

Health Effects of Gasoline Exposure.

I. Exposure Assessment for U.S. Distribution Workers

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Personal exposures were estimated for a large cohort of workers in the U.S. domestic system for distributing gasoline by trucks and marine vessels. This assessment included development of a rationale and methodology for extrapolating vapor exposures prior to the availability of measurement data, analysis of existing measurement data to estimate task and job exposures during 1975-1985, and extrapolation of truck and marine job exposures before 1975. A worker's vapor exposure was extrapolated from three sets of factors: the tasks in his or her job associated with vapor sources, the characteristics of vapor sources (equipment and other facilities) at the work site, and the composition of petroleum products producing vapors. Historical data were collected on the tasks in job definitions, on work-site facilities, and on product composition. These data were used in a model to estimate the overall time-weighted-average vapor exposure for jobs based on estimates of task exposures and their duration. Task exposures were highest during tank filling in trucks and marine vessels. Measured average annual, full-shift exposures during 1975-1985 ranged from 9 to 14 ppm of total hydrocarbon vapor for truck drivers and 2 to 35 ppm for marine workers on inland waterways. Extrapolated past average exposures in truck operations were highest for truck drivers before 1965 (range 140 - 220 ppm). Other jobs in truck operations resulted in much lower exposures. Because there were few changes in marine operations before 1979, exposures were assumed to be the same as those measured during 1975-1985. Well-defined exposure gradients were found across jobs within time periods, which were suitable for epidemiologic analyses.

Introduction

An individual's exposure to an airborne agent is the time profile of the air concentration in his or her breathing zone. This exposure profile is processed to formulate epidemiologic exposure variables such as ever exposed, years of exposure, and cumulative exposure for an agent. Epidemiologic studies of cancer risk from inhaled agents frequently require the evaluation of exposure across large intervals of time, much of it before the collection of exposure measurements. The central problem for retrospective exposure estimation in this type of study is how to infer the environmental conditions without direct measurements. This problem may be divided into two subproblems: a) What factors and emission mechanism determine the

presence of the agent in a work location? b) If an agent is present, what factors affect its concentration in the workers' breathing zones?

A strategy was developed to answer these questions for an epidemiologic study of cancer risk for workers in the U.S. domestic gasoline distribution system, both truck and marine operations. The objectives of the exposure assessment were a) to develop a rationale and methodology to estimate historic marketing and marine distribution worker exposures to gasoline, b) to apply these methods to the U.S. gasoline distribution workers cohort, and c) to classify this cohort into groups with substantially different histories of gasoline exposure, suitable for an epidemiologic analysis of cancer risks.

Rationale

Determining the presence or absence of an agent is easier generally than estimating its air concentration. A mechanistic model of exposure was developed for gasoline vapor, which is shown in Figure 1 (1). At its simplest, the model requires three elements: a source of vapor emissions, a worker in the area of the source, and transport of

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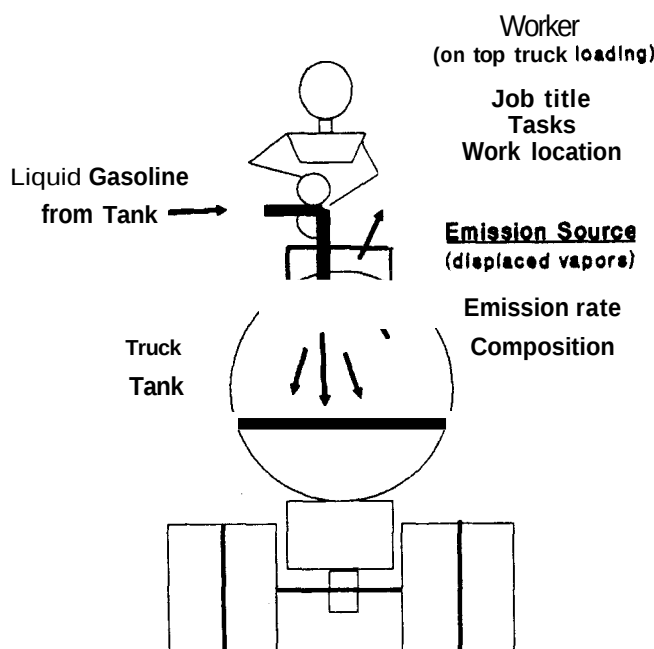


FIGURE 1. Source-receptor model representation of a worker (the receptor) loading a tanker truck with gasoline. (The open hatch is the emission source.)

the vapor emissions into the worker's breathing zone. An industrial hygiene analysis of each work situation can determine if sources of gasoline vapor emissions are present. An analysis of tasks and work locations for each job title can identify those that put a worker in close proximity to an emission source where emissions might reasonably be transported into the breathing zone (the factors are shown in Table 1). Because historical work situations and job titles can be evaluated by interviewing long-term workers, it is possible to determine with a high degree of certainty which job titles and work situations have been historically associated with gasoline vapor exposure.

Estimating exposure intensity without exposure measurements is more difficult. The goal of exposure assessment for epidemiologic studies is not precise estimates of individuals' exposure intensity, but to identify groups with clearly different exposure intensities so their risks of disease may be compared. Therefore, exposure groups based on differences in sources of exposure (e.g., exposure situations with different emission rates) and/or large differences in potential contact with emissions are likely to produce different average exposures when it is difficult to make precise estimates of the average per se. It also is relatively easy to identify exposure situations that represent the extremes: those with minimal exposure and those with a high likelihood for intense exposures. These situations represent the boundaries of the intensity continuum for a population. The mechanistic model of exposure provides a means of assessing the quantitative effects of historic changes in factors affecting exposure. One such model is elaborated below. The combined mechanistic model and industrial hygiene analysis approach can both

estimate approximate exposure intensities and sort the potentially exposed into subgroups by approximate intensity in an epidemiologically useful way.

Potential Agents

An exposure classification for epidemiology requires selection of a hypothetical agent whose potential effects are to be examined in the epidemiologic analysis. For the present study, total hydrocarbons (THC) was the hypothesized agent. However, THC was also a reasonable surrogate for one or more of the major hydrocarbon components in the vapor mixture from gasoline based on an assessment of the scientific literature and the sampling data, which showed that after approximately 1969 there was relatively little change in the amounts of the measured components of gasoline (2-5). Benzene was an exception to this because the benzene content of gasoline has varied over time as a result of changes in gasoline blending practices by the refineries. THC also may not be a good surrogate for the minor components of gasoline vapor because they appear to be more variable than the major components.

Methods

An individual's exposure to gasoline vapors was determined by a) the tasks in his or her job definition, b) characteristics of vapor sources associated with work-site facilities for handling petroleum products, and c) the composition of the products handled. The source-receptor model shown in Figure 1 was developed to express the relationship between exposure and work-site factors (5,6). Two types of emission sources for vapors were identified: displacement of vapors from a tank during filling and evaporation from open liquids, such as spills or open tanks. The job tasks that bring a worker in contact with the vapors from these sources and the site factors that affect exposure intensity were identified through an industrial hygiene analysis (Table 1). Exposure measurements were used to quantify exposure intensities associated with specific combinations of job tasks, types of work sites, and types of products, although only common combinations had been measured.

Task-TWA Exposure Model. Given an estimate of average exposure intensity for each task with exposure by work-site type and time spent on the tasks, a time-weighted average (TWA) exposure could be estimated for each job title and work-site type.

$$\text{task-TWA} = \frac{\sum_{j=1}^{\text{all tasks}} [(\text{task mean})_j (\text{task time})_j]}{\sum_{j=1}^{\text{all tasks}} (\text{task time})_j}$$

This is the task-TWA exposure model. The task-TWA for a job title is an estimate of the arithmetic mean, which is needed to calculate the cumulative exposure dose index.

Table 1. Source of gasoline vapor emissions and factors affecting exposure intensity.

	Factors
Displaced vapors (loading and delivery)	Size and venting of space (open area vs. confined area) Proximity to source (immediate work area or general area) Pump rate (related to truck size) Splash vs. submerged loading" Vapor recovery system' Top or bottom truck loading' Marine loading at site" Tight connection and remote tank vent at delivery site'
Spills	Volume spilled (overflow vs. drips) Proximity (immediate work area vs. general area) Frequency (rare vs. common) Size and venting of space Overflow controls (preset meters)"
Clothing contamination (contact/splashes)	Frequency (rare vs. common) Length of delivery route (affects duration of exposure to volatilized vapors)

*Factors that are part of the equipment configuration at a terminal or delivery site.

(discussed below). The advantage of this approach is it allows back extrapolation of the TWA mean based on historical data on tasks.

Past exposures of gasoline distribution workers were extrapolated with the task-TWA exposure model based on major changes in job definitions and work-site characteristics that had occurred across the industry. Changes in worker behavior over time also were used to modify exposure, such as care in the prevention of small spills and concern about inhaling vapors.

Recent Exposure Measurements. Exposure data had been collected by the four participating companies over the period 1975-1985. Approximately 600 samples had been collected by several methods, which were generally comparable with the American Petroleum Institute recommended method for 55 compounds and the total hydrocarbon (THC) concentration (7). A small number of samples were collected by the University of Massachusetts to fill data gaps and verify earlier observations. Three types of sampling data were available: short-term personal samples (15-90 min) to measure task exposures, full-shift personal samples, and fixed location area samples to measure low-level background exposures away from emission sources. These data were used to construct and verify the exposures extrapolated by the task-TWA exposure model.

Generic Jobs. For truck operations, four generic job groups were identified based on their potential for work around emission sources of gasoline vapors: driver, loader, terminal operator, and other terminal job. Each of the companies then went through all job titles appearing in job histories from their segment of the cohort and assigned them to one of the generic job groups (Table 2). Drivers performed four types of tasks: loading trucks, driving,

making deliveries, and other nonexposed tasks. Most of their exposure was received during loading and deliveries. Loaders performed only truck loading or nonexposed tasks. Terminal operators performed some loading, a variety of mechanical and maintenance tasks with some exposure potential and nonexposure tasks. This group included a wide range of job titles with variable potential for exposure but generally less than truck drivers. Other terminal job included all jobs with no potential for direct contact with emission sources. These workers were exposed only to background levels of vapor in the terminal area, such as clerks and managers.

A similar process was followed for the marine operations, which consist of inland barges and domestic seagoing tankers. Although there are important differences between these two types of marine operations, two generic job groups were identified for both: deck personnel and other shipboard job. The deck personnel are all workers involved with the loading and discharge of cargo, which are the major sources of vapor emissions. Other shipboard job tasks are involved only with indirect exposures to gasoline vapors. Companies assigned all job titles to one of the generic groups or a third category for land-based, predominantly office jobs.

Historic Working Conditions. Extensive information on recent and past truck and marine operations was collected by site visits, interviews of long-term employees and annuitants from each of the participating companies, and company completion of facilities questionnaires on the history of equipment and operations at specific terminal sites and on selected marine vessels. These data were blended with published reports of industry-wide activities to develop job descriptions of tasks, work-site descriptions of typical operations, and historical changes across the industry. For facilities at truck terminals, four factors were obtained: splash or submerged top loading, metered or valved top-loading controls, bottom loading, and presence of a vapor recovery system. For marine vessels, four types of data were obtained: loading with hatches open or with remote venting, voyage frequency, percentage of gasoline in cargo, and area of operations. These data on individual terminals and vessels allowed the individualization of exposure estimates for subjects who worked at these sites and improved exposure classification.

A matrix for assigning TWA exposures by type of truck operations and generic jobs (shown in Table 5) was calculated for the four time periods. The task-TWA model was used to estimate driver exposures by type of loading and delivery facilities using measured or extrapolated exposure intensities for each task (loading, driving, delivery, and other). Intensities for tasks measured during 1975-1985 were adjusted to estimate earlier time periods by compensating for decreased concern about small spills, leaks, and minor clothing contamination, which will all contribute to inhalation exposure. Durations of tasks were adjusted based on interview reports and changes in truck size, pumping rates, and frequency of small deliveries.

Annualized TWA exposures were calculated for deck personnel on barges using regionalized task exposures for loading and discharging cargo, duration of loading and

Table 2. Generic job groups for petroleum distribution operations

Job title	Description
Truck and/or marine terminal jobs	
Driver	Positions truck at filling rack; loads truck (if no loader); drives transport truck to/from delivery sites; unloads gasoline at delivery site; performs clerical work as needed to record activities and transactions
Loader	Primarily loads gasoline trucks; may perform some plant maintenance; remains on the terminal site (makes no deliveries)
Terminal operator without marine facilities ^a	(Plant worker, maintenance worker, auto mechanic, and may include yard worker); mechanically skilled person whose primary responsibility is to maintain and repair equipment at a terminal; job may also include inventory-control procedures, pipeline transfers of products gauging storage tanks, sampling and testing products (including pipeline products), and occasional truck loading (e.g., monthly)
Terminal operator with marine facilities ^a	(Plant worker, maintenance worker, auto mechanic, or dock worker); same as terminal operator above but also performs any combination of tasks on dock, including position vessel and handle lines during docking and undocking; connect hose couplings to enable gasoline to be pumped to and from barges and tankers; use tape and thermometer to measure depth and temperature of products
Other terminal job	Category includes supervisor, clerk, and other support personnel with occasional (e.g., monthly) incidental exposure outdoors or during plant duties, as well as laborer, yard worker, dock worker (truck or warehouse loading dock at terminals without marine facilities) who are predominantly exposed to background concentrations from plant operations
Seagoing tanker and inland barge operations	
Deck personnel	(Ordinary seaman; able-bodied seaman; first, second, and third mates, etc.); Connect/disconnect hose couplings and/or activate pumps for cargo transfer operations; gauging during loading/unloading; tank washing and cleaning (seagoing tankers only); tank stripping and inspection; stand watches and perform variety of underway activities, including watching for obstructions in the vessel's path, measuring water depth, repairing and stowing gear, handling mooring lines, maintenance, lubricating machinery, assisting officers in loading/unloading cargo, etc.
Other marine/barge shipboard job	Engineering department: captain, pilot, navigator, and engine room personnel. Steward department: cook, etc.
Nonshipboard marine job	Supervisory, clerical, technical, etc.
Inland waterway barge operations	Same breakdown as for tankers above, except the captain is placed in the deck group for exposure reasons

^aAt a small terminal, terminal operators also perform loading.

discharging, watch duration and time onboard, each vessel's annual number of voyages, percentage of gasoline in cargo, and region of operations. TWA estimates were annualized to a 2000-hr work year to permit comparison to truck operation exposures. There were not enough data to estimate seagoing tanker exposures.

Dose Indices Two dose indices for the epidemiologic analyses were calculated from the exposure assessment and job histories: cumulative exposure and annual frequency of peak exposures. Cumulative exposure was calculated by multiplying the TWA exposure for each job in a subject's job history by the duration in the job and summing across all jobs. For truck operations, exposure assignments were based on the generic job assigned to each job title in a subject's work history. The truck terminals listed in the work history were used to identify type of facilities at the subject's work site so the appropriate exposure for each generic job could be drawn from the terminal exposure matrix. The marine subjects' cumulative exposures were calculated similarly for inland barge operations: the subjects' job history identified their job titles and vessels on which they served, titles were converted to generic jobs, and an annualized TWA for each generic job was assigned based on the job TWA estimated for each vessel listed in their history.

The annual frequency of peak exposures was determined by identifying the tasks with potential to produce peaks, estimating the annual number occurrences of the task, and then using the frequency distribution of expo-

sure intensities for the tasks to estimate the fraction of the total occurrences that exceed the minimum criteria for a peak. A peak exposure was defined as at least 500 ppm THC averaged over 15–90 min. The number of occurrences of a task was determined from the historical data. The frequency distributions had been measured for all of the truck driver and barge tasks associated with potential peaks during 1975–1985. For past truck operations, it was assumed that the frequency distributions would have the same general shape (lognormal with an approximately constant geometric standard deviation), but the geometric mean of the distribution would be shifted upward proportionally to the change in arithmetic mean exposures. It was not possible to estimate peak exposures of terminal operators, although it is likely that they had some peak exposures.

Findings and Conclusions

Measured Exposures in Truck Operations

Measurement data were available for 1975–1985, which were analyzed to estimate task and full-shift TWA exposures. These findings then became the basis for the backward extrapolation of historical exposures.

Task Samples. Truck loading was a major source of exposure for drivers, loaders, and some terminal operators (Table 3). Task samples for drivers showed an 8-fold

Table 3. Gasoline vapor exposures during loading and delivery tasks by drivers, 1975-1985.

Task type	N	THC arithmetic mean, ppm	SE	Range of sample duration, min
Loading				
Vapor recovery	139	130	14.2	7-60
Top loading	103	120	15.4	7-60
(3 companies, 8 sites)				
Bottom loading	36	157	32.4	8-60
(1 company, 1 site)				
Vapor recovery	81	17	2.8	8-60
Top loading	42	11	1.1	8-60
(1 company, 1 site)				
Bottom loading	39	24	5.6	15-40
(2 companies, 6 sites)				
Truck deliveries				
Large deliveries: remotely vented, large underground tanks using tight connections (1 company, 7 sites) ^a	32	9	1.8	15-30 ^b
Small deliveries: drivers from small terminals: some above-ground tanks and confined locations (OPA, 1988)	24	400 ^c	NR	15 ^b

Abbreviations: THC, total hydrocarbons; OPA, Ontario Petroleum Association; NR, not reported.

^aPart of these data have been published (4).

^bThe duration of these samples was estimated from the sampling time specified in the methods.

^cAverage exposure was rounded to one significant figure to represent the probable level of precision for our application of these data.

between loading without a vapor recovery (VR) system (130 ppm) and with a VR system (17 ppm). Bottom loading versus top loading of trucks showed no evidence of independent of VR systems, but this was difficult to interpret because there were few samples for top loading without VR and bottom loading without VR. Terminal operators occasionally load trucks and were assumed to have the same exposure as drivers during this task. Exposures had been measured only at one site, where they averaged 30 ppm for partial-shift samples. They showed no difference from drivers using the same type of equipment, probably because the samples were longer than the terminal samples (longer samples include more time with low exposures) and because the loaders generally did not leave a truck while it filled, whereas the drivers did. The exposure of loaders during truck filling was estimated by assuming that the observed short-task samples of drivers' exposures represented a limited set of longer task samples of loaders. The upper and lower boundaries, respectively, of the exposure, and the true mean was approximately the same between them.

Exposures of drivers make deliveries, and exposures during deliveries were substantially different for small-volume customer sites. Small-volume customers typically had small above-ground tanks (500 gal) that were vented through an opening at eye level (where deliveries are also vented) with a hand-held nozzle that drew gasoline within the tank. Tanks for large-volume deliveries after approximately 1950 were underground, had hose connections, and had remote venting for vapor recovery. Canadian data and simulations showed average exposures of approximately 400 ppm with high variability for small deliveries. Personal samples of large deliveries averaged 9 ppm.

There were few data for tasks performed by terminal operators. A few samples showed high exposures during

measurements of liquid levels in storage tanks. Other terminal jobs had no direct contact with emission sources through their task activities, and consequently there were no measurements for any of these tasks.

The driver task data showed common opportunities for high short-term exposures (peaks) during loading without VR and small deliveries. Terminal operators perform some tasks that may produce peak exposures, but they were rarely measured.

Full-Shift Job Exposure. Full-shift TWA samples (Table 4) also showed differences in exposure by types of terminal equipment: Drivers averaged 14 ppm for terminals without VR systems and 9 ppm for those with VR. These samples were obtained from drivers making only large deliveries. Although loading exposures were varied more than this, only a small fraction of a driver's work time is spent loading. Full-shift exposures of terminal operators were less than drivers at terminals with the same types of facilities: approximately 9 and 5 ppm without VR and with VR, respectively. There were few samples for other terminal jobs, but they were all very low (5 ppm). Thus, a gradient in job exposures was found in the full-shift data that was consistent with each job's potential for exposure. The 1975-1985 data showed a 7-fold range in exposures across the major jobs.

Extrapolation of Historical Exposure for Truck Operations

Four time periods with distinct characteristics were identified for truck operations: pre-1950, 1950-1964, 1965-1974, and 1975-1985. The characteristics of and differences among the time periods are summarized in Table 5. Although sharp transition dates are given, they represent median dates of changes, and some parts of the distribution system changed earlier and some later.

Table 4. Time-weighted average, full-shift exposures for truck operation jobs by type of facilities, 1975–1985.

Generic job/ terminal loading facility	N	THC arithmetic mean, ppm	SE
Driver			
No vapor recovery	98	14	1.5
Top loading (3 companies, 12 sites)	90	14	1.5
Bottom loading (2 companies, 2 sites)	8	18	2.4
Vapor recovery	94	9	1.6
Top loading (1 company, 1 site)	7	10"	1.5
Bottom loading (3 companies, 17 sites)	87	9	1.6
Terminal operator ^b			
Top load, no vapor recovery (3 companies, 12 sites)	37	9	1.3
Vapor recovery (3 companies, 41 sites)	112	5	0.8
Other terminal jobs ^c	14	5	1.3

THC, total hydrocarbons.

There were no THC data, so THC was extrapolated from benzene vapor level assuming THC vapor contains 1% benzene.

^a"Terminal operator" job also includes plant worker, yard worker (depending on job definition), maintenance worker, and auto mechanic.^c"Other terminal jobs" includes clerk, foreman, supervisor, warehouse worker, etc.

Past exposures were extrapolated with the task-TWA model using exposure data from 1975–1985, data from task simulations, and information on past operations and jobs. The accuracy of the model was checked by comparing the 1975–1985 task-TWA estimate for drivers at the two most common terminal configurations, top loading without VR

and bottom loading with VR, relative to the measured full-shift exposures. The extrapolations were within +64% to -27% of the observed mean THC concentrations.

Drivers. There were several important changes for earlier periods that affected exposures: use of splash loading (the filling spout is above the level of liquid in the tank, so gasoline splashes within the tank, creating aerosol and rapid evaporation), small deliveries (splash filling of small above-ground tanks without remote venting), and less concern about small spills, leaks, or minor contamination. Based on simulations, splash loading was estimated to be 200 ppm during 1965–1985. Loading exposures before 1965 were assumed to be 50% higher than those after 1965. There were reports of more small spills and less concern about contact with gasoline. Driving exposures were increased in the past because of increased clothing contamination, which is a vapor source within the truck cab. Factoring these into the task-TWA extrapolation results in substantially higher THC exposures for the three time periods preceding 1975, as shown in Table 6.

Drivers at small terminals had consistently the highest exposures, averaging approximately 200 ppm during 1950–1965. Drivers at large terminals showed a progressive reduction in exposure from the high values of 150–220 ppm in 1950–1965 down to the low values measured in 1975–1985. In the earlier time periods, exposures during small deliveries were the most important sources of exposure, which is consistent with the relatively large fraction of time spent on this activity, about one-third of total time, and the high potential for exposure for this task. We concluded that earlier time periods had much higher potential for driver exposures and estimated a 10- to 37-fold increase depending on the type of terminal and delivery operations.

Table 5. Historical changes affecting driver exposures to total hydrocarbons from gasoline during periods of major industry-wide changes.^a

	Loading	Driver task Driving	Delivery
1975–1985			
Fill time, 20 min; 10,000-gal trucks; 500-gal/min pump rates; spill controls ^b		Rubber gloves (less vapors in cab); clothing contamination rare; long delivery routes (70 min per trip)	Delivery time, 40 min; small terminals discontinued; most large deliveries; tight delivery connections; remote stack vents for tanks
1965–1974			
Fill time, 30 min; 8,000-gal trucks; 250-gal/min pump rates; spill controls ^b		Leather/canvas gloves; occasional clothing contamination; mixed-route length (50 min per trip)	Delivery time, 50 min; mixed terminal size; mixed delivery size; tight delivery connections; remote stack vents for tank.
1950–1964			
Fill time, 40 min; 6,000-gal trucks; 150-gal/min pump rates; limited spill controls		Leather/canvas gloves; limited concern about clothing contamination; many short routes (50 min per trip)	Delivery time, 50 min; mixed terminal size; many small deliveries; tight delivery connections; limited remote tank venting
Pre-1950			
Fill time, 40 min; 2,000-gal trucks; 50-gal/min pump rates; limited spill controls		Leather/canvas gloves; limited concern about clothing contamination; many short routes (50 min per trip)	Delivery time, 50 min; most small terminals; most small deliveries; loose delivery connections; remote tank venting rare

These are based on median dates of changes and median conditions. Specific companies and regions may have changed factors at different times, and loading and delivery times may have been somewhat longer or shorter depending on equipment. This does not include changes in factors identified for work sites that are known to affect exposures, e.g., vapor recovery and type of loading.

^bSpill controls included changes in operating practices and, in later years, equipment modifications such as high-level cutoff and preset meters.

^cTransition time of major post-war expansion of delivery system.

Table 6. Summary of extrapolated, full-shift, time-weighted average exposures to total hydrocarbons (ppm) from gasoline for generic jobs and specific site types by time periods.

Year and load type	Terminal size						
	Large				Small		Both
	Driver	Driver/loader	Loader	TO	Driver	TO	Other
Submerged	14 ^a	7	62	9 ^a	—	—	8
Splash	—	—	—	—	180	72	—
Vapor recovery	9 ^a	6	8	5 ^a	—	—	3
1965-1974							
Submerged	64	41	63	29	—	—	13
Splash	79	42	97	34	180	72	17
Vapor recovery	41	39	10	25 ^b	—	—	8
1950-1964							
Submerged	190	150	98	72	—	—	22
Splash	220	150	150	80	210	80	28
Pre-1950							
Splash	170	140	75	68	170	68	19

TO, terminal operator.

^aObserved values, not extrapolated.^bVapor recovery introduced in this time period, associated with frequent malfunctions and maintenance.

Loaders. The task-TWA model was used to extrapolate exposures of loaders. However, the data available for these estimates are limited and implied that exposures of loaders were not the same as drivers performing the same task. Rough estimates of exposure were developed assuming a proportionality with historic changes in driver exposures because both would be affected by changes in loading conditions and concern about exposures. Thus, exposures in Table 6 were highest for 1950-1964, approximately 150 ppm, and lower during later periods with exposure controls.

Terminal Operators. Because of the broad mix of job titles in the terminal operator group, it was difficult to develop an extrapolation that was consistent for all of the diverse job titles in this group, such as yardman and mechanic. The task-TWA model was divided into loading and other tasks. The loading component was taken from drivers using the same equipment. The other tasks component was given by rough estimates and multipliers based on estimated effects of changes in work activities and the concern about exposures from minor sources, such as small leaks or spills. Consequently, terminal operator's exposures in Table 6 were estimated to be highest in 1965, 80 ppm, and decline in more recent times down to 5-9 ppm measured in 1975-1985.

Other Terminal Job. This group was assumed to have background exposures, which were assumed proportional to general area emissions from loading, spills, leaks, storage tanks. As a result of higher general emissions in earlier time periods, the other terminal job exposures were increased. They were highest in 1950-1965 at 28

time periods and for workers at the same types of terminals. This gradient was consistent with qualitative assessment of contact with sources of gasoline vapor exposure. However, the quantitative estimates showed that the gradient was not consistent for job comparisons across time periods: for example, early-period terminal operators were as highly exposed as drivers in 1975-1985. The gradient also was not consistent across terminal types: Drivers at terminals with vapor recovery were less exposed than terminal operators at terminals with splash loading. Thus, care must be used in comparing workers classified by qualitative differences in generic job title alone.

Marine Exposures and Historical Extrapolations

Fewer data were available on marine exposures than on truck operations; the majority was obtained on barge operations on inland waterways. Marine operations were subdivided into vessel loading, underway, cargo discharge, and other activities. Exposure estimates are summarized by operation activity and region in Table 7. Most sampling data had been gathered on deck personnel to assess vessel loading because it presents the highest potential for exposure. Regional differences were observed in the average exposures during full-shift personal samples while loading: 250 ppm THC during loading several barges simultaneously in the western rivers region and 120 ppm during single-barge loading in the East Coast region. Topping-off the tanks (the final stage of filling) was associated with the highest task exposures observed: over 1500 ppm THC for 15-30 min per tank. Discharging cargo was associated with much lower exposures because vapors are not being forced out of the tank (16 ppm for a full shift).

Marine operations have very different work patterns from land-based operations. Marine workers are on-watch for 6 hr and off-watch for 6 hr continuously, 24 hr per day, while they are onboard a vessel. They also are onboard a

Overall Comparison among Truck Job Types

It was concluded that there was a substantial 10-fold gradient across the generic jobs: driver > loader > terminal operator > other terminal job that was consistent within

Table 7. Estimated time-weighted exposures for 1940–1985 for inland barge operations handling gasoline by loading configuration and region.^a

Task/operation	Full-shift TWA exposures, ppm THC		
	Deck personnel ^b		Other vessel jobs
	Open-hatch venting	Remote venting	All loading types
Loading			1 ^c
East Coast	120 ± 32	NA	NA
Western rivers and Gulf Coast	250 ± 38	NA	NA
West Coast	NA	2 ± 0.3	NA
Underway + wait	1 ± 0.2	1 ^d	1 ^d
Discharging	16 ± 6	1 ± 0.2	1

NA, not applicable for the epidemiologic study.

^aMean ± SE is given for those cases with measured data; the mean was rounded to two significant figures.

^bThe captain is included in the deck personnel group for some companies.

^cLoading exposures for nondeck crew jobs were assumed to be approximately equal to the underway level.

^dUnderway and waiting exposures were assumed to be the same for all exposure groups.

^eDischarging exposures were assumed to be the same for all on-board personnel during discharging with remote venting.

vessel for different time periods depending on the region, such as onboard for 40 days and on-shore for 20 days in the western rivers region, and 1 week onboard and 1 week on-shore in the East Coast region. Marine operations also tend to require more time than equivalent truck operations. For example, loading a barge requires 9–18 hr. As a result, loading and discharging cargo are full-shift operations (6-hr) for deck personnel and short-term tasks for truck drivers. To account for this difference and permit comparison of marine and truck exposures, an annualized TWA for a 2000-hr annual work period (8 hr per day, 5 days per week and 50 work weeks per year) was calculated. It was assumed that while marine personnel are onboard they are exposed to background vapor concentrations, even off duty.

The 1978–1985 annualized TWA for 2000 hr for deck personnel handling gasoline ranged from 2 to 35 ppm THC for loading with open-hatch venting of vapors. The lowest TWA was observed for barge operations with long voyages and the highest for those with short voyages and frequent loading. These levels of exposure are comparable to those seen for drivers during 1975–1985. Exposures for deck personnel on barges with remote venting of vapors during loading and cargo discharging were low, averaging 2 ppm in the few samples available.

Historical exposures in barge operations before 1978 were judged to be the same as those measured for barges with open-hatch venting. The work practices and equipment had not changed in any significant manner that would affect exposures. One company had used barges with remote venting since the 1940s, and its deck personnel were assigned the low value observed in the samples. Other shipboard job group was assigned 1 ppm, which was the background level for all barge operations.

Due to the limited exposure data for seagoing operations, quantitative exposures could not be estimated. However, deck personnel have potential for high vapor exposures on tankers transporting gasoline that used open-hatch venting during loading and discharging cargo. These workers also have potential exposures to a variety of other materials that have been routinely transported by tankers, such as crude oil and intermediate refinery products. Consequently, their exposure histories are more complex than those of the truck or inland barge workers.

Dose Indices

Cumulative Exposures. The cumulative exposure index was calculated for the truck and inland barge workers based on their personal job histories and the assigned exposures for the generic jobs. It ranged from 2 to 8000 ppm* year. Long-term drivers at small terminals had the highest values; short-term workers in other terminal jobs were lowest. Inland barge deck personnel had low to intermediate cumulative exposures. The wide range and relatively large numbers of workers with high values provided a suitable population for a reasonable test of the association of gasoline exposure with cancer risk, under the assumption of a linear relationship between ppm* year and risk.

Lifetime Frequency of Peak Exposures. The lifetime frequency of peak exposures index should be useful epidemiologically for detecting cancer risk associated with peak exposures above 500 ppm; however, because of the correlation between the frequency of peaks and cumulative exposure, it may be difficult to distinguish their separate effects. Peak exposures were calculated for truck and inland barge workers. They ranged from 0 to 24,000 peak exposures greater than 500 ppm lasting 15–90 min. Drivers at small terminals had the highest long-term frequencies because of the high frequency of peaks during loading and small deliveries. Although the peak exposures of barge deck personnel during topping-off reach higher concentrations and last longer than those of drivers, they are less frequent because of the much lower loading frequencies for barges. Consequently, deck personnel handling gasoline had generally lower lifetime frequencies of peak exposures than truck drivers.

Seagoing Tanker Exposures. Because quantitative exposures could not be estimated for seagoing tankers, it was not possible to calculate cumulative exposure or peak frequency for these workers. Years of work in deck personnel jobs on ships carrying gasoline was used as an index of potential exposure. Before 1980, nearly all ships used open-hatch venting, so no date criterion was used in the index. Again, a wide range in years of potential exposure was found (0–30 years), and there was a large group with many years of potential exposure. This also should provide a suitable test of the possible association with cancer risk.

Limitations and Uncertainties

The few exposure data for low-exposure jobs and domestic seagoing tanker operations, and the limited availability of data (only 1975–1985) were major limitations of this

study. To deal with these limitations, an extrapolation approach was developed. There were many sources of uncertainty in the quantitative extrapolation. The largest uncertainties are in the lowest exposure estimates. Although the absolute magnitude of the extrapolated past exposures is imprecise, there were large differences in exposure across the job groups, and the relative ranking of these exposures is well supported by the assessment of potential contact with emission sources and tasks associated with each job group. Loader exposures were very uncertain, but this was a small group with little influence on the epidemiologic analysis. Overall, it was unlikely that the uncertainty in the past exposure estimates would obscure the apparent differences in dose indices or job groups.

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