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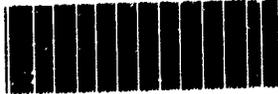
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January 13, 1986

Robert H. Brink
Executive Secretary
Interagency Testing Committee
U.S. EPA (TS-792)
Room 135-ET
401 M Street, S.W.
Washington, D.C. 20024

Dear Mr. Brink:

Interagency Testing Committee: Seventeenth Report

Amoco Corporation, on behalf of itself and its wholly-owned subsidiaries, wishes to comment on the Seventeenth Report of the Interagency Testing Committee (ITC). In this Report, cyclohexane (CAS 110-82-7) was added to the priority list under the new category of "recommended with intent to designate" (50 Federal Register 47603).

Neither Amoco Corporation nor its subsidiaries intentionally manufacture cyclohexane. Furthermore, we do not manufacture or process products, such as solvents, which may concentrate cyclohexane. We are, however, involved in the extraction and processing of crude oil, in which cyclohexane may be present as a natural constituent. Low concentrations of cyclohexane may, therefore, appear in certain naphtha streams separated from the original crude. These streams are not sold as consumer products, but rather are processed to raise the octane of gasoline. Following processing, the resulting concentration of cyclohexane in gasoline is very low, typically less than 0.5 percent, by weight.

Since cyclohexane exists only as an impurity in certain of our refinery streams, Amoco is not subject to the reporting requirements of TSCA sections 8(a) and 8(d), which are automatically triggered by the priority listing of cyclohexane. We do, nevertheless, wish to submit comments to this issue due to our concern over certain statements appearing in the Report.

Amoco is specifically concerned over the apparent overestimation of occupational and consumer exposure to cyclohexane within the petroleum industry. In the "Rationale for Recommendation" section of the Report, the statement is made that cyclohexane is present "in regular, premium, and unleaded gasoline to the extent of 1.58 volume percent"(50 FR

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47607). On the same page, the Report indicates that consumer exposure to cyclohexane may result through dermal or inhalation exposure to gasoline and from spills of other refined petroleum products and crude oil. We believe that both these statements are misleading.

Within the refining industry, cyclohexane is only likely to be found in the lighter boiling products, principally naphtha streams. Furthermore, not all naphtha streams contain cyclohexane and most which do are further processed before blending into gasoline. Therefore, the final concentration of cyclohexane in gasoline is dependent on the amount of unprocessed naphtha streams used in blending. Cyclohexane, if present at all, is found in much lower amounts in the middle distillate and heavier boiling petroleum products.

In the Report, an average concentration of 1.58 volume percent cyclohexane was presented for gasoline. This appears to be a very high concentration. Our data suggests that cyclohexane is present in most gasoline component streams at much lower levels. Of the refinery streams tested, only virgin or short-run naphtha contains this high a level of cyclohexane. Furthermore, since this stream is of a relatively low octane, it should be present mostly in leaded gasolines (now being phased out). For unleaded gasoline manufacture, virgin naphtha is usually reprocessed into higher octane streams. Our own analyses and published data suggests that cyclohexane is typically present in finished unleaded gasoline at levels less than 0.5 percent by weight.

The occupational and consumer exposure to cyclohexane from petroleum products is not as simple as implied in the Report. There is a large difference between the liquid composition of a refinery stream and the composition of the vapors to which consumers or workers may be exposed. This difference is largely dictated by the differential boiling points of the components of these complex streams.

In occupational exposures to gasoline, cyclohexane typically averages less than 0.5 percent by weight of the total vapor exposure. Available analyses of occupational exposures to gasoline vapors within the petroleum industry (e.g. bulk terminal operators, service station attendants, drivers, etc.) indicated that cyclohexane concentrations typically fall below 0.4 percent by weight or volume. Coupled with the generally low occupational and consumer exposures to gasoline vapors in general, the small percentage of cyclohexane present would be so low as to be insignificant.

The attached manuscript, which has been accepted for publication in the 'American Industrial Hygiene Association Journal', details various aspects of worker and consumer exposures to cyclohexane through gasoline vapor exposures. Note that in Table II cyclohexane is not mentioned, since it occurred at less than 0.5 percent by weight in the monitoring samples.

We appreciate the opportunity to comment on the Report and hope that our comments will be of assistance to the ITC in its deliberations. With regard to the presence of cyclohexane in gasoline, or in naphtha streams

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not used as solvents, Amoco believes that the Report greatly overstates the potential exposure of petroleum workers and consumers to cyclohexane.

Sincerely,

A handwritten signature in cursive script, appearing to read "WR Brink".

WRQ/gib

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ABSTRACT

Monitoring surveys of gasoline vapor exposures were conducted on truck drivers and terminal operators from five terminal loading facilities, on dockmen and seamen at two tanker/barge loading facilities, and on attendants at a single expressway service plaza. Results revealed wide variations in total C₆+ hydrocarbon exposures for each location, with overall 8-hour time-weighted averaged (TWA) geometric means of 5.7 mg/m³ (1.4 ppm) for the terminals, and 4.0 mg/m³ (1.0 ppm) for the service plaza, respectively. The exposures ranged from 0.8 to 120.8 mg/m³ (0.2-30.1 ppm) for the terminals, and from 1.1 to 130.3 mg/m³ (0.3-32.5 ppm) for the service plaza. For the terminals, exposures were not significantly different regardless of loading method or the presence or absence of vapor recovery systems. Comprehensive chemical analyses of terminal employee exposure samples revealed that the C₄ and C₅ hydrocarbon components constituted 74.8 ± 9.2 percent of the total exposure sample on a ug/sample basis. The C₆, C₇, and C₈+ components constituted 13.0 ± 1.9, 6.2 ± 3.0, and 5.9 ± 7.2 percent of the total samples, respectively. Comprehensive analyses of the marine employee exposure samples resulted in a similar distribution of components, that is, 66.6 ± 7.9, 17.5 ± 4.7, 9.2 ± 3.1, and 6.4 ± 1.9 percent for the C₄/C₅, C₆, C₇, and C₈+ components, respectively. However, the composition of these exposures was weighted more toward the C₅, C₆, and C₇ components when compared to the bulk terminal employee exposures. The analyses for both the terminal and marine loading exposures also revealed that four C₄/C₅ components, namely, n-butane, isobutane, n-pentane, and isopentane, comprised 90 to 92 percent of all the C₄/C₅ vapor components and approximately 61 to 67 percent of the total gasoline vapor samples. The composition of hydrocarbon constituents and their relative proportion in gasoline vapors appeared to remain fairly constant regardless of differences in gasoline blends, monitoring conditions, or magnitude or length of exposure. The geometric mean exposure to benzene through gasoline vapors was 0.8 mg/m³ (0.3 ppm) for the terminal employees, 0.5 mg/m³ (0.2 ppm) for the marine loading employees, and 0.7 mg/m³ (0.2 ppm) for the service station attendants on a TWA, 8-hour basis.

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Title: Gasoline Vapor Exposures. Part I. Characterization of Workplace Exposures.

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INTRODUCTION

A study in which rats and mice were exposed for two years to totally vaporized unleaded gasoline produced a dose-related incidence of renal damage and renal cancers in male rats, as well as an increased incidence of liver tumors in female mice.⁽¹⁾ A 90-day inhalation study of a leaded and an unleaded gasoline sample using rats and monkeys induced kidney lesions in male rats only.⁽²⁾ Furthermore, subchronic inhalation studies of a variety of petroleum naphthas commonly blended into gasoline showed that several were capable of producing kidney damage, but only in male rats.⁽³⁾ The above findings have raised concerns over the potential hazard of gasoline vapor exposures to human health. To help address these issues, an effort was made through this two-part report to consolidate existing relevant industrial hygiene monitoring and toxicological data with three prime objectives in mind: First, to describe the magnitude of exposures to gasoline vapors for terminal operators and truck drivers, marine loading operators, and service station attendants, three occupations where exposures are anticipated to be among the highest in the petroleum industry. Second, to determine the chemical composition of the gasoline vapors to identify the major hydrocarbon constituents, and, third, to evaluate the nephrotoxicity of the major constituents of gasoline vapors. The characterization of workplace exposures to gasoline vapors in the petroleum industry is described in Part I of this two-part report; the toxicologic evaluation of certain gasoline vapor components is described in Part II. The results of these findings are compared, where relevant, to data developed by others in the petroleum industry.

MATERIALS AND METHODS

Industrial Hygiene Monitoring Program

Monitoring data were available on five gasoline distribution terminals. Three were equipped with bottom loading and vapor recovery systems, one had bottom loading but no vapor recovery, and the fifth had top loading without vapor recovery. At these locations, personal exposures of both truck drivers and terminal operators were monitored with 3M 3500 Organic Vapor Monitors (3M Company, St. Paul, Minnesota) affixed to clothing in the breathing zone. Sampling duration averaged 9.2 hours and, as such, measured exposures to hydrocarbons throughout the employees' workday. A total of 183 samples were collected at the terminals over a 12-month period. Of those, 37 samples representing the full range of exposures were selected for more detailed compositional analysis. Specifically, 25 samples were analyzed for n-butane, isobutane, n-pentane, and isopentane plus various heavier hydrocarbons, and 12 samples were extensively analyzed for all components. The remaining 146 samples were analyzed for C₆+ hydrocarbons only.

Exposure monitoring data were also available for one service plaza location, consisting of paired gasoline service stations immediately off the exit ramps on either side of a major expressway. Here, service attendants were monitored in a manner similar to the terminal truck drivers and operators. Sampling lasted throughout the workday, and the duration for the 21 samples collected averaged 7.2 hours. All samples were analyzed for C₅+ hydrocarbons only.

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Lastly, as part of an industry project sponsored by the American Petroleum Institute (API)(4), detailed compositional exposure data were developed for workers involved in marine loading operations at two facilities. Specifically, 11 personal exposure samples were collected using 600 mg SKC charcoal tubes connected to MSA Model C-210 pumps. The flow rates were approximately 50 mL/min. Nine of these samples were collected from a tanker loading facility and two from a barge loading facility. Sampling for this survey averaged 3.8 hours and covered the typical workshift period for these employees. The samples were submitted to a contractor who performed the analytical work.

In addition to the previous monitoring surveys, a small ancillary monitoring study had been conducted at the Amoco Research Center to simulate consumer exposures to gasoline vapors while refueling automobiles. In this study, personal exposure samples were collected during the fueling of test cars. Sampling durations varied from 5 to 446 minutes, and the number of cars fueled during individual monitoring periods varied from 1 to 37. Two sampling methods were used simultaneously: 3M 3500 Organic Vapor Monitor diffusion badges, and 600 mg SKC charcoal tubes (SKC, Incorporated, Eighty-Four, Pennsylvania) connected to an MSA Model C-200 pump (Mine Safety Appliances Company, Pittsburgh, Pennsylvania) using flow rates of 56-78 mL/min. A total of six sample pairs were taken of which four were analyzed for C₆+ hydrocarbons only, while the remaining two were analyzed for C₄+ hydrocarbons.

The exposure results of all samples taken throughout this program were adjusted to an 8-hour time-weighted average (TWA, 8-hour) and assumed no other measurable exposure to hydrocarbons during nonmonitored periods. When the 3M 3500 Organic Vapor Monitor diffusion badge was used, sampling rates developed by 3M Company

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were used to calculate n-pentane and C₆+ hydrocarbon exposures. The rates were stated to be accurate to + 5 percent.(5) Sampling rates for the remaining C₄ and C₅ hydrocarbons were determined using 3M Company's Sampling Validation Protocol. Specific diffusion coefficients for these compounds were obtained from two reference sources which estimated the accuracy to be within +10 percent.(6,7) For the marine loading operation sample analyses where SKC charcoal tubes were used, desorption efficiencies for each component expected to be found in gasoline vapor were determined by the contractor using internal standard calibration prior to sample analysis.

Chemical Analysis

The 37 terminal samples plus 2 out of 6 automobile refueling exposure samples were analyzed using a Varian 3700 gas chromatograph (Varian Instrument Group, Palo Alto, California) equipped with a flame ionization detector and a capillary column 60 M long, 0.25 mm in diameter, and packed with a fused silica/DB-1 exchange bed. The carrier gas was hydrogen, flowing at a velocity of 40 cm/sec. The temperature programming began at -10°C, held for 4 minutes, and then increased at 2°C/min. up to 250°C. Carbon disulfide was the solvent used to desorb the hydrocarbons from the monitoring badges. The lower limit of detection for all compounds analyzed by this method was 1 ug per sample, with the exception of benzene which was 2 ug per sample. Analysis by this method allowed detection of C₄+ hydrocarbons.

All service station samples, 146 of the terminal samples, and 4 out of 6 refueling exposure samples were analyzed using a packed column Perkin-Elmer 3920 gas chromatograph (Perkin-Elmer Corporation, Norwalk, Connecticut) with a flame ionization detector and linear temperature programmer. The column was a 12-foot by

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1/8-inch stainless steel column packed with 10 percent SP-2100, 80/100 mesh Supelcoport. The carrier gas was nitrogen at a flow rate of 30 mL/min. Column temperature programming began at 0°C, and the temperature was increased at a rate of 8°C/min. to 154°C. This maximum temperature was held for 2 minutes. Again, carbon disulfide was used as the desorbing solvent. Analysis by this method detected C₃+ hydrocarbons only, for which the lower limit of detection was 30 ug per sample.

The marine loading operation survey was part of an industry-wide cooperative project to develop workplace exposure data for gasoline vapors.⁽⁴⁾ The samples were analyzed by a contractor, Research Triangle Institute (Research Triangle Park, North Carolina), as follows: an autosampler fed the samples to a Hewlett Packard 5890-A gas chromatograph equipped with a Level IV terminal, BASIC programmer, capillary column, and flame ionization detector. The column (60 M x 0.32 mm I.D.) was packed with nonpolar methyl silicone on a fused silica base. The typical operating conditions were: 0.6 mL/min helium carrier gas flow; 200°C injection port temperature; 275°C detector temperature; column temperature programming began at 40°C, was held for 8 min, and then increased at 6°C/min to 185°C, where it was held constant. This method allowed for the analysis of the individual components of each exposure sample, including C₃ hydrocarbons. Again, carbon disulfide was the solvent used to desorb the hydrocarbons from the charcoal tubes.

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RESULTS

Monitoring Program

The results of the monitoring survey of gasoline vapor exposures for truck drivers and terminal operators, marine loading operators, and service station attendants are summarized in Tables IA and IB. In Table IA, the exposure data are presented in three ways for convenience: They are the arithmetic mean and standard deviation, the range, and the geometric mean plus geometric standard deviation. With the exception of the geometric standard deviation, the data are presented both as mg/m^3 and ppm.

It was apparent from the data presented in this report that the exposures were not normally distributed and most likely fit a log-normal, or geometric, distribution. Therefore, the geometric mean is used, whenever possible, to describe the exposures presented throughout the text of this report. The arithmetic mean and standard deviation, plus the range, are provided in Table IA to supplement the exposure data in forms that may assist the reader in interpreting the results.

Refinery Terminal Exposures

It is readily apparent from this survey that large variations in exposure existed for all the above occupations. However, the 8-hour TWA exposures for C_6+ hydrocarbons at the terminals were, on average, less than 1.0 percent of the current established ACGIH-TLV for gasoline of $900 \text{ mg}/\text{m}^3$ (300 ppm)(8). The C_4+ exposure concentrations for the subset of 37 terminal samples were anywhere from 3 to 13 times higher than the respective terminal exposures that were measured on the basis of C_6+ hydrocarbons (see Table IA, Columns 1 and 2). However, once the C_4+ measurements were adjusted to exclude the contribution of the C_3 through C_5

hydrocarbons, they became similar in magnitude to the C₆+ terminal exposure results. Thus, no apparent discrepancy existed between the two different gas chromatographic analytical methods used for the subset of terminal samples and for the remaining 146 terminal samples. Nevertheless, the overall geometric mean exposure for this subset was 31.2 mg/m³ (10.5 ppm), which, on average, was still less than 4 percent of the current TLV for gasoline vapors. The exposures for the five terminals were compared statistically using a one-way analysis of variance⁽⁹⁾, and no statistical differences in exposures between the terminals were noted regardless of the method of loading or whether there was vapor recovery or not ($p < 0.05$).

Service Station Exposures

The 8-hour TWA exposures for C₆+ hydrocarbons at the service plaza were, on average, 0.4 percent of the established TLV. Thus, they were very similar in magnitude to the exposures experienced by the truck drivers and operators at the bulk terminals. Like the terminal exposures, large variations existed (Table IA). The results of a related monitoring study conducted to determine the extent of exposures to gasoline vapors while refueling cars are summarized in Table III. In this study, exposures were below the detection limit for the refueling of up to four cars, or for a total of 17 gallons of gasoline. Exposures were detectable only following refueling of 25 gallons of gasoline and above, the magnitude of which was at most one-fourth of those determined for the service station attendants (Table IA) on a TWA basis. For comparison, two types of monitoring devices were used in this survey, of which the 3M 3500 Organic Vapor Monitor diffusion badge consistently measured higher exposures. The reason for this finding was not determined.

Ship/Barge Loading Exposures

The C₄+ exposure concentrations for the marine loading operations were approximately 3 times higher than the comparable C₄+ terminal exposures, but were still, on average, approximately 10 percent of the TLV. Since a different sampling method was used to collect the marine loading exposures (charcoal tubes vs. diffusion badges), it is not known to what extent the higher exposure figures were a true reflection of the occupation or due to a difference in sampling methodology. However, in the small vehicle refueling study described previously, both charcoal tubes and diffusion badges were used, and the diffusion badge produced consistently higher exposure results. This would imply, therefore, that the measurements obtained for the marine loading operations were an accurate reflection of the exposures, and may even be low.

Compositional Analysis

Analysis of the 12 terminal exposure samples for C₄/C₅ hydrocarbon composition revealed that four C₄/C₅ compounds, namely n-butane, isobutane, n-pentane, and isopentane, comprised 90.0 ± 4.1 percent of all C₄/C₅ compounds found in the vapors and, in addition, constituted 67.4 ± 10.2 percent of the total sample on a ug per sample basis (see Table IB). All C₄ and C₅ components constituted 74.8 ± 9.2 percent of the total sample while the C₃ hydrocarbon contribution was negligible and amounted to only 0.2 ± 0.2 percent of the total sample. However, it is important to note that the efficiency of adsorbing C₃ hydrocarbons onto the monitoring badges is unknown. The C₆, C₇, and C₈+ components constituted 13.0 ± 1.9, 6.2 ± 3.0, and 5.9 ± 7.2 percent of the total samples, respectively. The distribution of gasoline vapor components by carbon number using the terminal exposure data is shown in Figure 1.

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By comparison, the distribution of the vapor components by carbon number for the marine operator exposures were as follows: 66.6 ± 7.9 percent for the C₄ and C₅ components, 17.5 ± 4.7 percent for the C₆ components, 9.2 ± 3.1 percent for the C₇ components, and 6.4 ± 1.9 percent for the C₈+ components. For these exposures, the four butane and pentane compounds comprised 92.1 ± 3.4 percent of all C₄/C₅ vapor components and 61.3 ± 7.8 percent of the total sample (see Table IB).

Chemical analysis of the 12 terminal and 11 marine loading exposure samples by individual component is shown in Table II. Of approximately 70 individual compounds analyzed for, fewer than 23 were present at 0.5 percent or more by weight in the total sample. These 20 to 22 compounds, on average, accounted for at least 89 percent of the total sample for the terminal exposures and over 94 percent for the marine loading exposures. Occurring at greater than 0.5 percent by weight, but excluded from this list, are a number of unidentified C₅ alkenes that coeluted with the gas chromatographic solvent, some unidentified C₁₀+ hydrocarbons, and possibly 2,3,2-trimethylpentane which coeluted with toluene.

DISCUSSION

It was expected that the gasoline vapor exposures obtained in this survey would be below the current ACGIH-TLV. C₆+ total hydrocarbon exposure data compiled by the American Petroleum Institute from an industry-wide survey revealed that, of 4,789 available samples, 97.1 percent measured less than 90 mg/m^3 (22.5 ppm), while only 0.44 percent exceeded 450 mg/m^3 (112.3 ppm).⁽¹⁰⁾ The API data are depicted graphically in Figure 2. It should be noted that the data in Figure 2 were obtained from all aspects of the petroleum industry, including refining, marketing, research and

development, etc., and thus do not necessarily reflect exposure to gasoline vapor hydrocarbons alone. Also, both area and personal sampling were included in these data.

Refinery Terminal Exposures

A survey conducted in 1975 of five gasoline bulk handling facilities reported that the 10-hour TWA exposures for driver-salesmen and loaders would probably not exceed 100 ppm for the facilities that were monitored, except one in which a 240 ppm level was exceeded 5 percent of the time. (11) Our survey showed that all exposures were well below 100 ppm for the terminal facilities monitored, with the highest recorded exposure being 237.6 mg/m³ (79.6 ppm) TWA, 8-hour.

Of interest in the monitoring survey of the five terminal facilities was the apparent lack of difference in 8-hour TWA exposures between the different terminals regardless of the mode of loading, that is, top or bottom loading, or whether vapor recovery was present or not. An earlier survey conducted for the Shell Oil Company concluded that vapor recovery systems reduced time-weighted average exposures by 50 to 80 percent relative to facilities without vapor recovery systems. (11) The Shell Oil survey focused on comparing the different types of loading methods and systems, and so some effort was made to account for such variables as weather and equipment malfunctions. Our survey, on the other hand, was designed as a scoping endeavor in which no attempts were made to take variables such as these into account. A number of variables were identified in our survey that could have greatly affected the overall exposure pattern. These include the fact that the terminals were monitored at different times of the year under substantially different climatic conditions; some of the terminals handled

gasoline alone whereas others handled distillate fuels as well; and the frequency of load pick-up (and hence potential exposure) varied greatly with each terminal facility and employee. Thus, it is probable that the contributions played by these and other variables may have overshadowed those of the loading and/or vapor control system. This can be inferred by the large variation in exposures that were obtained for each facility. This is not to say that vapor recovery is not effective; rather, it implies that when exposures are normally low, the effects of vapor control may be outweighed by other factors, all having considerable influence on the time-weighted average exposure outcome.

Service Station Exposures

For the service station attendants in our survey, all exposure measurements were far below the recommended TLV, with the highest 8-hour, TWA exposure being measured at 130.3 mg/m^3 (32.5 ppm). The geometric mean was 4.0 mg/m^3 (1.0 ppm). These exposures correlated well with, and in fact were lower than, exposures documented for service station attendants in a survey conducted by McDermott and Vos.⁽¹²⁾ In their survey, 84 exposure measurements from seven service stations ranged from 0.42 to 114.29 ppm (TWA, 8-hour), with an arithmetic mean of approximately 9.6 ppm.

The low exposures to gasoline vapor hydrocarbons were further underscored through the monitoring of refueling of motor vehicles at our research facilities. In this study, exposures were below the limits of detection with refuelings of less than 17 gallons of gasoline (22-minute sample collection duration) using two different monitoring devices simultaneously. However, it should be cautioned that only six duplicate samples were used in this study and, as such, are too few to adequately reflect the average "real-world" exposure of the self-serve consumer whose exposures would depend

greatly upon refueling habits and prevailing weather conditions. Nevertheless, it does allow the inference that consumer exposures to gasoline vapors under periodic self-serve conditions would likely be very small.

In 1983, the API sponsored a project to determine airborne concentrations of selected gasoline components during typical self-serve refueling operations.⁽¹⁴⁾ In this project, a total of 288 samples were collected from 13 service stations in six cities and covered the exposures resulting from the pumping of unleaded, leaded, and premium gasolines. It was determined that the average refueling operation took approximately 2 minutes, but in order to obtain sufficient sample to analyze, monitoring of 4 to 5 refuelings was necessary. Thus, each of the 288 samples collected represented 4 to 5 refuelings. The geometric mean of the exposures in this survey, measured as total hydrocarbons, averaged 139.0 mg/m^3 (46.6 ppm). However, it should be noted that these represent maximum or peak exposures since monitoring was undertaken only during the refueling process. Assuming an average refueling time of 2 minutes and no further exposures, the 8-hour TWA exposures to gasoline vapors in this study would center around a geometric mean of 0.6 mg/m^3 (0.2 ppm). Thus, this study confirms the contention that time-weighted consumer exposures to gasoline vapors are very low overall, and much lower than those for the three occupations described in this report.

Ship/Barge Loading Exposures

For the marine operations, while the overall 8-hour, TWA exposures were below the ACGIH-TLV, one of the 11 exposure samples was measured at 1580.4 mg/m^3 (529.4 ppm) TWA, 8-hour. Thus, in this specific occupation, the recommended TLV for gasoline vapor is likely to be exceeded on occasion due to the very nature of the fuel

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transferring process. The refueling operations for marine loading facilities involve the transfer of fuels at high volume and pressure into the open hatchways of tanker/barge storage tanks. This causes "pluming" and the displacement of larger volumes of volatiles to occur to a much greater extent than exists for the refueling operations at non-marine bulk loading terminals. Therefore, marine operators are likely to experience high intermittent exposures to gasoline fumes. It should be noted, however, that the number of employees involved in marine loading operations is small compared to non-marine bulk loading terminals.

Compositional Analysis

In the comprehensive chemical analysis of the 12 terminal exposure samples, a total of 20 individual compounds each comprising at least 0.5 percent by weight of the sample collectively accounted for approximately 89.0 percent of the gasoline vapors. For the marine loading exposures, 22 individual compounds accounted for 94 percent of the vapor sample. Compared to the terminal analyses, however, the composition of the marine loading exposures was weighted slightly more toward the C₅, C₆, and C₇ components, at the expense of the C₄ compounds. This weighting toward the heavier components can be rationalized by considering the loading operation. As was mentioned previously, marine loading operations can generate pluming of vapors because of the high volume and pressures involved. Hence, the loading operation creates a greater degree of aerosolization of the gasoline, resulting in the release of a larger proportion of heavier components into the air and breathing zone of the employees.

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In 1978, a comprehensive compositional study was reported by McDermott and Killiany.⁽¹³⁾ Their report, based on detailed analyses of 95 gasoline vapor exposure samples from bulk loading facilities, identified 21 individual components (each comprising 0.5 percent or greater by volume) which accounted for approximately 92 percent of the gasoline vapors. A comparison of the composition of gasoline vapor exposures from our survey and that of McDermott and Killiany is shown on Table II. It reveals few differences in gasoline vapor composition, particularly with respect to the alkane and aromatic components and despite the slight compositional shift observed for the marine loading exposures. The similarity in chemical composition can be explained by virtue of gasoline being blended from a large but common pool of hydrocarbons. For example, 151 compounds were identified in the gasoline blend tested by MacFarland et al., with 42 accounting for 75 percent of the mixture.⁽¹⁾ However, the consistency in proportion of the hydrocarbons detected in the occupation exposure samples was unexpected in light of the fact that the samples were taken approximately eight years apart under different monitoring and exposure conditions and from two different petroleum companies, whose blending tactics may vary substantially. This suggests that the composition of the gasoline vapors remains fairly constant regardless of the gasoline blend (barring, of course, special additives) or exposure conditions. Seemingly, the only parameter that changes significantly is the magnitude of exposure.

That the composition of gasoline vapors remains fairly constant is further supported by the API-sponsored project in which exposures to various vapor components of gasoline were measured during refueling operations.⁽¹⁴⁾ Analysis of 152 samples in this project revealed that n-pentane, n-hexane, and benzene constituted 10.9 ± 4.2 , 1.7 ± 0.9 , and

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2.2 ± 1.1 percent of the total exposures, respectively. Again, as can be seen from Table II, the proportions of these components were very similar to the percent composition obtained for these compounds both in our survey as well as in the McDermott and Killiany report. Based on these findings, it would appear reasonable to assume that the composition of the remaining components of the gasoline vapors in the API-sponsored study would also be similar.

This reproducibility in the composition of gasoline vapors has two important consequences. The first is that exposure to individual components within gasoline vapors could be estimated using total C₄+ hydrocarbon exposure data; such an estimation capability would especially apply to the four major C₄ and C₅ compounds which have been found in this survey to constitute approximately 61 to 74 percent by weight of the total gasoline vapor samples. The second important consequence relates to the possibility of evaluating the toxicity of gasoline vapors on the basis of the individual hydrocarbon components. For example, in the chronic inhalation study of unleaded gasoline in which renal damage and cancers were observed in male rats, the animals were exposed to a totally vaporized material.⁽¹⁾ The animals were, therefore, exposed to a full spectrum of at least 151 compounds in varying proportions, of which 42 accounted for 75 percent of the composition. However, based on the results of this survey and that conducted by McDermott and Killiany⁽⁸⁾, it is apparent that gasoline vapors are comprised of around 20 hydrocarbon components accounting for greater than 90 percent of the vapor composition and which occur in surprisingly consistent proportions. Also, of these 20 or so hydrocarbons, 61 percent or higher (depending on occupational exposures) is made up of four C₄/C₅ hydrocarbons. There appears to be a substantial difference between the composition of occupational exposures to gasoline

vapor and totally vaporized gasoline; thus, evaluating the toxicity of a gasoline vapor rather than the totally vaporized liquid would present a better means of determining the possible hazards associated with "real world" exposures to gasoline vapors.

Benzene Exposures

Because of the concern over the toxicity of benzene, the exposure to benzene as a component of the gasoline vapor was monitored for the terminal workers, the marine loading operators, and the service station attendants. The geometric mean 8-hour, TWA exposure to benzene for the terminal operators and truck drivers based on 183 samples (which included the subset of 37 samples) was 0.8 mg/m^3 (0.3 ppm). For the service station attendants, it was 0.7 mg/m^3 (0.2 ppm) based on 21 samples, and for the marine loading operators, it was 0.5 mg/m^3 (0.2 ppm) based on 11 samples. Only 5 of the 215 samples taken, or approximately 2 percent, exceeded 3.2 mg/m^3 (1.0 ppm), with the highest benzene exposure reading being 19.5 mg/m^3 (6.1 ppm). The results are compatible with those discussed by McDermott and Vos⁽¹²⁾ and Runion^(15, 16), and support the contention that benzene exposures through gasoline vapor exposure are very low for the workplaces specified above and should be even lower for consumers. In support of this last statement, benzene was not detected (limit of detection: 2 ug/sample) in any of the samples collected in the refueling study undertaken in this report.

The API-sponsored project of self-service automobile refueling operations found that the geometric mean exposure to benzene was 2.6 mg/m^3 (0.8 ppm) during the refueling operations based on 282 sample analyses.⁽¹⁴⁾ Again, these results reflect the maximum or peak exposures to benzene since measurements were taken only during

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the refueling operations. In this study, on an 8-hour, TWA basis (assuming no further exposure and a 2-minute refueling time), the exposure to benzene would average 0.01 mg/m³ (0.003 ppm). Therefore, these results further support the conclusion of this report that consumer exposures to benzene through gasoline vapors are very low.

CONCLUSIONS

The following conclusions may be drawn from this report:

- o Exposures to gasoline vapor for terminal operators and truck drivers, marine loading operators, and service station attendants are expected to be substantially below the established ACGIH-TLV for gasoline. Consumer exposures are anticipated to be significantly lower than these worker exposures.

- o Four C₄/C₅ compounds, namely, n-butane, isobutane, n-pentane, and isopentane, comprise at least 90 percent of all C₄/C₅ hydrocarbons in gasoline vapor samples and constitute from 61 to 67 percent by weight of the total gasoline vapor samples. All C₄ and C₅ hydrocarbons comprise at least 67 to 74 percent of total gasoline vapors, depending on the occupational setting.

- o The chemical composition of gasoline vapors appears to be remarkably constant regardless of the gasoline blend, monitoring (exposure) conditions, or magnitude of exposure.

0 0 2 4

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- o Benzene exposures from gasoline vapors are very low for terminal workers and service station attendants, with 98 percent of the exposures in this limited survey falling below 1.0 ppm. TWA (8-hour). Again, consumer exposures to benzene through automobile refueling are expected to be significantly lower than this.

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REFERENCES

1. MacFarland, E. N., C. E. Ulrich, C. E. Holdsworth, D. N. Kitchen, W. H. Halliwell, and S. C. Blum: A Chronic Inhalation Study with Unleaded Gasoline Vapor. J. Amer. Coll. Toxicol. 3: 231-248 (1984).
2. Kuna, R. A. and C. E. Ulrich: Subchronic Inhalation Toxicity of Two Motor Fuels. J. Amer. Coll. Toxicol. 3(4): 217-229 (1984).
3. Halder, C. A., T. M. Warne, and N. S. Hatoum: Renal Toxicity of Gasoline and Related Petroleum Naphthas in Male Rats. In Renal Effects of Petroleum Hydrocarbons. Volume VII. Advances in Modern Environmental Toxicity. (M. A. Mehlman, G. P. Hemstreet, III, J. J. Thorpe, and N. K. Weaver, eds.), pp. 73-88. Princeton Scientific Publishers, Incorporated, Princeton, New Jersey (1984).
4. Ward, W. L.: Personal communication. American Petroleum Institute, Washington, D.C. Information disclosed with permission. "Characterizing Downstream Gasoline Worker Exposures": Analytical work performed under contract for API by Research Triangle Institute, Research Triangle Park, North Carolina (1984).
5. 3M Organic Vapor Monitor Sampling Guide, 3M Company, St. Paul, Minnesota, (May 1981).

6. Elliott, R. W., and H. Watts: Diffusion of Some Hydrocarbons in Air: A Regularity in the Diffusion Coefficients of a Homologous Series. Can. J. Chem. 50: 31-34 (1972).
7. Barr, R. F., and H. Watts: Diffusion of Some Organic and Inorganic Compounds. J. Chem. Eng. Data 17: 45-46 (1972).
8. TLVs: Threshold Limit Values for Chemical Substances and Physical Agents in the Work Environment with Intended Changes for 1983-84, p. 21, American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio (1983).
9. Snedecor, G. W. and W. G. Cochran: One-way Analysis of Variance for Samples of Unequal Sizes. In Statistical Methods, Chapter 12, Iowa State University Press, Iowa (1980).
10. Ward, W. L.: Personal communication. American Petroleum Institute, Washington, D.C. Information disclosed with permission. (Information also disclosed to Office of Toxic Substances, USEPA, Washington, D.C., September 1983 by R. Diakun. Title of presentation: "Characterization of Work Place Exposures.")
11. Phillips, C. F., and R. K. Jones: Gasoline Vapor Exposure during Bulk Handling Operations. Am. Ind. Hyg. Assoc. J. 39: 118-128 (1978).

12. McDermott, H. J., and G. A. Vos: Service Station Attendants' Exposure to Benzene and Gasoline Vapors. Am. Ind. Hyg. Assoc. J. 40: 315-321 (1979).
13. McDermott, H. J., and S. E. Killiany, Jr.: Quest for a Gasoline TLV. Am. Ind. Hyg. Assoc. J. 39: 110-117 (1978).
14. Gasoline Exposure Study for the American Petroleum Institute. CEC Job No. 18629-15, Clayton Environmental Consultants, Inc., Southfield, Michigan (August 1983). (American Petroleum Institute, Washington, D.C., sponsor.) Information disclosed with permission.
15. Runion, H. E.: Benzene in Gasoline. Am. Ind. Hyg. Assoc. J. 36: 338-350 (1975).
16. Runion, H. E.: Benzene in Gasoline II. Am. Ind. Hyg. Assoc. J. 38: 391-393 (1978).

TABLE IA
SUMMARY OF MONITORING SURVEY OF GASOLINE VAPOR EXPOSURES

Location	Total Exposure		Sample Size	Exposures, mg/M ³ (ppm) ^A		Sample Size	TWA, 8-hour Benzene	Sample Size
	TWA, 8-hour C ₆ + Hydrocarbons			TWA, 8-hour C ₄ + Hydrocarbons				
Terminal 1								
Bottom Loading-Vapor Recovery			46			8		56
Arithmetic Mean ± S.D. ^B	10.3 ± 19.1	(2.6 ± 4.8)		39.6 ± 63.1	(13.3 ± 21.1)		1.0 ± 1.2	(0.3 ± 0.4)
Range	2.0 - 111.2	(0.5 - 37.7)		9.4 - 195.1	(3.1 - 65.4)		0.2 - 6.9	(0.1 - 2.0)
Geometric Mean	4.8	(1.2)		22.4	(7.5)		0.8	(0.3)
Geometric Standard Deviation	2.9			2.5			1.9	
Terminal 2								
Bottom Loading-Vapor Recovery			16			6		22
Arithmetic Mean ± S.D.	4.5 ± 4.1	(1.1 ± 1.0)		46.3 ± 93.8	(15.5 ± 31.4)		0.7 ± 0.4	(0.2 ± 0.1)
Range	2.0 - 14.6	(0.5 - 3.6)		1.3 - 237.6	(0.4 - 79.6)		0.1 - 2.1	(0.0 - 0.7)
Geometric Mean	3.3	(0.8)		11.3	(3.8)		0.5	(0.2)
Geometric Standard Deviation	2.1			5.6			2.4	
Terminal 3								
Bottom Loading-Vapor Recovery			18			6		24
Arithmetic Mean ± S.D.	15.2 ± 13.9	(3.8 ± 3.5)		47.9 ± 41.2	(16.0 ± 13.8)		0.8 ± 0.5	(0.3 ± 0.2)
Range	2.1 - 50.9	(0.5 - 12.7)		17.6 - 127.8	(5.9 - 42.5)		0.2 - 2.6	(0.1 - 0.8)
Geometric Mean	10.1	(2.5)		37.5	(12.6)		0.7	(0.2)
Geometric Standard Deviation	2.7			2.1			1.8	
Terminal 4								
Bottom Loading-No Vapor Recovery			31			7		38
Arithmetic Mean ± S.D.	11.6 ± 21.6	(2.9 ± 5.4)		89.8 ± 59.3	(30.1 ± 19.9)		1.1 ± 1.0	(0.3 ± 0.3)
Range	0.8 - 120.8	(0.2 - 30.1)		21.9 - 183.5	(7.3 - 61.5)		0.2 - 5.9	(0.1 - 1.8)
Geometric Mean	5.7	(1.4)		72.6	(24.3)		0.8	(0.3)
Geometric Standard Deviation	3.0			2.1			2.1	
Terminal 5								
Top Loading-No Vapor Recovery			33			10		43
Arithmetic Mean ± S.D.	14.3 ± 17.6	(3.6 ± 4.4)		46.4 ± 31.1	(15.5 ± 10.4)		0.9 ± 0.5	(0.3 ± 0.2)
Range	2.0 - 65.5	(0.5 - 18.3)		9.9 - 109.2	(3.3 - 36.6)		0.1 - 2.3	(0.0 - 0.7)
Geometric Mean	7.2	(1.8)		37.3	(12.5)		0.7	(0.2)
Geometric Standard Deviation	3.3			2.1			2.0	
Terminals, Overall			146			37		183
Arithmetic Mean ± S.D.	11.5 ± 17.8	(2.9 ± 4.4)		53.4 ± 58.2	(17.9 ± 19.5)		1.0 ± 0.9	(0.3 ± 0.3)
Range	0.8 - 120.8	(0.2 - 30.1)		1.3 - 237.6	(0.4 - 79.6)		0.1 - 6.9	(0.0 - 2.8)
Geometric Mean	5.7	(1.4)		31.2	(10.5)		0.8	(0.3)
Geometric Standard Deviation	3.0			3.0			2.0	
Service Station 1			21					21
Arithmetic Mean ± S.D.	17.0 ± 37.5	(4.5 ± 9.4)		ND			1.0 ± 1.1	(0.3 ± 0.3)
Range	1.1 - 138.3	(0.3 - 32.5)		ND			0.0 - 4.2	(0.0 - 1.5)
Geometric Mean	4.0	(1.0)		ND			0.7	(0.2)
Geometric Standard Deviation	4.5			ND			2.6	
Marine Loading Facilities						11		11
Arithmetic Mean ± S.D.	ND			246.0 ± 451.8	(82.4 ± 151.4)		2.3 ± 5.7	(0.7 ± 1.8)
Range	ND			9.1 - 1580.4	(3.0 - 529.4)		0.1 - 19.5	(0.0 - 6.1)
Geometric Mean	ND			69.4	(29.9)		0.5	(0.2)
Geometric Standard Deviation	ND			4.5			5.5	

^AIn the conversion of mg/m³ to ppm, an average molecular weight of 73 was used for C₄+ samples and 98 for C₆+ samples. These molecular weights were calculated assuming a distribution of hydrocarbons as shown in Figure 1.

^B S.D. = Standard Deviation.

ND = Not Done

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TABLE IV**SUMMARY OF MONITORING SURVEY OF GASOLINE VAPOR EXPOSURES**

Location	Composition, %		Sample Size
	Four C ₄ /C ₅ Isomers ^A of Total Exposure Sample	Four C ₄ /C ₅ Isomers of Total C ₄ /C ₅ Components	
Terminal 1 Bottom Loading--Vapor Recovery	65.2 ± 13.1 ^B	90.9 ± 1.8	4
Terminal 2 Bottom Loading--Vapor Recovery	74.2 ± 21.72	92.0 ± 11.4	2
Terminal 3 Bottom Loading--Vapor Recovery	-	-	0
Terminal 4 Bottom Loading--No Vapor Recovery	68.5 ± 0.7	87.7 ± 2.0	3
Terminal 5 Top Loading--No Vapor Recovery	64.9 ± 2.7	89.7 ± 2.0	3
Terminals, Overall	67.4 ± 10.2	90.0 ± 4.1	12
Service Station 1	-	-	0
Marine Loading Facilities	61.3 ± 7.8	92.1 ± 3.4	11

^An-butane, isobutane, n-pentane, and isopentane

^BArithmetic mean ± standard deviation.

0 0 3 0

TABLE II
AVERAGE COMPOSITION OF GASOLINE VAPOR EXPOSURES

Compound	Compositional Make-up ^A				
	Amoco Oil ^B (wt %)	Amoco Oil ^C (wt %)	Shell Oil ^D (vol %)	API ^E (wt %)	
Alkanes					
C ₃	n-propane	-	0.8 (1.1)		
C ₄	n-butane	33.7 (7.8)	21.2 (10.4)	38.1 (5.7)	
	isobutane	4.1 (0.8)	3.4 (1.6)	5.2 (1.9)	
C ₅	n-pentane	8.1 (2.5)	9.4 (1.5)	7.0 (4.0)	
	isopentane	21.6 (3.7)	27.2 (6.7)	22.9 (6.1)	
C ₆	cyclopentane	-	-	0.7 (0.7)	
	2,3-dimethylbutane	1.3 (0.7)	3.3 (1.8)	0.7 (0.5)	
	2-methylpentane	3.4 (1.3)	4.9 (1.4)	2.1 (1.3)	
	3-methylpentane	2.0 (0.7)	3.2 (0.9)	1.6 (0.9)	
	methylcyclopentane	1.1 (0.6)	1.5 (0.4)	1.3 (0.4)	
C ₇	n-hexane	1.8 (0.7)	3.1 (0.7)	1.5 (0.9)	
	2,3-dimethylpentane	0.6 (0.3)	0.9 (0.8)	0.7 (0.6)	
	2,4-dimethylpentane	-	0.8 (0.5)	-	
	2-methylhexane	0.6 (0.3)	1.1 (0.3)	-	
	3-methylhexane	0.7 (0.4)	1.1 (0.3)	-	
C ₈	n-heptane	-	0.7 (0.2)	-	
	2,2,4-trimethylpentane	0.7 (0.5)	1.8 (1.2)	0.5 (0.5)	
Alkenes					
C ₄	isobutylene	-	-	1.1 (1.5)	
	1-butene	-	1.0 (0.7)	-	
	trans-2-butene	1.2 (0.5)	-	-	
	cis-2-butene	0.9 (0.3)	1.2 (0.7)	-	
C ₅	2-methyl-1-butene	0.9 (0.4)	-	1.6 (2.1)	
	2-methyl-2-butene	-	1.5 (0.7)	1.7 (1.8)	
	1-pentene	-	0.7 (0.4)	-	
	trans-2-pentene	0.8 (0.6)	-	-	
	cis-2-pentene	-	-	1.2 (1.7)	
Aromatics					
C ₆	benzene	2.2 (1.0)	0.6 (0.3)	0.7 (0.4)	2.2 (1.1)
C ₇	toluene	3.1 (1.6) ^F	4.0 (1.8) ^F	1.8 (1.3)	2.2 (1.8)
C ₈	xylene (p,m,o)	0.9 (0.7)	1.5 (0.7)	0.5 (0.6)	1.1 (1.5)
	Total Percent	<u>99.7</u>	<u>94.1</u>	<u>91.7</u>	

^A Components listed comprise at least 0.5 percent by wt. or vol. Composition less than 0.5 percent denoted by -. Composition presented as arithmetic mean (⁺ standard deviation).

^B N = 12. Bulk terminal exposures.

^C N = 11. Marine loading exposures.

^D N = 95. Adapted from McDermott, H.J., and Killiany, S.E. *AIHA Journal* 39: 110-117 (1978).
Permission granted by journal.

^E N = 152. Report to the American Petroleum Institute (API) by Clayton Environmental Consultants (August, 1983). Information disclosed with permission.

^F Toluene coeluted with 2,3,3-trimethylpentane on the analytical column. However, the major proportion is assumed to be toluene.

0 0 3 1

TABLE III
GAZOLINE VAPOR EXPOSURES FROM REFUELING OF TEST CARS

Description	Monitoring Duration, Min.	Total Hydrocarbons, Method 1A		Total Hydrocarbons, Method 3B	
		ppm/m ³ (ppm)	ppm/m ³ (ppm)	ppm/m ³ (ppm)	ppm/m ³ (ppm)
1. Packed 1 car; 5-gal gasoline. Also added 1 quart of oil.	5	NDC	-	ND	-
2. Packed 3 cars; 10-gal gasoline.	11	ND	-	ND	-
3. Packed 4 cars; 17-gal gasoline.	23	ND	-	ND	-
4. Packed 6 cars; 25-gal gasoline.	37	12.7 (4.38)D	0.72 (0.24)	34.3 (0.13)	1.4 (0.06)
5. Packed 37 cars; 173-gal gasoline. (Period includes lunch and other breaks).	354	2.9 (0.98)	3.1 (0.71)	0.5 (0.10)	4.0 (1.01)

7-SMC charcoal tubes.

PpM 3300 Organic Vapor diffusion badge.

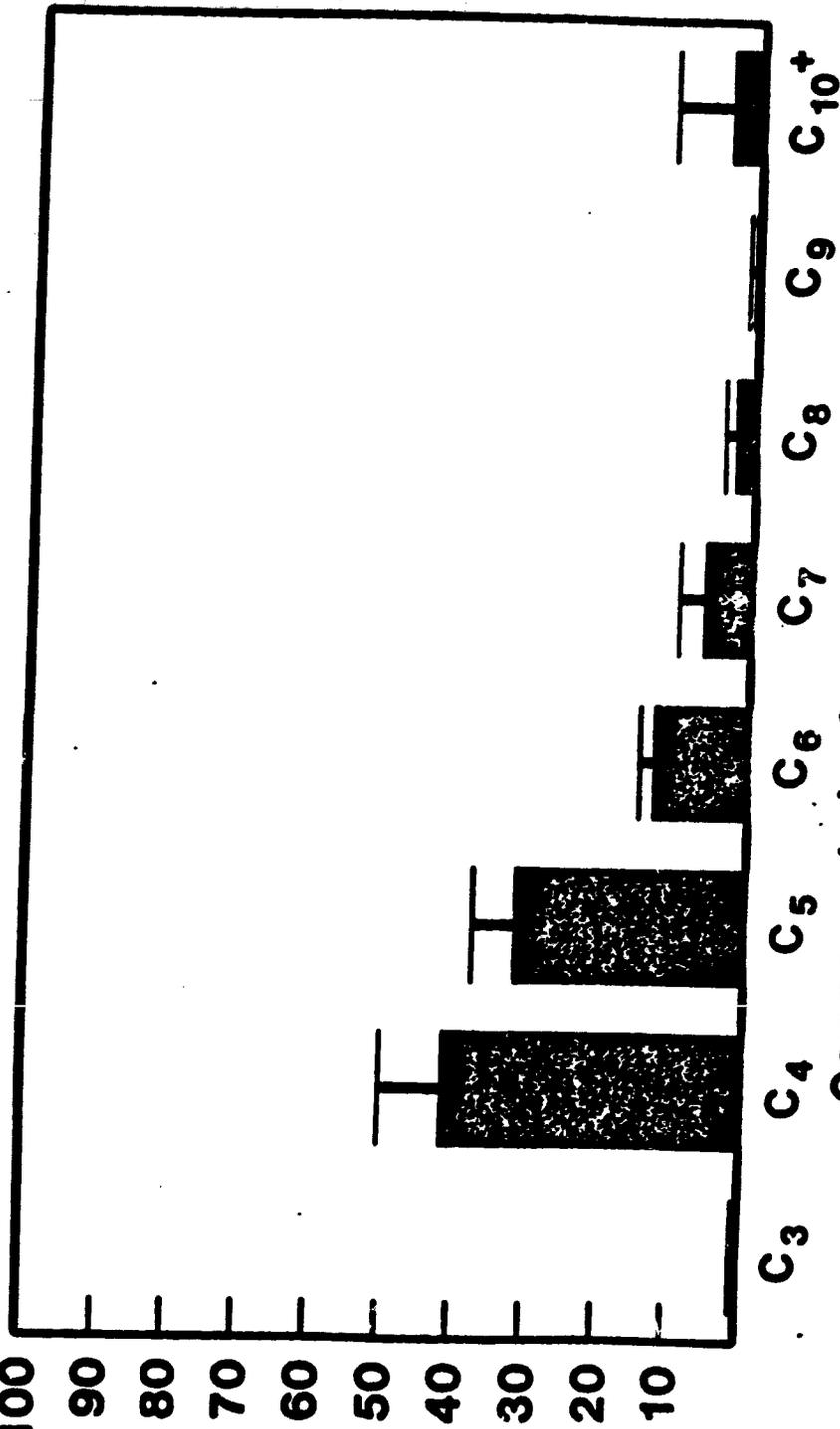
C Not detected. Lower limit of detection for total hydrocarbons was 30 ug/sample.

D Average molecular weight of 73 was used to convert ppM to ppm.

Figure 1--Distribution of gasoline vapor exposure components by carbon number based on extensive chemical analysis of twelve bulk terminal monitoring samples.

0 0 . 3 3

% Composition (by Wt.)



Components by Carbon Number

Figure 2--Distribution of C₆+ hydrocarbon exposures from all aspects of the petroleum industry (Source: American Petroleum Institute). A total of 4,789 samples were collected and summarized in the above chart. An average molecular weight of 98 was used in the conversion of mg/m³ to ppm.

0 0 3 5

