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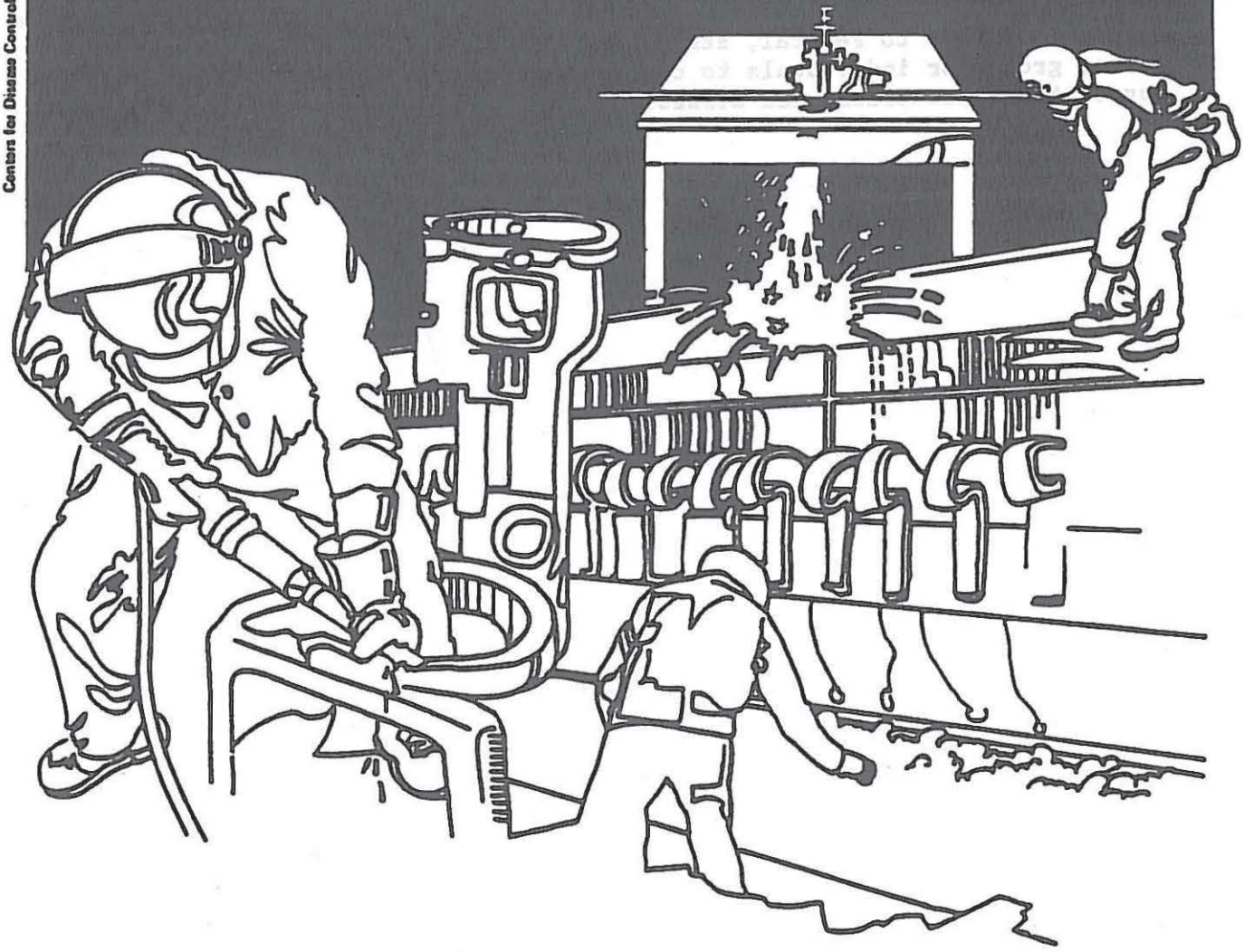

Health Hazard Evaluation Report

HETA 81-385-1659
TEXACO CHEMICAL COMPANY
PORT NECHES, TEXAS

PREFACE

The Hazard Evaluations and Technical Assistance Branch of NIOSH conducts field investigations of possible health hazards in the workplace. These investigations are conducted under the authority of Section 20(a)(6) of the Occupational Safety and Health Act of 1970, 29 U.S.C. 669(a)(6) which authorizes the Secretary of Health and Human Services, following a written request from any employer or authorized representative of employees, to determine whether any substance normally found in the place of employment has potentially toxic effects in such concentrations as used or found.

The Hazard Evaluations and Technical Assistance Branch also provides, upon request, medical, nursing, and industrial hygiene technical and consultative assistance (TA) to Federal, state, and local agencies; labor; industry and other groups or individuals to control occupational health hazards and to prevent related trauma and disease.

HETA 81-385-1659
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TEXACO CHEMICAL COMPANY
PORT NECHES, TEXAS

NIOSH INVESTIGATORS:
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I. SUMMARY

In July 1981, the National Institute for Occupational Safety and Health received a request from the Oil, Chemical and Atomic Workers Union to evaluate the genotoxicity associated with occupational exposures to ethylene oxide (EtO) at the Texaco Chemical Company, Port Neches, Texas. This request cited union concerns resulting from recent reports of animal carcinogenicity and adverse reproductive effects as a justification for the study.

On March 30 and 31, 1985, NIOSH investigators collected blood samples for cytogenetic analyses and industrial hygiene samples for evaluation of the occupational environment. The effects of occupational exposure to ethylene oxide (EtO) on the incidences of sister chromatid exchanges (SCE) and chromosomal aberrations (CA) in circulating lymphocytes were assessed in a cross-sectional epidemiologic study. Workers in three occupational environments were compared: individuals who were unexposed to chemicals (referent individuals); workers in production units manufacturing EtO (production workers); and workers in a quality assurance laboratory, where there were many chemical exposures among which, at least historically, EtO had been one of the more common (laboratory workers). The quality assurance laboratory workers were included in this study as a positive reference group.

Analyses of the CA data and the SCE data lead to the following conclusions about the low level EtO exposures (< 2 ppm annual mean TWAs) in the EtO production units: 1) these exposures appear to produce marginally significant ($p=0.06$) increases in the group mean SCE frequency per chromosome per cell in nonsmokers compared to control nonsmokers, but 2) these exposures are not associated with an overwhelming increase in genotoxicity effect (as measured by either the SCE or CA assays). Significant elevations ($p< 0.05$) observed in both the group mean SCE frequency per chromosome per cell and in group mean transformed CA frequency of laboratory workers compared to those frequencies observed in referents can not be attributed solely to EtO because of the complex nature of this working environment.

Based on the industrial hygiene and the cytogenetic findings of this evaluation, it was concluded that employment in the EtO production units was not associated with an overwhelming genotoxicity response, although a marginally significant effect ($p=0.06$) on group mean SCE frequency was observed in nonsmokers. Recommendations are contained in Section VIII.

KEYWORDS: SIC 2810 (Chemical Manufacturing), ethylene oxide, chromosomal aberrations, sister chromatid exchange, genotoxicity, laboratory workers, chemical workers.

II. INTRODUCTION

In July, 1981, the Oil, Chemical and Atomic Workers Union (OCAW) requested the National Institute for Occupational Safety and Health (NIOSH) to evaluate potential genotoxic effects among union members at a plant manufacturing ethylene oxide (EtO). The request was initiated because of recent reports of animal and human carcinogenic effects at levels lower than the current OSHA occupational permissible exposure level (PEL) of 50 ppm 8-hour time-weighted average (TWA) exposure. This standard was in large part based on the irritative properties of acute exposure to EtO. Subsequent to conducting this study, OSHA lowered the PEL to 1 ppm 8-hour TWA exposure as published in the Federal Register (49 CFR 25733) on June 22, 1984.

The field activities of this investigation took place during the first three months of 1982, culminating with the collection of industrial hygiene and biological samples during the last week of March. This report summarizes available industrial hygiene data which consists of EtO time-weighted average exposures observed in the production units and in a laboratory by Texaco, and instantaneous exposure levels measured in the production units by NIOSH. This report also presents results on two cytogenetic assays, the sister chromatid exchange (SCE) assay and the chromosomal aberration (CA) assay. The biological (and health) significance of these assays is unknown to date, except that many of the chromosomal aberrations would lead to cell death; therefore, the frequencies of chromosomal changes measured by these assays can not be used to predict adverse health effects in an individual. However, on a population basis, increases in these assays have been associated with exposure to carcinogenic agents.

Participants in the cytogenetic study were employees whose work involved potential exposure to EtO and referents who were either Texaco employees or community residents with little potential for exposure to EtO or other industrial chemicals. The Texaco employees with potential exposure were workers in EtO production units and the workers in the quality assurance laboratory. Two detailed reports which fully discuss industrial hygiene data and the SCE assay finding and CA assay findings are addendums to this report, and are available from NIOSH.

III. SUMMARY OF INDUSTRIAL HYGIENE DATA

The EtO exposures documented in the production units and laboratory are briefly summarized.

During the two days of 1982, while NIOSH collected the blood samples, the company conducted personal sampling and chemical analysis of time weighted average (TWA) exposures. The personal sampling and chemical analyses were conducted by the company according to the procedures outlined in the NIOSH Sampling and Analytical Method S286 with minor modifications (i.e., use of a 1000 mg JXC Columbia charcoal tube and a different packed column for the gas chromatograph).

A. Company TWA Exposure Data

We decided that a brief summary of the current and historic data collected by the company was justified to look at the trend in exposure. The arithmetic annual mean TWAs and their standard deviations are presented for both the laboratory and the production units in Table 1. The standard deviations are relatively large compared to the annual mean TWA values, indicating considerable variability.

The annual mean TWA exposures in the production units have been less than 2 ppm (ranging between 0.9 and 1.73). In the laboratory, the annual mean TWA exposures have declined over the past five years from 12.7 ppm in 1978 to 0.15 ppm in 1982.

B. NIOSH Instantaneous Exposure Data

NIOSH was able to conduct a limited evaluation of instantaneous exposures to EtO in the production unit workers' breathing zones by taking area air samples with a Foxboro/Wilkes Miran 103® infrared analyzer. The instrument was calibrated to read between 1 and 100 ppm. The main purpose of these measurements was to determine if brief instantaneous exposures represented exposure to elevated levels of EtO. We determined the greatest potential for peak exposures to EtO in the production units occurred when employees collected quality assurance samples to be sent to the laboratory for analysis. Four separate cycles of sample collection were monitored for exposure levels, with the cycle starting at ambient exposure levels which would be present for an indefinite time between cycles and the cycle moving through various exposure levels during the different phases of sample collection which last for discreet time periods. These measurements are summarized in Table 2. Exposure levels greater than 100 ppm could not be quantified and are noted as > 100 ppm.

In the production units, while most of a worker's time is spent in a control room where the potential for exposure is low, the infrequent but routine collection of quality assurance samples appears to involve a potential for exposure to high EtO levels over a fairly short time period. The exposure levels range from 5 ppm or less, the ambient level in the sampling location, to over 100 ppm during the sample collection. NIOSH has recently recommended to OSHA at the 1983 Permissible Exposure Standard Hearing that a short-term exposure limit of 5 ppm during any 10-minute period and 0.1 ppm 8-hour TWA exposure limit be promulgated. The exposure time of the quality assurance sample collection and the short-term exposure level exceeded the NIOSH recommended short-term exposure limit. No instantaneous readings were taken in the laboratory environment.

IV. SUMMARY OF SCE ASSAY FINDINGS

Two analytical approaches were used to evaluate the SCE assay data. A number of the issues involved in these analyses are beyond the scope of this summary report and therefore, for a detailed discussion, the reader is referred to the full detailed SCE report. The techniques used to culture cells, to prepare slides and to score assays followed standard procedures such as those recommended in "The Guidelines for Studies of Human Populations Exposed to Mutagens and Reproductive Hazards" published by the March of Dimes Birth Defects Foundation. One analytic approach is based on the differences in group mean SCE frequency per chromosome per cell between groups of exposed workers and controls. This has been the traditional approach for analysis of SCE data. The other approach is based on comparing the differences in the distribution of SCE frequency per chromosome per cell for every person in a group to an expected distribution. The purpose of this comparison is to determine if one group tends to have more high frequency cell individuals (HFCI); that is, more individuals with a cell distribution containing a greater than expected number of cells with high SCE frequency per chromosome per cell, than another group. This second analytical approach has evolved as an innovation to increase the assay's sensitivity and needs further application before results can be meaningfully interpreted.

All of the analyses are adjusted for the effect of cigarette smoking. Three controls and three laboratory workers smoked cigars and/or pipes. The cytogenetic data on these cigar and pipe smokers are not discussed in this report because the numbers are small, although these data are discussed in the attached detailed report. Group mean SCE frequency per chromosome per cell for the major exposure and smoking stratifications considered in the analyses are presented in Table 3.

For the evaluation of the group mean SCE frequency per chromosome per cell data, a t-test, a stepwise multiple regression and simple multiple regression were used. The results by comparison of the t-test analyses are summarized in Table 4.

Using a level of significance of 0.05 (i.e., p-value equal to or less than 0.05), significant elevations in group mean SCE frequency per chromosome per cell were associated with the following (the number in parentheses preceding the comparison refers to the comparison number given in Table 4):

(1) smoking among comparison individuals,

(2) smoking among workers in the production units,

(5) working in the laboratory versus the working situations of the unexposed referent individuals when evaluation was restricted to nonsmokers,

(6) working in the laboratory versus working in the production units when the evaluation was restricted to nonsmokers,

(8) working in the laboratory versus the working situations of the unexposed referent individuals when the evaluation was restricted to cigarette smokers.

Increases in the group mean SCE frequency per chromosome per cell were observed in the following comparisons with the noted p-values (the number in the parentheses preceding the comparison refers to the comparison number given in Table 4):

(4) working in the production units versus the working situations of the unexposed referent individuals when the evaluation was restricted to nonsmokers (p-value = 0.06), and

(10) working in the laboratory and not smoking versus the working situations of the unexposed referent individuals smoking cigarettes (p-value = 0.06).

The stepwise multiple regression and simple multiple regression analyses considered the influences of age, smoking status, number of cigarettes smoked per day, employment group, length of employment in an exposed department, number of prescribed medications in the past six months and mean weekly alcohol consumption (handled both as beer, wine, and liquor independently or as a total). These analyses indicated that only smoking status and employment group were significant predictors of group mean SCE frequency.

The first step in conducting the second analytical approach, based on the differences in the distribution of SCE frequency per chromosome per cell, was to establish an expected distribution of SCE frequency per chromosome per cell. This was done separately for nonsmokers and cigarette smokers. The expected distribution of SCE frequency per chromosome per cell was established for these two groups by pooling all cells of referent subjects within each smoking group. The 95th percentile of each expected distribution of SCE frequency per chromosome per cell was determined and used as the cutoff for identifying a cell as having a high SCE frequency. The 95th percentile was 0.302 SCEs per chromosome per cell (or 13.9 SCEs per cell with 46 chromosomes) for nonsmokers and 0.391 SCEs per chromosome per cell (or 18.0 SCEs per cell with 46 chromosomes) for cigarette smokers. Next, the distribution of scored cells from each study participant was compared to the appropriate (i.e., nonsmoker or cigarette smoker) expected distribution of SCE frequency per chromosome per cell. The purpose of this comparison was to determine how many individuals in each employment group had more than 5% of scored cells (considering chance occurrence) above the 95th percentile of the expected distribution of SCE frequency per chromosome per cell. If 80 cells were scored, then one would expect 5% or 4 cells to have a SCE frequency per chromosome per cell above the 95th percentile

cutoff. Since additional cells by chance could have SCE frequency per chromosome per cell above this cutoff, we used the upper 95% confidence limit of 5% of scored cells, to identify a study participant who had a greater than expected number of cells with high SCE frequency per chromosome per cell. If 80 cells were scored from a study participant then the upper 95% confidence limit for 5% of scored cells was 7 cells; the participant was denoted as a high frequency cell individual (HFCI) if he had 8 or more cells above the 95th percentile of the expected distribution of SCE frequency per chromosome per cell.

As Table 5 indicates among nonsmokers, 2 of the 25 referent individuals (8%) were HFCIs, 12 of the 30 production unit workers (40%) were HFCIs, and 13 of 14 laboratory workers (93%) were HFCIs. Among the cigarette smokers, 1 of the 14 referent individuals (7%) was an HFCI, 4 of the 14 production unit workers (29%) were HFCIs and 7 of the laboratory workers (70%) were HFCIs.

The differences in proportions of HFCIs in the different employment groups stratified by either cigarette smoking status or nonsmoker status were evaluated using Chi-square tests and Fisher's Exact Test. Ratio of odds (RO) comparing the odds of being an HFCI individual for either the workers in the production units or laboratory workers compared to the odds of being an HFCI individual for referent individuals were calculated. The chi-square values with p-values, the p-values for Fisher's Exact Test and the ROs with their confidence intervals are presented for nonsmokers and cigarette smokers in Table 6. All of these comparisons except the one comparing the EtO production unit workers who smoked cigarettes to referents who smoked cigarettes were associated with p-values for the Chi-square values and Fisher's Exact p-values less than 0.05.

V. Summary of CA Assay Finding

The analysis of the CA data was based on considering the differences in group mean transformed CA frequencies and percent abnormal cells (percent of cells with at least one chromosomal aberration) between groups of exposed workers and referents. The CA categories considered include: chromatid deletions (CTD-DEL); chromatid exchanges (CTD-EX); isochromatid deletions (ISOCTD-DEL), a category which could include both chromatid-type and chromosome-type aberrations; chromosome exchanges (CHR-EX); total chromatid aberrations (CTD-TOT) a category which combines CTD-DEL and CTD-EX; percent abnormal cell (%ABN); and total aberration per cell (ABR/CELL). All transformed values were derived using the Tukey Freeman Transformation which is discussed in the CA detailed report.

The statistical evaluation of group mean transformed frequencies and %ABN was based on the t-test and the stepwise multiple regression procedures. The t-tests were not adjusted for confounders. However, smoking status and the weighted value of x-rays received within the last ten years (the two most strongly suspected confounders) as well as age, number of cigarettes smoked, months employed in an exposed

department, number of prescribed medications used in the last 6 months, and average number of total alcoholic beverages consumed per week were considered in a stepwise multiple regression procedure. None of these potential confounding variables appeared to be significantly influencing the observations associated with employment. For a more detailed discussion of these issues, a comprehensive consideration of statistical analysis and cytogenetic laboratory technique, the reader is referred to the CA detailed technical report.

The untransformed group mean CA frequencies and percentages with the standard error of the means are presented in Table 7. Using a level of significance of 0.05 (i.e., p-value equal to or less than 0.05), no significant elevations in group mean transformed CA frequencies or percent abnormal cells were observed between the controls and the production unit workers. Significant elevations between referents and laboratory workers were observed in the following CA categories: CTD-DEL, CTD-EX, CTD-TOT, %ABN and ABR/CELL.

VI. DISCUSSION

A marginally significant elevation (p=0.06) of group mean SCE frequency per chromosome per cell in nonsmokers working in the production units compared to the nonsmoking reference group was observed. The elevation of group mean SCE frequency per chromosome per cell in production unit workers who smoked cigarettes relative to their referent counterpart did not approach significance. The results of the analysis based on the occurrence of HFCIs indicated that the proportion of individuals with high SCE frequency per chromosome per cell distributions was significantly greater among those working in the production units relative to referent individuals among nonsmokers. No significant elevation of group mean transformed CA frequencies or %ABN in production unit workers was observed relative to referents.

The annual mean TWA exposure levels to EtO for the workers in the production unit have been less than 2 ppm since 1978. The short-term exposures during quality control sample collection were shown to reach peaks of 100 ppm or more for brief periods of time. Therefore, these low TWA exposures which included transient high peak exposure levels appear to produce marginally significant increases (p=0.06) in genotoxicity as measured by group mean SCE frequency per chromosome per cell, at least in nonsmokers but no indication of an increase in CAs. The number of individuals with high SCE frequency distribution (i.e. HFCIs) was significantly increased in the production workers who were nonsmokers relative to the referents who were nonsmokers. We assume that other exposures in the production units which were believed not to be genotoxic, and unmeasured personal variables which could not be controlled in the analysis, do not explain the elevations.

The laboratory environment was associated with a significant increase in group mean SCE frequency per chromosome per cell and with a greater proportion of members having high SCE frequency per chromosome distributions relative to referent individuals in both nonsmokers and cigarette smokers. Additionally, employment in the laboratory environment was associated with significant increases in a number of CA categories including CTD-DEL, CTD-EX, CTD-TOT, %ABN and ABR/CELL.

The laboratory workers were included in the study as a positive reference group. The results of this study confirmed the previously observed effects of employment in a chemical laboratory and provided a useful comparison since this employment group was assumed to have the greatest genotoxic burden.

Employment in the laboratory environment involved potential exposure to a multitude of chemicals, which would have included several potentially genotoxic agents such as glycol ethers and ethanolamines. EtO was, at least historically, probably one of the most prevalent potential exposure agents because it was the major product and the major intermediate reagent at the plant. Historical industrial hygiene records indicated that yearly mean TWA exposure levels to EtO had been as high as 12.7 ppm in 1978, but these levels had steadily declined until in 1982 (collected at the time of this study), the mean TWA exposure level was 0.15 ppm. No short-term exposure data were available from the laboratory environment so continued possible exposure to transient high EtO levels could not be ruled out. The genotoxicity effects observed in laboratory workers could be attributed to several factors: the genotoxic effects of multiple chemicals, the chronic effect of historically high exposure to EtO, the recent effects of low EtO TWA exposure levels, the recent effects of undocumented high short-term exposures to EtO, or a combination of the above factors.

VII. CONCLUSION

These findings lead to the following conclusions: (1) The quality assurance laboratory's complex chemical environment (which historically has involved the highest annual mean TWA exposure levels to EtO) is associated with an increase in the group mean SCE frequency per chromosome per cell, in the proportion of individuals with cell distributions containing an increase in high SCE frequencies per cell relative to that of the comparison group and in specific group mean transformed CA frequencies and %ABN. (2) The production unit's environment appears to produce an elevation in the group mean SCE frequency among workers who do not smoke which was marginally significant ($p=0.06$). The same environment does not produce an increase in mean SCE frequency per chromosome per cell approaching statistical significance in cigarette smokers. Among nonsmokers, a significant increase was observed also in the proportion of production unit workers whose cell distributions of SCE frequency per chromosome per cell were elevated relative to the proportion in appropriate referent individuals. No evidence was observed which indicated that employment in the production unit was associated with an increase in any of the CA categories considered.

Overall, this suggests that the current and/or recent working environments (of the EtO production units) have sufficient activity to only marginally increase (p=0.06) the traditional SCE measure of genotoxicity. Statistically significant increases in genotoxicity as measured by both the SCE and the CA assays were associated with employment in the laboratory environment. The modest observed effects in the production unit workers are presumed to be related to EtO. The other potential exposures in the production area are not known to be associated with SCEs (however, sufficient research may not be available, especially for propylene oxides). It is possible that these marginal effects in production unit workers could be attributable to the high dose rate of EtO exposure during quality assurance sample collection.

VIII. RECOMMENDATION

The health implications of increased SCE and CA frequencies are not known at the current time. Some research has shown an association between genetic alteration and environmental factors causing cancer, reproductive difficulties, premature aging, and other health outcomes at a population level [Brusick, D., Principles of Genetic Toxicology, Chapter 3]. A marginally significant increase (p=0.06) in group mean SCE frequency per chromosome per cell and a significant increase in the proportion of HFCI for nonsmoking production unit workers compared to appropriate referents was observed. Nonetheless, the findings of the current study do not demonstrate an overwhelming increase of genotoxicity weighing the results of the SCE and CA assays together. The annual mean exposure to EtO in the EtO production departments had been 1.73 ppm or less during the period from 1978 through 1982 with short-term peak exposures over 100 ppm.

The NIOSH Current Intelligence Bulletin (CIB) Number 35 recommends that EtO be regarded as a potential occupational carcinogen. Since the occupational exposure conditions at this plant include EtO, NIOSH's position in the CIB urging "an employer to take all reasonable steps to reduce exposure to the (lowest) extent possible" is relevant to this hazard evaluation of EtO for the occupational environments evaluated.

As a final statement the researchers would like to reiterate that while genotoxicity assays are believed to document the effects of various environmental exposures, they cannot be interpreted as predictive of the probability of specific adverse health effects for individuals.

IX. AUTHORSHIP AND ACKNOWLEDGEMENTS

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X. DISTRIBUTION AND AVAILABILITY OF REPORT

Copies of this report are currently available upon request from NIOSH, Division of Standards Development and Technology Transfer, Publications Dissemination Section, 4676 Columbia Parkway, Cincinnati, Ohio 45226. After 90 days, the report will be available through the National Technical Information Service (NTIS), 5285 Port Royal, Springfield, Virginia 22161. Information regarding its availability through NTIS can be obtained from NIOSH Publications Office at the Cincinnati address. Copies of this report have been sent to:

1. Oil Chemical and Atomic Workers Union International
2. Texaco, Inc.
3. NIOSH, Region VI
4. OSHA, Region VI

For the purpose of informing affected employees, copies of this report shall be posted by the employer in a prominent place accessible to the employees for a period of 30 calendar days.

Table 1

ARITHMETIC ANNUAL MEAN TWA
PERSONAL EXPOSURE LEVELS
BY WORK ENVIRONMENT

Year	Production Units in ppm (± Standard Deviation)	Number of TWA Exposure Levels Observed Each Year	Laboratory in ppm (± Standard Deviation)	Number of TWA Exposure Levels Observed Each Year
1978	1.3 (± 2.8)	12	12.7 (± 8.0)	4
1979	0.9 (± 0.7)	7	7.9 (± 8.0)	8
1980	--	0	1.55 (± 1.77)	9
1981	--	0	0.57 (± 0.48)	5
1982	1.73 (± 5.46)	40	0.15 (± 0.05)	24

Table 2

INFRARED ANALYZER EXPOSURE MEASUREMENTS
BY STAGE OF SAMPLE COLLECTION

Cycle Number	Phase of Sample Collection	Exposure Level (ppm)	Length of Time (sec.)
1	Ambient	2-5	--
	Flushing Bomb	> 100	45
	Fill and Bleed Lines	25-55	180
	Ambient	5	--
2	Ambient	3-5	--
	Flushing Bomb	10-15	30
	Fill and Bleed Lines	25-30	30
	Disconnect	74	5
	Disconnect	25	10
	Ambient	5	--
3	Ambient	5	--
	Flushing Bomb	20-30	15-30
	Fill and Bleed Lines	> 100 ppm	30-40
	Disconnect	5- > 100 ppm	45
	Ambient	5	--
4	Ambient	5	--
	Flushing Bomb	10-20	35
	Fill and Bleed Lines	> 100	35
	Disconnect	25-50	45
	Residual	15-20	60
	Ambient	5	--

Table 3

GROUP MEAN SCE FREQUENCY

Group	Number of People in Groups	Mean SCE Frequency Per Chromosome ± Standard Deviation (SCE Frequency Per Cell)
Referent Individuals Who Did Not Smoke	25	0.163 ± .026 (7.50)
Referent Individuals Who Smoked Cigarettes	14	0.208 ± .033 (9.57)
Workers in the Production Units Who Did Not Smoke	30	0.175 ± .027 (8.05)
Workers in the Production Units Who Smoked Cigarettes	14	0.223 ± .033 (10.26)
Laboratory Workers Who Did Not Smoke	14	0.232 ± .042 (10.67)
Laboratory Workers Who Smoked Cigarettes	10	0.232 ± .033 (10.67)

Table 4

GROUP MEAN SCE FREQUENCY COMPARISONS WITH STUDENT'S t-TEST STATISTIC*

Comparison Number	Smoking and Exposure Groups Compared: Group Observed to Have the Higher Mean SCE Frequency	Smoking and Exposure Groups Compared: Group Observed to Have the Lower Mean SCE Frequency	Value of Student's t-Test Statistic	Degrees of Freedom	p-Value (One-Sided Test)
1	Referent Individuals Who Smoked Cigarettes	Referent Individuals Who Did Not Smoke	4.76	37	<0.001
2	Workers in the Production Units Who Smoked Cigarettes	Workers in the Production Units Who Did Not Smoke	5.09	42	<0.001
3	Laboratory Workers Who Smoked Cigarettes	Laboratory Workers Who Did Not Smoke	0.01	22	0.50
4	Workers in the Production Units Who Did Not Smoke	Referent Individuals Who Did Not Smoke	1.61	53	0.06
5	Laboratory Workers Who Did Not Smoke	Referent Individuals Who Did Not Smoke	6.35	37	<0.001
6	Laboratory Workers Who Did Not Smoke	Workers in the Production Units Who Did Not Smoke	5.40	42	<0.001
7	Workers in the Production Units Who Smoked Cigarettes	Referent Individuals Who Smoked Cigarettes	1.16	26	0.13
8	Laboratory Workers Who Smoked Cigarettes	Referent Individuals Who Smoked Cigarettes	1.74	22	0.05
9	Laboratory Workers Who Smoked Cigarettes	Workers in the Production Units Who Smoked Cigarettes	0.70	22	0.25
10	Laboratory Workers Who Did Not Smoke	Referent Individuals Who Smoked Cigarettes	1.65	26	0.06

* Actual Group Mean SCE Frequencies and Standard Deviation are shown in Table 3.

Table 5

HFCI ASSESSMENT

	NONSMOKERS	CIGARETTE SMOKERS
95th Percentile	0.302 SCE Per Chromosome (13.9 SCE Per Cell)	0.391 SCE Per Chromosome (18.0 SCE Per Cell)
Referent Individuals		
HFCI*	2	1
Non-HFCI	23	13
% Rate HFCI	8% (2/25)	7% (1/14)
Workers in Production Units		
HFCI	12	4
Non-HFCI	18	10
% Rate HFCI	40% (12/30)	29% (4/14)
Laboratory Workers		
HFCI	13	7
Non-HFCI	1	3
% Rate HFCI	93% (13/14)	70% (7/10)

* HFCI had 8 or more cells (of 80 counted) above the 95th percentile.

Table 6

HFCI SCE DISTRIBUTION ANALYSES

Comparison	Chi-Square	Chi-Square P-Value	Fischer's Exact P-Value	Ratio of Odds	Ratio of Odds Confidence Interval
Production Unit Workers Who Do Not Smoke to Referent Individuals Who Do Not Smoke	7.36	< 0.01	0.007	7.67	1.52, 38.72
Laboratory Workers Who Do Not Smoke to Referent Individuals Who Do Not Smoke	23.55	< 0.001	< 0.001	149.50	12.33, 1812.17
Production Unit Workers Who Smoked Cigarettes to Referent Individuals Who Smoked Cigarettes	2.19	> 0.05	0.16	5.20	0.51, 53.52
Laboratory Workers Who Smoked Cigarettes to Referent Individuals Who Smoked Cigarettes	10.37	< 0.005	0.002	30.33	2.63, 348.55

Table 7

MEAN CHROMOSOMAL ABERRATION CATEGORY FREQUENCIES AND MEAN PERCENTAGE ABNORMAL CELLS BY EMPLOYMENT GROUP
(ALL CHROMOSOME ABERRATION CATEGORY FREQUENCIES EXCEPT %ABN ARE REPORTED PER 100 CELLS IN THIS TABLE)

Employment Group	Controls	Production Units Workers	Laboratory Worker
Group Size	41	43	27
CTD-DEL (± S.E.M.)	0.510 (± 0.094)	0.591 (± 0.118)	0.815* (± 0.129)
CTD-EX (± S.E.M.)	0.080 (± 0.033)	0.140 (± 0.048)	0.285* (± 0.086)
ISOCTD-DEL (± S.E.M.)	0.544 (± 0.100)	0.547 (± 0.096)	0.574 (± 0.133)
CHR-EX (± S.E.M.)	0.183 (± 0.052)	0.116 (± 0.052)	0.148 (± 0.059)
CTD-TOT (± S.E.M.)	0.590 (± 0.109)	0.730 (± 0.121)	1.100** (± 0.164)
%ABN (± S.E.M.)	1.208 (± 0.168)	1.275 (± 0.148)	1.771* (± 0.254)
ABR/CELL (± S.E.M.)	1.318 (± 0.185)	1.393 (± 0.170)	1.827* (± 0.259)

S.E.M. - Standard Error of the Mean

* - $p \leq 0.05$ in t-test comparison of controls and laboratory workers.
** - $p \leq 0.01$ in one-sided t-test comparison of controls and laboratory workers.

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