
NMB	-	-
JFK	-	2
TJH	-	-
LMB	-	2
Mass T.A.		
S-CT	20	6
Mass P.A.		
TMB	-	3
PANY&NJ		
HT	10-40	5
LT	7-27	5
GWB	15-30	5
GB	35-45	7
BB	10-15	7
OBC	5-10	6

¹ Dashed indicates no data.

² Only the data from the two day-time shifts were used to parallel the historical data.

Discussion

In relating exposure to mortality, three issues stand out.

First, limited evidence indicates that exposures in the past were generally higher than in the present. A comparison of the past exposure measurement data with current measurement data indicates that exposures were about three times higher at locations where there has only been a moderate increase in traffic and no engineering changes were made to reduce exposures. Vehicle emissions data provided by the EPA indicates that CO emissions from the average vehicle on the road has declined about 65% since the mid-1970's, with the decline continuing presently. Current 8-hour TWA exposures are generally all within the single digit ppm range, with some facilities having exposure concentrations as low as 2-3 ppm as an 8-hour TWA.

Second, average personal 8-TWA CO exposures between facilities are presently no more than 4-fold different (see table on page I-3). The differences in exposure are believed to be due to differences in traffic tolled per lane and the prevailing weather conditions and surrounding topographical conditions. Maryland facilities generally have less traffic and higher winds and correspondingly have the lowest exposures. Dissimilarities in exposure to CO may exist between sites at each transit authority. For instance, employees stationed inside the tunnels, especially in the past, may have had appreciably higher exposures than any other job category. In the past, it had been documented that CO exposures were typically between 50-200 ppm inside the Holland and Lincoln Tunnels in the 1940's, and between 20-110 ppm inside the Sumner-Callahan Tunnel during the 1960's. Employees in the Holland and Lincoln Tunnel were without fresh air ventilation until 1978 and the booths inside the Sumner-Callahan Tunnel, although provided for ventilation, are ineffective in reducing tunnel exposures. Occasionally, concentrations within the tunnels would reach or exceed 250 ppm, which was the level at which the authorities set their alarms on the CO monitoring equipment.

The third issue is that short-term exposures occur that are appreciably higher than the mean exposures over an extended time. Section F describes within-shift

exposure variation and shows that 1-minute peak exposures typically occur that are about 10-fold higher than the mean exposures. Not fully understood is what effect, if any, short-term exposure has on long-term mortality and for how long exposure to elevated CO concentrations must last before any adverse effect would be detected. On an acute toxicity basis, it would require several minutes time before the blood carboxyhemoglobin level would be appreciably affected. Therefore, one might speculate that very short-term elevations in CO exposure as seen among toll collectors might not have any significant physiological effect and that exposures integrated over at least several minutes are more relevant. Additional research in this area is needed.

The extent of historical data on past exposures is in need of perspective. Detailed exposure monitoring data at all locations is seriously lacking. Usually, there is little if any data to document early exposures (pre- 1970). When there does exist some early data, long periods of time elapse without subsequent monitoring. The exposure monitoring data are also often questionable because of inadequate mention of the type of monitoring technique used, the conditions present during the monitoring period (including traffic and weather conditions), or the sampling duration. Some historical monitoring techniques were less accurate than others. Furthermore, the conditions present during any time can dramatically affect the CO concentration, and short-term concentrations can exist that significantly exceed long-term integrated averages. Early sampling strategies sought to monitor during "worst case" situations to identify locations or situations most likely to exceed the allowable exposure criteria. Current sampling strategies emphasize the need to obtain a representative sample. Thus, comparison of current and past sampling data is difficult in most instances.

Quantitative exposure estimates are the most desirable for epidemiological studies since the relationship between health effects and quantitative exposure is usually continuous. With a statistical prediction model approach, the exposure estimates are objectively produced from sampled data, and they do not rely on subjective judgements. An alternative approach is to use a deterministic or mathematical model which is developed from physical principles and may not involve any data from the study, but it will rely on subjective judgements.

The regression model development is a two step process: 1) identify a number of factors which may influence exposure levels. 2) use the factors as independent variables and regress the dependent variable, which in this case would be measured CO level, upon them. There are several key requirements that must be satisfied before this approach is feasible. First, there must be an adequate number of exposure measurements sampled under a variety of conditions described by the exposure factors. At least 100 measurements would be required as a bare minimum to have adequate prediction precision. These measurements would have to be distributed over the various combination of exposure factors likely to be encountered in the epidemiologic study, i.e. the cells in an exposure matrix. Second, all exposure factors found to be significantly related to CO levels must be known for the entire period of the epidemiologic study. This approach could clearly not be adopted to the existing data for this study because the existing data do not meet the first or second requirements. Past exposure data are scant for all locations included in the study population and associated variables such as traffic and weather conditions are not known during the period that the exposure data were collected. Often the measurement technique is not reported and no assurance can be offered regarding the accuracy or representativeness of the data. In fact, the data were probably taken only in suspected high exposure areas.

More recent exposure data (current data) was collected between 1989 and 1991. We considered trying a simple prediction equation using traffic count, emissions from vehicles, and wind speed as dependent variables. This equation would take the form:

$$CO_{past} = b_0 + b_1 * WS + b_2 * TC + b_3 * E + b_4 * J$$

where WS equals wind speed, TC equals traffic count; E equals emissions from vehicles; J equals job category (e.g. toll collectors); and the b_i are obtained from the current data by fitting the model

$$CO_{cur} = \beta_0 + \beta_1 * WS + \beta_2 * TC + \beta_3 * E + \beta_4 * J + e.$$

where CO_{cur} is a current 8-hour exposure.

Three other problems exist: 1) A factor to account for engineering design changes in the tunnels and the toll booths should also be incorporated, when appropriate to reflect such modifications. Unfortunately, the effect of many engineering modifications on exposure can only be speculated, since no objective data are available to assess this influence. 2) Only 9 shifts of exposure data during the winter and 9 shifts of exposure data during the summer were collected at most of the locations included in the epidemiological study, and the determining variable conditions which influence exposure often did not vary much. 3) Past levels of the independent variables can only be roughly estimated. In summary, this approach is not likely to have much utility either.

Estimation by ranked exposure category requires somewhat less precision. One must know in which category a job belongs for a given year. This is somewhat risky, because current jobs with high exposure (relative to other jobs), may have had low exposure in past years, and vis-a-vera. Historical data which characterizes the past is lacking. In this study it is also not clear what conditions the past exposure data represent. The unknown effect of engineering design changes also increases the possibility of misclassification. The biggest drawback of the method is that the numerical values assigned to the categories must reflect the size of the difference in exposure between the categories. For example, if five categories were devised and assigned the values 1,2,3,4, and 5, then the difference between the average exposure level in the 5th category and the average in the 4th category must be the same as the analogous difference between the 2nd and the 1st categories. Although we feel more comfortable with this than with the statistical prediction model approach, we still feel the exposure assessment with this approach would be too unreliable.

Finally, qualitative estimates assign exposures within jobs or time to non-numerical level categories, e.g. high, medium and low. This approach can be used when the data are incomplete and several subjective judgements are required. This approach has the same drawbacks as the previous approach except there is no need for the assignment of numerical values. However, our life table analysis program requires numerical data on exposure in order to be utilized.

In summary, because of the limitations of the historical extent of exposure data, regarding both quantity and reliability, the data do not generally lend itself to sophisticated mathematical analysis. Ideally, large amounts of reliable information on exposure and the variables which influence exposure are needed to construct a statistical prediction model. A statistical prediction model is developed by fitting a regression model to observational data. Due to the lack of observational data in this situation, this approach cannot be applied. Generally, limited data are best presented graphically or in simple statistical terms, as has been done in this report. Referral from the epidemiological study to the exposure data should therefore be limited to descriptive means only. The epidemiological mortality data should be analyzed by less data intensive means, such as by duration or period employed.

