Revised Final Report

Evaluation of Human Health Risks Associated with Fog Oil Training at Fort Leonard Wood, Missouri

Preliminary Risk Evaluation Report

Prepared for
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Kansas City District

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LIST OF ABBREVIATIONS, ACRONYMS AND SYMBOLS

ACGIH = American Conference of Governmental Industrial Hygienists
AL_c = action level for carcinogenic effects
AL_n = action level for noncarcinogenic effects
ASTM = American Society for Testing and Materials
AT_c = averaging time, carcinogenic effects
AT_n = averaging time
BRAC = Defense Base Realignment and Closure
BTEX = benzene, toluene, ethylbenzene, and xylene
BW = body weight
C = carcinogen
CAG = USEPA Carcinogen Assessment Group
CAS = Chemical Abstract Service
CF = conversion factor
COPC = chemical of potential concern
d = day
DOD = US Department of Defense
EIS = Environmental Impact Statement
EPA = U.S. Environmental Protection Agency
EPC = exposure point concentration
F = Fahrenheit
GC = gas chromatographic
GC/FID = gas chromatographic/flame ionization detection
gph = gallons per hour
gpm = gallons per minute
HBA = Harland Bartholomew & Associates, Inc.
HEAST = Health Effects Assessment Summary Tables
HI = hazard index
HQ = hazard quotient
h = hour
IF = intake factor
IF_c = intake factor for carcinogens
IF_n = intake factor for noncarcinogens
IR = inhalation rate
IRIS = Integrated Risk Information System
kg = kilogram
L = liter
m = meter
m^3 = cubic meter
MDNR = Missouri Department of Natural Resources
mg = milligram
NA = not applicable
NC = noncarcinogen
NEPA = National Environmental Policy Act
OSHA = Occupational Safety and Health Administration
PAH = polynuclear aromatic hydrocarbon

PRE = preliminary risk evaluation
PRG = preliminary remediation goal
Parsons ES = Parsons Engineering Science, Inc.
ppm = parts per million
RfC = reference concentration
RfD = reference dose
RfD_i = reference dose, inhalation
SF_i = slope factor, inhalation
SVOC = semivolatile organic compound
THC = total hydrocarbons
THQ = target hazard quotient
TLV = threshold limit value
TR = target risk
TWA = time-weighted average
µg = microgram
URF = unit risk factor
EPA = United States Environmental Protection Agency
VOC = volatile organic compound
y = year
Σ = sum
< = less than
> = greater than
$\leq$ = less than or equal to
$\geq$ = greater than or equal to

1.0 EXECUTIVE SUMMARY

Recommendations of the 1995 Defense Base Realignment and Closure Commission require the closing of Fort McClellan, Alabama and relocation of essential missions to other installations. Pursuant to the National Environmental Policy Act of 1969 (NEPA) the Army is required to prepare an Environmental Impact Statement (EIS) to address the environmental and socioeconomic impacts of relocating the U.S. Army Military Police School and U.S. Army Chemical School, and several associated support units to Fort Leonard Wood (FLW), Missouri.

One of the missions to be transferred to FLW is obscurant (or "smoke") training with fog oil. As part of the EIS process, a comprehensive review of the available scientific literature was conducted to evaluate the human health effects associated with fog oil obscurant training. The human health literature evaluation report has been included as Appendix E to this report (COE KC 1996a).

The preponderance of evidence from the literature on the health effects of obscurant generated with SGF-2 (Standard Grade Fuel) fog oil manufactured after 1986 in accordance with military specification, MIL-F-12070C, Amendment 2 (US Army, 1986) and specifications thereafter, indicate there is limited potential for adverse effects to humans (COE KC 1996a). In 1986, military manufacturing specifications for SGF-2 were altered to required manufacturers to remove carcinogens and potential carcinogens from the oil.

The recently proposed modification to the 1986 specification requires manufacturers to certify the fog oil is not carcinogenic by conducting modified Ames tests, mouse skin tests, and a Food and Drug Administration analytical procedure for determining the presence of polynuclear aromatic hydrocarbons (PAHs) (U.S. Army, 1995). When implemented, the 1995 proposed MIL-PRF-12070E specification will provide further assurance of human health protection by requiring actual documentation, through testing, of each batch of fog oil manufactured.

The term "smoke" is used by the military and in this report to represent the fog oil obscurant cloud produced by specially designed generators. Generators produce obscurant clouds by a process of vaporization followed by condensation of the fog oil into many small droplets (about one micron in diameter). The small droplets of fog oil comprising the obscurant cloud are not produced by a combustion process as the term "smoke" would imply.

Toxicological research documented in the literature (COE KC 1996a) demonstrates that currently used SGF-2 has low toxicity when ingested, presents minimal toxicity from dermal exposure, and has limited potential for pulmonary effects unless the Threshold Limit Value-Time Weighted Average (TLV-TWA) of 5 mg/m^3 is exceeded for prolonged periods of time.

The TLV-TWA standard of 5 mg/m^3 was established by the Occupational Safety and Health Administration (OSHA), the American Conference of Governmental Industrial Hygienists (ACGIH), and other national and international organizations to protect workers in industrial settings from harmful exposures to mineral oil mists in the air. The OSHA/ACGIH 5mg/m^3 TLV-TWA is considered a safe concentration when workers are repeatedly exposed for up to 8 hours per day and 5 days per week for a worker's career. This health protective standard was established for mineral oils which were severely acid treated; severely hydrotreated; or severely solvent treated to reduce the content of carcinogens and many other toxic compounds. To

meet the 1986 military manufacturing specifications, fog oil is severely treated to remove carcinogens and therefore represents the type of mineral oil upon which the OSHA/ACGIH standard was based.

The scientific literature on fog oil revealed an absence of information on hydrocarbon constituents in smoke generated from SGF-2 oils manufactured under recent military specifications. There was also conjecture that the chemical constituents of fog oil could be altered by the internal heat within fog oil generators to produce toxic compounds. Information was not found in the literature to address this concern. Therefore, an analytical study was conducted as part of this health evaluation to fill these critical information gaps.

The results of the chemical analysis of fog oil and smoke (Appendix B) were used to conduct a preliminary human health risk evaluation (PRE) in accordance with U.S. Environmental Protection Agency (EPA) guidance. The PRE assessed the toxicity and carcinogenic risk of individual compounds of concern found in fog oil smoke and served to provide weight- of-evidence with other toxicological findings from the literature to evaluate the potential for human health effects from fog oil exposure.

Samples of fog oil smoke produced by an M56 turbine generator and an M157 pulse jet generator and liquid fog oil were collected and analyzed for over 100 different volatile organic compounds and semivolatile organic compounds, including PAHs. The compounds analyzed included the major carcinogenic and toxic compounds that could reasonably be expected to be present in petroleum based mineral oils. The M56 and M157 generators were selected because of their planned use in fog oil obscurant training at Fort Leonard Wood.

Results of the chemical analyses of liquid fog oil and fog oil smoke did not indicate that the chemical composition of the fog oil had been altered by heat of the generators. The fog oil was tested for mutagenicity by a modified Ames test to evaluate the carcinogenic potential of the oil. Results of the modified Ames test were negative indicating the fog oil was not carcinogenic.

The PRE determined that exposure to a total oil concentration in air of less than or equal to 5 mg/m^3 is associated with an insignificant noncancer hazard and cancer risk. Conversely, the PRE determined that sustained exposures to concentrations greater than 5 mg/m^3 may be associated with a significant hazard and/or risk. Additionally, occasional, brief exposures to levels of between 5 and 10 mg/m^3 total oil for unprotected personnel are not considered a threat to human health. In general, the findings of the PRE support the TLV-TWA limit established by OSHA and ACGIH to protect workers from exposure to mineral oil mists in the air.

The Army has developed personal protection policies which guard the health and safety of those involved in fog oil obscurant training. The Army's "Smoke Operations" manual FM 3-50 instructs individuals involved in smoke training to "wear respiratory protection (mask) when in high concentrations of oil smoke or after 4 hours in low concentration of oil smoke (haze)." This existing Army policy provides ample assurance that exposures will not exceed the 5 mg/m^3 TLV-TWA for mineral oil (e.g., fog oil) mist as established by ACGIH and OSHA and determined as a safe by the PRE.

It is not expected that individuals positioned away from fog oil training areas, but within the boundaries of Fort Leonard Wood, and those outside the facility boundary will be exposed to

fog oil at concentrations that would pose a health risk. Factors which serve to assure insignificant human exposures beyond training ranges are; 1) training ranges are strategically positioned to reduce the possibility of significant fog oil exposures to individuals in cantonment areas and at off-post locations; 2) the fog oil operating permit restricts the wind direction and meteorological conditions under which training is allowed to limit the possibility of the obscurant cloud from reaching the on-post cantonment area and the FLW boundary; 3) the duration of planned fog oil training events is limited and will seldom exceed 30 minutes; and 4) fog oil obscurant clouds disperse rapidly to low concentrations that will not be harmful.

Site-specific air dispersion modeling conducted to support the FLW EIS air quality analysis predicted concentrations of less than 30 $\mu g/m^3$ at the boundary of FLW and at the edge of the FLW cantonment area when 481 gallons of fog oil are used in one hour (COE KC, 1997). This volume is the limit currently allowed during a 24 hour period by the FLW air permit for fog oil training. The highest volume modeled (i.e., the highest daily amount used at FMC) was 1900 gallons per hour and resulted in a concentration of less than 149 $\mu g/m^3$ at the edge of the FLW cantonment and FLW boundary. All modeling was conducted to adhere to wind directions and atmospheric stability classes allowed by the FLW air permit. The results indicate that potential exposures to the general public will be 34 to 167 times lower than safe exposure level determined by the PRE for fog oil and the safe exposure level established by the American Conference of Industrial Governmental Hygienists (ACGIH, 1994) for mineral oil mists in the workplace. Considering the low concentration, and limited frequency and duration of fog oil exposures predicted for the general public, adverse health impacts are not anticipated.

2.0 INTRODUCTION

The production of obscurant smoke for concealment purposes has been a part of military tactics since prior to World War I (Driver et al., 1993). Different methods are used by the military to generate obscurant smokes, including the production of smoke by specially-designed smoke generators, using Standard Grade Fuel-2 (SGF-2) fog oil. Training in the production and the strategic deployment of fog oil smoke is presently conducted at Fort McClellan, Alabama and other Department of Defense (DOD) installations. Due to recommendations by the Base Closure and Realignment Commission, the fog oil obscurant training mission will be moved from Fort McClellan to Fort Leonard Wood, Missouri.

Transfer of the fog oil obscurant training mission (and other missions) from Fort McClellan to Fort Leonard Wood has necessitated preparation of an Environmental Impact Statement (EIS) as directed by the National Environmental Policy Act (NEPA). Included in the EIS is an examination of the potential impacts of the proposed activity to on and off-post residents at Fort Leonard Wood.

A literature review of the human health effects of fog oil was conducted as an initial evaluation of the effects (Appendix E). Examination of the literature revealed that in-depth analyses had not been performed to determine the chemical composition of smoke produced by the M56 turbine and M157 pulse jet generators using the new generation of SGF-2 fog oil manufactured after 1986. It was in 1986 that the Army manufacturing specifications for fog oil changed to require manufacturers to eliminate carcinogens or potential carcinogens from fog oil. The potential carcinogenicity of the oil is mainly related to compounds that are significantly reduced by severe hydrotreating, severe acid treating or severe solvent treating. These processes are

used by manufacturers to reduce carcinogens in fog oil to concentrations whereby the whole oil does not exhibit carcinogenic tendencies (Palmer, 1990).

Specific information on the composition of smoke and liquid fog oil to be used at FLW was considered necessary to assess the potential human health effects of exposure to fog oil smoke. Therefore, as part of this health evaluation, fog oil smoke and liquid fog oil were analyzed for over 100 aliphatic and aromatic compounds with health significance. The fog oil used in the monitoring program was also tested for mutagenicity using a modified Ames test method, which offered additional weight-of-evidence for assessing the carcinogenic potential of the oil.

The M56 and M157 generators were selected for fog oil smoke production in the monitoring program because of their planned use for obscurant training at Fort Leonard Wood. The composition of liquid SGF-2 fog oil was compared to the composition found in smoke to determine if the internal heat of the M56 and M157 generators caused an alteration of compounds. It should be noted that "fog oil smoke" is actually comprised of very small fog oil droplets produced by a process of fog oil vaporization within the generator, followed by condensation once vapor is cooled in the atmosphere outside the generator. Exhaust from combusted diesel fuel used (in these field tests) to run the generator is also comingled with fog oil vapor before discharge from the generator. It follows that products of the diesel fuel combustion were assessed for toxicity and carcinogenicity along with those compounds present in fog oil smoke.

Results of the fog oil smoke monitoring program and related analytical work provided the necessary information for conducting a PRE on fog oil "smoke." The results of existing toxicological studies contained in the literature, combined with results of this PRE and modified Ames tests, comprised the weight-of-evidence considered for evaluating the health effects of exposure to fog oil smoke. The PRE methodology used highly simplified and conservative (health-protective) exposure assumptions which tend to overestimate adverse health effects of fog oil smoke.

3.0 TECHNICAL APPROACH

3.1 General Sampling Design

Field testing was performed to determine if chemicals of potential concern (COPCs) were present in the smoke. Since two smoke generators are expected to see predominant use during fog oil obscurant training at Fort Leonard Wood, tests were done with each generator to determine if smoke characteristics were different. Fog oil from Lot Number 21095, manufactured in March 1991 by American Lubricating Company, Inc. was used in the testing program with the M56 and M157 generators. The sampling program was conducted with the assistance of Product Management (PM) Smoke/Obscurants at the U.S. Army Aberdeen Proving Ground, Edgewood, Maryland in December 1995.

The fog oil obscurant cloud was sampled at stations located downwind of the generators. The distances of stations from the generators and the types of samples taken for each test were:

Test 1- M56 Generator	Test 2 - M157 Generator
2 Reference (Background)	2 Reference (Background)
11 meters	< 1 meter
11 meters	< 1 meter
25 meters	11 meters
25 meters	11 meters
200 meters	100 meters
200 meters	100 meters
Liquid SGF-2 Fog Oil	Liquid SGF-2 Fog Oil
Field (Trip) Blank	Laboratory (Method) Blank

Liquid SGF-2 fog oil was analyzed for reference purposes in order to determine if there were any chemical transformations occurring during smoke generation from the internal temperatures of 1,050°F and 1,400°F, within the M56 and M157 generators, respectively.

Fog oil smoke was produced by the M56 turbine generator in Test 1. Diesel fuel was used in Test 1 to power the M56 turbine engine and to create the hot exhaust necessary to produce smoke from liquid fog oil. The M56 generates smoke by injecting SGF-2 oil through a nozzle into the turbine exhaust. Heat from the turbine exhaust vaporizes the SGF-2 fog oil within the exhaust cone. When vaporized fog oil exits the generator, it cools and condenses into small (approximately one micron (μm) sized) oil droplets which collectively make up the obscurant "smoke." Fog oil flow is controlled by a thermocouple located in the exhaust nozzle. The rate of fog oil usage by the M56 in this test was 1.33 gallons per minute (gpm) or 80 gallons per hour (gph). Given the force of the exhaust and the 1,050° F exhaust gas temperature, the smoke cloud begins to form several feet from the generator (U.S. Army, 1995).

The M157 pulse jet generator system consisting of two M54 generators was used in Test 2. In Test 2 obscurant smoke was produced using one of the two generators. For Test 2, the M157 was powered by diesel fuel. Each M157 generator is capable of vaporizing 0.67 gpm of fog oil (40 gph). The primary fuel (diesel) is pulsed, along with air, into a combustion chamber at a rate of 60 cycles per second. The pressure created by the explosion closes the engine valve and forces the gases through an exhaust tube. When the exhaust gas has reached the proper operating temperature of 1,475-1,575° F (measured by a thermocouple in the exhaust stream), fog oil is then fed to the generator.

The heated exhaust gas from combustion of primary fuel passes into a vaporization chamber where fog oil is injected into the exhaust gas stream. Vaporization occurs as the fog oil is mixed with the exhaust gases and forced into the atmosphere through one of three exhaust jets, where it cools and condenses into very small liquid droplets. The small recondensed oil droplets form a white smoke cloud. The temperature of the smoke as it is discharged from the exhaust port is between 700-1,000° F (U.S. Army, 1995).

3.2 Sample Collection and Analysis

Evacuated Summa polished 6-liter canisters were used to collect whole air (grab) samples for analysis of volatile organic compounds (VOCs) ranging in carbon number from C_2 through C_{10}. XAD-2 adsorbent cartridges connected to SKC sampling pumps, were used to collect semivolatile organic compounds (SVOCs) with carbon number greater than C_{10}. Samples of liquid SGF-2 oil used for smoke generation were collected and analyzed for the same suite of target analytes as analyzed in the smoke emission samples (Battelle, 1996). See Appendix B, *Fog Oil Sampling and Analysis* (Battelle, 1996) for a complete listing of analyzed compounds, methods of sampling and analysis, and results for Tests 1 and 2.

Wind direction was variable on the days the sampling was conducted and therefore moved the main axis of the fog oil plume back and forth over about a 60 degree arc. To ensure an adequate sample was obtained for analysis, the Summa grab samples were taken only when the fog oil cloud surrounded the person taking the sample. The XAD-2 samples collected continuously at the stations within 25 m of the generators were taken from fixed locations because the fog oil plume blanketed those stations throughout the test procedures. The back and forth movement of the fog oil plume at the 100 m and 200 m distances from the generator required movement of the XAD-2 samplers to maintain their position within the fog oil plume. Care was taken when moving the samplers to adhere to the prescribed 100 m and 200 m distances from the generator. The strategy to move XAD-2 samplers at the 100 m and 200 m stations was implemented to ensure that a representative sample for chemical analysis was obtained.

In the analysis of the fog oil and smoke samples, volatile and semivolatile hydrocarbons were determined. The VOC analyses included C_5 to C_{10} alkanes, cycloalkanes, and alkyl benzenes. The semi-volatile analyses included C_{10} to C_{36} n-alkanes and isoprenoids, decalins, 2- to 6-ringed parent and alkylated PAHs, and total hydrocarbons. As part of the semivolatile hydrocarbon analysis, selected oxygen and sulfur heterocyclic compounds; which include dibenzofurans, benzothiophenes, and dibenzothiophenes, were determined.

The volatile hydrocarbon and PAHs (including decalins) were analyzed by capillary column gas chromatography/mass spectrometry. The C_{10} to C_{36} n-alkanes and isoprenoids, and total hydrocarbons (THC) were determined using capillary column gas chromatography/flame ionization detection (GC/FID) methodologies.

3.3 Fog Oil Mutagenicity Test

Liquid fog oil was tested for mutagenicity by a modified Ames test designed specifically for oils. A negative result for mutagenicity indicates the oil is not a likely carcinogen.

An Ames test method modified for petroleum extracts was performed using methods of Blackburn et al. (1984) which are now detailed in ASTM Method E 1687-95. The test involved exposing a TA98 strain of the bacterium, *Salmonella typhimurium*, to different concentrations of the oil extract. This strain of *S. typhimurium* has a mutation which does not allow synthesis of the amino acid, histidine and is therefore histidine-dependent. An oil is determined to be

mutagenic if the exposed bacterium reverts from histidine dependence to histidine independence. The conversion from histidine dependence to independence is attributable to genetic mutation caused by the oil.

The initial experimental design called for modified Ames tests to be performed on liquid fog oil used in each generator and on fog oil smoke samples collected from the two generators. Because the volume of oil in smoke samples was insufficient to perform a modified Ames test, mutagenicity tests were only conducted with liquid fog oil. The composition of semivolatiles (includes PAHs) in liquid fog oil and smoke produced from the fog oil was nearly identical. These analytical data support the assumption that the results of mutagenicity testing of liquid fog oil should be the same as results from samples of fog oil smoke. The modified Ames test was conducted by Microbiological Associates, Inc. (MBA, 1996) and results are contained in Appendix D.

3.4 Risk Evaluation Approach

This PRE was performed using EPA (1995a) guidance for risk screening and with results of the hydrocarbon analyses of fog oil smoke (Battelle, 1996; Appendix B) to identify chemicals of potential concern. This risk evaluation deviated slightly from normal EPA risk screening guidance by using exposure times, frequencies, and durations that reflected those occurring while soldiers conduct fog oil training, rather than relying on EPA default exposures. The PRE contained the following elements:

1. Data Evaluation,
2. Identification of Chemicals of Potential Concern (COPCs),
3. Exposure Assessment,
4. Toxicity Assessment,
5. Risk Characterization, and
6. Uncertainty Analysis.

All tabulated data directly associated with the text of the PRE are presented in Appendix A.

The PRE was conducted in two parts: a highly conservative analysis, and a moderately conservative analysis. Human health toxicity values were not available for many of the compounds identified in fog oil smoke because EPA (1995a, 1995b, and 1996) has not yet developed the values. Thus, representative compounds of similar chemical structure that had toxicity values noted in the literature were chosen to evaluate toxicities of those compounds which were present in the samples for which toxicity values were not available.

The highly conservative analysis included all compounds detected, while the moderately conservative analysis included only compounds having toxicity values and those which are closely related to compounds having toxicity values. Therefore, there is a *low level* of certainty associated with the highly conservative analysis, and a *moderate level* of certainty associated with the moderately conservative analysis.

The availability of toxicity information on the chemicals of potential concern is vital to the performance of a valid risk assessment. Comprehensive toxicological databases for a multitude of chemicals have been established and are continually updated (EPA, 1995a, 1995b, and 1996). Because EPA Region IX provides the largest number of useful toxicity values for this particular application, these values (EPA, 1995a) were used to conduct the PRE.

4.0 RESULTS

4.1 Chemical Analytical Results

4.1.1 Volatile Organic Compounds (VOCs)

In Test #1 (M56 generator), concentrations of targeted VOCs in samples nearest the generator (11 m) ranged from approximately 10 to 70 mg/m^3. A propene (C3-ene) had an estimated concentration of around 200 mg/m^3. Total BTEX concentrations were found at relatively low concentrations at approximately 80 mg/m^3. Sample replication precision was $\pm$ 25 %. At the 200+ m sampling station, VOCs were not found at concentrations above background levels.

In Test #2 (M157 generator), considerably higher concentrations of target analytes were found in the air samples. At the 0.5 m station, Total BTEX concentrations were the highest for all sample stations at approximately 21,000 mg/m^3, of which benzene made up half. Concentrations of all the targeted VOCs generally ranged from 1,000 to 12,000 mg/m^3 (individual). There were two compounds, propyne and a butene, that had values of approximately 25,000 and 80,000 mg/m^3, respectively. At the 11 m station, VOC concentrations between duplicates were different by a factor of four. Concentration of the Total BTEX was approximately 800 mg/m^3 in the highest VOC concentration duplicate. VOC concentrations at the 100 m station were near but above background levels for most target analytes. Most of the BTEX compounds were still present at 24 mg/m^3 Total BTEX.

The VOC composition in fog oil was similar to the composition in fog oil smoke produced from the M56 generator, but not for the M157 generator. Only a few of the higher molecular weight compounds determined in the fog oil samples were observed in the Test #2 (M157 generator) smoke samples. It is assumed that operating design differences between generators contribute to this difference. Table 10 of Appendix B depicts VOC compounds identified for Test 1 and 2.

4.1.2 Semivolatile Organic Compounds (SVOCs)

In the SGF-2 fog oils, there were no saturated hydrocarbons (n-alkanes or isoprenoids--pristane and phytane), even at the low parts per million level (0.1 ppm). The total hydrocarbon (THC) concentration, which consisted almost totally of unresolvable compounds shown as a hump in the GC trace (unresolved complex mixture-UCM), was 830,000 mg/kg (oil basis). The major portion of compounds in the UCM was between the boiling points of the n-alkanes C_{17} and C_{33}. Unlike other mineral oils which have been characterized in the laboratory, very small amounts of resolved compounds were evident in this SGF-2 fog oil.

Depending on the location of the samplers, THC concentrations in samples ranged from 4 to 12,000 mg/m^3; reference THC concentrations were <1 mg/m^3. The compositions (relative distributions) of the resolved compounds and UCM in air, were basically unchanged relative to the test oils. No n-alkanes or isoprenoids were found in any of the air samples, similar to the fog oil.

The fog oil has a dominance of the three-ringed PAHs, especially the sulfur-heterocyclic compounds--dibenzothiophenes. The dibenzothiophenes as a group (alkyl homologues) are approximately 2.5 times higher than the phenanthrene group, the next largest alkyl group. The concentrations of the individual unsubstituted semivolatile compounds were very low compared to their alkyl homologues. For instance in Test 1 of fog oil, phenanthrene, typically the highest priority pollutant PAH, was 90 mg/kg oil, whereas the alkyl phenanthrene group was 3,200 mg/kg.

In the air samples, the composition of the PAHs was unchanged compared to the test oils. The PAH distribution plots of the air samples clearly demonstrated the consistency in composition in all air samples of both tests. Concentrations of PAHs reflected those of THC and the saturated hydrocarbons. Total PAH concentrations were highest in the 0.5 m station sample in Test 2 (M157 generator) at 140 to 220 mg/m^3. Although VOCs were not detected in samples at the 200 m station, remnant fog oil PAHs (mostly, dibenzothiophenes) were found at a concentration of approximately 7 mg/m^3 Total PAHs, 20 to 30 times lower than the most concentrated air samples at the 0.5 m station. Lower detection limits in PAH analysis compared to the VOCs allowed these analytes to be detected.

As part of the semivolatile organic characterization, fifteen major peaks in the chromatogram of the GC/MS analysis of the neat fog oil and two fog oil smoke samples were identified by a computer library search routine, and concentrations were estimated. The peak heights of all peaks in the chromatograms were relatively low and insignificant compared to the large unresolved complex mixture. Although resolvable peaks in most oils are saturated hydrocarbons, the peaks in these test oils and fog oil smoke were mostly individual alkylated PAHs. The lack of saturated hydrocarbons was confirmed by the GC/FID analysis. Other compounds included the ubiquitous phthalates, which were probably sampling/handling contaminants. Tables 11 and 12 in Appendix B depict results of SVOC analyses.

4.1.3 Total Fog Oil Concentration with Distance from Generators

The total fog oil concentration in air at the stations monitored downwind of the M56 and M157 generators are shown in Figures 1 and 2, respectively. In an effort to obtain a linear regression of concentration with distance, a log to log comparison was made. The regression line for each graph was based on visual interpretation of the data points. The total fog oil concentrations found at different distances downwind of the two generators would be expected to vary somewhat due to different wind conditions on the two days the generators were separately sampled and the different rates of fog oil smoke production by the two generators. As interpreted from the graphs, the concentrations of total fog oil differed widely for the two

Figure 1. Fog Oil Concentration With Distance From The M56 Generator

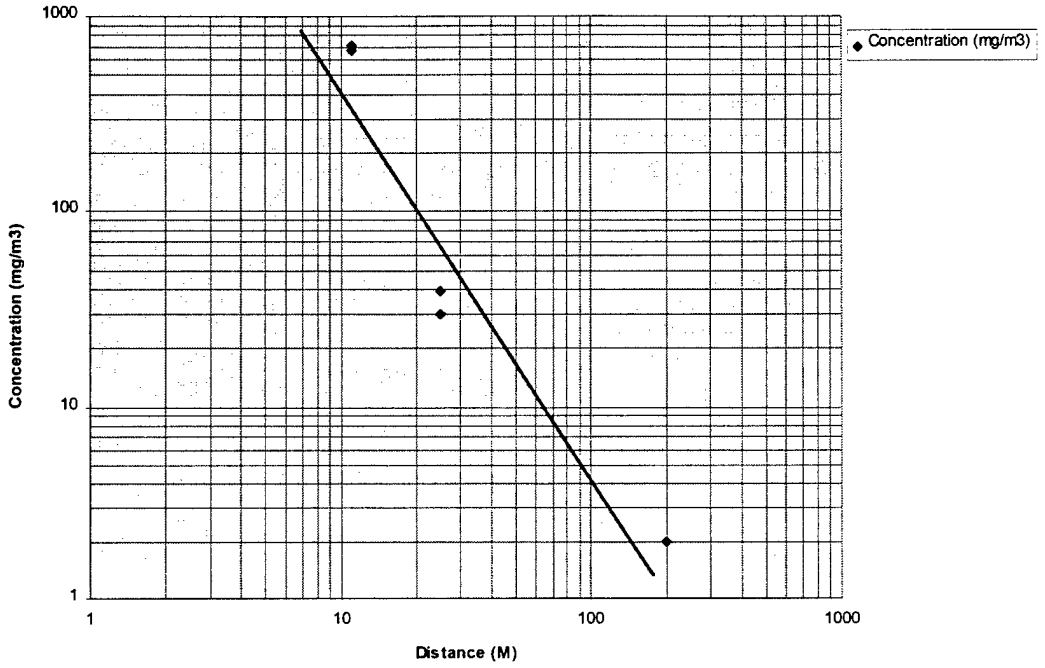
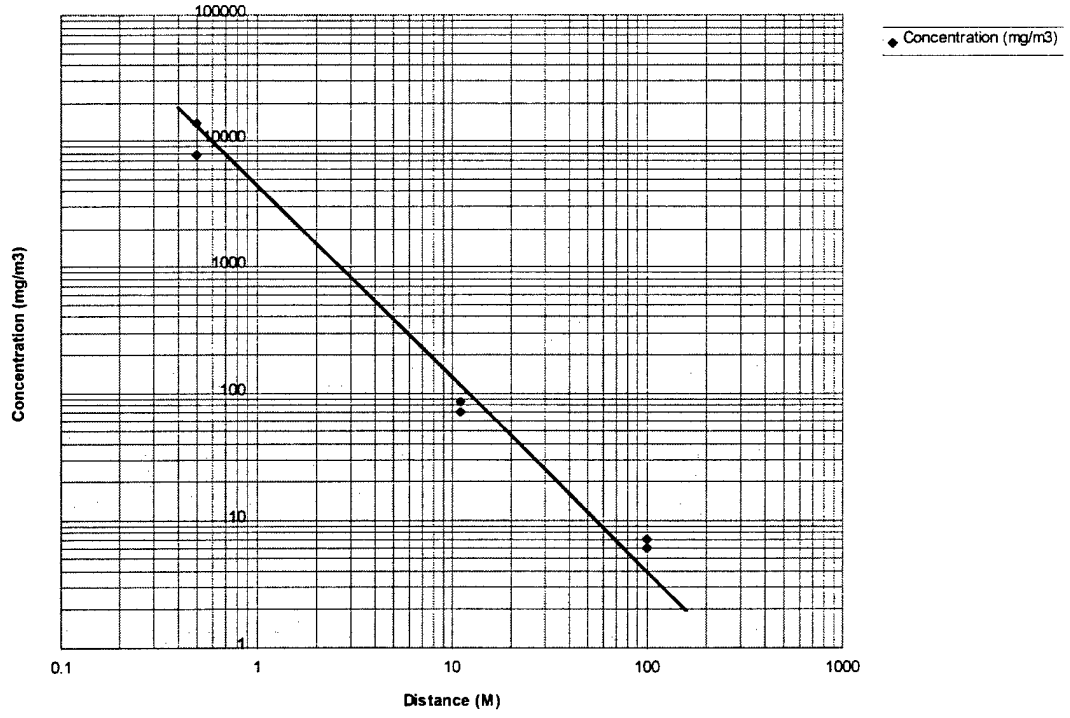


Figure 2. Fog Oil Concentration With Distance From The M157 Generator



generators when comparing distances within 50 m; however, by 100 m and 200 m the fog oil concentrations for the generators were within 1 to 3 mg/m^3 of each other.

4.2 Modified Ames Test Results

Two samples of SGF-2 fog oil used in the field monitoring program were tested for mutagenicity by a modified Ames test. The SGF-2 fog oil was not mutagenic as determined by the modified Ames test. The Ames mutagenicity test is only an indicator of the potential carcinogenicity of a material. Therefore, an Ames test result cannot be used by itself to judge whether or not a material is carcinogenic. In this study, the Ames testing was conducted to provide additional weight-of-evidence by which to evaluate the carcinogenic nature of fog oil. Results of the fog oil mutagenicity test are contained in Appendix C.

4.3 Human Health Risk Evaluation Results

4.3.1 Data Evaluation

Analytical data used to conduct the PRE were reviewed using an EPA Level III Data Validation process (Parsons ES, 1996; Appendix D). Data validation is recommended by EPA to guard against the use of invalid analytical data in the PRE.

A few VOC and PAH values that were eliminated because of blank contamination by data validation from the PRE had an insignificant effect on calculation of hazard or risk due to the very low levels of contamination in the blanks.

The VOC results were qualified due to trip blank contamination. Trip blank contamination was noted for benzene, cyclohexene, 1-heptene and 1,2,4,-trimethylbenzene at concentrations ranging from 1 to 3 µg/m^3. Values for these VOC compounds were excluded from the PRE when their concentration at a sample location was less than 5 times the trip blank concentration.

The PAH results were qualified due to field and method blank contamination. PAHs detected in trip and method blanks were decalin, C-1 decalins, naphthalene, C1 and C2 naphthalenes, dibenzofuran, fluorene, and phenanthrene at concentrations ranging from 0.12 to 0.91 µg/m^3. Values for these PAH compounds were excluded from the PRE when their concentration at a sample location was less than 5 times the trip blank or method blank concentration.

The VOCs detected during Tests 1 and 2 are presented in Tables A1 and A2, respectively of Appendix A. The SVOCs, detected during Tests 1 and 2, are presented in Table A3 in Appendix A.

4.3.2 Identification of the COPCs

The COPCs consist of all of those compounds detected in Tests 1 and 2 (Tables 1A through 3A in Appendix A). Note that the detected compounds in Tables 1A through 3A are grouped by their association with representative compounds. Compounds having toxicity values available for quantitative risk assessment were selected as representative compounds in order to

approximate, as nearly as possible, the hazards and risks associate with compounds lacking toxicity values.

Some detected compounds are more closely related structurally to the representative compounds than others. Compounds which are very similar in structure to the representative compound (e.g., assigning naphthalene toxicity values to represent C-1 naphthalenes) are considered more reliable surrogates for toxicity and therefore add greater certainty to the risk evaluation. Thirty-three target VOCs were identified in fog oil smoke samples. Of those, toxicity values were found for seven. The detected VOCs and their toxicity values based on noncarcinogenic effects were:

Detected VOCs	RfD_i (mg/kg/d)
Benzene	1.7E-03
Toluene	1.1E-01
Ethylbenzene	2.9E-01
m-Xylene	2.0E-01
Styrene	2.9E-01
Methyl cyclohexane	8.6E-01
Cyclohexanone	5.0E+00

With respect to noncarcinogenic effects, benzene was the most toxic of the VOC compounds detected in smoke. The highest concentration for benzene was 12,105 µg/m3 at the 0.5 m station downwind from the M157 generator. Of all VOCs analyzed, propyne had the highest concentration of 87,536 μ/m^3 at the 0.5 meter station from the M157. In general, total VOC concentration decreased by about two orders of magnitude by 11 m from the generators and at 100 m the highest concentration for any VOC (propyne) was 80 $\mu g/m^3$.

The two VOC carcinogens were 1,3-butadiene and benzene. Of the two, 1,3-butadiene is the more potent. Both were found at about the same concentration at the closest station in Test 2 (0.5 m from M157). At the 11 m station, 1,3-butadiene was not detected whereas benzene concentrations decreased at about the same rate as the other VOCs with increasing distance from the source. At the sampling stations located 11 m and 0.5 m from the generator in Test 1 and 2, respectively, 1,3 - butadiene was found in the fog oil smoke, but was not present in the liquid fog oil.

Because 1,3 - butadiene is a compound associated with diesel fuel it was therefore assumed to have come from the incomplete combustion of the diesel fuel used to operate the generators. 1,3 - butadiene could not be detected in stations at 25 m and further distances from the generators.

Fifty-seven SVOCs were targeted for analysis in liquid fog oil and fog oil smoke. Of those, only seven were not detected in fog oil smoke. Toxicity values were found for seven of the 50

SVOCs found in fog oil smoke. The following are the detected SVOCs and their noncarcinogenic toxicity values.

Detected SVOCs	RfD_i (mg/kg/d)
Naphthalene	4.0E-02
Biphenyl	5.0E-02
Acenaphthene	6.0E-02
Dibenzofuran	4.0E-03
Fluorene	4.0E-02
Anthracene	3.0E-01
Pyrene	3.0E-02

Of the SVOCs for which toxicity values were found, dibenzofuran was the most toxic. The highest concentration of dibenzofuran was 69 $\mu g/m^3$ at the 0.5 station in Test 2 (M157). Of all SVOCs detected, C3-dibenzothiophene was present in the highest concentration of 41,456 $\mu g/m^3$ at the 0.5 m station in Test 2.

Carcinogenic risk factors were found for three of the 50 SVOCs detected in fog oil smoke. The SVOC carcinogens in smoke were benz(a)anthracene, chrysene and benzo(b)fluoranthene. Benz(a)anthracene and benzo(b)fluoranthene had equal carcinogenic slope factors and were the most potent of the three carcinogens detected for which EPA carcinogenic risk values were found. The highest concentration for benz(a)anthracene and benzo(b)fluoranthene was found at the 0.5 m station in Test 2 (M157 generator), and was 340 $\mu g/m^3$ and 109 $\mu g/m^3$, respectively. Chrysene was the least potent of the four, but had the highest concentration of 867 $\mu g/m^3$, again at the 0.5 m station in Test 2.

Of the SVOC carcinogens found in fog oil smoke, benz(a)anthracene was not present in the liquid fog oil. This compound is commonly associated with diesel fuel and like 1,3 - butadiene, was assumed to have come from the incomplete combustion of the diesel fuel used to operate the generators. Benz(a)anthracene was found at the 0.5 meter station in Test 2, but was not detected at 11m station and those more distant from the generators.

The carcinogenic compounds analyzed in fog oil were among those commonly found in petroleum fuels and gasolines, but were present in much less concentration. A complete listing of VOC and SVOCs detected at the different stations and their concentrations are depicted on Tables 4A, 5A, 6A and 7A in Appendix A.

4.3.3 Exposure Assessment

The objective of the exposure assessment in this PRE is to estimate the exposure point concentrations (EPCs) at various distances downwind of the generators, and compare the EPCs to calculated chemical-specific action levels which are protective of human health. For this risk evaluation, an EPC for a given compound at a given location is equal to the maximum concentration measured at that location irrespective of the generator used to produce smoke. This approach is typical of screening-type evaluations, such as the PRE.

The maximum EPCs measured at each location during Test 1 are presented in Tables A4 and A5 of Appendix A. Likewise, the maximum EPCs measured at each location during Test 2 are presented in Tables A6 and A7 of Appendix A. As expected, the concentrations generally decrease at greater distances downwind from the source.

The methodology used to estimate hazards and risks in the PRE is similar to that provided by EPA Region IX for risk screening (EPA, 1995a). This methodology is based upon making comparisons to published preliminary remediation goals (PRGs) listed in the guidance. This risk evaluation differed slightly from the EPA (1995a) screening method by the use of chemical-specific values that were developed for use in the fog oil risk evaluation instead of using the PRGs. The PRGs were not used because they are based on standard residential and commercial/industrial exposure scenarios that do not provide an adaquate match for anticipated fog oil exposures to soldiers involved in training. Instead, chemical-specific values ("action levels") were modified from EPA default values (EPA,1995a) only to the extent they are calculated based on exposure variables specific to fog oil obscurant training. The exposure variables used to calculate the action levels are presented in Table A8 of Appendix A.

Table A9 (Appendix A) presents the formulas used to calculate the action levels. Two types of action levels have been calculated: one type (AL_n) is used to evaluate potential noncarcinogenic effects, and the other type (AL_c) is used to evaluate potential carcinogenic effects. Tables A10 through A12 (Appendix A) list the toxicity values from EPA (1995a) used to calculate the action levels. The action levels calculated are presented in Tables A13 through A15 (Appendix A). Further explanation of the toxicity values is provided in the next section.

4.3.4 Toxicity Assessment

The objective of the toxicity assessment is to weigh available evidence regarding the potential for particular chemicals to cause adverse effects in exposed individuals, and to provide, where possible, an estimate of the relationship between the extent of exposure to a chemical and the increased likelihood and/or severity of adverse effects.

The toxicity values used (Tables A10 through A12, Appendix A) were those for inhalation published by EPA (1995a) Region IX. There are two types of toxicity values which are used in this PRE: the inhalation reference dose (RfD_i) and the inhalation slope factor (SF_i). The RfD_i is used to assess noncarcinogenic effects, and the units are in mg/kg/d; that is, the RfD_i is in the form of a dose. The RfD_i is the dose at which adverse noncarcinogenic health effects are unlikely to occur. The SF_i is used to assess carcinogenic effects, and the units are in $(mg/kg/d)^{-1}$; that is, risk per dose.

4.3.5 Risk Characterization

Ultimately, the purpose of the risk characterization in this PRE is to estimate the levels of excess noncarcinogenic hazards and excess carcinogenic risks which may be encountered and relate them to levels which may be considered significant or insignificant as defined by numerical criteria. "Excess" hazards and risks are those hypothetically associated with exposure to fog oil smoke during training exercises.

A hazard quotient and/or risk was calculated for each chemical where possible. The hazard quotient (HQ) is an indicator of the potential for adverse noncarcinogenic effects to occur. The calculated risk represents the hypothetical probability that an individual will develop cancer due to exposure to the chemical in question. The following equations describe the calculations:

$$HQ = C/AL_n$$
$$risk = (C/AL_c) \times 10^{-6}$$

where,

HQ = hazard quotient
AL_n = action level for noncarcinogenic effects
C = measured ambient air concentration of a given chemical
AL_c = action level for carcinogenic effects

Cumulative hazards and risks are presented in Tables A16 through A19 (Appendix A) for all chemicals detected. The cumulative noncarcinogenic effects are represented by a hazard index, which equals the sum of all HQs, as follows:

$$\text{hazard index} = \sum (HQ_1, HQ_2 \ldots Hqi)$$

Likewise, the cumulative carcinogenic effects are represented by the sum of all chemical-specific risks, as follows:

$$risk_T = \sum (risk_1, risk_2, \ldots risk_i)$$

where $risk_T$ = the total (cumulative) risk.

Tables A16 through A19 (Appendix A) present the comprehensive lists of compound-specific and location-specific hazard quotients and risks for all compounds detected in Tests 1 and 2. It should be noted that the level of certainty associated with each value calculated varies across the range of compounds. Table A16 presents all hazard quotients for Test 1; Table A17 presents all hazard quotients for Test 2; Table A18 presents all risks for Test 1; and Table A19 presents all risks for Test 2.

EPA's target cumulative non-carcinogenic, toxicity hazard index for Superfund sites equals 1. EPA's target range for cumulative carcinogenic risk associated with Superfund sites is 1 in 1,000,000 (10^{-6}) to 1 in 10,000 (10^{-4}). While Fort Leonard Wood is not a Superfund site, these benchmarks were used herein to make judgments about the significance of the risk associated with exposure to fog oil smoke emissions.

For purposes of this preliminary risk evaluation the following criteria applied:

(1) an insignificant level of exposure is that in which the hazard index is less than or equal to 1, and the risk is less than or equal to 10^{-6};

(2) a nominally insignificant level of exposure is that in which the hazard index is less than or equal to 1, and the risk is greater than 10^{-6}, but less than or equal to 10^{-4}; and

(3) a significant level of exposure is that in which the hazard index is greater than 1, and/or the risk is greater than 10^{-4}.

4.3.5.1 Highly Conservative Risk Analysis

Tables 1 and 2 present the summaries of maximal excess hazards and risks for Tests 1 and 2, respectively, using the most conservative analysis. Associated with this analysis is a low level of certainty; that is, the hazard indices and risks are biased high due to the inclusion of all chemicals. The inclusion of all chemicals requires the use of representative compounds which may not be closely related structurally to the detected compounds and therefore increase the uncertainty of the results.

For Test 1 (Table 1) total fog oil exposures higher than 690 mg/m^3 (found within 11 m of the generator) pose a significant hazard and/or risk, while concentration of 35 mg/m^3 or less (at the 25 m station and beyond) are nominally insignificant from the standpoint of health hazard and/or risk. For Test 2 (Table 2), concentrations of 10,750 and 77 mg/m^3 (found at the 0.5 m and 11 m stations respectively) are considered to pose a significant hazard and/or risk, while concentrations of about 5 mg/m^3 found at distances at or slightly greater (within meters) than 100 m present a nominally insignificant hazard and/or risk.

4.3.5.2 Moderately Conservative Risk Analysis

The second analysis, as presented in Tables 3 and 4, is considered more reliable, and should be used for decision-making purposes. In the second analysis, compounds lacking toxicity values and lacking closely-related representative compounds were eliminated from the analysis. The compounds which were eliminated may be deduced by comparing Tables 3 and 4 with Tables 1 and 2, respectively. Based upon these findings, the following conclusions may be drawn with respect to exposures to fog oil smoke at different distances downwind of the generator:

(1) **TEST 1 (M56 Generator; Table 3):**
   (a) Concentrations greater than 690 mg/m^3 (found at locations up to 11 m from the generator) are associated with a significant level of hazard and/or risk;
   (b) Concentrations ranging from 690 to 35 mg/m^3 (found at locations 11 and 25 m, respectively) are associated with a potentially significant level of hazard and/or risk, although this is not directly quantifiable; and
   (c) Concentrations less than or equal to 35 mg/m^3 (found at locations greater than or equal to 25 m from the generator) may be considered "safe."

(2) **TEST 2 (M157 Generator; Table 4):**
   (a) Concentrations ranging from 77 mg/m^3 to 10,750 mg/m^3 (found at locations of 11 m and 0.5 m from the generator) are associated with a significant level of hazard and/or risk;

(b) Concentrations ranging between 77 mg/m^3 and 7 mg/m^3 (found at locations between 11m and 100 m from the generator) are associated with a potentially significant level of hazard and/or risk, although this is not directly quantifiable;

(c) Concentrations from 6-7 mg/m^3 (found at locations around 100 m from the generator) may be considered nominally "safe"; and

(d) A concentration of about 5mg/m^3 (found at locations only slightly beyond 100 m of the generator) may be considered "safe."

Table 5 relates total fog oil concentration in the air to cumulative risk and cumulative hazard indices for the M56 and M157 generators. Figures 1 and 2 relate total oil concentration in air to the distance from each generator, the M56 and M157, respectively. For Test 1, with the M56 Generator, the oil concentration at 100 meters is estimated at 5 mg/m^3. For Test 2, with the M157 Generator, the oil concentration at 100 meters is estimated at about 4 mg/m^3. The regression line for the two graphs (Figures 1 and 2) were hand drawn based on a visual "best fit."

Combining results for Tests 1 and 2, the PRE determined that exposure to a total oil concentration in air of less than or equal to about 30 mg/m^3 is associated with a hazard index of 1 (Figure 3). Likewise, the PRE determined that a total oil concentration in air of less than or equal to about 10 mg/m^3 is associated with a cancer risk of 10^{-6} (Figure 4). It is therefore safe to assume that a field action level set at 5 mg/m^3 will be protective with a reasonable margin of safety.

TABLE 1
SUMMARY OF EXCESS HAZARDS AND RISKS FOR TEST 1
LOW LEVEL OF CERTAINTY; HIGH LEVEL OF CONSERVATISM[1]

Location	Cumulative Hazard Index	Cumulative Risk	Primary Source(s) of Hazard or Risk[2]
200 m	0.03		
25 m	1		
11 m	19 *		dibenzothiophenes, benzene, C2/C3-fluorenes
200 m		2E-06 *	C3-ene, C4-ene, 1,3-butadiene
25 m		8E-07	
11 m		2E-04 *	C3-ene, C4-ene, 1,3-butadiene, 1-hexene, 1-heptene, benzo(e)pyrene, 1-octene benzo(b)fluoranthene, benzene

(1) An asterisk ("*") indicates that the value exceeds the stated criterion of a hazard index = 1, or a risk = 10^{-6}, as appropriate.
(2) Those chemicals causing the cumulative hazard index or risk to exceed the stated criteria. The chemicals are listed in order from highest hazard index or risk to lowest.

TABLE 2
SUMMARY OF EXCESS HAZARDS AND RISKS FOR TEST 2
LOW LEVEL OF CERTAINTY; HIGH LEVEL OF CONSERVATISM[1]

Location	Cumulative Hazard Index	Cumulative Risk	Primary Source(s) of Hazard or Risk[2]
100 m	0.2		
11 m	7 *		benzene, C2/C3-dibenzothiophenes
0.5 m	540 *		dibenzothiophenes, benzene, benzothiophenes, naphthalenes, fluorenes, fluoranthenes/pyrenes, phenanthrenes/anthracenes, toluene, dibenzofuran, m,p-xylene, acenaphthylene
100 m		8E-05 *	propyne, C4-ene, 2-pentene, 1,3-pentadiene, 1-hexene, 3-methyl-1,3-butadiene, 2-butene, cyclohexadiene, 1-nonene, 3-methyl-1-butene, 3-penten-1-yne, cyclopentene, 1,4-cyclohexadiene, 1-octene
11 m		3E-03 *	propyne, C4-ene, 1,3-pentadiene, 1-hexene, 2-butene, 2-pentene, 2-methyl-1,3-butadiene, 1,4-cyclohexadiene, 1-heptene, 1-nonene, 1-penten-1-yne, 3-methyl-1-butene, cyclohexadiene, cyclopentene, 1-octene, 4-methyl-1-pentene, cyclohexene, benzene, benzo(e)pyrene
0.5 m		9E-02 *	propyne, C4-ene, 1,3-butadiene, 1-pentadiene, 1-hexene, 2-methyl-1,3-butadiene, 1,4-cyclohexadiene, 1-heptene, cyclohexadiene, 2-pentene, 2-butene, 3-penten-1-yne, 1-nonene, 3-methyl-1-butene, cyclopentene, 1-octene, 4-methyl-1-pentene, cyclohexene, benzo(e)pyrene, benzene, benzo(a)anthracene, benzo(b)fluoranthene, chrysenes

1) An asterisk ("*") indicates that the value exceeds the stated criterion of a hazard index = 1, or a risk = 10^{-6}, as appropriate.
2) Those chemicals causing the cumulative hazard index or risk to exceed the stated criteria. The chemicals are listed in order from highest hazard index or risk to lowest.

TABLE 3
SUMMARY OF EXCESS HAZARDS AND RISKS FOR TEST 1
MODERATE LEVEL OF CERTAINTY; MODERATE LEVEL OF CONSERVATISM[1]

Location	Cumulative Hazard Index	Cumulative Risk	Primary Source(s) of Hazard or Risk[2]
200 m	< 0.03		
25 m	< 1		
11 m	19 *		dibenzothiophenes, benzene, C2/C3–fluorenes
200 m		5E–07	(1,3–butadiene)
25 m		< 8E–07	
11 m		4E–05 *	1,3–butadiene, benzo(e)pyrene, benzo(b)fluoranthene

(1) An asterisk ("*") indicates that the value exceeds the stated criterion of a hazard index = 1, or a risk = 10^{-6}, as appropriate.
(2) Those chemicals causing the cumulative hazard index or risk to exceed the stated criteria. The chemicals are listed in order from highest hazard index or risk to lowest. A chemical listed in parentheses is associated with the highest risk, even though the criterion is not exceeded.

TABLE 4
SUMMARY OF EXCESS HAZARDS AND RISKS FOR TEST 2
MODERATE LEVEL OF CERTAINTY; MODERATE LEVEL OF CONSERVATISM[1]

Location	Cumulative Hazard Index	Cumulative Risk	Primary Source(s) of Hazard or Risk[2]
100 m	< 0.2		
11 m	7 *		benzene, C2/C3–dibenzothiophenes
0.5 m	531 *		dibenzothiophenes, benzene, naphthalenes, fluorenes, fluoranthenes/pyrenes, phenanthrenes/anthracenes, toluene, dibenzofuran, m,p–xylene, acenaphthylene
100 m		3E–06 *	3–methyl–1,3–butadiene
11 m		9E–05 *	2–methyl–1,3–butadiene, benzene, benzo(e)pyrene
0.5 m		9E–03 *	1,3–butadiene, 2–methyl–1,3–butadiene, benzo(e)pyrene, benzene, benzo(a)anthracene, benzo(b)fluoranthene, chrysenes

1) An asterisk ("*") indicates that the value exceeds the stated criterion of a hazard index = 1, or a risk = 10^{-6}, as appropriate.
2) Those chemicals causing the cumulative hazard index or risk to exceed the stated criteria. The chemicals are listed in order from highest hazard index or risk to lowest.

TABLE 5
CUMULATIVE HAZARD INDEX AND CUMULATIVE RISK
AT DIFFERENT FOG OIL CONCENTRATIONS

Station (m)	Generator	Total Oil (mg/m^3)	Average Oil Conc. (mg/m^3)	Cumulative Risk	Cumulative Hazard Index
11 11	M56 M56	675 710	693	4E-05	19
25 25	M56 M56	39 30	35	<8E-07	<1
200 200	M56 M56	2.2 2.2	2.2	5E-07	<0.03
0.5 0.5	M157 M157	13,806 7,691	10,749	9E-03	540
11 11	M157 M157	71 84	77	9E-05	7
100 100	M157 M157	6.0 7.2	6.6	3E-06	0.2

FIGURE 3. RELATIONSHIP OF OIL CONCENTRATION IN AIR TO HAZARD INDEX

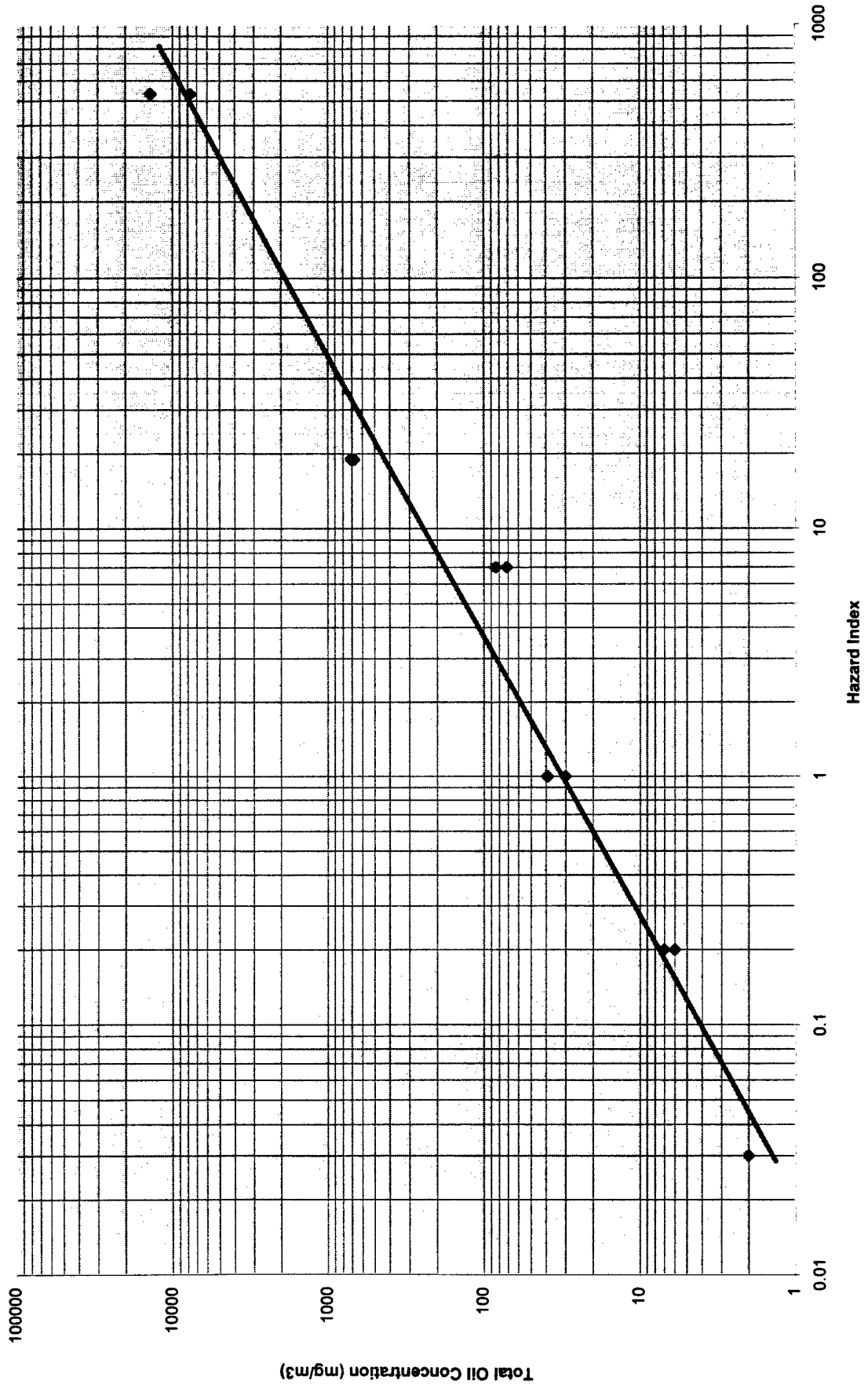
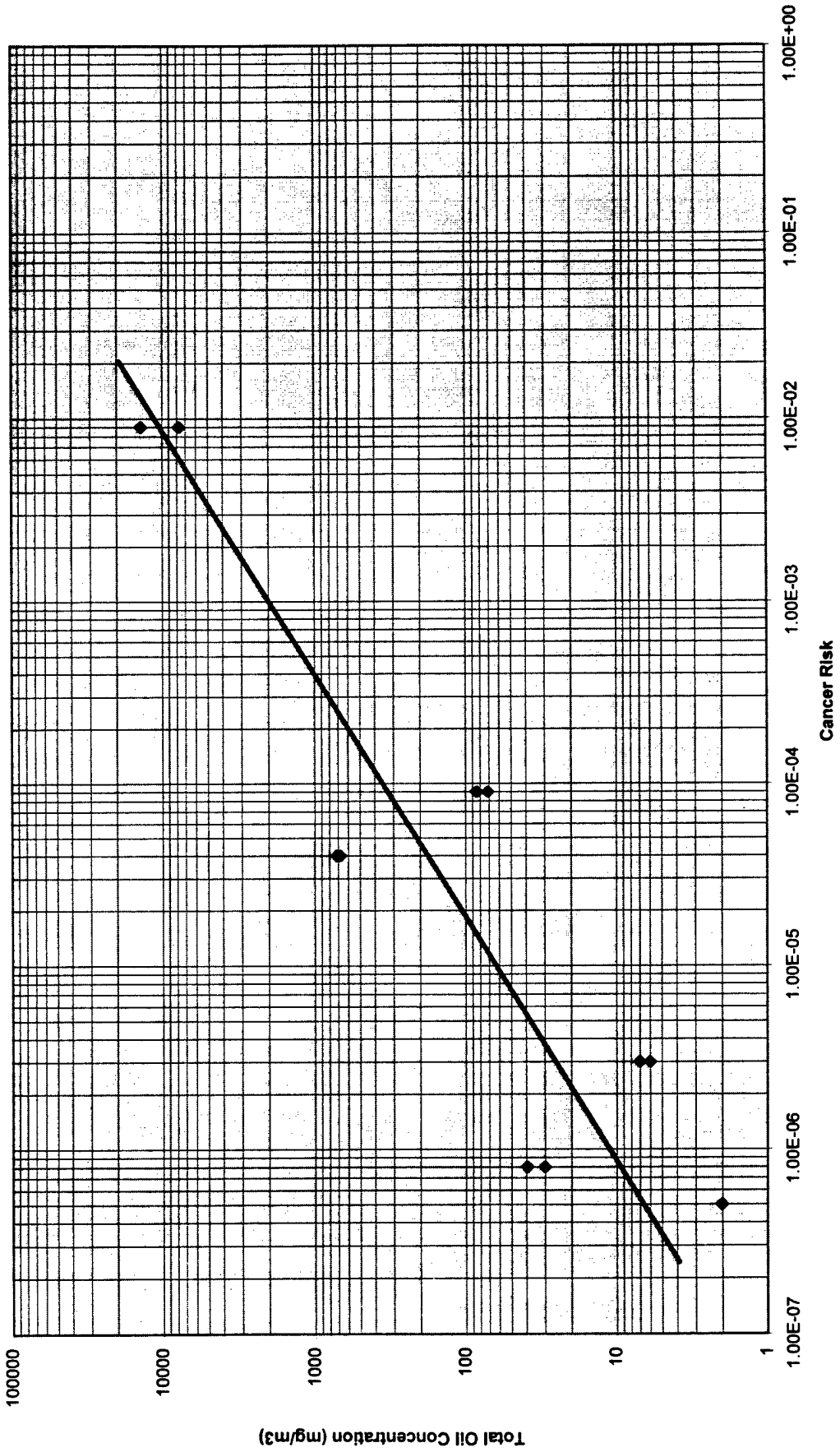


FIGURE 4. RELATIONSHIP OF OIL CONCENTRATION IN AIR TO CANCER RISK



4.3.5.3 Other Considerations

The American Conference of Governmental Industrial Hygienists (ACGIH) has established a threshold limit value (TLV) for occupational exposure to mineral oil mists (ACGIH, 1994-1995). The threshold limit value-time weighted average (TLV-TWA) for oil mist is 5 mg/m^3. The TLV-TWA is the time weighted average concentration for a normal 8-hour work day and a 40-hour workweek, to which nearly all workers may be repeatedly exposed, day after day, without adverse effects (ACGIH, 1994-1995).

Since military personnel involved in fog oil obscurant training would be exposed no more than 1 hour per day during a given week (see Table A8, Appendix A for PRE exposure assumptions), an appropriate adjusted TLV would be 40 mg/m^3 total oil mist (8 X 5 mg/m^3 = 40 mg/m^3). However, even this level was exceeded at several locations. For example, in the worst-case, at 0.5 m from the source in Test 2, the maximum oil concentration measured in air was 85.6mg/6.2 L or 13,806 mg/m^3, which is greater than 300 times the adjusted TLV. At 100 m in Test 2 the maximum oil concentration in air was 7.2 mg/m^3 and represents an acceptable TLV-TWA exposure.

4.3.6 Uncertainty Analysis

There are several categories of uncertainty associated with site-specific risk assessments. One is the initial selection of substances used to characterize exposures, noncarcinogenic hazards, and carcinogenic risks on the basis of the sampling data and available toxicity information. Other sources of uncertainty are inherent in the toxicity values used to characterize hazards and risks for each substance. Additional uncertainties are inherent in the exposure assessment for individual substances and individual exposures. These uncertainties are driven by the degree of reliability of the chemical monitoring data, the models used to estimate exposure concentrations in the absence of monitoring data, and the population intake parameters. Finally, additional uncertainties are incorporated into the risk assessment when exposures to several substances, across multiple pathways, are summed.

The use of the EPA Region IX toxicity values is conservative, but it also introduces a significant level of uncertainty into the assessment. Most of these values are not based on reliable inhalation studies as they should ideally be. Rather, they are derived mainly from oral toxicity values. In fact, relatively few chemicals have been adequately evaluated via the inhalation route. This is the reason that the EPA Risk Information System (IRIS; EPA, 1996) and the EPA Health Effects Assessment Summary Tables (HEAST; EPA, 1995b) do not provide inhalation toxicity values such as reference concentrations (RfCs) and unit risk factors (URFs) for most chemicals.

An example of the uncertainty attached to evaluating many of the chemicals detected in fog oil smoke may be seen with PAHs. Neither IRIS nor HEAST list any inhalation values for PAHs, presumably because there are insufficient data, and extrapolation from oral studies is tenuous. Extrapolation is tenuous because PAHs are known to act at the portal-of-entry. Thus, it is difficult to estimate effects due to inhalation based on oral data.

The nonconservative approach then would be to not evaluate PAHs at all via the inhalation route. Yet the fact remains that there is substantial evidence that inhaled PAHs cause adverse health effects such as lung tumors, hence the need to include them in the quantitative evaluation in the present case. The same logic applies to chemicals other than PAHs.

Another major source of uncertainty in this PRE is the use of "surrogate" toxicity values; that is, the use of toxicity values for representative compounds for chemicals lacking toxicity values. The representative compounds associated with various compounds or groups of compounds are presented in Tables A1 through A3 (Appendix A). It should be noted that one result of this approach is that there are varying levels of certainty across all compounds detected. Essentially, each compound falls into one of three relative levels of certainty with regard to the toxicity value used:

(1) highest level of certainty, meaning that EPA (1995a) provides a toxicity value for the compound;
(2) moderate level of certainty, meaning that the EPA (1995a) provides a toxicity value for a compound which is closely related structurally; and
(3) low level of certainty, meaning that the EPA (1995a) provides a toxicity value only for a compound which is related structurally, but not closely related.

5.0 CONCLUSIONS

The human health effects of exposures to fog oil were evaluated based on review of existing toxicity literature (HBA, 1996; Appendix E), indepth chemical analysis of fog oil for chemicals of concern in fog oil smoke and liquid fog oil (Appendix B) and by a preliminary risk evaluation (PRE) documented in this report. The preponderance of evidence in the literature on the health effects of smoke generated with SGF-2 (Standard Grade Fuel) fog oil manufactured after 1986 by military specification, MIL-F-12070C, Amendment 2 and specifications thereafter, indicate there is limited potential for adverse effects to humans. The literature on the toxicity of fog oil documents that currently used SGF-2 has low toxicity when ingested, presents minimal toxicity from dermal exposure, and has limited potential for pulmonary effects unless the Threshold Limit Value-Time Weighted Average (TLV-TWA) of 5 mg/m^3 is exceeded for prolonged periods of time.

The TLV-TWA standard of 5 mg/m^3 was established by the Occupational Safety and Health Administration (OSHA), the American Conference of Governmental Industrial Hygienists (ACGIH), and other national and international organizations to protect workers in industrial settings from harmful exposures to mineral oil mists in the air. The OSHA/ACGIH 5mg/m^3 TLV-TWA is considered a safe concentration when workers are repeatedly exposed for up to 8 hours per day and 5 days per week for a worker's career. This health protective standard was for mineral oils which are severely acid treated, severely hydrotreated or severely solvent treated to reduce the content of carcinogens and other toxic compounds. To meet the 1986 military manufacturing specifications, fog oil is severely treated to remove carcinogens and therefore represents the type of mineral oil upon which the OSHA/ACGIH standard was based.

The human health literature on fog oil revealed no detailed analyses had been conducted to determine the hydrocarbon composition of the new generation of liquid fog oil manufactured

after 1986 (Palmer, 1990; Driver et al., 1993; and HBA, 1996). Other unanswered questions involved the hydrocarbon composition of smoke produced by M56 and M157 generators and whether the high internal temperatures of the generators could cause significant alteration to the chemicals present in fog oil. The M56 and M157 generators were of interest in this health evaluation because of their planned use in fog oil obscurant training at Fort Leonard Wood.

In an effort to develop this critical information, a sampling/analytical program was conducted. Results of the chemical anlyses confirmed that polynuclear aromatic hydrocarbon concentrations in liquid fog oil were very low. A comparison between the hydrocarbon composition of liquid fog oil and the smoke produced by two different generators clearly demonstrated no significant hydrocarbon alterations had occurred due to heat of the generators. The hydrocarbon analytical program contributed valuable information on chemicals of potential human health concern in obscurant fog oil smoke and served as the basis of the preliminary risk evaluation.

The PRE determined that sustained exposure of military personnel to fog oil smoke at concentration of about 5mg/m^3 (or less) present an insignificant hazard and/or risk. Additionally, occasional, brief excursions to levels between 5 and 10 mg/m^3 for unprotected personnel should be considered an insignificant health threat. These finding generally agree with the TLV-TWA established by OSHA and ACGIH for protection of workers in industrial settings from exposure to mineral oil mists in the air.

The risk evaluation applied the highest protective, health-based criteria used at Superfund sites by EPA when deciding whether or not to implement risk management options. While Fort Leonard Wood is not a Superfund site, these protective criteria were used to make judgements about the significance of risks associated with exposure to fog oil smoke emissions. The exposure frequencies and durations used in the PRE in combination with the downwind location of sampling stations would indicate the results of the PRE are worse-case. However, the intended purpose of a PRE is to provide a conservative prediction of hazard and/or risk so that human health protection is assured.

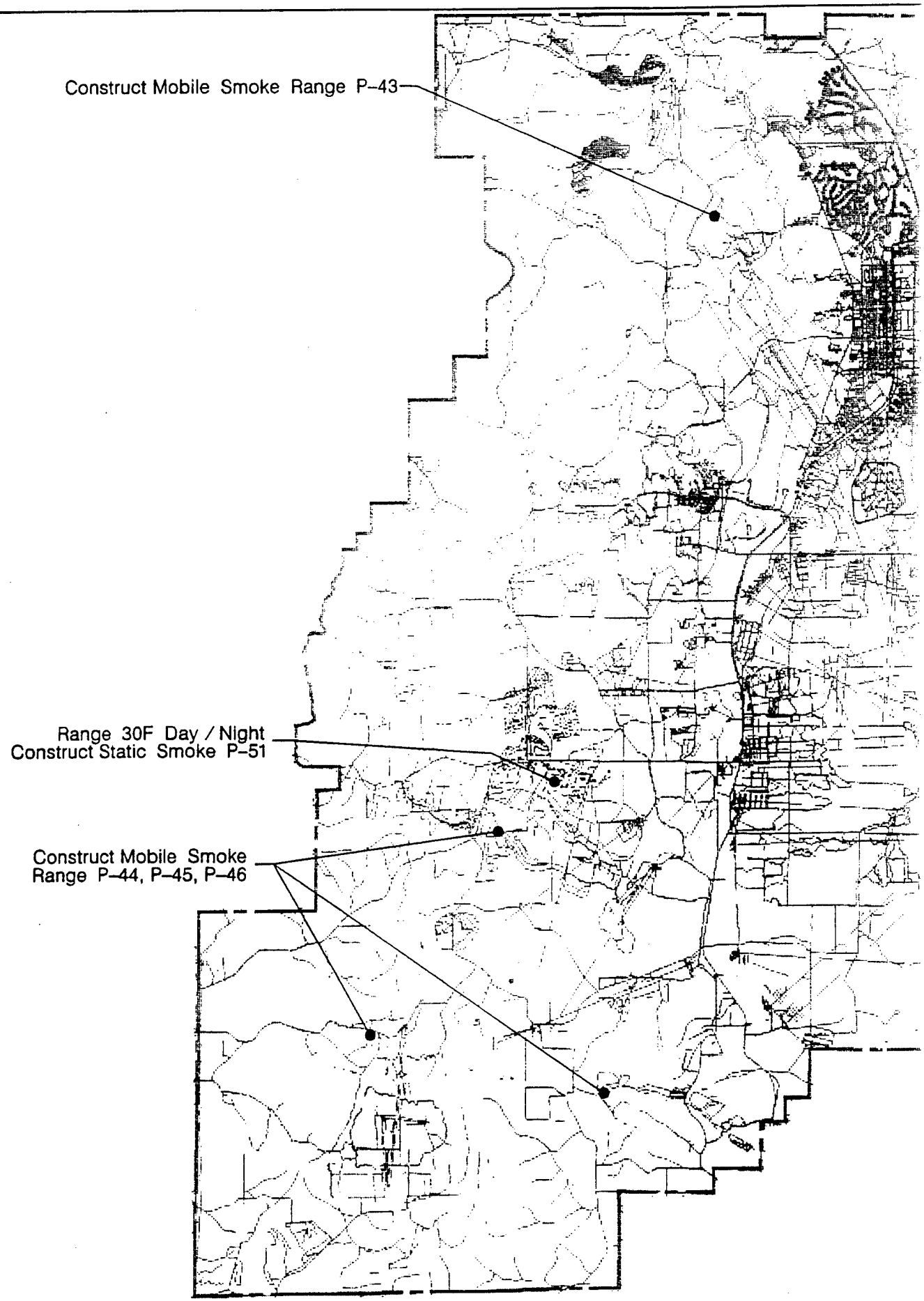
Although the PRE used exposure times, frequencies, and durations estimated for military personnel involved with the Chemical School as a career, the results represent more than a "workplace" estimate of risk. The toxicity values used in the PRE for the compounds of concern found in fog oil were obtained from USEPA toxicity data bases (EPA, 1995b and 1996). These published values are adjusted downward by EPA, through the use of uncertainty factors to protect sensitive individuals (e.g., children, women and elders) in the human population. Although protective of very sensitive human receptors, they do not protect the rare, ultra-sensitive individual that may react to any number of different airborne exposures, whether man-made or produced by nature. The exposure times, durations and concentrations used in the PRE are estimated to be greater than those exposures anticipated for the general public.

It is highly unlikely that individuals positioned away from fog oil training areas, but within the boundaries of Fort Leonard Wood (FLW), and those outside the facility boundary will be exposed to fog oil at concentrations that would pose a health risk. Figure 5 depicts the locations of fog oil obscurant training areas at Fort Leonard Wood. Each training area has been assigned a restrictive set of meteorological conditions such as wind direction and speed under

which training can be conducted. The area-specific meteorological restriction are part of a fog oil operating permit issued by the Missouri Department of Natural Resources (MDNR) and were devised to avoid unhealthy exposure of fog oil obscurant to individuals outside the training areas. The fog oil operating permit also specifies that training shall not contribute to a safety hazard to air traffic or vehicular traffic on highways accessible to the public. To assure compliance with conditions of the permit, observers will be positioned at strategic places around the training area to monitor wind conditions and obscurant cloud movement.

Site-specific air dispersion modeling conducted to support the FLW EIS air quality analysis predicted concentrations of less than 30 $\mu g/m^3$ at the boundary of FLW and at the edge of the FLW cantonment area when 481 gallons of fog oil are used in one hour (COE KC, 1997). This volume is the limit currently allowed during a 24 hour period by the FLW air permit for fog oil training. The highest volume modeled (i.e., the highest daily amount used at FMC) was 1900 gallons per hour and resulted in a concentration of less than 149 $\mu g/m^3$ at the edge of the FLW cantonment and FLW boundary. All modeling was conducted to adhere to wind directions and atmospheric stability classes allowed by the FLW air permit. The results indicate that potential exposures to the general public will be 34 to 167 times lower than safe exposure level determined by the PRE for fog oil and the safe exposure level established by the American Conference of Industrial Governmental Hygienists (ACGIH, 1994) for mineral oil mists in the workplace. Considering the low concentration, and limited frequency and duration of fog oil exposures anticipated for the general public, adverse health impacts are not anticipated.

As part of the fog oil training Air Permit, monitoring will be conducted at FLW prior to and concurrent with fog oil training. The monitoring study is summarized in Appendix K of the Final Environmental Impact Statement (FEIS) conducted for the Relocation of U.S. Army Chemical School and U.S. Army Military Police School to Fort Leonard Wook, Missouri (COE KC, 1997). It is anticipated the results of the monitoring program will confirm safe levels of fog oil in the cantonment areas and off-post. In the event concerns are identified from the fog oil monitoring, an Adaptive Management Strategy plan, contained in Appendix K of the FEIS, will be used to address and mitigate the concern. A Public Awareness Program will be implemented by FLW prior to the initiation of fog oil training to inform the public on fog oil issues of interest.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Construct Static Smoke P-51
Construct Mobile Smoke
Range P-44, P-45, P-46

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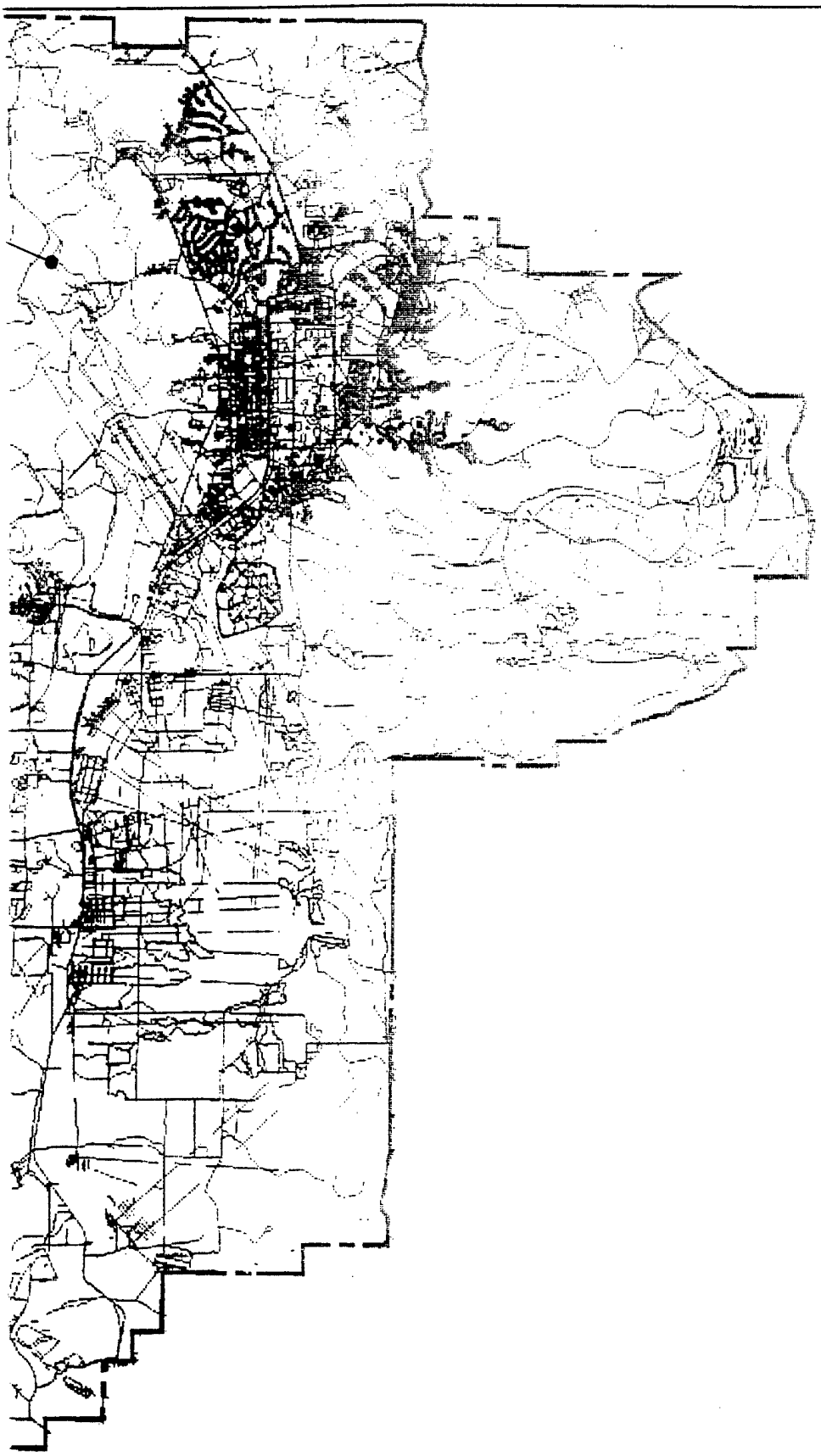

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HARLAND BARTHOLOMEW & ASSOCIATES, INC
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HARLAND BARTHOLOMEW & ASSOCIATES, INC ST LOUIS, MISSOURI	KANSAS CITY DISTRICT US ARMY CORPS OF ENGINEERS KANSAS CITY, MISSOURI

ENVIRONMENTAL IMPACT STATEMENT

RELOCATION OF U.S. ARMY CHEMICAL SCHOOL AND U.S. ARMY MILITARY POLICE SCHOOL TO FORT LEONARD WOOD, MISSOURI

OBSCURANT TRAINING AREAS
FORT LEONARD WOOD
BRAC 1995 PROJECTS

DATE: APRIL 1996	FIGURE NO. 5

6.0 REFERENCES

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Appendix A

TABLE A1
REPRESENTATIVE COMPOUNDS FOR TEST 1 VOCs[1]

Representative Compound [2]	CAS No.	Detected Compound [3]	Peak No. [4]	Status [5]	Comments
1,3–Butadiene	106–99–0	C3–ene	1	Y	Uncertainty high for compounds other than 1,3–butadiene.
		C4–ene	2		
		1,3–butadiene	3		
		1–hexene	7		
		1–heptene	10		
		1–octene	13		
n–Hexane	110–54–3	isobutane	4	Y	Uncertainty high; n–hexane is the most toxic alkane. Risk likely to be over–estimated.
Benzene	71–43–2	benzene	8	Y	
Cyclohexanone	108–94–1	cyclohexene/C6–ol	9	Y	Uncertainty high.
Methyl cyclohexane	108–82–2	1,2–dimethyl cyclopropane	5	Y	Uncertainty high for compounds other than methyl cyclohexane.
		1,2–dimethyl cyclopropane	6		
		methyl cyclohexane	11		
		ethyl cyclohexane	14		
		dimethyl adamantane	26		
		unknown d	27		
		unknown e	28		
		dimethyl adamantane	29		
		dimethyl adamantane	30		
Toluene	108–88–3	toluene	12	Y	

TABLE A1
REPRESENTATIVE COMPOUNDS FOR TEST 1 VOCs[1]

Representative Compound [2]	CAS No.	Detected Compound [3]	Peak No. [4]	Status [5]	Comments
m–Xylene	108–38–3	m,p–xylene	15	Y	Uncertainty high for compounds other than xylenes. Risk likely to be over–estimated.
		1–nonene/o–xylene	16		
		unknown a	17		
		ethyl, methylbenzene	18		
		1,2,4–trimethylbenzene	19		
		diethylbenzene	20		
		methyl, propylbenzene	21		
		tetramethylbenzene	22		
		ethyl, dimethylbenzene	23		
		unknown b	24		
		unknown c	25		

(1) Test 1 was conducted with the M56 Generator on 12/13/95. VOCs = volatile organic compounds.
(2) The compound used to assess the toxicity of the detected compound(s).
(3) The compound actually detected in air.
(4) Chromatographic peak corresponding to the detected compound (Appendix B).
(5) Y = "yes," indicating there is a reasonable toxicity value available with which to evaluate the representative compound.
N = "no," indicating there is not a reasonable toxicity value available with which to evaluate the representative compound.

TABLE A2
REPRESENTATIVE COMPOUNDS FOR TEST 2 VOCs [1]

Representative Compound [2]	CAS No.	Detected Compound [3]	Peak No. [4]	Status [5]	Comments
1,3-Butadiene	106-99-0	propyne	1	Y	Uncertainty high for compounds other than 1,3-butadiene.
		C4-ene	2		
		C4-ene	3		
		1,3-butadiene	4		
		2-butene (z)	5		
		2-butene (e)	6		
		3-methyl-1-butene	7		
		2-methyl-1,3-butadiene	10		
		2-pentene	11		
		2-pentene	12		
		2-pentene	13		
		1,3-pentadiene	14		
		cyclopentene	16		
		4-methyl-1-pentene	17		
		1-hexene	18		
		1,4-cyclohexadiene	19		
		1,4-cyclohexadiene	20		
		cyclohexadiene	22		
		cyclohexene	23		
		1-heptene	24		
		1-octene	26		
		1-nonene	30		
		3-penten-1-yne	15		
Methylcyclohexane	108-82-2	1,2-dimethyl cyclopropane	8	Y	Uncertainty high.
		1,2-dimethyl cyclopropane	9		
Benzene	71-43-2	benzene	21	Y	

TABLE A2
REPRESENTATIVE COMPOUNDS FOR TEST 2 VOCs [1]

Representative Compound [2]	CAS No.	Detected Compound [3]	Peak No. [4]	Status [5]	Comments
Toluene	108-88-3	toluene	25	Y	
Ethylbenzene	100-41-4	ethylbenzene	27	Y	
m-Xylene	108-38-3	m,p-xylene	28	Y	
		4-ethyltoluene	31		
		1,3,5-trimethylbenzene	32		
		1,2,4-trimethylbenzene	33		
Styrene	100-42-5	styrene	29	Y	

(1) Test 2 was conducted with the M157 Generator on 12/14/95. VOCs = volatile organic compounds.
(2) The compound used to assess the toxicity of the detected compound(s).
(3) The compound actually detected in air.
(4) Chromatographic peak corresponding to the detected compound (Appendix B).
(5) Y = "yes," indicating there is a reasonable toxicity value available with which to evaluate the representative compound.
N = "no," indicating there is not a reasonable toxicity value available with which to evaluate the representative compound.

TABLE A3
REPRESENTATIVE COMPOUNDS FOR TESTS 1 AND 2 SVOCs [1]

Representative Compound [2]	CAS No.	Detected Compound [3]	Status [5]	Comments
Methylcyclohexane	108-87-2	Decalin C1-decalins C2-decalins C3-decalins C4-decalins	Y	Uncertainty high.
Dibenzofuran	35367-38-5	dibenzofuran benzo(b)thiophene C1-benzo(b)thiophenes C2-benzo(b)thiophenes C3-benzo(b)thiophenes C4-benzo(b)thiophenes dibenzothiophene C1-dibenzothiophenes C2-dibenzothiophenes C3-dibenzothiophenes	Y	Uncertainty high for compounds other than dibenzofuran.
Naphthalene	91-20-3	naphthalene C1-naphthalenes C2-naphthalenes C3-naphthalenes C4-naphthalenes	Y	
1,1-Biphenyl	92-52-4	biphenyl	Y	
Acenaphthene	83-32-9	acenaphthylene acenaphthene	Y	

TABLE A3
REPRESENTATIVE COMPOUNDS FOR TESTS 1 AND 2 SVOCs [1]

Representative Compound [2]	CAS No.	Detected Compound [3]	Status [5]	Comments
Fluorene	86-73-7	fluorene C1-fluorenes C2-fluorenes C3-fluorenes fluoranthene	Y	
Anthracene	120-12-7	anthracene phenanthrene C1-phenanthrenes/anthracenes C2-phenanthrenes/anthracenes C3-phenanthrenes/anthracenes C4-phenanthrenes/anthracenes	Y	
Pyrene	129-00-0	pyrene C1-fluoranthenes/pyrenes C2-fluoranthenes/pyrenes C3-fluoranthenes/pyrenes	Y	
Benz(a)anthracene	56-55-3	benz(a)anthracene	Y	
Chrysene	218-01-9	chrysene C1-chrysenes C2-chrysenes C3-chrysenes C4-chrysenes	Y	
Benzo(b)fluoranthene	205-99-2	benzo(b)fluoranthene	Y	

TABLE A3
REPRESENTATIVE COMPOUNDS FOR TESTS 1 AND 2 SVOCs [1]

Representative Compound [2]	CAS No.	Detected Compound [3]	Status [5]	Comments
Benzo(k)fluoranthene	207-08-9	perylene	Y	
Benzo(a)pyrene	50-32-8	benzo(e)pyrene	Y	

(1) Test 1 was conducted with the M56 Generator on 12/13/95. Test 2 was conducted with the M157 Generator on 12/14/96. SVOCs = semivolatile organic compounds. Most of the SVOCs listed are polycyclic aromatic hydrocarbons (PAHs), but include other closely related compounds as well.
(2) The compound used to assess the toxicity of the detected compound(s).
(3) The compound actually detected in air.
(4) Chromatographic peak corresponding to the detected compound (Appendix B).
(5) Y = "yes," indicating there is a reasonable toxicity value available with which to evaluate the representative compound.
N = "no," indicating there is not a reasonable toxicity value available with which to evaluate the representative compound.

TABLE A4
EXPOSURE POINT CONCENTRATIONS FOR TEST 1 VOCs ($\mu g/m^3$) [1]

Compound	Peak No. [2]	Distance Downwind from Generator (m)		
		200	25	11
C3–ene	1	2	NA	199
C4–ene	2	1	NA	71
1,3–butadiene	3	1	NA	65
isobutane	4	6	NA	35
1,2–dimethyl cyclopropane	5	1	NA	42
1,2–dimethyl cyclopropane	6	–	NA	17
1–hexene	7	1	NA	31
benzene	8	–	NA	36
cyclohexene/C6–ol	9	2	NA	8
1–heptene	10	–	NA	18
methyl cyclohexane	11	–	NA	14
toluene	12	2	NA	16
1–octene	13	–	NA	12
ethyl cyclohexane	14	–	NA	13
m,p–xylene	15	1	NA	30
1–nonene/o–xylene	16	1	NA	19
unknown a	17	–	NA	13
ethyl, methylbenzene	18	–	NA	14
1,2,4–trimethylbenzene	19	–	NA	35
diethylbenzene	20	–	NA	31
methyl, propylbenzene	21	–	NA	22
tetramethylbenzene	22	–	NA	60
ethyl, dimethylbenzene	23	–	NA	45
unknown b	24	–	NA	28
unknown c	25	–	NA	21

TABLE A4
EXPOSURE POINT CONCENTRATIONS FOR TEST 1 VOCs ($\mu g/m^3$) [1]

Compound	Peak No. [2]	Distance Downwind from Generator (m)		
		200	25	11
dimethyl adamantane	26	–	NA	33
unknown d	27	–	NA	45
unknown e	28	–	NA	45
dimethyl adamantane	29	–	NA	25
dimethyl adamantane	30	–	NA	26

(1) Maximum concentration detected at each location. A dash ("–") indicates that the compound was not detected. NA = not analyzed.

TABLE A5
EXPOSURE POINT CONCENTRATIONS FOR TEST 1 SVOCs ($\mu g/m^3$) [1]

Compound	Distance Downwind from Generator (m)		
	200	25	11
Decalin	–	–	7.70
C1–decalins	–	–	19.00
C2–decalins	–	5.51	95.00
C3–decalins	–	7.76	160.00
C4–decalins	–	7.88	140.00
benzo(b)thiophene	–	–	1.87
C1–benzo(b)thiophenes	–	0.65	2.90
C2–benzo(b)thiophenes	–	0.44	9.80
C3–benzo(b)thiophenes	–	0.96	32.00
C4–benzo(b)thiophenes	–	2.58	62.29
naphthalene	–	5.33	44.00
C1–naphthalenes	–	3.43	76.00
C2–naphthalenes	–	8.23	220.00
C3–naphthalenes	0.41	14.81	360.00
C4–naphthalenes	0.33	18.43	389.44
biphenyl	0.05	0.33	5.90
acenaphthylene	–	–	0.45
acenaphthene	0.05	0.42	4.50
dibenzofuran	–	–	2.20
fluorene	–	0.83	14.68
C1–fluorenes	0.07	3.98	78.12
C2–fluorenes	0.49	22.10	291.66
C3–fluorenes	1.32	45.53	690.90
anthracene	–	–	67.00
phenanthrene	–	4.92	79.00

TABLE A5
EXPOSURE POINT CONCENTRATIONS FOR TEST 1 SVOCs ($\mu g/m^3$) [1]

Compound	Distance Downwind from Generator (m)		
	200	25	11
C1–phenanthrenes/anthracenes	0.59	21.34	310.00
C2–phenanthrenes/anthracenes	2.12	44.80	740.00
C3–phenanthrenes/anthracenes	1.49	43.65	610.00
C4–phenanthrenes/anthracenes	0.86	25.23	353.82
dibenzothiophene	0.12	6.02	118.28
C1–dibenzothiophenes	0.70	39.67	580.00
C2–dibenzothiophenes	2.82	99.25	1,800.00
C3–dibenzothiophenes	3.38	115.19	1,700.00
fluoranthene	0.22	1.10	–
pyrene	0.07	0.80	–
C1–fluoranthenes/pyrenes	–	3.77	71.00
C2–fluoranthenes/pyrenes	–	8.50	120.00
C3–fluoranthenes/pyrenes	–	10.45	180.00
benz(a)anthracene	–	–	–
chrysene	–	1.50	29.00
C1–chrysenes	–	2.39	48.00
C2–chrysenes	–	3.44	78.00
C3–chrysenes	–	2.46	67.00
C4–chrysenes	–	–	2.10
benzo(b)fluoranthene	–	0.19	5.50
benzo(k)fluoranthene	–	–	–
benzo(e)pyrene	–	0.20	5.60
benzo(a)pyrene	–	–	–
perylene	–	0.70	–
indeno(1,2,3–cd)pyrene	–	–	–

TABLE A5
EXPOSURE POINT CONCENTRATIONS FOR TEST 1 SVOCs ($\mu g/m^3$) [1]

Compound	Distance Downwind from Generator (m)		
	200	25	11
dibenz(a,h)anthracene	–	–	–
benzo(g,h,i)perylene	–	–	–

(1) Maximum concentration detected at each location. A dash ("–") indicates that the compound was not detected. NA = not analyzed.

TABLE A6
EXPOSURE POINT CONCENTRATIONS FOR TEST 2 VOCs ($\mu g/m^3$) [1]

Compound	Peak No. [2]	Distance Downwind from Generator (m)		
		100	11	0.5
propyne	1	80	2,730	87,536
C4–ene	2	25	965	17,260
C4–ene	3	22	944	27,487
1,3–butadiene	4	–	–	12,587
2–butene (z)	5	4	165	3,059
2–butene (e)	6	1	67	1,252
3–methyl–1–butene	7	2	69	2,149
1,2–dimethyl cyclopropane	8	6	229	7,041
1,2–dimethyl cyclopropane	9	4	124	3,806
2–methyl–1,3–butadiene	10	6	181	5,659
2–pentene	11	2	65	2,209
2–pentene	12	1	50	1,360
2–pentene	13	4	88	2,907
1,3–pentadiene	14	7	280	8,566
3–penten–1–yne	15	2	71	2,496
cyclopentene	16	1	59	1,807
4–methyl–1–pentene	17	1	50	1,646
1–hexene	18	7	250	7,413
1,4–cyclohexadiene	19	2	111	3,330
1,4–cyclohexadiene	20	1	70	2,091
benzene	21	–	414	12,105
cyclohexadiene	22	3	66	3,403
cyclohexene	23	–	43	1,369
1–heptene	24	–	114	3,481
toluene	25	8	216	6,194

TABLE A6
EXPOSURE POINT CONCENTRATIONS FOR TEST 2 VOCs ($\mu g/m^3$) [1]

Compound	Peak No. [2]	Distance Downwind from Generator (m)		
		100	11	0.5
1–octene	26	2	58	1,766
ethylbenzene	27	2	73	2,089
m,p–xylene	28	3	77	2,147
styrene	29	2	77	2,175
1–nonene	30	3	71	2,258
4–ethyltoluene	31	1	26	585
1,3,5–trimethylbenzene	32	–	12	325
1,2,4–trimethylbenzene	33	–	82	1,532

(1) Maximum concentration detected at each location. A dash ("–") indicates that the compound was not detected. NA = not analyzed.

TABLE A7
EXPOSURE POINT CONCENTRATIONS FOR TEST 2 SVOCs ($\mu g/m^3$) [1]

Compound	Distance Downwind from Generator (m)		
	100	11	0.5
Decalin	–	–	482.97
C1–decalins	–	3.76	1,094.34
C2–decalins	1.95	12.51	1,879.14
C3–decalins	3.27	18.29	1,828.16
C4–decalins	2.81	14.32	1,705.71
benzo(b)thiophene	0.06	0.55	77.43
C1–benzo(b)thiophenes	0.17	1.63	222.02
C2–benzo(b)thiophenes	0.20	2.26	331.01
C3–benzo(b)thiophenes	0.33	3.83	555.58
C4–benzo(b)thiophenes	0.44	6.28	1,033.46
naphthalene	–	14.95	2,157.54
C1–naphthalenes	1.54	15.37	2,087.99
C2–naphthalenes	2.25	26.84	3,473.91
C3–naphthalenes	2.87	38.40	4,919.74
C4–naphthalenes	3.06	40.70	6,239.69
biphenyl	0.12	1.08	130.79
acenaphthylene	0.26	3.41	598.92
acenaphthene	0.12	1.09	160.88
dibenzofuran	–	–	69.01
fluorene	–	4.33	759.77
C1–fluorenes	0.89	11.14	2,052.85
C2–fluorenes	3.91	48.63	7,789.78
C3–fluorenes	8.85	112.86	17,322.75
anthracene	0.17	1.63	458.08
phenanthrene	–	11.41	2,213.41

TABLE A7
EXPOSURE POINT CONCENTRATIONS FOR TEST 2 SVOCs ($\mu g/m^3$) [1]

Compound	Distance Downwind from Generator (m)		
	100	11	0.5
C1–phenanthrenes/anthracenes	4.54	48.34	8,922.21
C2–phenanthrenes/anthracenes	8.74	88.32	14,916.72
C3–phenanthrenes/anthracenes	8.47	92.18	16,196.13
C4–phenanthrenes/anthracenes	5.04	53.46	9,638.89
dibenzothiophene	1.14	14.15	2,532.61
C1–dibenzothiophenes	7.67	85.60	14,859.90
C2–dibenzothiophenes	18.86	204.95	33,537.11
C3–dibenzothiophenes	21.47	245.93	41,456.32
fluoranthene	0.22	1.60	277.65
pyrene	0.21	2.46	544.20
C1–fluoranthenes/pyrenes	0.95	10.55	2,473.94
C2–fluoranthenes/pyrenes	1.91	17.60	3,456.04
C3–fluoranthenes/pyrenes	2.19	23.05	4,815.43
benz(a)anthracene	–	–	339.68
chrysene	0.30	3.23	867.86
C1–chrysenes	0.51	5.49	1,539.72
C2–chrysenes	0.67	7.73	1,804.40
C3–chrysenes	0.54	5.69	1,596.47
C4–chrysenes	–	–	–
benzo(b)fluoranthene	0.05	0.56	109.56
benzo(k)fluoranthene	–	–	–
benzo(e)pyrene	0.05	0.40	121.83
benzo(a)pyrene	–	–	–
perylene	–	–	–
indeno(1,2,3–cd)pyrene	–	–	–

TABLE A7
EXPOSURE POINT CONCENTRATIONS FOR TEST 2 SVOCs ($\mu g/m^3$) [1]

Compound	Distance Downwind from Generator (m)		
	100	11	0.5
dibenz(a,h)anthracene	–	–	–
benzo(g,h,i)perylene	–	–	–

(1) Maximum concentration detected at each location. A dash ("–") indicates that the compound was not detected. NA = not analyzed.

TABLE A8
EXPOSURE VARIABLES

Symbol	Definition	Value	Units	Reference
THQ	target hazard quotient	1	none	EPA, 1995a
RfD_i	reference dose, inhalation	Varies [a]	mg/kg–d	see toxicity assessment
BW	body weight	70	kg	EPA, 1989b
AT_n	averaging time, noncarcinogenic effects	730	d	EPA, 1995a
ET	exposure time	1	h/d	US Army, 1995
CF	conversion factor	1,000	µg/mg	EPA, 1995a
EF	exposure frequency	88 [b]	d/y	US Army, 1995
ED	exposure duration	2	y	US Army, 1995
IR	inhalation rate	4.8 [c]	m^3/h	EPA, 1990
TR	target risk	1E–06	none	EPA, 1995a
AT_c	averaging time, carcinogenic effects	25,550	d	EPA, 1989b
SF_i	slope factor, inhalation	Varies [a]	$(mg/kg–d)^{-1}$	see toxicity assessment

(a) The value is chemical–specific.
(b) Based on the number of multiple training events planned for FY 1996 at Fort McClellan, Alabama.
(c) Value for vigorous physical exercise.

TABLE A9
DERIVATIONS OF ACTION LEVELS AND INTAKE FACTORS

Noncarcinogenic Effects

$$AL_n\ (\mu g/m^3) = \frac{THQ \times RfD_i \times BW \times AT_n \times CF}{ET \times EF \times ED \times IR}$$

$$= IF_n \times RfD_i$$

$$IF_n\ (kg\text{-}d\text{-}\mu g/mg\text{-}m^3) = \frac{THQ \times BW \times AT_n \times CF}{ET \times EF \times ED \times IR}$$

$$= \boxed{6.05E+04}$$

where,

AL_n = action level for noncarcinogenic effects

IF_n = intake factor for noncarcinogenic effects

all other variables from Table A8

Carcinogenic Effects

$$AL_c\ (\mu g/m^3) = \frac{TR \times BW \times AT_c \times CF}{ET \times EF \times ED \times IR \times SF_i}$$

$$= IF_c / SF_i$$

$$IF_c\ (kg\text{-}d\text{-}\mu g/mg\text{-}m^3) = \frac{TR \times BW \times AT_c \times CF}{ET \times EF \times ED \times IR}$$

$$= \boxed{2.12E+00}$$

where,

AL_c = action level for carcinogenic effects

IF_c = intake factor for carcinogenic effects

all other variables from Table A8

TABLE A10
TOXICITY VALUES FOR TEST 1 VOCs

Detected Compound	Representative Compound	Toxicity Value for Representative Compound[1]	
		RfD_i (mg/kg/d)	SF_i $(mg/kg/d)^{-1}$
C3–ene	1,3–Butadiene	–	9.8E–01
C4–ene	1,3–Butadiene	–	9.8E–01
1,3–butadiene	1,3–Butadiene	–	9.8E–01
isobutane	n–Hexane	5.7E–02	–
1,2–dimethyl cyclopropane	Methyl cyclohexane	8.6E–01	–
1,2–dimethyl cyclopropane	Methyl cyclohexane	8.6E–01	–
1–hexene	1,3–Butadiene	–	9.8E–01
benzene	Benzene	1.7E–03	2.9E–02
cyclohexene/C6–ol	Cyclohexanone	5.0E+00	–
1–heptene	1,3–Butadiene	–	9.8E–01
methyl cyclohexane	Methyl cyclohexane	8.6E–01	–
toluene	Toluene	1.1E–01	–
1–octene	1,3–Butadiene	–	9.8E–01
ethyl cyclohexane	Methyl cyclohexane	8.6E–01	–
m,p–xylene	m–Xylene	2.0E–01	–
1–nonene/o–xylene	m–Xylene	2.0E–01	–
unknown a	m–Xylene	2.0E–01	–
ethyl, methylbenzene	m–Xylene	2.0E–01	–
1,2,4–trimethylbenzene	m–Xylene	2.0E–01	–
diethylbenzene	m–Xylene	2.0E–01	–
methyl, propylbenzene	m–Xylene	2.0E–01	–
tetramethylbenzene	m–Xylene	2.0E–01	–
ethyl, dimethylbenzene	m–Xylene	2.0E–01	–
unknown b	m–Xylene	2.0E–01	–

TABLE A10
TOXICITY VALUES FOR TEST 1 VOCs

Detected Compound	Representative Compound	Toxicity Value for Representative Compound[1]	
		RfD_i (mg/kg/d)	SF_i $(mg/kg/d)^{-1}$
unknown c	m–Xylene	2.0E–01	–
dimethyl adamantane	Methyl cyclohexane	8.6E–01	–
unknown d	Methyl cyclohexane	8.6E–01	–
unknown e	Methyl cyclohexane	8.6E–01	–
dimethyl adamantane	Methyl cyclohexane	8.6E–01	–
dimethyl adamantane	Methyl cyclohexane	8.6E–01	–

(1) All toxicity values are from USEPA (1995a) unless otherwise noted. A dash ("–") indicates that no value is available. RfD_i = reference dose for inhalation; SF_i = slope factor for inhalation.

TABLE A11
TOXICITY VALUES FOR TEST 2 VOCs

Detected Compound	Representative Compound	Toxicity Value for Representative Compound[1]	
		RfD_i (mg/kg/d)	SF_i $(mg/kg/d)^{-1}$
propyne	1,3–Butadiene	–	9.8E–01
C4–ene	1,3–Butadiene	–	9.8E–01
C4–ene	1,3–Butadiene	–	9.8E–01
1,3–butadiene	1,3–Butadiene	–	9.8E–01
2–butene (z)	1,3–Butadiene	–	9.8E–01
2–butene (e)	1,3–Butadiene	–	9.8E–01
3–methyl–1–butene	1,3–Butadiene	–	9.8E–01
1,2–dimethyl cyclopropane	Methylcyclohexane	8.6E–01	–
1,2–dimethyl cyclopropane	Methylcyclohexane	8.6E–01	–
2–methyl–1,3–butadiene	1,3–Butadiene	–	9.8E–01
2–pentene	1,3–Butadiene	–	9.8E–01
2–pentene	1,3–Butadiene	–	9.8E–01
2–pentene	1,3–Butadiene	–	9.8E–01
1,3–pentadiene	1,3–Butadiene	–	9.8E–01
3–penten–1–yne	1,3–Butadiene	–	9.8E–01
cyclopentene	1,3–Butadiene	–	9.8E–01
4–methyl–1–pentene	1,3–Butadiene	–	9.8E–01
1–hexene	1,3–Butadiene	–	9.8E–01
1,4–cyclohexadiene	1,3–Butadiene	–	9.8E–01
1,4–cyclohexadiene	1,3–Butadiene	–	9.8E–01
benzene	Benzene	1.7E–03	2.9E–02
cyclohexadiene	1,3–Butadiene	–	9.8E–01
cyclohexene	1,3–Butadiene	–	9.8E–01
1–heptene	1,3–Butadiene	–	9.8E–01

TABLE A11
TOXICITY VALUES FOR TEST 2 VOCs

Detected Compound	Representative Compound	Toxicity Value for Representative Compound[1]	
		RfD_i (mg/kg/d)	SF_i $(mg/kg/d)^{-1}$
toluene	Toluene	1.1E−01	–
1−octene	1,3−Butadiene	–	9.8E−01
ethylbenzene	Ethylbenzene	2.9E−01	–
m,p−xylene	m−Xylene	2.0E−01	–
styrene	Styrene	2.9E−01	–
1−nonene	1,3−Butadiene	–	9.8E−01
4−ethyltoluene	m−Xylene	2.0E−01	–
1,3,5−trimethylbenzene	m−Xylene	2.0E−01	–
1,2,4−trimethylbenzene	m−Xylene	2.0E−01	–

(1) All toxicity values are from USEPA (1995a) unless otherwise noted. A dash ("−") indicates that no value is available. RfD_i = reference dose for inhalation; SF_i = slope factor for inhalation.

TABLE A12
TOXICITY VALUES FOR SVOCs

Detected Compound	Representative Compound	Toxicity Value for Representative Compound[1]	
		RfD_i (mg/kg/d)	SF_i $(mg/kg/d)^{-1}$
Decalin	Methylcyclohexane	8.6E−01	–
C1−decalins	Methylcyclohexane	8.6E−01	–
C2−decalins	Methylcyclohexane	8.6E−01	–
C3−decalins	Methylcyclohexane	8.6E−01	–
C4−decalins	Methylcyclohexane	8.6E−01	–
benzo(b)thiophene	Dibenzofuran	4.0E−03	–
C1−benzo(b)thiophenes	Dibenzofuran	4.0E−03	–
C2−benzo(b)thiophenes	Dibenzofuran	4.0E−03	–
C3−benzo(b)thiophenes	Dibenzofuran	4.0E−03	–
C4−benzo(b)thiophenes	Dibenzofuran	4.0E−03	–
naphthalene	Naphthalene	4.0E−02	–
C1−naphthalenes	Naphthalene	4.0E−02	–
C2−naphthalenes	Naphthalene	4.0E−02	–
C3−naphthalenes	Naphthalene	4.0E−02	–
C4−naphthalenes	Naphthalene	4.0E−02	–
biphenyl	1,1−Biphenyl	5.0E−02	–
acenaphthylene	Acenaphthene	6.0E−02	–
acenaphthene	Acenaphthene	6.0E−02	–
dibenzofuran	Dibenzofuran	4.0E−03	–
fluorene	Fluorene	4.0E−02	–
C1−fluorenes	Fluorene	4.0E−02	–
C2−fluorenes	Fluorene	4.0E−02	–
C3−fluorenes	Fluorene	4.0E−02	–
anthracene	Anthracene	3.0E−01	–

TABLE A12
TOXICITY VALUES FOR SVOCs

Detected Compound	Representative Compound	Toxicity Value for Representative Compound[1]	
		RfD_i (mg/kg/d)	SF_i $(mg/kg/d)^{-1}$
phenanthrene	Anthracene	3.0E−01	–
C1−phenanthrenes/anthracenes	Anthracene	3.0E−01	–
C2−phenanthrenes/anthracenes	Anthracene	3.0E−01	–
C3−phenanthrenes/anthracenes	Anthracene	3.0E−01	–
C4−phenanthrenes/anthracenes	Anthracene	3.0E−01	–
dibenzothiophene	Dibenzofuran	4.0E−03	–
C1−dibenzothiophenes	Dibenzofuran	4.0E−03	–
C2−dibenzothiophenes	Dibenzofuran	4.0E−03	–
C3−dibenzothiophenes	Dibenzofuran	4.0E−03	–
fluoranthene	Fluorene	4.0E−02	–
pyrene	Pyrene	3.0E−02	–
C1−fluoranthenes/pyrenes	Pyrene	3.0E−02	–
C2−fluoranthenes/pyrenes	Pyrene	3.0E−02	–
C3−fluoranthenes/pyrenes	Pyrene	3.0E−02	–
benz(a)anthracene	Benz(a)anthracene	–	7.3E−01
chrysene	Chrysene	–	7.3E−03
C1−chrysenes	Chrysene	–	7.3E−03
C2−chrysenes	Chrysene	–	7.3E−03
C3−chrysenes	Chrysene	–	7.3E−03
C4−chrysenes	Chrysene	–	7.3E−03
benzo(b)fluoranthene	Benzo(b)fluoranthene	–	7.3E−01
benzo(k)fluoranthene	Benzo(k)fluoranthene	–	7.3E−02
benzo(e)pyrene	Benzo(a)pyrene	–	7.3E+00
benzo(a)pyrene	Benzo(a)pyrene	–	7.3E+00

TABLE A12
TOXICITY VALUES FOR SVOCs

Detected Compound	Representative Compound	Toxicity Value for Representative Compound[1]	
		RfD_i (mg/kg/d)	SF_i $(mg/kg/d)^{-1}$
perylene	Benzo(k)fluoranthene	–	7.3E−02
indeno(1,2,3−cd)pyrene	Indeno(1,2,3−cd)pyrene	–	7.3E−01
dibenz(a,h)anthracene	Dibenz(a,h)anthracene	–	7.3E+00
benzo(g,h,i)perylene	Indeno(1,2,3−cd)pyrene	–	7.3E−01

(1) All toxicity values are from USEPA (1995a) unless otherwise noted. A dash ("−") indicates that no value is available. RfD_i = reference dose for inhalation; SF_i = slope factor for inhalation.

TABLE A13
ACTION LEVELS FOR TEST 1 VOCs ($\mu g/m^3$)[1]

Detected Compound	Basis for Action Level	
	Noncarcinogenic Effects	Carcinogenic Effects
C3–ene	–	2.2E+00
C4–ene	–	2.2E+00
1,3–butadiene	–	2.2E+00
isobutane	3.4E+03	–
1,2–dimethyl cyclopropane	5.2E+04	–
1,2–dimethyl cyclopropane	5.2E+04	–
1–hexene	–	2.2E+00
benzene	1.0E+02	7.3E+01
cyclohexene/C6–ol	3.0E+05	–
1–heptene	–	2.2E+00
methyl cyclohexane	5.2E+04	–
toluene	6.7E+03	–
1–octene	–	2.2E+00
ethyl cyclohexane	5.2E+04	–
m,p–xylene	1.2E+04	–
1–nonene/o–xylene	1.2E+04	–
unknown a	1.2E+04	–
ethyl, methylbenzene	1.2E+04	–
1,2,4–trimethylbenzene	1.2E+04	–
diethylbenzene	1.2E+04	–
methyl, propylbenzene	1.2E+04	–
tetramethylbenzene	1.2E+04	–
ethyl, dimethylbenzene	1.2E+04	–
unknown b	1.2E+04	–
unknown c	1.2E+04	–

TABLE A13
ACTION LEVELS FOR TEST 1 VOCs ($\mu g/m^3$)[1]

Detected Compound	Basis for Action Level	
	Noncarcinogenic Effects	Carcinogenic Effects
dimethyl adamantane	5.2E+04	–
unknown d	5.2E+04	–
unknown e	5.2E+04	–
dimethyl adamantane	5.2E+04	–
dimethyl adamantane	5.2E+04	–

(1) VOCs = volatile organic compounds.

TABLE A14
ACTION LEVELS FOR TEST 2 VOCs ($\mu g/m^3$)[1]

Detected Compound	Basis for Action Level	
	Noncarcinogenic Effects	Carcinogenic Effects
propyne	–	2.2E+00
C4–ene	–	2.2E+00
C4–ene	–	2.2E+00
1,3–butadiene	–	2.2E+00
2–butene (z)	–	2.2E+00
2–butene (e)	–	2.2E+00
3–methyl–1–butene	–	2.2E+00
1,2–dimethyl cyclopropane	5.2E+04	–
1,2–dimethyl cyclopropane	5.2E+04	–
2–methyl–1,3–butadiene	–	2.2E+00
2–pentene	–	2.2E+00
2–pentene	–	2.2E+00
2–pentene	–	2.2E+00
1,3–pentadiene	–	2.2E+00
3–penten–1–yne	–	2.2E+00
cyclopentene	–	2.2E+00
4–methyl–1–pentene	–	2.2E+00
1–hexene	–	2.2E+00
1,4–cyclohexadiene	–	2.2E+00
1,4–cyclohexadiene	–	2.2E+00
benzene	1.0E+02	7.3E+01
cyclohexadiene	–	2.2E+00
cyclohexene	–	2.2E+00
1–heptene	–	2.2E+00
toluene	6.7E+03	–

TABLE A14
ACTION LEVELS FOR TEST 2 VOCs ($\mu g/m^3$)[1]

Detected Compound	Basis for Action Level	
	Noncarcinogenic Effects	Carcinogenic Effects
1–octene	–	2.2E+00
ethylbenzene	1.8E+04	–
m,p–xylene	1.2E+04	–
styrene	1.8E+04	–
1–nonene	–	2.2E+00
4–ethyltoluene	1.2E+04	–
1,3,5–trimethylbenzene	1.2E+04	–
1,2,4–trimethylbenzene	1.2E+04	–

(1) VOCs = volatile organic compounds.

TABLE A15
ACTION LEVELS FOR SVOCs ($\mu g/m^3$)[1]

Detected Compound	Basis for Action Level	
	Noncarcinogenic Effects	Carcinogenic Effects
Decalin	5.2E+04	–
C1–decalins	5.2E+04	–
C2–decalins	5.2E+04	–
C3–decalins	5.2E+04	–
C4–decalins	5.2E+04	–
benzo(b)thiophene	2.4E+02	–
C1–benzo(b)thiophenes	2.4E+02	–
C2–benzo(b)thiophenes	2.4E+02	–
C3–benzo(b)thiophenes	2.4E+02	–
C4–benzo(b)thiophenes	2.4E+02	–
naphthalene	2.4E+03	–
C1–naphthalenes	2.4E+03	–
C2–naphthalenes	2.4E+03	–
C3–naphthalenes	2.4E+03	–
C4–naphthalenes	2.4E+03	–
biphenyl	3.0E+03	–
acenaphthylene	3.6E+03	–
acenaphthene	3.6E+03	–
dibenzofuran	2.4E+02	–
fluorene	2.4E+03	–
C1–fluorenes	2.4E+03	–
C2–fluorenes	2.4E+03	–
C3–fluorenes	2.4E+03	–
anthracene	1.8E+04	–
phenanthrene	1.8E+04	–

TABLE A15
ACTION LEVELS FOR SVOCs ($\mu g/m^3$)[1]

Detected Compound	Basis for Action Level	
	Noncarcinogenic Effects	Carcinogenic Effects
C1–phenanthrenes/anthracenes	1.8E+04	–
C2–phenanthrenes/anthracenes	1.8E+04	–
C3–phenanthrenes/anthracenes	1.8E+04	–
C4–phenanthrenes/anthracenes	1.8E+04	–
dibenzothiophene	2.4E+02	–
C1–dibenzothiophenes	2.4E+02	–
C2–dibenzothiophenes	2.4E+02	–
C3–dibenzothiophenes	2.4E+02	–
fluoranthene	2.4E+03	–
pyrene	1.8E+03	–
C1–fluoranthenes/pyrenes	1.8E+03	–
C2–fluoranthenes/pyrenes	1.8E+03	–
C3–fluoranthenes/pyrenes	1.8E+03	–
benz(a)anthracene	–	2.9E+00
chrysene	–	2.9E+02
C1–chrysenes	–	2.9E+02
C2–chrysenes	–	2.9E+02
C3–chrysenes	–	2.9E+02
C4–chrysenes	–	2.9E+02
benzo(b)fluoranthene	–	2.9E+00
benzo(k)fluoranthene	–	2.9E+01
benzo(e)pyrene	–	2.9E–01
benzo(a)pyrene	–	2.9E–01
perylene	–	2.9E+01
indeno(1,2,3–cd)pyrene	–	2.9E+00

TABLE A15
ACTION LEVELS FOR SVOCs ($\mu g/m^3$)[1]

Detected Compound	Basis for Action Level	
	Noncarcinogenic Effects	Carcinogenic Effects
dibenz(a,h)anthracene	–	2.9E–01
benzo(g,h,i)perylene	–	2.9E+00

(1) SVOCs = semivolatile organic compounds.

TABLE A16
EXCESS NONCANCER HAZARDS FOR TEST 1

Detected Compound	Hazard Quotient at Each Location[1]		
	200 m	25 m	11 m
Volatiles			
C3–ene	0.0E+00	0.0E+00	0.0E+00
C4–ene	0.0E+00	0.0E+00	0.0E+00
1,3–butadiene	0.0E+00	0.0E+00	0.0E+00
isobutane	1.7E–03	0.0E+00	1.0E–02
1,2–dimethyl cyclopropane	1.9E–05	0.0E+00	8.1E–04
1,2–dimethyl cyclopropane	0.0E+00	0.0E+00	3.3E–04
1–hexene	0.0E+00	0.0E+00	0.0E+00
benzene	0.0E+00	0.0E+00	3.5E–01
cyclohexene/C6–ol	6.6E–06	0.0E+00	2.6E–05
1–heptene	0.0E+00	0.0E+00	0.0E+00
methyl cyclohexane	0.0E+00	0.0E+00	2.7E–04
toluene	3.0E–04	0.0E+00	2.4E–03
1–octene	0.0E+00	0.0E+00	0.0E+00
ethyl cyclohexane	0.0E+00	0.0E+00	2.5E–04
m,p–xylene	8.3E–05	0.0E+00	2.5E–03
1–nonene/o–xylene	8.3E–05	0.0E+00	1.6E–03
unknown a	0.0E+00	0.0E+00	1.1E–03
ethyl, methylbenzene	0.0E+00	0.0E+00	1.2E–03
1,2,4–trimethylbenzene	0.0E+00	0.0E+00	2.9E–03
diethylbenzene	0.0E+00	0.0E+00	2.6E–03
methyl, propylbenzene	0.0E+00	0.0E+00	1.8E–03
tetramethylbenzene	0.0E+00	0.0E+00	5.0E–03
ethyl, dimethylbenzene	0.0E+00	0.0E+00	3.7E–03
unknown b	0.0E+00	0.0E+00	2.3E–03

TABLE A16
EXCESS NONCANCER HAZARDS FOR TEST 1

Detected Compound	Hazard Quotient at Each Location[1]		
	200 m	25 m	11 m
unknown c	0.0E+00	0.0E+00	1.7E−03
dimethyl adamantane	0.0E+00	0.0E+00	6.3E−04
unknown d	0.0E+00	0.0E+00	8.7E−04
unknown e	0.0E+00	0.0E+00	8.7E−04
dimethyl adamantane	0.0E+00	0.0E+00	4.8E−04
dimethyl adamantane	0.0E+00	0.0E+00	5.0E−04
Semivolatiles			
Decalin	0.0E+00	0.0E+00	1.5E−04
C1−decalins	0.0E+00	0.0E+00	3.7E−04
C2−decalins	0.0E+00	1.1E−04	1.8E−03
C3−decalins	0.0E+00	1.5E−04	3.1E−03
C4−decalins	0.0E+00	1.5E−04	2.7E−03
benzo(b)thiophene	0.0E+00	0.0E+00	7.7E−03
C1−benzo(b)thiophenes	0.0E+00	2.7E−03	1.2E−02
C2−benzo(b)thiophenes	0.0E+00	1.8E−03	4.1E−02
C3−benzo(b)thiophenes	0.0E+00	4.0E−03	1.3E−01
C4−benzo(b)thiophenes	0.0E+00	1.1E−02	2.6E−01
naphthalene	0.0E+00	2.2E−03	1.8E−02
C1−naphthalenes	0.0E+00	1.4E−03	3.1E−02
C2−naphthalenes	0.0E+00	3.4E−03	9.1E−02
C3−naphthalenes	1.7E−04	6.1E−03	1.5E−01
C4−naphthalenes	1.4E−04	7.6E−03	1.6E−01
biphenyl	1.7E−05	1.1E−04	2.0E−03
acenaphthylene	0.0E+00	0.0E+00	1.2E−04

TABLE A16
EXCESS NONCANCER HAZARDS FOR TEST 1

Detected Compound	Hazard Quotient at Each Location[1]		
	200 m	25 m	11 m
acenaphthene	1.4E−05	1.2E−04	1.2E−03
dibenzofuran	0.0E+00	0.0E+00	9.1E−03
fluorene	0.0E+00	3.4E−04	6.1E−03
C1−fluorenes	2.9E−05	1.6E−03	3.2E−02
C2−fluorenes	2.0E−04	9.1E−03	1.2E−01
C3−fluorenes	5.5E−04	1.9E−02	2.9E−01
anthracene	0.0E+00	0.0E+00	3.7E−03
phenanthrene	0.0E+00	2.7E−04	4.4E−03
C1−phenanthrenes/anthracenes	3.3E−05	1.2E−03	1.7E−02
C2−phenanthrenes/anthracenes	1.2E−04	2.5E−03	4.1E−02
C3−phenanthrenes/anthracenes	8.2E−05	2.4E−03	3.4E−02
C4−phenanthrenes/anthracenes	4.7E−05	1.4E−03	1.9E−02
dibenzothiophene	5.0E−04	2.5E−02	4.9E−01
C1−dibenzothiophenes	2.9E−03	1.6E−01	2.4E+00
C2−dibenzothiophenes	1.2E−02	4.1E−01	7.4E+00
C3−dibenzothiophenes	1.4E−02	4.8E−01	7.0E+00
fluoranthene	9.1E−05	4.5E−04	0.0E+00
pyrene	3.9E−05	4.4E−04	0.0E+00
C1−fluoranthenes/pyrenes	0.0E+00	2.1E−03	3.9E−02
C2−fluoranthenes/pyrenes	0.0E+00	4.7E−03	6.6E−02
C3−fluoranthenes/pyrenes	0.0E+00	5.8E−03	9.9E−02
benz(a)anthracene	0.0E+00	0.0E+00	0.0E+00
chrysene	0.0E+00	0.0E+00	0.0E+00
C1−chrysenes	0.0E+00	0.0E+00	0.0E+00
C2−chrysenes	0.0E+00	0.0E+00	0.0E+00

TABLE A16
EXCESS NONCANCER HAZARDS FOR TEST 1

Detected Compound	Hazard Quotient at Each Location[1]		
	200 m	25 m	11 m
C3–chrysenes	0.0E+00	0.0E+00	0.0E+00
C4–chrysenes	0.0E+00	0.0E+00	0.0E+00
benzo(b)fluoranthene	0.0E+00	0.0E+00	0.0E+00
benzo(k)fluoranthene	0.0E+00	0.0E+00	0.0E+00
benzo(e)pyrene	0.0E+00	0.0E+00	0.0E+00
benzo(a)pyrene	0.0E+00	0.0E+00	0.0E+00
perylene	0.0E+00	0.0E+00	0.0E+00
indeno(1,2,3–cd)pyrene	0.0E+00	0.0E+00	0.0E+00
dibenz(a,h)anthracene	0.0E+00	0.0E+00	0.0E+00
benzo(g,h,i)perylene	0.0E+00	0.0E+00	0.0E+00
Hazard Index at Each Location:	3.3E–02	1.2E+00	1.9E+01

(1) Hazard quotient = EPC/AL_{nc}; where: EPC = exposure point concentration, AL_{nc} = action level based on noncarcinogenic effects. A hazard quotient listed as "0.0E+00" means that no hazard quotient was quantifiable; the compound was not detected and/or an RfD_i was not available.

TABLE A17
EXCESS NONCANCER HAZARDS FOR TEST 2

Detected Compound	Hazard Quotient at Each Location[1]				
	200 m	100 m	25 m	11 m	0.5 m
Volatiles					
propyne	–	0.0E+00	–	0.0E+00	0.0E+00
C4–ene	–	0.0E+00	–	0.0E+00	0.0E+00
C4–ene	–	0.0E+00	–	0.0E+00	0.0E+00
1,3–butadiene	–	0.0E+00	–	0.0E+00	0.0E+00
2–butene (z)	–	0.0E+00	–	0.0E+00	0.0E+00
2–butene (e)	–	0.0E+00	–	0.0E+00	0.0E+00
3–methyl–1–butene	–	0.0E+00	–	0.0E+00	0.0E+00
1,2–dimethyl cyclopropane	–	1.2E–04	–	4.4E–03	1.4E–01
1,2–dimethyl cyclopropane	–	7.7E–05	–	2.4E–03	7.3E–02
2–methyl–1,3–butadiene	–	0.0E+00	–	0.0E+00	0.0E+00
2–pentene	–	0.0E+00	–	0.0E+00	0.0E+00
2–pentene	–	0.0E+00	–	0.0E+00	0.0E+00
2–pentene	–	0.0E+00	–	0.0E+00	0.0E+00
1,3–pentadiene	–	0.0E+00	–	0.0E+00	0.0E+00
3–penten–1–yne	–	0.0E+00	–	0.0E+00	0.0E+00
cyclopentene	–	0.0E+00	–	0.0E+00	0.0E+00
4–methyl–1–pentene	–	0.0E+00	–	0.0E+00	0.0E+00
1–hexene	–	0.0E+00	–	0.0E+00	0.0E+00
1,4–cyclohexadiene	–	0.0E+00	–	0.0E+00	0.0E+00
1,4–cyclohexadiene	–	0.0E+00	–	0.0E+00	0.0E+00
benzene	–	0.0E+00	–	4.0E+00	1.2E+02
cyclohexadiene	–	0.0E+00	–	0.0E+00	0.0E+00
cyclohexene	–	0.0E+00	–	0.0E+00	0.0E+00
1–heptene	–	0.0E+00	–	0.0E+00	0.0E+00
toluene	–	1.2E–03	–	3.2E–02	9.3E–01

TABLE A17
EXCESS NONCANCER HAZARDS FOR TEST 2

Detected Compound	Hazard Quotient at Each Location[1]				
	200 m	100 m	25 m	11 m	0.5 m
1-octene	–	0.0E+00	–	0.0E+00	0.0E+00
ethylbenzene	–	1.1E-04	–	4.2E-03	1.2E-01
m,p-xylene	–	2.5E-04	–	6.4E-03	1.8E-01
styrene	–	1.1E-04	–	4.4E-03	1.2E-01
1-nonene	–	0.0E+00	–	0.0E+00	0.0E+00
4-ethyltoluene	–	8.3E-05	–	2.1E-03	4.8E-02
1,3,5-trimethylbenzene	–	0.0E+00	–	9.9E-04	2.7E-02
1,2,4-trimethylbenzene	–	0.0E+00	–	6.8E-03	1.3E-01
Semivolatiles					
Decalin	–	0.0E+00	–	0.0E+00	9.3E-03
C1-decalins	–	0.0E+00	–	7.2E-05	2.1E-02
C2-decalins	–	3.7E-05	–	2.4E-04	3.6E-02
C3-decalins	–	6.3E-05	–	3.5E-04	3.5E-02
C4-decalins	–	5.4E-05	–	2.8E-04	3.3E-02
benzo(b)thiophene	–	2.5E-04	–	2.3E-03	3.2E-01
C1-benzo(b)thiophenes	–	7.0E-04	–	6.7E-03	9.2E-01
C2-benzo(b)thiophenes	–	8.3E-04	–	9.3E-03	1.4E+00
C3-benzo(b)thiophenes	–	1.4E-03	–	1.6E-02	2.3E+00
C4-benzo(b)thiophenes	–	1.8E-03	–	2.6E-02	4.3E+00
naphthalene	–	0.0E+00	–	6.2E-03	8.9E-01
C1-naphthalenes	–	6.4E-04	–	6.4E-03	8.6E-01
C2-naphthalenes	–	9.3E-04	–	1.1E-02	1.4E+00
C3-naphthalenes	–	1.2E-03	–	1.6E-02	2.0E+00
C4-naphthalenes	–	1.3E-03	–	1.7E-02	2.6E+00
biphenyl	–	4.0E-05	–	3.6E-04	4.3E-02

TABLE A17
EXCESS NONCANCER HAZARDS FOR TEST 2

Detected Compound	Hazard Quotient at Each Location[1]				
	200 m	100 m	25 m	11 m	0.5 m
acenaphthylene	–	7.2E−05	–	9.4E−04	1.7E−01
acenaphthene	–	3.3E−05	–	3.0E−04	4.4E−02
dibenzofuran	–	0.0E+00	–	0.0E+00	2.9E−01
fluorene	–	0.0E+00	–	1.8E−03	3.1E−01
C1−fluorenes	–	3.7E−04	–	4.6E−03	8.5E−01
C2−fluorenes	–	1.6E−03	–	2.0E−02	3.2E+00
C3−fluorenes	–	3.7E−03	–	4.7E−02	7.2E+00
anthracene	–	9.4E−06	–	9.0E−05	2.5E−02
phenanthrene	–	0.0E+00	–	6.3E−04	1.2E−01
C1−phenanthrenes/anthracenes	–	2.5E−04	–	2.7E−03	4.9E−01
C2−phenanthrenes/anthracenes	–	4.8E−04	–	4.9E−03	8.2E−01
C3−phenanthrenes/anthracenes	–	4.7E−04	–	5.1E−03	8.9E−01
C4−phenanthrenes/anthracenes	–	2.8E−04	–	2.9E−03	5.3E−01
dibenzothiophene	–	4.7E−03	–	5.8E−02	1.0E+01
C1−dibenzothiophenes	–	3.2E−02	–	3.5E−01	6.1E+01
C2−dibenzothiophenes	–	7.8E−02	–	8.5E−01	1.4E+02
C3−dibenzothiophenes	–	8.9E−02	–	1.0E+00	1.7E+02
fluoranthene	–	9.1E−05	–	6.6E−04	1.1E−01
pyrene	–	1.2E−04	–	1.4E−03	3.0E−01
C1−fluoranthenes/pyrenes	–	5.2E−04	–	5.8E−03	1.4E+00
C2−fluoranthenes/pyrenes	–	1.1E−03	–	9.7E−03	1.9E+00
C3−fluoranthenes/pyrenes	–	1.2E−03	–	1.3E−02	2.7E+00
benz(a)anthracene	–	0.0E+00	–	0.0E+00	0.0E+00
chrysene	–	0.0E+00	–	0.0E+00	0.0E+00
C1−chrysenes	–	0.0E+00	–	0.0E+00	0.0E+00
C2−chrysenes	–	0.0E+00	–	0.0E+00	0.0E+00

TABLE A17
EXCESS NONCANCER HAZARDS FOR TEST 2

Detected Compound	Hazard Quotient at Each Location[1]				
	200 m	100 m	25 m	11 m	0.5 m
C3–chrysenes	–	0.0E+00	–	0.0E+00	0.0E+00
C4–chrysenes	–	0.0E+00	–	0.0E+00	0.0E+00
benzo(b)fluoranthene	–	0.0E+00	–	0.0E+00	0.0E+00
benzo(k)fluoranthene	–	0.0E+00	–	0.0E+00	0.0E+00
benzo(e)pyrene	–	0.0E+00	–	0.0E+00	0.0E+00
benzo(a)pyrene	–	0.0E+00	–	0.0E+00	0.0E+00
perylene	–	0.0E+00	–	0.0E+00	0.0E+00
indeno(1,2,3–cd)pyrene	–	0.0E+00	–	0.0E+00	0.0E+00
dibenz(a,h)anthracene	–	0.0E+00	–	0.0E+00	0.0E+00
benzo(g,h,i)perylene	–	0.0E+00	–	0.0E+00	0.0E+00
Hazard Index at Each Location:	–	2.2E–01	–	6.6E+00	5.4E+02

(1) A dash ("–") indicates that no sample was collected at this location. Hazard quotient = EPC/AL_{nc}; where: EPC = exposure concentration, AL_{nc} = action level based on noncarcinogenic effects. A hazard quotient listed as "0.0+00" means that no hazard quotient was quantifiable; the compound was not detected and/or an RfD_i was not available.

TABLE A18
EXCESS CANCER RISKS FOR TEST 1

Detected Compound	Risk at Each Location[1]		
	200 m	25 m	11 m
Volatiles			
C3–ene	9.3E–07	–	9.2E–05
C4–ene	4.6E–07	–	3.3E–05
1,3–butadiene	4.6E–07	–	3.0E–05
isobutane	0.0E+00	–	0.0E+00
1,2–dimethyl cyclopropane	0.0E+00	–	0.0E+00
1,2–dimethyl cyclopropane	0.0E+00	–	0.0E+00
1–hexene	4.6E–07	–	1.4E–05
benzene	0.0E+00	–	4.9E–07
cyclohexene/C6–ol	0.0E+00	–	0.0E+00
1–heptene	0.0E+00	–	8.3E–06
methyl cyclohexane	0.0E+00	–	0.0E+00
toluene	0.0E+00	–	0.0E+00
1–octene	0.0E+00	–	5.6E–06
ethyl cyclohexane	0.0E+00	–	0.0E+00
m,p–xylene	0.0E+00	–	0.0E+00
1–nonene/o–xylene	0.0E+00	–	0.0E+00
unknown a	0.0E+00	–	0.0E+00
ethyl, methylbenzene	0.0E+00	–	0.0E+00
1,2,4–trimethylbenzene	0.0E+00	–	0.0E+00
diethylbenzene	0.0E+00	–	0.0E+00
methyl, propylbenzene	0.0E+00	–	0.0E+00
tetramethylbenzene	0.0E+00	–	0.0E+00
ethyl, dimethylbenzene	0.0E+00	–	0.0E+00
unknown b	0.0E+00	–	0.0E+00

TABLE A18
EXCESS CANCER RISKS FOR TEST 1

Detected Compound	Risk at Each Location[1]		
	200 m	25 m	11 m
unknown c	0.0E+00	–	0.0E+00
dimethyl adamantane	0.0E+00	–	0.0E+00
unknown d	0.0E+00	–	0.0E+00
unknown e	0.0E+00	–	0.0E+00
dimethyl adamantane	0.0E+00	–	0.0E+00
dimethyl adamantane	0.0E+00	–	0.0E+00
Semivolatiles			
Decalin	0.0E+00	0.0E+00	0.0E+00
C1–decalins	0.0E+00	0.0E+00	0.0E+00
C2–decalins	0.0E+00	0.0E+00	0.0E+00
C3–decalins	0.0E+00	0.0E+00	0.0E+00
C4–decalins	0.0E+00	0.0E+00	0.0E+00
benzo(b)thiophene	0.0E+00	0.0E+00	0.0E+00
C1–benzo(b)thiophenes	0.0E+00	0.0E+00	0.0E+00
C2–benzo(b)thiophenes	0.0E+00	0.0E+00	0.0E+00
C3–benzo(b)thiophenes	0.0E+00	0.0E+00	0.0E+00
C4–benzo(b)thiophenes	0.0E+00	0.0E+00	0.0E+00
naphthalene	0.0E+00	0.0E+00	0.0E+00
C1–naphthalenes	0.0E+00	0.0E+00	0.0E+00
C2–naphthalenes	0.0E+00	0.0E+00	0.0E+00
C3–naphthalenes	0.0E+00	0.0E+00	0.0E+00
C4–naphthalenes	0.0E+00	0.0E+00	0.0E+00
biphenyl	0.0E+00	0.0E+00	0.0E+00
acenaphthylene	0.0E+00	0.0E+00	0.0E+00

TABLE A18
EXCESS CANCER RISKS FOR TEST 1

Detected Compound	Risk at Each Location[1]		
	200 m	25 m	11 m
acenaphthene	0.0E+00	0.0E+00	0.0E+00
dibenzofuran	0.0E+00	0.0E+00	0.0E+00
fluorene	0.0E+00	0.0E+00	0.0E+00
C1–fluorenes	0.0E+00	0.0E+00	0.0E+00
C2–fluorenes	0.0E+00	0.0E+00	0.0E+00
C3–fluorenes	0.0E+00	0.0E+00	0.0E+00
anthracene	0.0E+00	0.0E+00	0.0E+00
phenanthrene	0.0E+00	0.0E+00	0.0E+00
C1–phenanthrenes/anthracenes	0.0E+00	0.0E+00	0.0E+00
C2–phenanthrenes/anthracenes	0.0E+00	0.0E+00	0.0E+00
C3–phenanthrenes/anthracenes	0.0E+00	0.0E+00	0.0E+00
C4–phenanthrenes/anthracenes	0.0E+00	0.0E+00	0.0E+00
dibenzothiophene	0.0E+00	0.0E+00	0.0E+00
C1–dibenzothiophenes	0.0E+00	0.0E+00	0.0E+00
C2–dibenzothiophenes	0.0E+00	0.0E+00	0.0E+00
C3–dibenzothiophenes	0.0E+00	0.0E+00	0.0E+00
fluoranthene	0.0E+00	0.0E+00	0.0E+00
pyrene	0.0E+00	0.0E+00	0.0E+00
C1–fluoranthenes/pyrenes	0.0E+00	0.0E+00	0.0E+00
C2–fluoranthenes/pyrenes	0.0E+00	0.0E+00	0.0E+00
C3–fluoranthenes/pyrenes	0.0E+00	0.0E+00	0.0E+00
benz(a)anthracene	0.0E+00	0.0E+00	0.0E+00
chrysene	0.0E+00	5.2E–09	1.0E–07
C1–chrysenes	0.0E+00	8.2E–09	1.7E–07
C2–chrysenes	0.0E+00	1.2E–08	2.7E–07

TABLE A18
EXCESS CANCER RISKS FOR TEST 1

Detected Compound	Risk at Each Location[1]		
	200 m	25 m	11 m
C3–chrysenes	0.0E+00	8.5E–09	2.3E–07
C4–chrysenes	0.0E+00	0.0E+00	7.2E–09
benzo(b)fluoranthene	0.0E+00	6.6E–08	1.9E–06
benzo(k)fluoranthene	0.0E+00	0.0E+00	0.0E+00
benzo(e)pyrene	0.0E+00	6.9E–07	1.9E–05
benzo(a)pyrene	0.0E+00	0.0E+00	0.0E+00
perylene	0.0E+00	2.4E–08	0.0E+00
indeno(1,2,3–cd)pyrene	0.0E+00	0.0E+00	0.0E+00
dibenz(a,h)anthracene	0.0E+00	0.0E+00	0.0E+00
benzo(g,h,i)perylene	0.0E+00	0.0E+00	0.0E+00
Risk at Each Location:	2.3E–06	8.1E–07	2.1E–04

(1) A dash ("–") indicates that no sample was collected at this location. Risk = $(EPC/AL_c) \times 10^{-6}$; where: EPC = exposure point concentration, AL_c = action level based on carcinogenic effects. A risk listed as "0.0E+00" means that no risk was quantifiable; the compound was not detected and/or an SF_i was not available.

TABLE A19
EXCESS CANCER RISKS FOR TEST 2

Detected Compound	Risk at Each Location[1]				
	200 m	100 m	25 m	11 m	0.5 m
Volatiles					
propyne	–	3.7E–05	–	1.3E–03	4.1E–02
C4–ene	–	1.2E–05	–	4.5E–04	8.0E–03
C4–ene	–	1.0E–05	–	4.4E–04	1.3E–02
1,3–butadiene	–	0.0E+00	–	0.0E+00	5.8E–03
2–butene (z)	–	1.9E–06	–	7.6E–05	1.4E–03
2–butene (e)	–	4.6E–07	–	3.1E–05	5.8E–04
3–methyl–1–butene	–	9.3E–07	–	3.2E–05	9.9E–04
1,2–dimethyl cyclopropane	–	0.0E+00	–	0.0E+00	0.0E+00
1,2–dimethyl cyclopropane	–	0.0E+00	–	0.0E+00	0.0E+00
2–methyl–1,3–butadiene	–	2.8E–06	–	8.4E–05	2.6E–03
2–pentene	–	9.3E–07	–	3.0E–05	1.0E–03
2–pentene	–	4.6E–07	–	2.3E–05	6.3E–04
2–pentene	–	1.9E–06	–	4.1E–05	1.3E–03
1,3–pentadiene	–	3.2E–06	–	1.3E–04	4.0E–03
3–penten–1–yne	–	9.3E–07	–	3.3E–05	1.2E–03
cyclopentene	–	4.6E–07	–	2.7E–05	8.4E–04
4–methyl–1–pentene	–	4.6E–07	–	2.3E–05	7.6E–04
1–hexene	–	3.2E–06	–	1.2E–04	3.4E–03
1,4–cyclohexadiene	–	9.3E–07	–	5.1E–05	1.5E–03
1,4–cyclohexadiene	–	4.6E–07	–	3.2E–05	9.7E–04
benzene	–	0.0E+00	–	5.7E–06	1.7E–04
cyclohexadiene	–	1.4E–06	–	3.1E–05	1.6E–03
cyclohexene	–	0.0E+00	–	2.0E–05	6.3E–04
1–heptene	–	0.0E+00	–	5.3E–05	1.6E–03
toluene	–	0.0E+00	–	0.0E+00	0.0E+00

TABLE A19
EXCESS CANCER RISKS FOR TEST 2

Detected Compound	Risk at Each Location[1]				
	200 m	100 m	25 m	11 m	0.5 m
1-octene	–	9.3E-07	–	2.7E-05	8.2E-04
ethylbenzene	–	0.0E+00	–	0.0E+00	0.0E+00
m,p-xylene	–	0.0E+00	–	0.0E+00	0.0E+00
styrene	–	0.0E+00	–	0.0E+00	0.0E+00
1-nonene	–	1.4E-06	–	3.3E-05	1.0E-03
4-ethyltoluene	–	0.0E+00	–	0.0E+00	0.0E+00
1,3,5-trimethylbenzene	–	0.0E+00	–	0.0E+00	0.0E+00
1,2,4-trimethylbenzene	–	0.0E+00	–	0.0E+00	0.0E+00
Semivolatiles					
Decalin	–	0.0E+00	–	0.0E+00	0.0E+00
C1-decalins	–	0.0E+00	–	0.0E+00	0.0E+00
C2-decalins	–	0.0E+00	–	0.0E+00	0.0E+00
C3-decalins	–	0.0E+00	–	0.0E+00	0.0E+00
C4-decalins	–	0.0E+00	–	0.0E+00	0.0E+00
benzo(b)thiophene	–	0.0E+00	–	0.0E+00	0.0E+00
C1-benzo(b)thiophenes	–	0.0E+00	–	0.0E+00	0.0E+00
C2-benzo(b)thiophenes	–	0.0E+00	–	0.0E+00	0.0E+00
C3-benzo(b)thiophenes	–	0.0E+00	–	0.0E+00	0.0E+00
C4-benzo(b)thiophenes	–	0.0E+00	–	0.0E+00	0.0E+00
naphthalene	–	0.0E+00	–	0.0E+00	0.0E+00
C1-naphthalenes	–	0.0E+00	–	0.0E+00	0.0E+00
C2-naphthalenes	–	0.0E+00	–	0.0E+00	0.0E+00
C3-naphthalenes	–	0.0E+00	–	0.0E+00	0.0E+00
C4-naphthalenes	–	0.0E+00	–	0.0E+00	0.0E+00
biphenyl	–	0.0E+00	–	0.0E+00	0.0E+00

TABLE A19
EXCESS CANCER RISKS FOR TEST 2

Detected Compound	Risk at Each Location[1]				
	200 m	100 m	25 m	11 m	0.5 m
acenaphthylene	–	0.0E+00	–	0.0E+00	0.0E+00
acenaphthene	–	0.0E+00	–	0.0E+00	0.0E+00
dibenzofuran	–	0.0E+00	–	0.0E+00	0.0E+00
fluorene	–	0.0E+00	–	0.0E+00	0.0E+00
C1–fluorenes	–	0.0E+00	–	0.0E+00	0.0E+00
C2–fluorenes	–	0.0E+00	–	0.0E+00	0.0E+00
C3–fluorenes	–	0.0E+00	–	0.0E+00	0.0E+00
anthracene	–	0.0E+00	–	0.0E+00	0.0E+00
phenanthrene	–	0.0E+00	–	0.0E+00	0.0E+00
C1–phenanthrenes/anthracenes	–	0.0E+00	–	0.0E+00	0.0E+00
C2–phenanthrenes/anthracenes	–	0.0E+00	–	0.0E+00	0.0E+00
C3–phenanthrenes/anthracenes	–	0.0E+00	–	0.0E+00	0.0E+00
C4–phenanthrenes/anthracenes	–	0.0E+00	–	0.0E+00	0.0E+00
dibenzothiophene	–	0.0E+00	–	0.0E+00	0.0E+00
C1–dibenzothiophenes	–	0.0E+00	–	0.0E+00	0.0E+00
C2–dibenzothiophenes	–	0.0E+00	–	0.0E+00	0.0E+00
C3–dibenzothiophenes	–	0.0E+00	–	0.0E+00	0.0E+00
fluoranthene	–	0.0E+00	–	0.0E+00	0.0E+00
pyrene	–	0.0E+00	–	0.0E+00	0.0E+00
C1–fluoranthenes/pyrenes	–	0.0E+00	–	0.0E+00	0.0E+00
C2–fluoranthenes/pyrenes	–	0.0E+00	–	0.0E+00	0.0E+00
C3–fluoranthenes/pyrenes	–	0.0E+00	–	0.0E+00	0.0E+00
benz(a)anthracene	–	0.0E+00	–	0.0E+00	1.2E–04
chrysene	–	1.0E–09	–	1.1E–08	3.0E–06
C1–chrysenes	–	1.8E–09	–	1.9E–08	5.3E–06
C2–chrysenes	–	2.3E–09	–	2.7E–08	6.2E–06

TABLE A19
EXCESS CANCER RISKS FOR TEST 2

Detected Compound	Risk at Each Location[1]				
	200 m	100 m	25 m	11 m	0.5 m
C3–chrysenes	–	1.9E–09	–	2.0E–08	5.5E–06
C4–chrysenes	–	0.0E+00	–	0.0E+00	0.0E+00
benzo(b)fluoranthene	–	1.7E–08	–	1.9E–07	3.8E–05
benzo(k)fluoranthene	–	0.0E+00	–	0.0E+00	0.0E+00
benzo(e)pyrene	–	1.7E–07	–	1.4E–06	4.2E–04
benzo(a)pyrene	–	0.0E+00	–	0.0E+00	0.0E+00
perylene	–	0.0E+00	–	0.0E+00	0.0E+00
indeno(1,2,3–cd)pyrene	–	0.0E+00	–	0.0E+00	0.0E+00
dibenz(a,h)anthracene	–	0.0E+00	–	0.0E+00	0.0E+00
benzo(g,h,i)perylene	–	0.0E+00	–	0.0E+00	0.0E+00
Risk at Each Location:	–	8.2E–05	–	3.0E–03	9.5E–02

(1) A dash ("–") indicates that no sample was collected at this location. Risk = $(EPC/AL_c) \times 10^{-6}$; where EPC = exposure point concentration, AL_c = action level based on carcinogenic effects. A risk listed as "0.0E+00" means that no risk was quantifiable; the compound was not detected and/or an SF_i was not available.

Appendix B

Fog Oil Sampling and Analyses

U.S. Army Corps of Engineers
Fort Leonard Wood, Missouri

Final Report

For

Harland Bartholomew & Associates, Inc.
Chesterfield, Missouri

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Battelle
Duxbury, Massachusetts

March 1996

Battelle
. . . Putting Technology To Work

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FIGURES

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APPENDICES

1.0 Introduction

Harland Bartholomew & Associates, Inc. (HBA) is conducting a human health risk assessment on fog oil "smoke", used by the U.S. Army to obscure visible detection and targeting during combat. For this assessment, information on the chemical composition and carcinogenicity of this fog oil and fog oil smoke needs to be acquired. For data support of the assessment, Battelle was contracted by HBA to conduct a fog oil smoke chemical characterization study. This study included collection of fog oil smoke samples during fog oil simulation tests using the M56 and M157 generators at the Aberdeen Proving Grounds in Maryland. All smoke and fog oil samples were subjected to detailed analysis for both volatile and semivolatile hydrocarbons of human health concern.

The chemical characteristics of fog oil smoke, which is produced by the heating of fog oil in specially designed generator and emitted to the atmosphere, are not presently known. It has been assumed that fog oil smoke composition is the same as the fog oil itself. To determine the validity of the hypothesis, both fog oil smoke and fog oil were chemically characterized for the important hydrocarbons of human health concern.

This report provides the results of the field sampling effort and analysis of samples and interpretation of the data as it pertains to the possible alteration of target constituents from the smoke generation process and exposure to the atmosphere.

2.0 Methods

In this section, sampling and analytical rationale is discussed, followed by sampling activities that were conducted at the Aberdeen Proving Grounds. The procedures for sampling and analysis used in this study are then reviewed.

2.1 Sampling and Analytical Designs.

To determine potential changes in fog oil composition and interaction with the atmosphere, fog oil smoke was collected at the point of emission from the generator and selected distances downwind of the generator. Because of the types of compounds that were expected to be produced in the smoke, both volatile and semivolatile collection devices were deployed.

The state-of-the-art sampling devices selected for this study was the Summa polished 6-liter canisters, which collects whole air samples for analysis of volatile organic compounds (VOCs) ranging in carbon number from C_2 through C_{10}, and XAD-2 adsorbent cartridges, which collects semivolatile organic compounds (SVOCs), ranging from C_{10} and above.

Fog oil (e.g., SGF-2) is a hydrocarbon based material, and as a result the organic compounds of

concern are the mono and polycyclic aromatic hydrocarbons, particularly the priority pollutant hydrocarbons. To adequately characterize fog oil smoke and fog oil, an expanded list of volatile and semivolatile hydrocarbon target analytes, beyond the priority pollutant hydrocarbons, were determined. The volatile compounds included alkanes from C_5 to C_{10}, cycloalkanes, and alkyl benzenes (Table 1). The semivolatile compounds were the n-alkanes and isoprenoids from C_{10} to C_{36}, decalins, 2- to 6-ringed parent and alkylated polycyclic aromatic hydrocarbons (PAHs), and total hydrocarbons (Table 2). Also, as part of the semivolatile hydrocarbon analysis, selected oxygen and sulfur heterocyclic compounds, that include dibenzofuran, benzothiophenes, and dibenzothiophenes were determined (Table 2). To achieve this high level of specificity, the volatile hydrocarbon and PAHs (including decalins) were analyzed by capillary column gas chromatography/mass spectrometry (GC/MS). The n-alkanes from C_{10} to C_{36} and isoprenoids, and total hydrocarbons (THC) were determined by capillary column gas chromatography/flame ionization detection (GC/FID) methodologies.

2.2 Sampling Activities

Two fog oil simulation drills (Tests #1 and #2) were conducted from December 12-14, 1995 at the Aberdeen Proving Grounds in Maryland during a 3-day field study. Test #1 involved sampling fog oil and smoke produced with the turbine M56 generator and Test #2 repeated sampling, but with the pulse jet M157 generator. Both generators were operated with diesel fuel.

On the first day of the field study sampling devices for the tests were set up and tested. Reference (or control) air samples were collected before each of the tests. The fog oil simulation drills lasted between 30 and 45 minutes.

Test #1. For Test #1 with the M56 generator, duplicate air samples were collected at three stations at the site during fog generation of SGF-2 oil. Sample collectors were deployed in the concentration area of the fog smoke at three stations--11 m, 25 m, and approximately 200 m downwind from the generation source. At each station, both types of samplers (Summa canisters and XAD-2 cartridges) were deployed. A fog oil (SGF-2) sample was also collected from the generator storage tank. Two additional field quality control samples (field trip blank and laboratory blank), and one reference sample were taken as part of the sample set. The total number of samples collected in Test #1 were one oil sample, 9 volatile organic samples (canisters), and 9 semivolatile organic samples (XAD-2 cartridges).

Test #2. For Test #2 with the M157 generator, duplicate air samples were also collected at three stations at the site during fog generation of another type of fog oil--<1 m, 11 m, and 100 m. Also, two fog oil samples used in the test (different than Test #1 oil) were collected from the generator storage tank. One reference sample was included with this sample set. The total number of samples collected in Test #2 were one oil samples, 7 volatile organic samples (canisters), and 7 semivolatile organic samples (XAD-2 cartridges)

2.3 Sampling Procedures

Airborne organics were collected using two sampling methods. The first method made use of evacuated Summa polished 6-liter canisters to collect whole air samples for VOCs. The second method used XAD-2 adsorbent material for collecting SVOCs. Battelle provided the sampling devices, set up the sampling devices at the site, and obtained samples of background air and fog oil smoke during the two tests for hydrocarbon analysis. Instructions for the use of these sampling devices are contained in Appendix A.

2.3.1 Volatile Organic Air Sampling.

Evacuated Summa polished 6-liter canisters were used to collect whole air samples. Each sampling canister was fitted with an orifice assembly to assure that an integrated sampling over time versus an instantaneous grab sample.

Preparation of Sampler. The six-liter canisters were cleaned initially by placing them in a 50° Celsius © oven. The cans then under went an evacuation/pressurization procedure using a five-step sequence of evacuation to less than 1 torr, and pressurization to 4 pounds per square inch (psig) using humidified ultra-zero air. A final canister vacuum of 100 millitorr (mtorr) was obtained with an oil-free mechanical pump. After the final evacuation step was completed, the canisters were stored in cardboard shipping boxes until sampling. All canister sampling was completed within two weeks of the initial cleaning.

Deployment and Operation of Sampler. At the request of Parsons Engineering staff, the orifice assembly specified in the work plan was not attached to the inlet of the canister because of concern that excessive particulate matter may plug the orifice and result in less than adequate sample. Sampling was therefore conducted by manually opening and closing the Nupro valve on the canister to obtain a "grab" sample. Upon receipt in the laboratory, a gauge was attached to the canister and an initial pressure reading was recorded. The canister was then pressurized to 5.0 psig to facilitate sample extraction.

2.3.2 Semivolatile Organic Air Sampling.

A filter/XAD-2 cartridge assembly connected to a SKC sampling pump was used to collect SVOCs. Air was drawn through the cartridge assembly at a rate of 4 liters per minute during sampling.

Preparation of XAD-2. Precleaned XAD-2 resin was purchased from Supelco, and was purified again just prior to shipment to the field site. The XAD-2 resin was extracted with dichloromethane (DCM) for 16 hours using the Soxhlet technique. After extraction, the cleaned XAD-2 was placed in a Pyrex column, 10 centimeters (cm) x 600 cm, which had sufficient space for fluidizing the XAD-2 bed while generating a minimum resin load at the exit of the column. The resin was dried by passing high-purity nitrogen, which was purified by passing it through a charcoal trap positioned between the nitrogen cylinder (size 1A) and the Pyrex column. The rate of nitrogen flow through the column was adjusted to agitate the

bed gently to remove the residual DCM. After drying, 8 grams (g) of XAD-2 was packed in each monitor tube to a bed depth of 3 inches (in). The quartz fiber filters (QAST, pallflex) were placed in an oven and heated at 400°C for 16 hours before use. A cleaned quartz fiber filter was placed in front of the cleaned XAD-2 tube. The filter/XAD-2 cartridge assembly was scaled at both ends, wrapped with aluminum foil, and labeled with a sample code ready for field use. When not in use, the filter/XAD-2 cartridge assembly was stored in a cooler at room temperature.

Preparation of Sampler. The filter/XAD-2 cartridge assembly was inserted into an air sampling device equipped with an SKC pump, which operated with DC voltage. Each sampling unit was preset in the laboratory to draw sample at a flow rate of 4 liters/minute. Each SKC pump is equipped with a small rotameter, enabling the operator to monitor actual flow throughout the sampling period.

Deployment and Operation of Sampler. Prior to use, each sampling device was fitted with one of the filter/XAD-2 cartridge assemblies. Sampling was started by manually activating the SKC pump. The rotameter flow was noted and recorded at the start and periodically during the sampling run. After sampling, the filter/XAD-2 cartridge was removed from each assembly, resealed, and placed in the cooler and kept at a constant temperature of 4°C. When each unit was returned to the laboratory, it was rechecked to verify that the initial settings had not changed.

2.4 Sample Analyses

Air and oil samples were analyzed for volatile and semivolatile organic compounds listed in Tables 1 and 2. Part of the PAH analysis included identifying (tentative) five major peaks.

2.4.1 Volatile Organic Analyses.

A Fisons MD 800 gas chromatograph/mass spectrometer (GC/MS) was used for the analyses of the volatile organics in the canister samples. The GC contains a Nutech Model 3550-A cryogenic preconcentration trap to refocus the collected organics onto the head of the analytical column. Analytes were chromatographically resolved on a Hewlett Packard HPl, 50 meter (m) by 0.32 millimeter (mm) interior diameter fused-silica capillary column (1 micrometer [μm] film thickness). Optimal analytical results were achieved by programming the GC oven with a temperature range of -50°C to 220°C, with a temperature increase of 8° C/min.

The mass spectrometer was operated in the total ionization mode so that all masses were scanned between 35 and 300 atomic mass units (a.m.u.) with a scan rate of 1 scan/0.5 seconds. Thirty major components, including the targeted compounds were identified by matching the mass spectra acquired from the samples to the mass spectral library from the National Institute of Standards and Technology (NIST). A method detection of 1 part per billion (ppb) was achieved with a 50 cc sample volume.

In addition to a mass spectrometer, the GC system was also equipped with a flame ionization detector (FID). The system was configured so that the column exit flow was split to direct one-half of the flow to the mass spectrometer and the remaining flow through the FID. With this detector, individual components were quantified, and a total carbon content was determined by summing the individual peaks from the chromatographic report. An equal per carbon response factor was assigned to the identified and unidentified VOCs using a benzene calibrant. Multiple runs of the benzene mixture were carried out during the analytical period.

For oil samples, the VOC composition was determined by injecting 1 uL of the oil into an evacuated cylinder. The cylinder was pressurized to 15 psig and then warmed to 50 C for 30 minutes to facilitate evaporation. A 60 cc gaseous sample aliquot was extracted from the cylinder (600 cc) and analyzed with the GC/FID-MS system.

Quality control samples and data quality objectives for this volatile organic analysis are presented in Table 3.

2.3.2 Semivolatile Organic Analyses.

Analysis of the air samples for the target compounds in Table 2 involved extraction of the XAD-2 resin (and filter) and instrumental analysis of the extract by GC/MS and GC/FID methodologies. Oil samples were sent to another laboratory identified by HBA for modified AMES testing.

Extraction of XAD-2. The filter and XAD-2 samples were Soxhlet extracted together with dichloromethane (DCM) for 16 hours. Before extraction, each XAD-2 resin sample, except one of the 0 meter duplicate samples from each test, was spiked with surrogate (deuterated PAH) compounds (Table 2). The extracts were concentrated by Kuderna-Danish (K-D) evaporation to a final volume of 1 mL. The two unspiked samples were supposed to be split and used for AMES testing, but there was not enough oil collected on the XAD-2 to conduct the test. The extracts designated for semivolatile organic analysis were spiked with recovery internal standards (Table 2).

Processing of Oils. Oil samples were diluted to 5 mg/mL in methylene chloride and spiked with recovery internal standards (Table 2). Five grams of neat (undiluted) oil were aliquoted for AMES testing.

Determination of n-Alkanes, Isoprenoids, and THC by GC/FID. XAD-2 extracts and oil samples were analyzed for *n*-alkanes from C_{10} to C_{36}, isoprenoid hydrocarbons (Table 2), and THC by GC/FID. A 2 μL aliquot of the sample extract was injected into a gas chromatograph equipped with a high-resolution capillary column (J&W fused silica DB-5 column, 30 meters, 0.32 mm internal diameter, and 0.25 m film thickness) and a split-splitless injection port (operated in the splitless mode). The temperature program and capillary column were selected to achieve near-baseline separation of all of the saturated hydrocarbons listed in Table 2. Prior to sample analysis, a five-point response factor (RF) calibration was established demonstrating the

linear range of the analysis. Check standards were analyzed with every 10 samples to validate the integrity of the initial calibration. The calibration solution were composed of C_{10} through C_{36} *n*-alkanes, pristane and phytane. Quantitation of the individual components (i.e., alkanes) were performed by the method of internal standard using the response factors for the individual components relative to the internal standard 5 -androstane. THC (resolved plus unresolved hydrocarbons) was quantified by the method of internal standards using the baseline corrected total area of the chromatogram and the average hydrocarbon response factor determined over the entire analytical range. Special care was taken to minimize mass discrimination for the analysis of heavy molecular weight products such as fuel oils.

The GC/FID conditions were:

Initial column temperature:	35° C
Initial hold time:	5 minutes
Program rate:	6° C/minute
Final column temperature:	320° C
Final hold time:	10 minutes
Injector temperature:	275°C
Detector temperature:	325°C
Column flow rate (Hydrogen)	1 mL/minute

Quality control samples and data quality objectives for this GC/FID analysis are presented in Tables 4 and 5.

Determination of Decalins, PAHs, and Selected Heterocyclic Compounds by GC/MS. Decalins, PAHs, and heterocyclic aromatic compounds were determined in all samples by GC/MS in the sensitive selective ion monitoring (SIM) mode. Approximately 10 unknowns were identified (tentatively) in the oil samples and 2 other air samples by GC/MSD in the full scan mode. A 2μL aliquot of the sample extract was injected into a gas chromatograph equipped with a high resolution capillary column (J&W fused silica DB5 column, 30 meters, 0.25 mm internal diameter, and 0.25 m film thickness) operated in the splitless mode. The temperature program and capillary column were selected in order to achieve near-baseline separation of all of the PAH compounds listed in Table 2.

The GC/MS conditions are:

Initial column temperature:	40° C
Initial hold time:	1 minute
Program rate:	6° C/minute
Final column temperature:	290° C
Final hold time:	20 minutes
Injection port temperature:	300°C
Detector temperature:	280°C
Column flow rate (Helium):	1 mL/minute

The electronic Pressure Control conditions are:

Vacuum compensation:	On
Pressure at injection:	40 psi
Hold time:	0.80 min.
Pressure program ramp:	99 psi/min.
Final pressure:	7.7 psi

Prior to sample analysis, a five-point initial calibration composed of the 16 priority pollutant compounds and dibenzothiophene was established demonstrating the linear range of the analysis. Check standards were analyzed with every 10 samples to validate the integrity of the initial calibration. The method of internal standards using the average relative response factors (RRF) generated from the linear initial calibration were used to quantify the target analytes. PAH alkyl homologues were quantified using the straight baseline integration of each level of alkylation and the RRF of the respective unsubstituted parent PAH compound. PAH concentrations are surrogate corrected. Quality control samples and data quality objectives for this GC/MS analyses are provided on Table 6.

3.0 Results and Discussion

3.1 Field Observations

Results of the field sampling effort on December 13 (Test #1) and December 14 (Test #2) for XAD-2 samples and canister samples are summarized in Tables 7 and 8, respectively. Field information sheets are provided in Appendix B.

As indicated in Table 1, the duplicate XAD-2 samples were generally collected over the same time period. However, during Test 1 at the 25-meter sampling location, one of the XAD samples was collected for 21 minutes, the other was obtained for 5 minutes. During Test 2, the sampling duration was very short at the less than 1-meter location due to the high particulate loading which caused the sampling device to stop after several minutes of operation. The total sampled volume at this location was roughly estimated from the recorded time and flow rate.

Unfortunately, a duplicate set of canister samples were not collected at the 25-meter location (Table 2). Examination of the two canisters at the laboratory indicated that no samples had been collected. Either the canister valves were not opened or the swaglock caps to the valves were left in the sealed position. In either case, no sample was drawn into the canisters.

3.2 Volatile Organic Compounds

Results of the VOC analysis are presented in Table 9 for fog oil samples and Table 10 for Tests #1 and #2. Target analytes listed in Table 1 and approximately 20 other non-target

compounds with tentative identifications from mass spectral library searches were determined in both test samples. The mass spectral library search results are provided in Appendix C. Representative chromatographic traces from the GC/FID and GC/MS analysis for Tests #1 and #2 are also provided in Appendix C. Raw area reports for all canister sample analyses are tabulated in Appendix D. Units for VOC concentrations in air are ug/m^3.

The composition of the two test fog oils (Table 9) were determined to be very similar, as illustrated in Figure 1. The same major VOCs were identified in both oils and constituted approximately 40% of the total resolvable compounds in the oil. The major components of the VOC fraction were the alkylated benzenes, C_2- thru C_4-benzenes. BTEX relative amounts were 10 to 25 % of the alkylated benzenes. The only difference between the oils was in the higher-molecular weight VOCs in the region of peaks 26-28. This difference was probably an analysis artifact in which the less volatile components may have condensed onto the surface of the sampling cylinder used for Test #1 oil sample.

In Test #1 (Table 10), concentrations of targeted VOCs in samples nearest the generator (11 m) ranged from approximately 10 to 70 ug/m^3. A propene (C3-ene) had an estimated concentration of around 200 ug/m^3. Total BTEX concentrations were found at relatively low concentrations at approximately 80 ug/m^3. Sample replication precision was $\pm$ 25 %. At the 200+ m sampling station, VOCs were not found at concentrations above background.

In Test #2 (Table 10), considerably higher concentration of target analytes were found in the air samples. At the ½ m station, Total BTEX concentrations were the highest for all sample stations at approximately 21,000 ug/m^3, of which benzene made up half. Concentrations of all the targeted VOCs generally ranged from 1,000 to 12,000 ug/m^3 (individual). There were two compounds, propyne and a butene, that had values of approximately 25,000 and 80,000 ug/m^3, respectively. At the 11-m station, VOC concentrations between duplicates were different by a factor of four. Concentration of the Total BTEX was approximately 800 ug/m^3 in the highest VOC concentration duplicate. Although not recorded in the field notes, one of the duplicate samples was probably taken outside the centerline of the plume. VOC concentrations at the 100-m station were near but above background levels for most target analytes. Most of the BTEX compounds were still present at 24 ug/m^3 Total BTEX.

Although the VOC compositions of two test fog oils were similar, the VOC compositions of the air (smoke) samples in each of the two tests were surprisingly different. The two test oil compared similarly with the smoke samples of only Test #1 (with the M56 generator), but differently with the smoke samples of Test #2 (with the M157 generator). Only a few of the higher molecular weight compounds determined in the fog oil samples were observed in the Test #2 smoke samples. The reason for this anomaly cannot be explained.

Although the smoke VOCs were different on the two test days, the composition of the VOCs at the various sampling location on each test day was essentially the same. This is especially evident in Test #2 where compositions at the three distances (<1, 11, and 100 m) were very

similar. In Figure 2, distributions of VOCs in fog oil smoke from all three distances in Test #2 illustrate the similarities in composition. Benzene was used to normalize because it is one of the less reactive VOCs. Normalized individual values from the three sample locations were generally within 20 percent of the mean value for each VOC. These results suggested that ambient air dilution was the primary factor in affecting the individual concentrations at the various locations downwind.

The one exception to this VOC result was peak #4, 1,3-butadiene. Figure 2 (Test #2 with the M157 generator) shows that the <1 meter location contained appreciable amounts of this compound which become undetectable at 11 and 100 meters. For this compound, the probable controlling factor in its concentration was atmospheric reactivity.

3.3 Semivolatile Organic Compounds

The semivolatile organic compounds for these samples are characterized by the analysis of saturated hydrocarbon compounds (SHCs), a gas chromatographic (GC) trace, and decalins, polycyclic aromatic hydrocarbons, and oxygen-heterocyclic aromatic and sulfur-heterocyclic aromatic compounds PAHs. The results of the SHC and PAH target analytes analysis are presented in Tables 11 and 12. Each sample has a corresponding GC trace provided in Appendix E. To assist in the interpretation of the data, distribution plots for the PAHs were prepared for each sample (Appendix F).

Based on the laboratory matrix blank and the field blank, eight PAH target analytes were identified as potential very low-level contaminants in the samples (low ppb). These contaminants either originated from laboratory processing or from the XAD-2 resin. Generally, only naphthalene at very low amounts originates from laboratory processing; the other compounds are contaminants of the XAD-2 resin. The contaminant compounds were decalin, C1-decalins, naphthalene, C1-naphthalenes, C2-naphthalenes, dibenzofuran, fluorene, and phenanthrene. The effect of contaminants were only of concern for samples in which oil weights were less than one (1) mg, such as the Reference samples and the 200 m samples. The samples in which the contaminants had a major contribution were indicated by "B" next to the analyte in the PAHs results table. In the laboratory matrix blank and field blank GC traces (Appendix E), there were a number of peaks which corresponded to surrogate and recovery internal standard added as part of the analysis. These peaks (standards) were also present in the air samples.

In the SGF-2 fog oils, there were no saturated hydrocarbons (n-alkanes or isoprenoids--pristane and phytane), even at the low parts per million level (0.1 ppm). The total hydrocarbon (THC) concentration (Table 11), which consisted almost totally of unresolvable compounds shown as a hump in the GC trace (unresolved complex mixture-UCM), was 830,000 mg/kg (oil basis). The GC trace of the test oil is provided in Figure 3. The major portion of compounds in the UCM was between the boiling points of the n-alkanes C_{17} and C_{33}. Unlike other mineral oils which have been characterized in this laboratory, very small amounts of resolved compounds were evident in this SGF-2 fog oil.

Depending on the location of the samplers, THC concentrations in the smoke samples ranged from 4 to 12,000 mg/m^3; reference THC concentrations were <1 mg/m^3 (Table 11). The compositions (relative distributions) of the resolved compounds and UCM in air, were basically unchanged relative to the test oils. No n-alkanes or isoprenoids were found in any of the air samples, similar to the fog oil. A representative GC trace for the air samples is shown in Figure 4.

According to the PAH data (Table 12), which are useful fingerprinting sources of oils, the two fog oils in Tests #1 and #2 were identical. Both oils have a dominance of the three-ringed PAHs, especially the sulfur-heterocyclic compounds--dibenzothiophenes (Figure 5). The dibenzothiophenes as a group (alkyl homologues) are approximately 2.5 times higher than the phenanthrene group, the next largest alkyl group. (The base (stock) oil for this fog oil has PAH signature of a Middle East crude oil). The priority pollutant concentrations were very low compared to the alkyl homologue PAHs; proportionally, 98% of the Total PAH concentration is non-priority pollutant PAHs. For instance in Test #1 fog oil, phenanthrene, typically the highest priority pollutant PAH, was 90 mg/kg oil, whereas the alkyl phenanthrene group was 3,200 mg/kg.

In the air samples, the composition of the PAHs was unchanged compared to the test oils. The PAH distribution plots of the air samples, represented in Figure 6, showed nicely the consistency in composition in all air samples of both tests. Concentrations of PAHs reflected those of THC and the saturated hydrocarbons. Total PAH concentrations were highest in the ½ m station sample in Test #2 at 140 to 220 mg/m^3. Although VOCs were not detected in samples at the 200+ m station, remnant fog oil PAHs (mostly, dibenzothiophenes) were found at a concentration of approximately 7 mg/m^3 Total PAHs, 20 to 30 times lower than the most concentrated air samples at the ½ m station. Lower detection limits in PAH analysis compared to the VOCs allowed these analytes to be detected.

As part of the semivolatile organic characterization, fifteen major peaks in the chromatogram of the GC/MS analysis of the neat fog oil and two fog oil smoke samples were identified by a computer library search routine (Table 13) and concentrations estimated. The peak heights of all peaks in the chromatograms were relatively low and insignificant compared to the large unresolved complex mixture. Although in most oils resolvable peaks are saturated hydrocarbons, the peaks in these test oils and fog oil smoke were mostly individual alkylated PAHs. The lack of saturated hydrocarbons was confirmed by the GC/FID analysis. Other compounds included the ubiquitous phthalates, which were probably sampling/handling contaminants.

4.0 References

Wilbery, W.T., N.T. Murphy, R.M. Riggan. 1988. Method TO-14. In Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air. U.S. Environmental Protection Agency, Research Triangle Park, NC. EPA-600/4-89-017.

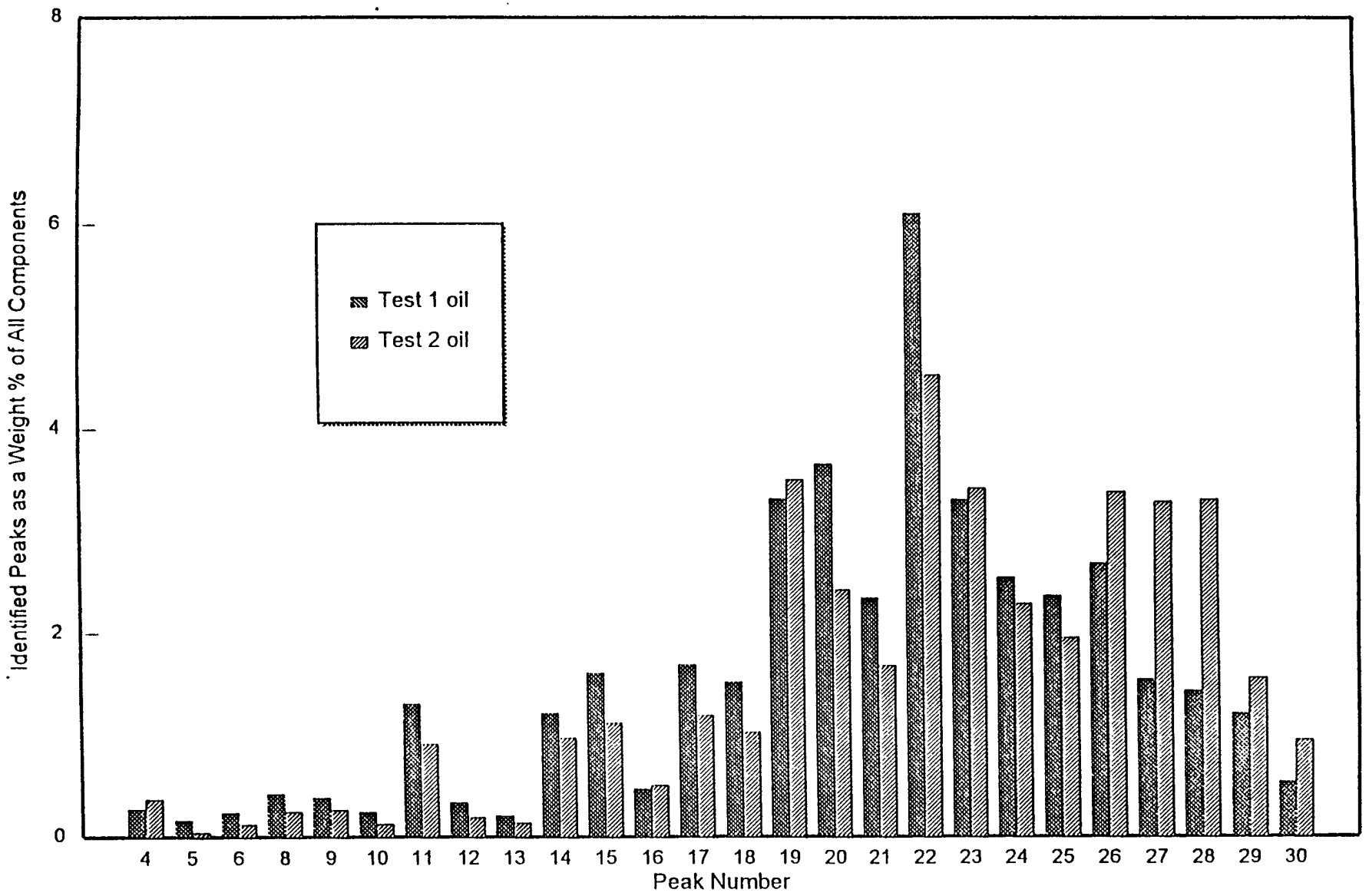

Figure 1a. **Distribution of identified VOC peaks in the the two tested fog oils (weight % compared to all components)**

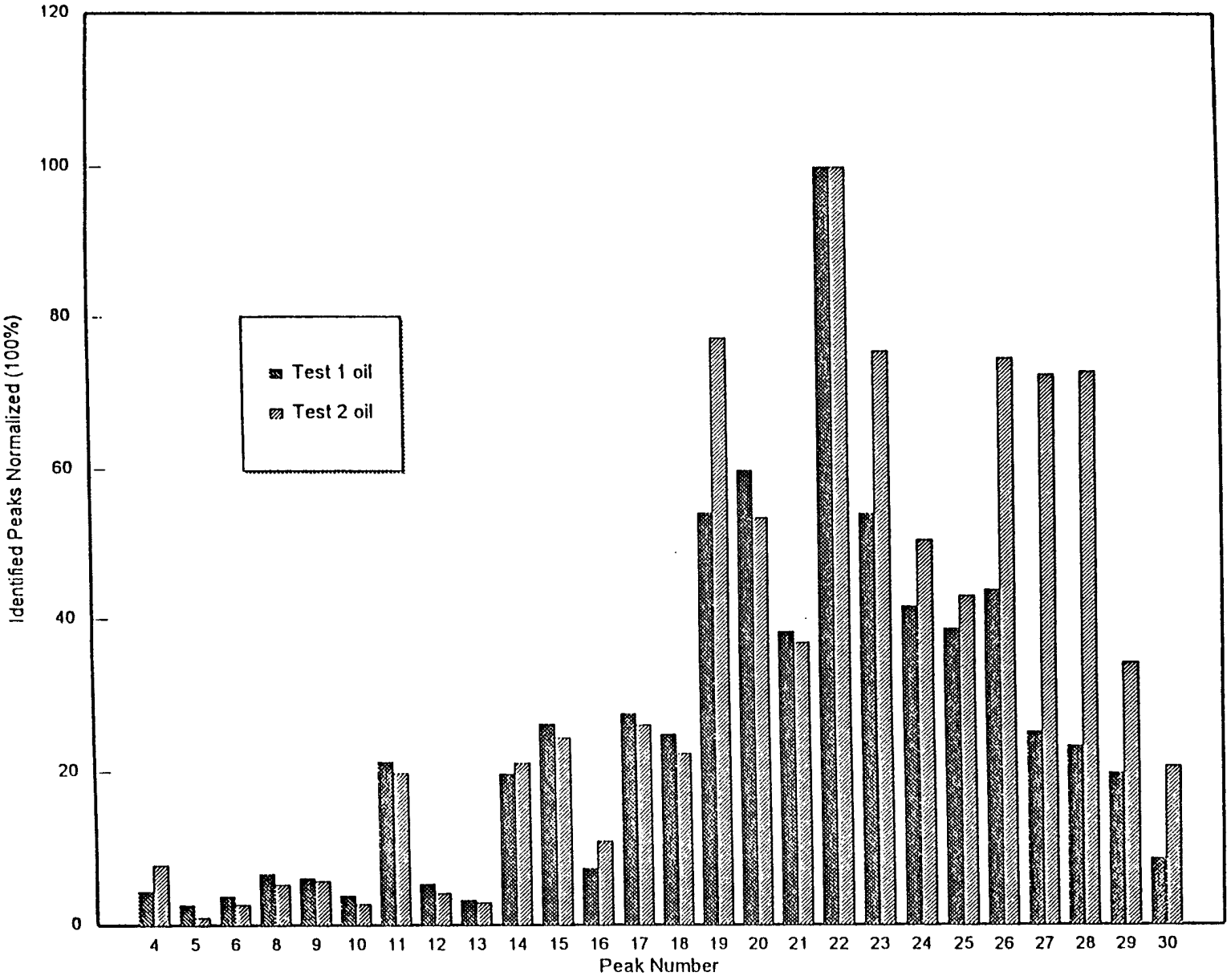

Figure 1b. Distribution of identified VOC peaks in the two tested fog oils (weight % normalized to peak 22)

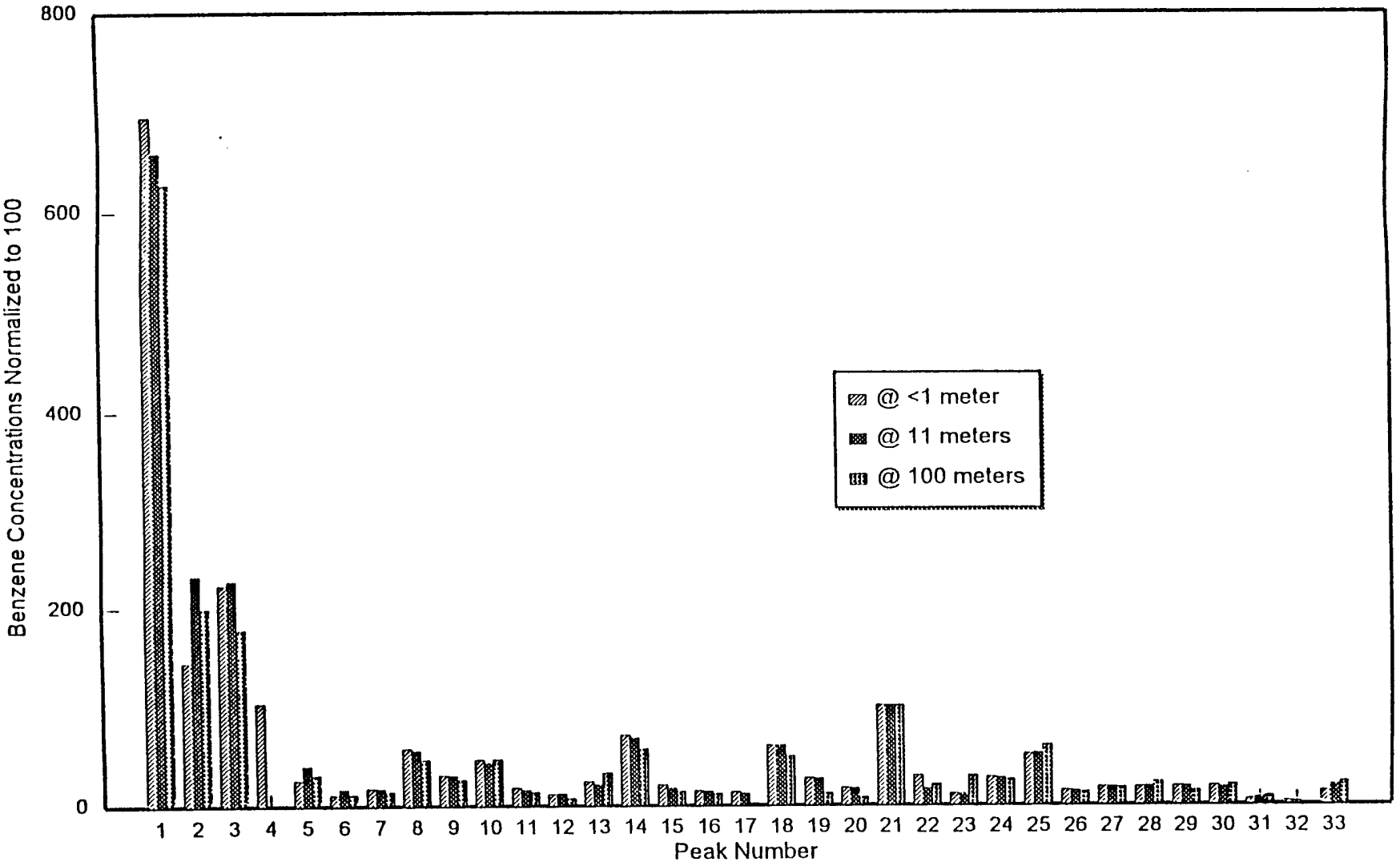

Figure 2. Distribution of VOCs in smoke for Test #2 (normalized to peak 21-benzene)

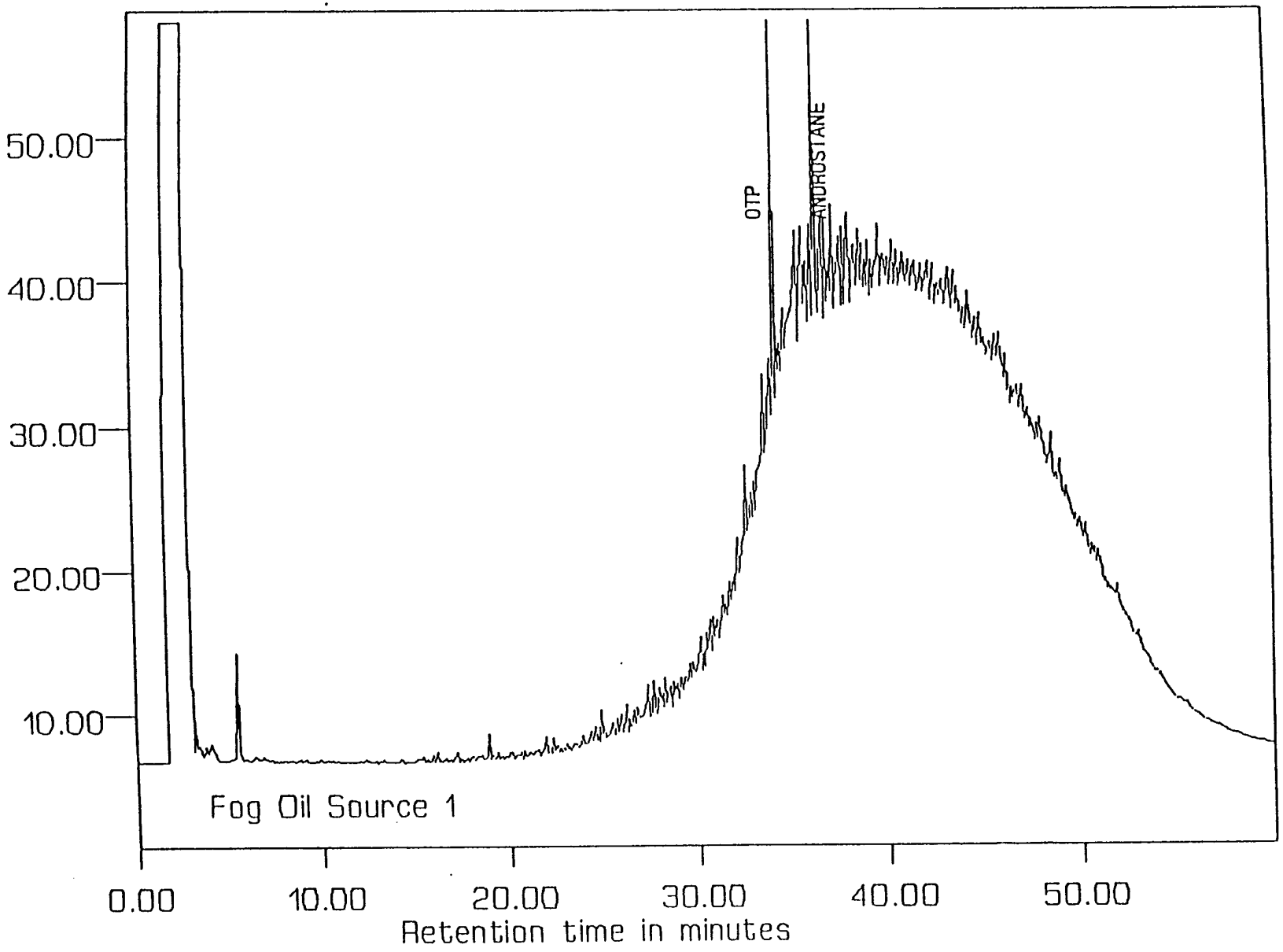

Figure 3. **Semivolatile organic GC trace of fog oil used in Tests #1 and #2**

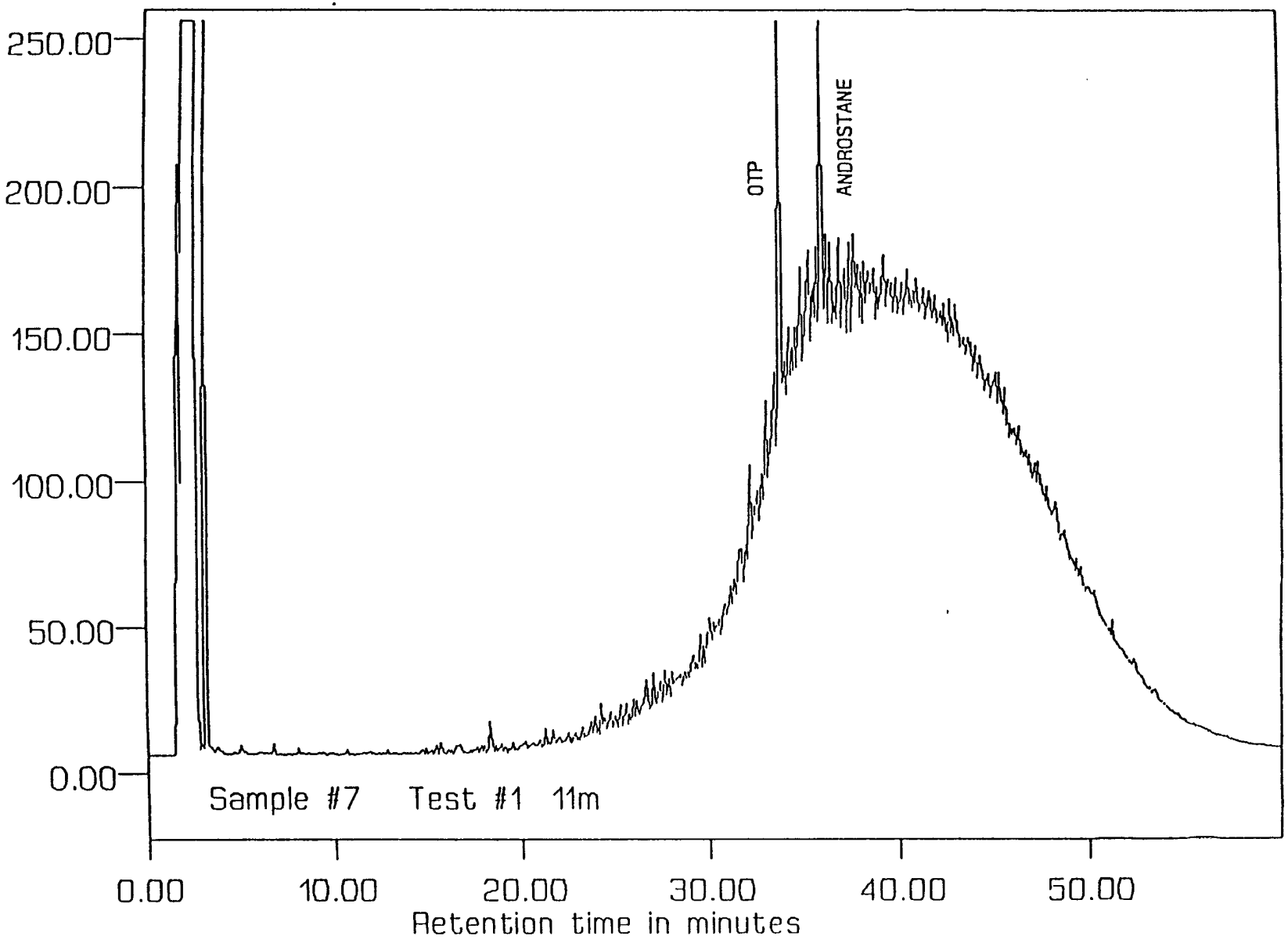

Figure 4. **Semivolatile organic GC trace of a representative air sample (Test #2 - 11m)**

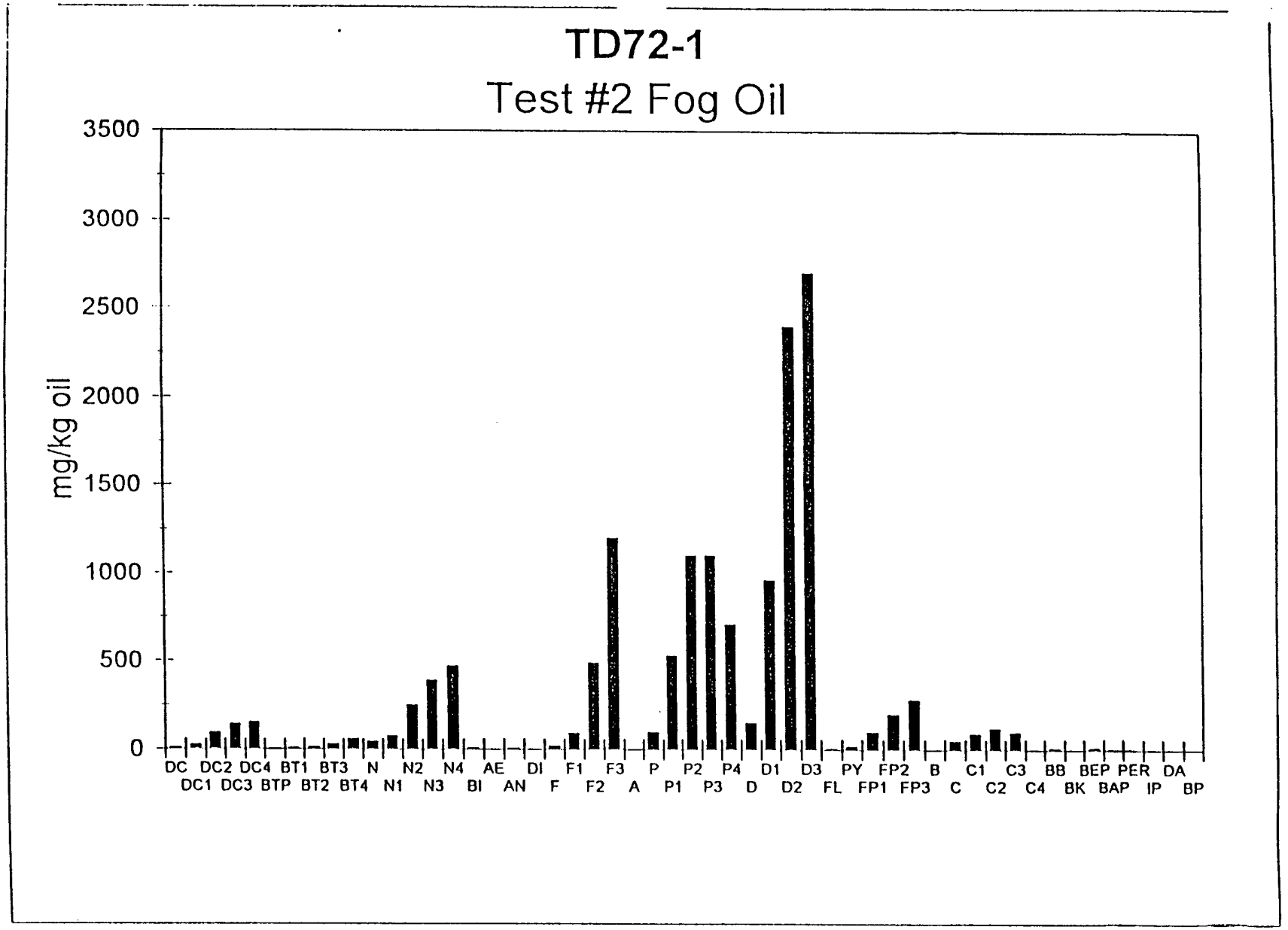

Figure 5. **PAH distribution plot of fog oil used in Tests #1 and #2**

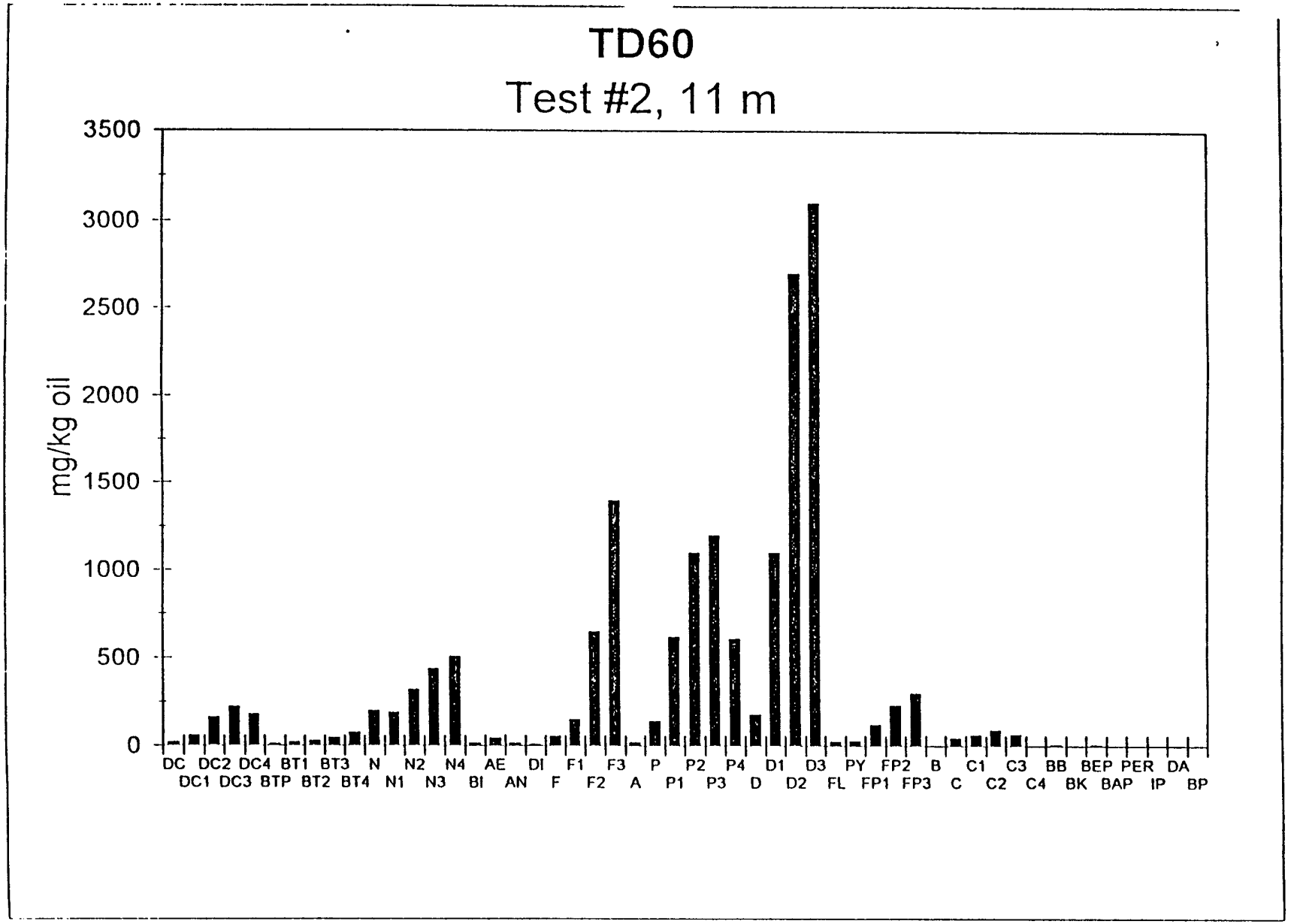

Figure 6. **PAH distribution plot of a representative air sample (Test #2 - 11m)**

Table 1. List of Target Volatile Organic Compounds

Compound Identification
*Benzene
*Toluene (C_1-benzene)
*Ethylbenzene (C_2-benzene)
*m,p-Xylenes (C_2-benzenes)
*o-Xylene (C_2-benzene)
4-Ethyltoluene
1,3,5-trimethylbenzene
1,2,4-trimethylbenzene
Styrene
21 major unknown VOCs

*Priority pollutant compounds—listed in EPA SW-846 Methods.

Table 2. List of Target Semivolatile Organic Compounds

GC/MS Target Analytes		GC/FID Target Analytes	GC/MS Spiking Compounds
Decalin	**Phenanthrene**	C_{10}-C_{36} *n*-alkanes	SIS Compounds
C_1-decalins	1-methylphenanthrene	Pristane	Naphthalene-d_8
C_2-decalins	C_1-phenanthrenes/anthracenes	Phytane	Fluorene-d_{10}
C_3-decalins	C_2-phenanthrenes/anthracenes		Chrysene-d_{12}
C_4-decalins	C_3-phenanthrenes/anthracenes	THC	
Naphthalene	C_4-phenanthrenes/anthracenes		RIS Compounds
1-methylnaphthalene	Dibenzothiophene		Acenaphthene-d_{10}
2-methylnaphthalene	C_1-dibenzothiophenes		Phenanthrene-d_{10}
2,6-dimethylnaphthalene	C_2-dibenzothiophenes		Benzo[*a*]pyrene-d_{12}
2,3,5-trimethylnaphthalene	C_3-dibenzothiophenes		
C_1-naphthalenes	**Fluoranthene**		
C_2-naphthalenes	**Pyrene**		
C_3-naphthalenes	C_1-fluoranthenes/pyrenes		**GS/FID Spiking Compounds**
C_4-naphthalenes	C_2-fluoranthenes/pyrenes		SIS Compound
Biphenyl	C_3-fluoranthenes/pyrenes		*o*-terphenyl
Acenaphthylene	**Benz[*a*]anthracene**		
Dibenzofuran	**Chrysene**		RIS Compound
Acenaphthene	C_1-chrysenes		5α-androstane
Fluorene	C_2-chrysenes		
C_1-fluorenes	C_3-chrysenes		
C_2-fluorenes	C_4-chrysenes		
C_3-fluorenes	**Benzo[*b*]fluoranthene**		
Benzothiophene	**Benzo[*k*]fluoranthene**		
C_1-benzothiophenes	Benzo[*e*]pyrene		
C_2-benzothiophenes	**Benzo[*a*]pyrene**		
C_3-benzothiophenes	Perylene		
Anthracene	**Indeno[1,2,3-*c,d*]pyrene**		
	Dibenz[*a,h*]anthracene		
	Benzo[*g,h,i*]perylene		

BOLD compounds are EPA Priority Pollutant PAHs

Table 3. Data Quality Objectives and Criteria - Volatile Organic Compounds in Air (GC/MS)

Element or Sample Type	Minimum Frequency	Data Quality Objective/ Acceptance Criteria
Initial Calibration (All target analytes)	Prior to every batch of analysis	4-point calibration curve over 0-100 $\mu g/m^3$, RSD ≤ 15%
Continuing Calibration (All target analytes - mid-level standard)	Once per day	PD ≤ 15% for 90% of analytes PD ≤ 20% for 10% of analytes
Reference (oil) Standard	One per batch of field samples	PD ≤ 10% of mean for all previous values
Procedural Blank	One per batch of field samples	No more than 2 analytes to exceed 5x target MDL, unless analyte not detected in associated sample(s) or analyte concentration > 10x blank value.
Duplicate SRM/Sample Analysis	One per batch of field samples	RPD ≤ 25%
Target MDLs	Air	0.5 $\mu g/m^3$

Table 4. Data Quality Objectives and Criteria - THC by GC-FID (Conducted as part of Saturated Hydrocarbon Analysis--see Table 5)

Element or Sample Type	Minimum Frequency	Data Quality Objective/ Acceptance Criteria
Procedural Blank	One per batch of field samples	<2 times MDL
Reference (oil) Standard	One per batch	PD ≤ 10%
Duplicate Sample Analysis	One per batch of field samples	RPD ≤ 20%
Target MDLs	Sediment Water Oil	1 μg/g (dry weight) 10 μg/L 1 μg/g oil

Table 5. Data Quality Objectives and Criteria - Saturated Hydrocarbons (GC/FID)

Element or Sample Type	Minimum Frequency	Data Quality Objective/ Acceptance Criteria
Initial Calibration (All target analytes)	Prior to every batch of analysis	5-point calibration curve over 2 orders of magnitude, RSD ≤ 15%
Continuing Calibration (All target analytes - mid-level standard)	Every 10 field samples or 12 hours, whichever is more frequent, and at end of analytical batch	PD ≤ 15% for 90% of analytes PD ≤ 20% for 10% of analytes
SRM	One per batch of field samples	PD ≤ ± 20% of certified value for all analytes
Matrix Spikes	Two per batch of field samples	%R 40-125%
Reference (oil) Standard	One per batch of field samples	PD ≤10% of mean for all previous values
Procedural Blank	One per batch of field samples	No more than 2 analytes to exceed 5x target MDL, unless analyte not detected in associated sample(s) or analyte concentration > 10x blank value.
Duplicate SRM/Sample Analysis	One per batch of field samples	RPD ≤ 25%
Surrogate Standards	Every sample	%R 40-125%
Target MDLs	Sediment Tissue Water Oil	0.05-0.1 μg/g (dry weight) 0.05-0.1 μg/g (dry weight) 0.5-1.0 μg/L 0.025-0.05 μg/mg

Table 6. Data Quality Objectives and Criteria - PAHs and Decalins (GC/MS)

Element or Sample Type	Minimum Frequency	Data Quality Objective/ Acceptance Criteria
Initial Calibration (all parent PAHs and decalin and selected alkyl homologues)	Prior to every sequence	5 point calibration curve over two orders of magnitude. % RSD ≤ 25%
Continuing Calibration	Every 12 field samples or 16 hours, whichever is more frequent, and at end of analytical sequence with appropriate mid-level standard	% RSD ≤ 25% for 90% of analytes. % RSD ≤ 35% for 10% of analytes.
Matrix SRM	Two per batch/every 20 field samples	Values must be within ± 20% of true value on average for all analytes > 10x MDL, not to exceed ± 25% of true value for more than 30% of individual analytes.
Matrix Spikes	Two per batch/every 20 field samples	%R target analytes 40-125%
Instrumental SRM (PAHs)	One per sequence	Value must be within 15% of true value for all analytes
Oil Standard	One per batch/every 20 field samples	Values must be within ± 10% of the mean of all previous values.
Procedural Blank	One per batch/every 20 field samples	No more than 2 analytes to exceed 5x target MDL unless analyte not detected in associated sample(s) or analyte concentration > 10x blank value.
Duplicate SRM or Sample Analysis	One per batch/every 20 field samples	RPD ≤ 30%
Internal Standard/Surrogates	Every sample	%R 40-125%
Target MDLs	Tissue Sediment Water Oil	1-5 ng/g (dry weight) 1-5 ng/g (dry weight) 5-10 ng/L 0.5-2.5 ng/mg

Table 7. Summary Information for Canister Sampling For Tests #1 and #2

Sample Description	Sample ID	Comments
Test 1, Reference	90-015	Grab sample collected
Test 1, 200+ meters	88-001	Grab sample collected
Test 1, 200+ meters	91-002	Grab sample collected
Test 1, 25 meters	91-003	No sample collected - vacuum still at 30" Hg
Test 1, 25 meters	91-033	No sample collected - vacuum still at 30" Hg
Test 1, 11 meters	88-013	Grab sample collected
Test 1, 11 meters	88-014	Grab sample collected
Test 2, Reference	90-016	Grab sample collected
Test 2, 100 meters	91-045	Grab sample collected
Test 2, 100 meters	91-026	Grab sample collected
Test 2, 11 meters	91-012	Grab sample collected
Test 2, 11 meters	91-069	Grab sample collected
Test 2, <1 meter	88-058	Grab sample collected
Test 2, < 1 meter	88-029	Grab sample collected
Trip Blank	88-019	Filled with zero air upon return

Table 8. Summary Information For XAD-2 Sampling For Tests #1 and #2

Sample Description	Sample ID	Volume Sampled (Liters)		Sampling Time (Min)	Comments
		Rotameter	Corrected[b]		
Test 1, Reference	#5	77.3	70.3	15	
Test 1, 200+ meters	#2	97.9	89.1	22	Moved station from 300 meters to 200 meters within first 5 min
Test 1, 200+ meters	#15	102.4	93.2	23	Moved station from 300 meters to 200 meters within first 5 min
Test 1, 25 meters	#10	101.7	92.5	21	
Test 1, 25 meters	#13	25.5	23.2	5	
Test 1, 11 meters	#7	78.8	71.7	17	
Test 1, 11 meters	#8[a]	75.0	68.3	16	
Test 2, Reference	#9	83.8	76.3	20	
Test 2, 100 meters	#3	236.4	215.1	46	
Test 2, 100 meters	#16	213.7	194.5	46	
Test 2, 11 meters	#6	90.0	81.9	20	
Test 2, 11 meters	#12	88.0	80.1	20	
Test 2, <1 meter	#4[a]	6.8	6.2	1-2	Total sampled volume could be ±2.0 L of listed value
Test 2, < 1 meter	#1	12.1	11.0	3-4	Total sampled volume could be ±2.0 L of listed value
Laboratory Blank	#17	-	-	-	
Field Blank	#14	-	-	-	

(a) 50 μl of spiking solution DY29 was spiked to all XAD-2 samples prior to extraction except for samples #4 and #8.
(b) Volume corrected to 25°C, 1 atm.

Table 9. Weight Percent Composition of VOCs For Tested Fog Oils.

Peak ID and Compound	Test #1 weight % of total	Test #1 ID peaks normalize	Test #2 weight % of total	Test #2 ID peaks normalized
Peak 4 -- isobutane	0.27	4	0.36	8
Peak 5 -- 1,2-dimethyl cyclopropane (z)	0.16	3	0.04	1
Peak 6 -- 1,2-dimethyl cyclopropane (e)	0.23	4	0.12	3
Peak 8 -- benzene	0.41	7	0.24	5
Peak 9 -- cyclohexene/C6-ol	0.38	6	0.26	6
Peak 10 -- 1-heptene	0.24	4	0.12	3
Peak 11 -- methyl cyclohexane	1.30	21	0.90	20
Peak 12 -- toluene	0.33	5	0.19	4
Peak 13 -- 1-octene	0.20	3	0.13	3
Peak 14 -- ethyl cyclohexane	1.21	20	0.96	21
Peak 15 -- m,p-xylene	1.60	26	1.11	24
Peak 16 -- 1-nonene/o-xylene	0.46	7	0.50	11
Peak 17 -- unknown a	1.68	28	1.18	26
Peak 18 -- 4-ethyltoluene	1.52	25	1.01	22
Peak 19 -- 1,2,4-trimethylbenzene	3.31	54	3.50	77
Peak 20 -- diethylbenzene	3.66	60	2.42	53
Peak 21 -- methyl, propylbenzene	2.34	38	1.67	37
Peak 22 -- tetramethylbenzene	6.11	100	4.53	100
Peak 23 -- ethyl, dimethylbenzene	3.30	54	3.42	76
Peak 24 -- unknown b	2.55	42	2.29	51
Peak 25 -- unknown c	2.37	39	1.95	43
Peak 26 -- dimethyl adamantane	2.68	44	3.38	75
Peak 27 -- unknown d	1.54	25	3.28	73
Peak 28 -- unknown e	1.43	23	3.30	73
Peak 29 -- dimethyl adamantane	1.21	20	1.56	34
Peak 30 -- dimethyl adamantane	0.53	9	0.94	21
% of all peaks that are identified	41.01		39.38	

Table 10. Concentrations of Volatile Organic Compounds For Tests #1 and #2 (ug/m3).

Peak ID and Compound	Sampling Location and Canister ID				
	reference 90-015	200+ m 88-001	200+ m 91-002	11 m 88-013	11 m 88-014
Peak 1 -- C3-ene	1	2	2	191	199
Peak 2 -- C4-ene	0	1	0	62	71
Peak 3 -- 1,3-butadiene	0	1	0	48	65
Peak 4 -- isobutane	8	6	5	29	35
Peak 5 -- 1,2-dimethyl cyclopropane (z)	0	1	0	26	42
Peak 6 -- 1,2-dimethyl cyclopropane (e)	0	0	0	8	17
Peak 7 -- 1-hexene	2	1	0	27	31
Peak 8 -- benzene	4	4	4	36	34
Peak 9 -- cyclohexene/C6-ol	3	2	0	8	8
Peak 10 -- 1-heptene	1	1	1	15	18
Peak 11 -- methyl cyclohexane	0	0	0	13	14
Peak 12 -- toluene	2	2	2	16	15
Peak 13 -- 1-octene	0	0	0	12	12
Peak 14 -- ethyl cyclohexane	0	0	0	13	12
Peak 15 -- m,p-xylene	0	1	1	25	30
Peak 16 -- 1-nonene/o-xylene	0	1	1	16	19
Peak 17 -- unknown a	0	0	0	13	13
Peak 18 -- 4-ethyltoluene	0	0	0	14	14
Peak 19 -- 1,2,4-trimethylbenzene	1	1	1	30	35
Peak 20 -- diethylbenzene	0	0	0	28	31
Peak 21 -- methyl, propylbenzene	1	0	0	22	14
Peak 22 -- tetramethylbenzene	0	0	0	60	38
Peak 23 -- ethyl, dimethylbenzene	0	0	0	45	18
Peak 24 -- unknown b	0	0	0	28	18
Peak 25 -- unknown c	0	0	0	19	21
Peak 26 -- dimethyl adamantane	0	0	0	32	33
Peak 27 -- unknown d	0	0	0	45	23
Peak 28 -- unknown e	0	0	0	45	38
Peak 29 -- dimethyl adamantane	0	0	0	19	25
Peak 30 -- dimethyl adamantane	0	0	0	26	14

Table 10 Continued. Concentrations of Volatile Organic Compounds For Tests #1 and #2 (ug/m3).

Peak ID and Compound	Sampling Location and Canister ID							
	reference 90-016	100 m 91-045	100 m 91-026	11 m 91-012	11 m 91-069	<1 m 88-058	<1 m 88-029	blank 88-019
Peak 1 -- propyne	0	75	80	2730	643	87536	70126	0
Peak 2 -- C4-ene	0	24	25	965	226	17260	15486	0
Peak 3 -- C4-ene	0	22	22	944	195	27487	23170	0
Peak 4 -- 1,3-butadiene	0	0	0	0	0	12587	10565	0
Peak 5 -- 2-butene (z)	0	4	4	165	31	3059	2698	0
Peak 6 -- 2-butene (e)	0	1	1	67	15	1252	1092	0
Peak 7 -- 3-methyl-1-butene	0	2	2	69	17	2149	1801	0
Peak 8 -- 1,2-dimethyl cyclopropane (z)	0	6	6	229	56	7041	5950	0
Peak 9 -- 1,2-dimethyl cyclopropane (e)	2	3	4	124	29	3806	3217	0
Peak 10 -- 2-methyl-1,3-butadiene	0	6	6	181	44	5659	4855	0
Peak 11 -- 2-pentene (z)	1	2	2	65	16	2209	1896	0
Peak 12 -- 2-pentene (e)	0	1	1	50	10	1360	1167	0
Peak 13 -- C5-ene	0	4	4	88	22	2907	2500	0
Peak 14 -- 3-penten-1-yne	0	7	7	280	65	8566	7462	0
Peak 15 -- 1,3-pentadiene	0	2	2	71	16	2496	2177	0
Peak 16 -- cyclopentene	0	1	1	59	14	1807	1529	0
Peak 17 -- 4-methyl-1-pentene	0	0	1	50	12	1646	1377	0
Peak 18 -- 1-hexene	1	6	7	250	58	7413	6216	0
Peak 19 -- 1,4-cyclohexadiene	0	1	2	111	23	3330	2852	0
Peak 20 -- 1,4-cyclohexadiene	0	1	1	70	13	2091	1848	0
Peak 21 -- benzene	4	12	12	414	100	12105	10563	3
Peak 22 -- cyclohexadiene	0	2	3	66	26	3272	3403	0
Peak 23 -- cyclohexene	3	3	4	43	12	1369	1148	2
Peak 24 -- 1-heptene	1	3	3	114	25	3481	2910	1
Peak 25 -- toluene	2	8	7	216	47	6194	5433	0
Peak 26 -- 1-octene	0	1	2	58	12	1766	1495	0
Peak 27 -- ethylbenzene	1	2	2	73	17	2089	1895	0
Peak 28 -- m.p-xylene	1	2	3	77	19	2147	1943	0
Peak 29 -- styrene	0	2	2	77	17	2175	2034	0
Peak 30 -- 1-nonene	0	3	2	71	17	2258	2073	0
Peak 31 -- 4-ethyltoluene	0	1	1	26	6	585	583	0
Peak 32 -- 1,3,5-trimethylbenzene	0	0	0	12	3	325	321	0
Peak 33 -- 1,2,4-trimethylbenzene	1	3	2	82	18	1482	1532	1

Table 11. Concentrations of Saturated Hydrocarbons and THC For Tests #1 and #2

Client/Field ID:	Sample #17, Laboratory Matrix Blank^	Sample #14, Field Blank	Test 1 Oil Dec. 13, 1995	Sample #5, Reference for Test #1	Sample #7, Test #1, 11 m
BOS Sample ID:	TD70	TD67	TD71-1	TD59	TD61
Batch ID:	96-033	96-033	96-027	96-033	96-033
Matrix:	Oil	Oil	Oil	Oil	Oil
Sample Weight (mg, oil weight)	0.08	0.06	55.20	1.08	48.40
Sample Volume (L)	83.8	83.8	NA	70.3	71.7
Dilution:	1.01	1.01	10.00	1.01	1.01
Reporting Unit:	mg/kg oil	mg/kg oil	mg/kg oil	mg/kg oil	mg/kg oil
Reporting Limit:	5 mg/kg	5 mg/kg	5 mg/kg	5 mg/kg	5 mg/kg
Analyte					
C10	ND	ND	ND	ND	ND
C11	ND	ND	ND	ND	ND
C12	ND	ND	ND	ND	ND
C13	ND	ND	ND	ND	ND
C14	ND	ND	ND	ND	ND
C15	ND	ND	ND	ND	ND
C16	ND	ND	ND	ND	ND
C17	ND	ND	ND	ND	ND
Pristane	ND	ND	ND	ND	ND
C18	ND	ND	ND	ND	ND
Phytane	ND	ND	ND	ND	ND
C19	ND	ND	ND	ND	ND
C20	ND	ND	ND	ND	ND
C21	ND	ND	ND	ND	ND
C22	ND	ND	ND	ND	ND
C23	ND	ND	ND	ND	ND
C24	ND	ND	ND	ND	ND
C25	ND	ND	ND	ND	ND
C26	ND	ND	ND	ND	ND
C27	ND	ND	ND	ND	ND
C28	ND	ND	ND	ND	ND
C29	ND	ND	ND	ND	ND
C30	ND	ND	ND	ND	ND
C31	ND	ND	ND	ND	ND
C32	ND	ND	ND	ND	ND
C33	ND	ND	ND	ND	ND
C34	ND	ND	ND	ND	ND
C35	ND	ND	ND	ND	ND
C36	ND	ND	ND	ND	ND
Surrogate Recoveries %	74	73	83	77	58
THC mg/kg			830000.00		
THC ug/m3	500.00	1500.00	NA	24000.00	760000.00

Table 11. Concentrations of Saturated Hydrocarbons and THC For Tests #1 and #2

Client/Field ID:	Sample #8, Test #1, 11 m	Sample #10, Test #1, 25 m	Sample #13, Test #1, 25 m	Sample #15, Test #1, 200+ m	Sample #2, Test #1, 200+ m
BOS Sample ID:	TD62	TD64	TD66	TD68	TD56
Batch ID:	96-033	96-033	96-033	96-033	96-033
Matrix:	Oil	Oil	Oil	Oil	Oil
Sample Weight (mg, oil weight)	48.40	3.60	0.89	0.24	0.17
Sample Volume (L)	68.3	92.5	23.2	93.2	89.1
Dilution:	1.01	1.01	1.01	1.01	1.01
Reporting Unit:	mg/kg oil	mg/kg oil	mg/kg oil	mg/kg oil	mg/kg oil
Reporting Limit:	5 mg/kg	5 mg/kg	5 mg/kg	5 mg/kg	5 mg/kg
Analyte					
C10	ND	ND	ND	ND	ND
C11	ND	ND	ND	ND	ND
C12	ND	ND	ND	ND	ND
C13	ND	ND	ND	ND	ND
C14	ND	ND	ND	ND	ND
C15	ND	ND	ND	ND	ND
C16	ND	ND	ND	ND	ND
C17	ND	ND	ND	ND	ND
Pristane	ND	ND	ND	ND	ND
C18	ND	ND	ND	ND	ND
Phytane	ND	ND	ND	ND	ND
C19	ND	ND	ND	ND	ND
C20	ND	ND	ND	ND	ND
C21	ND	ND	ND	ND	ND
C22	ND	ND	ND	ND	ND
C23	ND	ND	ND	ND	ND
C24	ND	ND	ND	ND	ND
C25	ND	ND	ND	ND	ND
C26	ND	ND	ND	ND	ND
C27	ND	ND	ND	ND	ND
C28	ND	ND	ND	ND	ND
C29	ND	ND	ND	ND	ND
C30	ND	ND	ND	ND	ND
C31	ND	ND	ND	ND	ND
C32	ND	ND	ND	ND	ND
C33	ND	ND	ND	ND	ND
C34	ND	ND	ND	ND	ND
C35	ND	ND	ND	ND	ND
C36	ND	ND	ND	ND	ND
Surrogate Recoveries %	93	76	74	75	73
THC mg/kg					
THC ug/m3	630000.00	49000.00	59000.00	4900.00	5600.00

Table 11. Concentrations of Saturated Hydrocarbons and THC For Tests #1 and #2

Client/Field ID:	Test 2 Oil Dec. 14, 1995	Sample #9, Reference for Test #2	Sample #1, Test #2, 1/2 m	Sample #4, Test #2, 1/2 m	Sample #12, Test #2, 11 m
BOS Sample ID:	TD72-1	TD63	TD55-D	TD58-D	TD65
Batch ID:	96-027	96-033	96-033	96-033	96-033
Matrix:	Oil	Oil	Oil	Oil	Oil
Sample Weight (mg, oil weight)	51.20	0.04	84.60	85.60	6.70
Sample Volume (L)	NA	76.3	11.0	6.2	80.1
Dilution:	10.00	1.01	20.00	20.00	1.01
Reporting Unit:	mg/kg oil	mg/kg oil	mg/kg oil	mg/kg oil	mg/kg oil
Reporting Limit:	5 mg/kg	5 mg/kg	5 mg/kg	5 mg/kg	5 mg/kg
Analyte					
C10	ND	ND	ND	ND	ND
C11	ND	ND	ND	ND	ND
C12	ND	ND	ND	ND	ND
C13	ND	ND	ND	ND	ND
C14	ND	ND	ND	ND	ND
C15	ND	ND	ND	ND	ND
C16	ND	ND	ND	ND	ND
C17	ND	ND	ND	ND	ND
Pristane	ND	ND	ND	ND	ND
C18	ND	ND	ND	ND	ND
Phytane	ND	ND	ND	ND	ND
C19	ND	ND	ND	ND	ND
C20	ND	ND	ND	ND	ND
C21	ND	ND	ND	ND	ND
C22	ND	ND	ND	ND	ND
C23	ND	ND	ND	ND	ND
C24	ND	ND	ND	ND	ND
C25	ND	ND	ND	ND	ND
C26	ND	ND	ND	ND	ND
C27	ND	ND	ND	ND	ND
C28	ND	ND	ND	ND	ND
C29	ND	ND	ND	ND	ND
C30	ND	ND	ND	ND	ND
C31	ND	ND	ND	ND	ND
C32	ND	ND	ND	ND	ND
C33	ND	ND	ND	ND	ND
C34	ND	ND	ND	ND	ND
C35	ND	ND	ND	ND	ND
C36	ND	ND	ND	ND	ND
Surrogate Recoveries %	83	75	77	99	74
THC mg/kg	830000.00				
THC ug/m3	NA	1000.00	9700000.00	17000000.00	100000.00

Table 11. Concentrations of Saturated Hydrocarbons and THC For Tests #1 and #2

Client/Field ID:	Sample #6, Test #2, 11 m	Sample #16, Test #2, 100 m	Sample #3, Test #2, 100 m
BOS Sample ID:	TD60	TD69	TD57
Batch ID:	96-033	96-033	96-033
Matrix:	Oil	Oil	Oil
Sample Weight (mg, oil weight)	5.65	1.48	1.67
Sample Volume (L)	81.9	194.5	215.1
Dilution:	1.01	1.01	1.01
Reporting Unit:	mg/kg oil	mg/kg oil	mg/kg oil
Reporting Limit:	5 mg/kg	5 mg/kg	5 mg/kg
Analyte			
C10	ND	ND	ND
C11	ND	ND	ND
C12	ND	ND	ND
C13	ND	ND	ND
C14	ND	ND	ND
C15	ND	ND	ND
C16	ND	ND	ND
C17	ND	ND	ND
Pristane	ND	ND	ND
C18	ND	ND	ND
Phytane	ND	ND	ND
C19	ND	ND	ND
C20	ND	ND	ND
C21	ND	ND	ND
C22	ND	ND	ND
C23	ND	ND	ND
C24	ND	ND	ND
C25	ND	ND	ND
C26	ND	ND	ND
C27	ND	ND	ND
C28	ND	ND	ND
C29	ND	ND	ND
C30	ND	ND	ND
C31	ND	ND	ND
C32	ND	ND	ND
C33	ND	ND	ND
C34	ND	ND	ND
C35	ND	ND	ND
C36	ND	ND	ND
Surrogate Recoveries %	73	71	75
THC mg/kg			
THC ug/m3	97000.00	12000.00	12000.00

Table 12. Concentrations of PAHs For Tests #1 and #2

Client/Field ID:	Sample #17, Laboratory Matrix Blank^		Sample #17, Laboratory Matrix Blank^		Sample #14, Field Blank		Sample #14, Field Blank		North Slope Crude	
BOS Sample ID:	TD70		TD70		TD67		TD67		TW07NSC	
Batch ID:	96-033		96-033		96-033		96-033		96-033	
Matrix:	Oil		Oil		Oil		Oil		Oil	
Sample Weight (mg, oil weight)	1.00		1.00		1.00		1.00		5.09	
Sample Volume (L)	83.8		83.8		83.8		83.8		NA	
Dilution:	1.01		1.01		1.01		1.01		1.00	
Reporting Unit:	mg/kg oil		ug/m3*		mg/kg oil		ug/m3*		mg/kg oil	
Reporting Limit:	5 mg/kg				5 mg/kg				5 mg/kg	
Decalin	39	B	0.47	B	31	B	0.37	B	670	
C1-decalins	52	B	0.62	B	ND		ND		1100	
C2-decalins	ND		ND		ND		ND		1400	
C3-decalins	ND		ND		ND		ND		800	
C4-decalins	ND		ND		ND		ND		320	
Benzo[b]thiophene	ND		ND		ND		ND		ND	
C1-benzo[b]thiophenes	ND		ND		ND		ND		ND	
C2-benzo[b]thiophenes	ND		ND		ND		ND		ND	
C3-benzo[b]thiophenes	ND		ND		ND		ND		ND	
C4-benzo[b]thiophenes	ND		ND		ND		ND		ND	
Naphthalene	76	B	0.91	B	66	B	0.79	B	770	
C1-naphthalenes	21	B	0.25	B	16	B	0.19	B	1500	
C2-naphthalenes	18	B	0.22	B	ND		ND		1700	
C3-naphthalenes	ND		ND		ND		ND		1100	
C4-naphthalenes	ND		ND		ND		ND		580	
Biphenyl	ND		ND		ND		ND		210	
Acenaphthylene	ND		ND		ND		ND		ND	
Acenaphthene	ND		ND		ND		ND		14	
Dibenzofuran	11	B	0.13	B	ND		ND		62	
Fluorene	10	B	0.12	B	ND		ND		100	
C1-fluorenes	ND		ND		ND		ND		230	
C2-fluorenes	ND		ND		ND		ND		300	
C3-fluorenes	ND		ND		ND		ND		320	
Anthracene	ND		ND		ND		ND		14	
Phenanthrene	47	B	0.56	B	32	B	0.39	B	290	
C1-phenanthrenes/anthracenes	ND		ND		ND		ND		630	
C2-phenanthrenes/anthracenes	ND		ND		ND		ND		700	
C3-phenanthrenes/anthracenes	ND		ND		ND		ND		460	
C4-phenanthrenes/anthracenes	ND		ND		ND		ND		230	
Dibenzothiophene	ND		ND		ND		ND		220	
C1-dibenzothiophenes	ND		ND		ND		ND		390	
C2-dibenzothiophenes	ND		ND		ND		ND		480	
C3-dibenzothiophenes	ND		ND		ND		ND		440	
Fluoranthene	ND		ND		ND		ND		3.8	J
Pyrene	ND		ND		ND		ND		11	
C1-fluoranthenes/pyrenes	ND		ND		ND		ND		66	
C2-fluoranthenes/pyrenes	ND		ND		ND		ND		120	
C3-fluoranthenes/pyrenes	ND		ND		ND		ND		140	
Benz(a)anthracene	ND		ND		ND		ND		ND	
Chrysene	ND		ND		ND		ND		22	
C1-chrysenes	ND		ND		ND		ND		85	
C2-chrysenes	ND		ND		ND		ND		120	
C3-chrysenes	ND		ND		ND		ND		77	
C4-chrysenes	ND		ND		ND		ND		41	
Benzo(b)fluoranthene	ND		ND		ND		ND		6.7	
Benzo(k)fluoranthene	ND		ND		ND		ND		ND	
Benzo(e)pyrene	ND		ND		ND		ND		12	
Benzo(a)pyrene	ND		ND		ND		ND		ND	
Perylene	ND		ND		ND		ND		ND	
Indeno(1,2,3-c,d)pyrene	ND		ND		ND		ND		ND	
Dibenz(a,h)anthracene	ND		ND		ND		ND		ND	
Benzo(g,h,i)perylene	ND		ND		ND		ND		3.5	J
Total PAH	270		3.3		140		1.7		16000	
2-methylnaphthalene	21	B	0.25	B	15	B	0.18	B	NM	
1-methylnaphthalene	10	B	0.12	B	8.3	B	0.099	B	NM	
2,6-dimethylnaphthalene	5.4	B	0.064	B	ND		ND		NM	
2,3,5-trimethylnaphthalene	ND		ND		ND		ND		NM	
1-methylphenanthrene	ND		ND		ND		ND		NM	

^ Assume oil weight of 1.00 mg.

* Average of 14 sample volumes = 83.8 cubic meters.

B, Laboratory/XAD-2 contaminant is major contributor to analyte concentration.

J, concentration below reporting limit (5 mg/kg).

NM, not measured in sample.

Table 12. Continued, Concentrations of PAHs For Tests #1 and #2

Client/Field ID:	Test 1 Dec. 13, 1995		Sample #5, Reference for Test #1		Sample #5, Reference for Test #1	
BOS Sample ID:	TD71-1		TD59		TD59	
Batch ID:	96-027		96-033		96-033	
Matrix:	Oil		Oil		Oil	
Sample Weight (mg, oil weight)	55.20		1.10		1.10	
Sample Volume (L)	NA		70.3		70.3	
Dilution:	10.00		1.01		1.01	
Reporting Unit:	mg/kg oil		mg/kg oil		ug/m3	
Reporting Limit:	5 mg/kg		5 mg/kg			
Decalin	6.6		22	B	0.34	B
C1-decalins	19		24	B	0.37	B
C2-decalins	78		ND		ND	
C3-decalins	160		ND		ND	
C4-decalins	140		ND		ND	
Benzo[b]thiophene	1.7	J	ND		ND	
C1-benzo[b]thiophenes	2.5	J	ND		ND	
C2-benzo[b]thiophenes	12		ND		ND	
C3-benzo[b]thiophenes	26		ND		ND	
C4-benzo[b]thiophenes	58		ND		ND	
Naphthalene	41		71	B	1.1	B
C1-naphthalenes	75		18	B	0.28	B
C2-naphthalenes	240		14	B	0.22	B
C3-naphthalenes	370		ND		ND	
C4-naphthalenes	430		ND		ND	
Biphenyl	5.9		4.6	J	0.073	
Acenaphthylene	ND		ND		ND	
Acenaphthene	4.8	J	5.5	B	0.087	B
Dibenzofuran	1.7	J	9.8	B	0.15	B
Fluorene	17		14		0.21	
C1-fluorenes	89		ND		ND	
C2-fluorenes	490		ND		ND	
C3-fluorenes	1100		ND		ND	
Anthracene	ND		ND		ND	
Phenanthrene	89		60	B	0.93	B
C1-phenanthrenes/anthracenes	520		10		0.16	
C2-phenanthrenes/anthracenes	1000		ND		ND	
C3-phenanthrenes/anthracenes	1100		ND		ND	
C4-phenanthrenes/anthracenes	640		ND		ND	
Dibenzothiophene	150		6.4		0.10	
C1-dibenzothiophenes	970		ND		ND	
C2-dibenzothiophenes	2400		ND		ND	
C3-dibenzothiophenes	2800		ND		ND	
Fluoranthene	7.0		17		0.27	
Pyrene	14		4.6	J	0.072	
C1-fluoranthenes/pyrenes	84		ND		ND	
C2-fluoranthenes/pyrenes	200		ND		ND	
C3-fluoranthenes/pyrenes	290		ND		ND	
Benz(a)anthracene	ND		ND		ND	
Chrysene	48		ND		ND	
C1-chrysenes	81		ND		ND	
C2-chrysenes	120		ND		ND	
C3-chrysenes	81		ND		ND	
C4-chrysenes	ND		ND		ND	
Benzo(b)fluoranthene	6.7		ND		ND	
Benzo(k)fluoranthene	ND		ND		ND	
Benzo(e)pyrene	6.3		ND		ND	
Benzo(a)pyrene	ND		ND		ND	
Perylene	ND		ND		ND	
Indeno(1,2,3-c,d)pyrene	ND		ND		ND	
Dibenz(a,h)anthracene	ND		ND		ND	
Benzo(g,h,i)perylene	ND		ND		ND	
Total PAH	14000		280		4.4	
2-methylnaphthalene	66		19	B	0.30	B
1-methylnaphthalene	68		11	B	0.18	B
2,6-dimethylnaphthalene	48		5.2	B	0.081	B
2,3,5-trimethylnaphthalene	69		ND		ND	
1-methylphenanthrene	140		1.8	J	0.029	

B, Laboratory/XAD-2 contaminant is major contributor to analyte concentration.

Table 12. Continued, Concentrations of PAHs For Tests #1 and #2

Client/Field ID:	Sample #7, Test #1, 11 m		Sample #7, Test #1, 11 m	Sample #8, Test #1, 11 m		Sample #8, Test #1, 11 m
BOS Sample ID:	TD61		TD61	TD62		TD62
Batch ID:	96-033		96-033	96-033		96-033
Matrix:	Oil		Oil	Oil		Oil
Sample Weight (mg, oil weight)	48.40		48.40	48.40		48.40
Sample Volume (L)	71.7		71.7	68.3		68.3
Dilution:	1.01		1.01	1.01		1.01
Reporting Unit:	mg/kg oil		ug/m3	mg/kg oil		ug/m3
Reporting Limit:	5 mg/kg			5 mg/kg		
Decalin	11		7.7	7.8		5.5
C1-decalins	28		19	21		15
C2-decalins	140		95	98		69
C3-decalins	230		160	190		130
C4-decalins	210		140	170		120
Benzo[b]thiophene	2.1	J	1.4	2.6	J	1.9
C1-benzo[b]thiophenes	4.3	J	2.9	ND		ND
C2-benzo[b]thiophenes	15		9.8	13		9.0
C3-benzo[b]thiophenes	47		32	33		24
C4-benzo[b]thiophenes	63		43	88		62
Naphthalene	65		44	42		30
C1-naphthalenes	110		76	74		52
C2-naphthalenes	320		220	260		180
C3-naphthalenes	540		360	440		310
C4-naphthalenes	460		310	550		390
Biphenyl	8.7		5.9	6.3		4.4
Acenaphthylene	ND		ND	0.64	J	0.45
Acenaphthene	6.7		4.5	5.1		3.6
Dibenzofuran	3.3	J	2.2	2.3	J	1.6
Fluorene	22		15	21		15
C1-fluorenes	85		57	110		78
C2-fluorenes	320		220	410		290
C3-fluorenes	890		600	970		690
Anthracene	ND		ND	95		67
Phenanthrene	120		79	89		63
C1-phenanthrenes/anthracenes	470		310	380		270
C2-phenanthrenes/anthracenes	1100		740	720		510
C3-phenanthrenes/anthracenes	900		610	820		580
C4-phenanthrenes/anthracenes	520		350	500		350
Dibenzothiophene	180		120	170		120
C1-dibenzothiophenes	860		580	650		460
C2-dibenzothiophenes	2600		1800	1700		1200
C3-dibenzothiophenes	2500		1700	1800		1300
Fluoranthene	ND		ND	ND		ND
Pyrene	ND		ND	ND		ND
C1-fluoranthenes/pyrenes	110		71	85		60
C2-fluoranthenes/pyrenes	180		120	130		89
C3-fluoranthenes/pyrenes	270		180	170		120
Benz(a)anthracene	ND		ND	ND		ND
Chrysene	43		29	29		20
C1-chrysenes	72		48	43		30
C2-chrysenes	120		78	57		40
C3-chrysenes	100		67	51		36
C4-chrysenes	31		21	ND		ND
Benzo(b)fluoranthene	8.1		5.5	2.7	J	1.9
Benzo(k)fluoranthene	ND		ND	ND		ND
Benzo(e)pyrene	8.3		5.6	2.6	J	1.8
Benzo(a)pyrene	ND		ND	ND		ND
Perylene	ND		ND	ND		ND
Indeno(1,2,3-c,d)pyrene	ND		ND	ND		ND
Dibenz(a,h)anthracene	ND		ND	ND		ND
Benzo(g,h,i)perylene	1.6	J	1.1	ND		ND
Total PAH	14000		9300	11000		7800
2-methylnaphthalene	100		67	65		46
1-methylnaphthalene	100		69	66		47
2,6-dimethylnaphthalene	77		52	58		41
2,3,5-trimethylnaphthalene	82		56	88		62
1-methylphenanthrene	85		57	92		65

B, Laboratory/XAD-2 contaminant is major contributor to analyte concentration.

Table 12. Continued, Concentrations of PAHs For Tests #1 and #2

Client/Field ID:	Sample #10, Test #1, 25 m		Sample #10, Test #1, 25 m		Sample #13, Test #1, 25 m		Sample #13, Test #1, 25 m		Sample #15, Test #1, 200+ m	
BOS Sample ID:	TD64		TD64		TD66		TD66		TD68	
Batch ID:	96-033		96-033		96-033		96-033		96-033	
Matrix:	Oil		Oil		Oil		Oil		Oil	
Sample Weight (mg, oil weight)	3.60		3.60		0.70		0.70		0.20	
Sample Volume (L)	92.5		92.5		23.2		23.2		93.2	
Dilution:	1.01		1.01		1.01		1.01		1.01	
Reporting Unit:	mg/kg oil		ug/m3		mg/kg oil		ug/m3		mg/kg oil	
Reporting Limit:	5 mg/kg				5 mg/kg				5 mg/kg	
Decalin	14	B	0.55	B	69	B	2.1	B	ND	
C1-decalins	27	B	1.0	B	99	B	3.0	B	ND	
C2-decalins	140		5.5		ND		ND		ND	
C3-decalins	200		7.8		ND		ND		ND	
C4-decalins	200		7.9		ND		ND		ND	
Benzo[b]thiophene	ND		ND		ND		ND		ND	
C1-benzo[b]thiophenes	7.1		0.28		22		0.65		ND	
C2-benzo[b]thiophenes	11		0.44		ND		ND		ND	
C3-benzo[b]thiophenes	25		0.96		27		0.83		ND	
C4-benzo[b]thiophenes	66		2.6		65		2.0		ND	
Naphthalene	67		2.6		180	B	5.3	B	380	B
C1-naphthalenes	88		3.4		100		3.0		120	B
C2-naphthalenes	210		8.2		160		4.9		200	
C3-naphthalenes	380		15		290		8.6		190	
C4-naphthalenes	470		18		530		16		150	
Biphenyl	7.2		0.28		11		0.33		ND	
Acenaphthylene	ND		ND		ND		ND		ND	
Acenaphthene	6.2		0.24		14	B	0.42	B	ND	
Dibenzofuran	4.9	J	0.19		14	B	0.42	B	ND	
Fluorene	21		0.83		23		0.71		ND	
C1-fluorenes	100		4.0		120		3.5		33	
C2-fluorenes	570		22		570		17		230	
C3-fluorenes	1200		46		1500		45		610	
Anthracene	ND		ND		ND		ND		ND	
Phenanthrene	110		4.4		160	B	4.9	B	190	B
C1-phenanthrenes/anthracenes	520		20		710		21		270	
C2-phenanthrenes/anthracenes	1100		43		1500		45		990	
C3-phenanthrenes/anthracenes	1100		44		1300		40		690	
C4-phenanthrenes/anthracenes	650		25		820		25		400	
Dibenzothiophene	150		6.0		180		5.3		48	
C1-dibenzothiophenes	1000		40		1200		37		320	
C2-dibenzothiophenes	2600		99		3300		98		1300	
C3-dibenzothiophenes	3000		120		3600		110		1600	
Fluoranthene	11		0.42		36		1.1		ND	
Pyrene	19		0.73		27		0.8		ND	
C1-fluoranthenes/pyrenes	97		3.8		120		3.7		ND	
C2-fluoranthenes/pyrenes	210		8.1		280		8.5		ND	
C3-fluoranthenes/pyrenes	270		10		330		10		ND	
Benz(a)anthracene	ND		ND		ND		ND		ND	
Chrysene	39		1.5		40		1.2		ND	
C1-chrysenes	58		2.3		79		2.4		ND	
C2-chrysenes	87		3.4		110		3.4		ND	
C3-chrysenes	63		2.5		ND		ND		ND	
C4-chrysenes	ND		ND		ND		ND		ND	
Benzo(b)fluoranthene	4.9	J	0.19		ND		ND		ND	
Benzo(k)fluoranthene	ND		ND		ND		ND		ND	
Benzo(e)pyrene	5.0		0.20		ND		ND		ND	
Benzo(a)pyrene	ND		ND		ND		ND		ND	
Perylene	1.8	J	0.068		ND		ND		ND	
Indeno(1,2,3-c,d)pyrene	ND		ND		ND		ND		ND	
Dibenz(a,h)anthracene	ND		ND		ND		ND		ND	
Benzo(g,h,i)perylene	ND		ND		ND		ND		ND	
Total PAH	15000		580		18000		530		7700	
2-methylnaphthalene	80		3.1		99		3.0		120	
1-methylnaphthalene	75		2.9		79		2.4		83	
2,6-dimethylnaphthalene	48		1.9		37		1.1		55	
2,3,5-trimethylnaphthalene	68		2.6		58		1.7		34	
1-methylphenanthrene	170		6.6		220		6.5		63	

B, Laboratory/XAD-2 contaminant is major contributor to analyte concentration.

Table 12. Continued, Concentrations of PAHs For Tests #1 and #2

Client/Field ID:	Sample #15, Test #1, 200+ m		Sample #2, Test #1, 200+ m		Sample #2, Test #1, 200+ m		Test 2 Dec. 14, 1995		Sample #9, Reference for Test #2	
BOS Sample ID:	TD68		TD56		TD56		TD72-1		TD63	
Batch ID:	96-033		96-033		96-033		96-027		96-033	
Matrix:	Oil		Oil		Oil		Oil		Oil	
Sample Weight (mg, oil weight)	0.20		0.20		0.20		51.20		0.80	
Sample Volume (L)	93.2		89.1		89.1		NA		76.3	
Dilution:	1.01		1.01		1.01		10.00		1.01	
Reporting Unit:	ug/m3		mg/kg oil		ug/m3		mg/kg oil		mg/kg oil	
Reporting Limit:			5 mg/kg				5 mg/kg		5 mg/kg	
Decalin	ND		91	B	0.20	B	7.4		ND	
C1-decalins	ND		ND		ND		24		ND	
C2-decalins	ND		ND		ND		93		ND	
C3-decalins	ND		ND		ND		140		ND	
C4-decalins	ND		ND		ND		150		ND	
Benzo[b]thiophene	ND		ND		ND		1.7	J	ND	
C1-benzo[b]thiophenes	ND		ND		ND		5.1		7.4	
C1-benzo[b]thiophenes	ND		ND		ND		11		ND	
C1-benzo[b]thiophenes	ND		ND		ND		26		ND	
C1-benzo[b]thiophenes	ND		ND		ND		58		ND	
Naphthalene	0.82	B	340	B	0.77	B	42		83	B
C1-naphthalenes	0.27	B	130	B	0.29	B	76		23	B
C2-naphthalenes	0.43		180		0.42		250		31	B
C3-naphthalenes	0.41		110		0.24		390		ND	
C4-naphthalenes	0.33		100		0.23		470		ND	
Biphenyl	ND		22		0.049		6.0		ND	
Acenaphthylene	ND		ND		ND		ND		ND	
Acenaphthene	ND		24		0.054		5.1		11	
Dibenzofuran	ND		41	B	0.092	B	1.6	J	13	B
Fluorene	ND		46	B	0.10	B	18		14	B
C1-fluorenes	0.071		33		0.074		93		ND	
C2-fluorenes	0.49		180		0.40		490		ND	
C3-fluorenes	1.3		570		1.3		1200		ND	
Anthracene	ND		ND		ND		ND		ND	
Phenanthrene	0.40	B	220	B	0.50	B	98		61	B
C1-phenanthrenes/anthracenes	0.59		240		0.53		530		ND	
C2-phenanthrenes/anthracenes	2.1		740		1.7		1100		ND	
C3-phenanthrenes/anthracenes	1.5		480		1.1		1100		ND	
C4-phenanthrenes/anthracenes	0.86		290		0.64		710		ND	
Dibenzothiophene	0.10		54		0.12		150		ND	
C1-dibenzothiophenes	0.70		310		0.69		960		ND	
C2-dibenzothiophenes	2.8		1000		2.3		2400		ND	
C3-dibenzothiophenes	3.4		1200		2.7		2700		ND	
Fluoranthene	ND		96		0.22		5.7		13	
Pyrene	ND		32		0.073		18		ND	
C1-fluoranthenes/pyrenes	ND		ND		ND		100		ND	
C2-fluoranthenes/pyrenes	ND		ND		ND		200		ND	
C3-fluoranthenes/pyrenes	ND		ND		ND		280		ND	
Benz(a)anthracene	ND		ND		ND		ND		ND	
Chrysene	ND		ND		ND		50		ND	
C1-chrysenes	ND		ND		ND		90		ND	
C2-chrysenes	ND		ND		ND		120		ND	
C3-chrysenes	ND		ND		ND		99		ND	
C4-chrysenes	ND		ND		ND		ND		ND	
Benzo(b)fluoranthene	ND		ND		ND		8.3		ND	
Benzo(k)fluoranthene	ND		ND		ND		ND		ND	
Benzo(e)pyrene	ND		ND		0		11		ND	
Benzo(a)pyrene	ND		ND		0		ND		ND	
Perylene	ND		ND		ND		ND		ND	
Indeno(1,2,3-c,d)pyrene	ND		ND		ND		ND		ND	
Dibenz(a,h)anthracene	ND		ND		ND		ND		ND	
Benzo(g,h,i)perylene	ND		ND		ND		ND		ND	
Total PAH	17		6500		15		14000		260	
2-methylnaphthalene	0.26		120		0.27		68		26	
1-methylnaphthalene	0.18		75		0.17		69		16	
2,6-dimethylnaphthalene	0.12		42		0.094		52		9.7	
2,3,5-trimethylnaphthalene	0.073		23		0.053		71		ND	
1-methylphenanthrene	0.14		61		0.14		150		ND	

B, Laboratory/XAD-2 contaminant is major contributor to analyte concentration.

Table 12. Continued, Concentrations of PAHs For Tests #1 and #2

Client/Field ID:	Sample #9, Reference for Test #2		Sample #1, Test #2, 1/2 m	Sample #1, Test #2, 1/2 m	Sample #4, Test #2, 1/2 m		Sample #4, Test #2, 1/2 m
BOS Sample ID:	TD63		TD55-D	TD55-D	TD58-D		TD58-D
Batch ID:	96-033		96-033	96-033	96-033		96-033
Matrix:	Oil		Oil	Oil	Oil		Oil
Sample Weight (mg, oil weight)	0.80		84.60	84.60	85.60		85.60
Sample Volume (L)	76.3		11.0	11.0	6.2		6.2
Dilution:	1.01		20.00	20.00	20.00		20.00
Reporting Unit:	ug/m3		mg/kg oil	ug/m3	mg/kg oil		ug/m3
Reporting Limit:			5 mg/kg		5 mg/kg		
Decalin	ND		16	130	35		480
C1-decalins	ND		31	240	79		1100
C2-decalins	ND		120	890	140		1900
C3-decalins	ND		190	1500	130		1800
C4-decalins	ND		160	1200	120		1700
Benzo[b]thiophene	ND		6.1	47	5.6		77
C1-benzo[b]thiophenes	0.078		17	130	16		220
C2-benzo[b]thiophenes	ND		28	210	24		330
C3-benzo[b]thiophenes	ND		45	350	40		560
C4-benzo[b]thiophenes	ND		95	730	75		1000
Naphthalene	0.87	B	140	1100	160		2200
C1-naphthalenes	0.24	B	150	1100	150		2100
C2-naphthalenes	0.33	B	300	2300	250		3500
C3-naphthalenes	ND		440	3400	360		4900
C4-naphthalenes	ND		590	4600	450		6200
Biphenyl	ND		9.7	75	9.5		130
Acenaphthylene	ND		45	340	43		600
Acenaphthene	0.12		13	100	12		160
Dibenzofuran	0.14	B	5.4	42	5.0		69
Fluorene	0.15	B	66	510	55		760
C1-fluorenes	ND		180	1400	150		2100
C2-fluorenes	ND		660	5000	560		7800
C3-fluorenes	ND		1500	12000	1300		17000
Anthracene	ND		31	240	33		460
Phenanthrene	0.64	B	170	1300	160		2200
C1-phenanthrenes/anthracenes	ND		750	5800	650		8900
C2-phenanthrenes/anthracenes	ND		1200	9400	1100		15000
C3-phenanthrenes/anthracenes	ND		1300	10000	1200		16000
C4-phenanthrenes/anthracenes	ND		760	5800	700		9600
Dibenzothiophene	ND		220	1700	180		2500
C1-dibenzothiophenes	ND		1300	9600	1100		15000
C2-dibenzothiophenes	ND		2800	22000	2400		34000
C3-dibenzothiophenes	ND		3500	27000	3000		41000
Fluoranthene	0.14		23	180	20		280
Pyrene	ND		48	370	39		540
C1-fluoranthenes/pyrenes	ND		130	980	180		2500
C2-fluoranthenes/pyrenes	ND		280	2100	250		3500
C3-fluoranthenes/pyrenes	ND		360	2700	350		4800
Benz(a)anthracene	ND		9.6	74	25		340
Chrysene	ND		48	370	63		870
C1-chrysenes	ND		79	610	110		1500
C2-chrysenes	ND		110	850	130		1800
C3-chrysenes	ND		85	660	120		1600
C4-chrysenes	ND		ND	ND	ND		ND
Benzo(b)fluoranthene	ND		7.6	59	7.9		110
Benzo(k)fluoranthene	ND		ND	ND	ND		ND
Benzo(e)pyrene	ND		5.6	43	8.8		120
Benzo(a)pyrene	ND		ND	ND	ND	J	ND
Perylene	ND		ND	ND	ND		ND
Indeno(1,2,3-c,d)pyrene	ND		ND	ND	ND		ND
Dibenz(a,h)anthracene	ND		ND	ND	ND		ND
Benzo(g,h,i)perylene	ND		ND	ND	ND		ND
Total PAH	2.7		18000	140000	16000		220000
2-methylnaphthalene	0.27		130	990	130		1800
1-methylnaphthalene	0.17		140	1100	140		1900
2,6-dimethylnaphthalene	0.10		62	470	47		650
2,3,5-trimethylnaphthalene	ND		64	490	61		840
1-methylphenanthrene	ND		210	1600	180		2500

B, Laboratory/XAD-2 contaminant is major contributor to analyte concentration.

Table 12. Continued, Concentrations of PAHs For Tests #1 and #2

Client/Field ID:	Sample #12, Test #2, 11 m		Sample #12, Test #2, 11 m	Sample #6, Test #2, 11 m	Sample #6, Test #2, 11 m	Sample #16, Test #2, 100 m	
BOS Sample ID:	TD65		TD65	TD60	TD60	TD69	
Batch ID:	96-033		96-033	96-033	96-033	96-033	
Matrix:	Oil		Oil	Oil	Oil	Oil	
Sample Weight (mg, oil weight)	6.70		6.70	5.80	5.80	1.40	
Sample Volume (L)	80.1		80.1	81.9	81.9	194.5	
Dilution:	1.01		1.01	1.01	1.01	1.01	
Reporting Unit:	mg/kg oil		ug/m3	mg/kg oil	ug/m3	mg/kg oil	
Reporting Limit:	5 mg/kg			5 mg/kg		5 mg/kg	
Decalin	14		1.2	18	1.3	32	B
C1-decalins	45		3.8	56	3.9	66	B
C2-decalins	150		13	160	12	190	
C3-decalins	220		18	220	16	130	
C4-decalins	170		14	180	13	230	
Benzo[b]thiophene	6.5		0.55	6.5	0.46	6.9	
C1-benzo[b]thiophenes	19		1.6	17	1.2	23	
C2-benzo[b]thiophenes	27		2.3	27	1.9	27	
C3-benzo[b]thiophenes	46		3.8	43	3.1	46	
C4-benzo[b]thiophenes	75		6.3	74	5.2	61	
Naphthalene	180		15	200	14	260	
C1-naphthalenes	180		15	190	14	190	
C2-naphthalenes	320		27	320	23	300	
C3-naphthalenes	460		38	440	31	400	
C4-naphthalenes	490		41	510	36	430	
Biphenyl	13		1.1	13	0.89	15	
Acenaphthylene	41		3.4	41	2.9	33	
Acenaphthene	13		1.1	13	0.90	14	
Dibenzofuran	6.4		0.54	5.9	0.42	9.2	B
Fluorene	52		4.3	54	3.8	44	
C1-fluorenes	130		11	150	10	120	
C2-fluorenes	580		49	650	46	470	
C3-fluorenes	1300		110	1400	100	1200	
Anthracene	19		1.6	19	1.3	22	
Phenanthrene	140		11	140	9.9	150	
C1-phenanthrenes/anthracenes	580		48	620	44	600	
C2-phenanthrenes/anthracenes	1100		88	1100	80	1200	
C3-phenanthrenes/anthracenes	1100		92	1200	82	1200	
C4-phenanthrenes/anthracenes	640		53	610	44	680	
Dibenzothiophene	170		14	180	12	160	
C1-dibenzothiophenes	1000		86	1100	75	970	
C2-dibenzothiophenes	2500		200	2700	190	2600	
C3-dibenzothiophenes	2900		250	3100	220	3000	
Fluoranthene	19		1.6	23	1.6	30	
Pyrene	29		2.5	26	1.8	25	
C1-fluoranthenes/pyrenes	130		11	120	8.7	130	
C2-fluoranthenes/pyrenes	210		18	230	16	220	
C3-fluoranthenes/pyrenes	280		23	300	21	300	
Benz(a)anthracene	ND		ND	ND	ND	ND	
Chrysene	39		3.2	44	3.1	ND	
C1-chrysenes	66		5.5	63	4.5	71	
C2-chrysenes	92		7.7	90	6.4	93	
C3-chrysenes	68		5.7	64	4.5	71	
C4-chrysenes	ND		ND	ND	ND	ND	
Benzo(b)fluoranthene	6.7		0.56	5.5	0.39	5.9	
Benzo(k)fluoranthene	ND		ND	ND	ND	ND	
Benzo(e)pyrene	4.7	J	0.40	6.1	0.43	ND	
Benzo(a)pyrene	ND		ND	ND	ND	ND	
Perylene	ND		ND	ND	ND	ND	
Indeno(1,2,3-c,d)pyrene	ND		ND	ND	ND	ND	
Dibenz(a,h)anthracene	ND		ND	ND	ND	ND	
Benzo(g,h,i)perylene	ND		ND	ND	ND	ND	
Total PAH	16000		1300	17000	1200	16000	
2-methylnaphthalene	160		14	170	12	170	
1-methylnaphthalene	170		14	170	12	170	
2,6-dimethylnaphthalene	63		5.3	73	5.1	60	
2,3,5-trimethylnaphthalene	76		6.3	64	4.5	52	
1-methylphenanthrene	210		18	210	15	190	

B, Laboratory/XAD-2 contaminant is major contributor to analyte concentration.

Table 12. Continued, Concentrations of PAHs For Tests #1 and #2

Client/Field ID:	Sample #16, Test #2, 100 m		Sample #3, Test #2, 100 m		Sample #3, Test #2, 100 m	
BOS Sample ID:	TD69		TD57		TD57	
Batch ID:	96-033		96-033		96-033	
Matrix:	Oil		Oil		Oil	
Sample Weight (mg, oil weight)	1.40		1.30		1.30	
Sample Volume (L)	194.5		215.1		215.1	
Dilution:	1.01		1.01		1.01	
Reporting Unit:	ug/m3		mg/kg oil		ug/m3	
Reporting Limit:			5 mg/kg			
Decalin	0.23	B	91		0.55	
C1-decalins	0.47	B	110		0.67	
C2-decalins	1.4		320		1.9	
C3-decalins	0.91		540		3.3	
C4-decalins	1.7		470		2.8	
Benzo[b]thiophene	0.049		10		0.062	
C1-benzo[b]thiophenes	0.17		27		0.16	
C1-benzo[b]thiophenes	0.19		32		0.20	
C1-benzo[b]thiophenes	0.33		49		0.29	
C1-benzo[b]thiophenes	0.44		72		0.44	
Naphthalene	1.8		380		2.3	
C1-naphthalenes	1.4		250		1.5	
C2-naphthalenes	2.2		370		2.2	
C3-naphthalenes	2.9		450		2.7	
C4-naphthalenes	3.1		450		2.7	
Biphenyl	0.11		20		0.12	
Acenaphthylene	0.24		43		0.26	
Acenaphthene	0.10		20		0.12	
Dibenzofuran	0.066	B	15	B	0.091	B
Fluorene	0.32		58		0.35	
C1-fluorenes	0.89		140		0.84	
C2-fluorenes	3.4		650		3.9	
C3-fluorenes	8.8		1500		8.9	
Anthracene	0.16		28		0.17	
Phenanthrene	1.0		230		1.4	
C1-phenanthrenes/anthracenes	4.3		750		4.5	
C2-phenanthrenes/anthracenes	8.7		1400		8.4	
C3-phenanthrenes/anthracenes	8.5		1300		7.8	
C4-phenanthrenes/anthracenes	4.9		830		5	
Dibenzothiophene	1.1		180		1.1	
C1-dibenzothiophenes	6.9		1300		7.7	
C2-dibenzothiophenes	19		2900		18	
C3-dibenzothiophenes	21		3600		21	
Fluoranthene	0.21		36		0.22	
Pyrene	0.18		35		0.21	
C1-fluoranthenes/pyrenes	0.95		140		0.82	
C2-fluoranthenes/pyrenes	1.6		320		1.9	
C3-fluoranthenes/pyrenes	2.2		310		1.9	
Benz(a)anthracene	ND		ND		ND	
Chrysene	ND		50		0.3	
C1-chrysenes	0.51		79		0.48	
C2-chrysenes	0.67		110		0.66	
C3-chrysenes	0.51		89		0.54	
C4-chrysenes	ND		ND		ND	
Benzo(b)fluoranthene	0.042		8.4		0.051	
Benzo(k)fluoranthene	ND		ND		ND	
Benzo(e)pyrene	ND		7.5		0.045	
Benzo(a)pyrene	ND		ND		ND	
Perylene	ND		ND		ND	
Indeno(1,2,3-c,d)pyrene	ND		ND		ND	
Dibenz(a,h)anthracene	ND		ND		ND	
Benzo(g,h,i)perylene	ND		ND		ND	
Total PAH	110		20000		120	
2-methylnaphthalene	1.3		240		1.4	
1-methylnaphthalene	1.2		220		1.3	
2,6-dimethylnaphthalene	0.43		78		0.47	
2,3,5-trimethylnaphthalene	0.37		81		0.49	
1-methylphenanthrene	1.4		240		1.4	

B, Laboratory/XAD-2 contaminant is major contributor to analyte concentration.

Table 13. Tentative Identification of Major 'Unknown' Peaks (compounds) in Fog Oil and Selected Air Samples

Fog Oil				Test #1, 11 m				Test #2, 1/2 m			
Retention Time (min)	Identification	Quality Match	Concentration (mg/kg oil)	Retention Time (min)	Identification	Quality Match	Concentration (mg/kg oil)	Retention Time (min)	Identification	Quality Match	Concentration (mg/kg oil)
17.65	C2-Naphthalene	97	245.30	17.73	C2-Naphthalene	96	222.26	-	-	-	-
-	-	-	-	17.82	C2-Naphthalene	94	185.41	-	-	-	-
-	-	-	-	20.34	C3-Naphthalene	97	232.33	20.25	C3-Naphthalene	97	350.25
-	-	-	-	-	-	-	-	21.2	Diethyl Phthalate	96	2112.02
-	-	-	-	23.43	C1-Fluorene	<90	185.04	-	-	-	-
-	-	-	-	24.29	Dibenzothiophene	91	138.03	-	-	-	-
25.20	saturated alkane	<90	500.36	25.42	Saturated Alkane	<90	398.17	25.21	Saturated Alkane	<90	505.45
25.38	C2-Fluorene	96	438.01	25.92	C2-Fluorene	<90	186.10	25.38	C2-Fluorene	<90	418.62
25.89	C1-Dibenzothiophene	91	609.52	26.16	C1-Dibenzothiophene	90	756.43	25.90	C1-Dibenzothiophene	93	893.72
26.25	C1-Dibenzothiophene	90	259.50	26.90	C1-Dibenzothiophene	<90	246.19	26.25	C1-Dibenzothiophene	90	370.08
26.58	C1-Dibenzothiophene	90	434.00	-	-	-	-	26.59	C1-Dibenzothiophene	91	427.32
27.55	C2-Dibenzothiophene	95	529.17	-	-	-	-	27.56	C2-Dibenzothiophene	94	626.96
27.66	C3-Fluorene	<90	254.63	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	27.81	C2-Dibenzothiophene	<90	332.50
27.92	C2-Dibenzothiophene	<90	760.93	-	-	-	-	27.93	C2-Dibenzothiophene	<90	1063.59
28.28	C2-Dibenzothiophene	91	1214.86	28.30	C2-Dibenzothiophene	<90	541.34	28.29	C2-Dibenzothiophene	95	1096.39
-	-	-	-	28.66	C2-Dibenzothiophene	93	1003.38	-	-	-	-
28.83	C2-Phenanthrene	93	435.84	-	-	-	-	28.84	C2-Phenanthrene	94	512.94
28.97	C3-Dibenzothiophene	<90	507.41	-	-	-	-	28.92	C3-Dibenzothiophene	<90	785.49
29.36	C3-Dibenzothiophene	<90	767.68	-	-	-	-	29.37	C3-Dibenzothiophene	<90	624.42
29.57	C3-Dibenzothiophene	<90	302.69	-	-	-	-	-	-	-	-
29.69	C3-Dibenzothiophene	<90	706.70	29.76	C3-Dibenzothiophene	<90	457.24	29.71	C3-Dibenzothiophene	<90	654.47
29.86	C3-Dibenzothiophene	<90	690.85					29.87	C3-Dibenzothiophene	<90	817.52
-	-	-	-	30.26	C3-Dibenzothiophene	<90	398.92	-	-	-	-
-	-	-	-	-	-	-	-	30.55	C3-Phenanthrene	<90	468.87
30.66	C3-Phenanthrene	<90	483.97	-	-	-	-	30.66	C3-Phenanthrene	<90	637.81
-	-	-	-	30.75	C3-Dibenzothiophene	<90	283.06	-	-	-	-
-	-	-	-	35.17	Phthalate	<90	241.75	-	-	-	-
-	-	-	-	35.31	Phthalate	<90	304.42	-	-	-	-
40.13	unknown	<90	267.26	-	-	-	-	-	-	-	-
-	-	-	-	40.39	Phthalate	<90	332.25	-	-	-	-
-	-	-	-	40.76	Phthalate	<90	325.45	-	-	-	-

Appendix C

FINAL REPORT

Study Title

SALMONELLA PREINCUBATION MUTAGENICITY ASSAY FOR A PETROLEUM EXTRACT

Test Article

TD71 and TD72

Authors

Valentine O. Wagner, III, M.S.
Jamie E. Sly

Study Completion Date

04/11/96

Performing Laboratory

Microbiological Associates, Inc.
9900 Blackwell Road and 9630 Medical Center Drive
Rockville, MD 20850

Laboratory Study Number

G96AG87-8.505

Sponsor Project Number

728715

Sponsor

Harland Bartholomew & Associates, Inc.
400 Woods Mill Road South, Suite 330
Chesterfield, MO 63017

STATEMENT OF COMPLIANCE

Study No. G96AG87-8.505 was conducted in compliance with the U.S. FDA Good Laboratory Practice Regulations as published in 21 CFR 58, the U.S. EPA GLP Standards 40 CFR 792 and 40 CFR 160, the UK GLP Compliance Programme, the Japanese GLP Standard and the OECD Principles of Good Laboratory Practice in all material aspects with the following exceptions:

> The identity, strength, purity and composition or other characteristics to define the test or control article have not been determined by the testing facility.
>
> Analyses to determine the uniformity, concentration, or stability of the test or control article were not performed by the testing facility.
>
> The stability of the test or control article under the test conditions has not been determined by the testing facility.

Valentine O. Wagner, III

Valentine O. Wagner, III, M.S.
Study Director

4/11/96
Date

QUALITY ASSURANCE STATEMENT

Study Title: *Salmonella* Preincubation Mutagenicity Assay For A Petroleum Extract

Study Number: G96AG87 - G96AG88.505

Study Director: Valentine O. Wagner, III, M.S.

This study has been divided into a series of in-process phases. Using a random sampling approach, Quality Assurance monitors each of these phases over a series of studies. Procedures, documentation, equipment records, etc., are examined in order to assure that the study is performed in accordance with the U.S. FDA Good Laboratory Practice Regulations (21 CFR 58), the U.S. EPA GLPs (40 CFR 792 and 40 CFR 160), the UK GLP Compliance Programme, the Japanese GLP Standard, and the OECD Principles of Good Laboratory Practice and to assure that the study is conducted according to the protocol and relevant Standard Operating Procedures.

The following are the inspection dates, phases inspected, and report dates of QA inspections of this study.

INSPECT ON 13 MAR 96, TO STUDY DIR 13 MAR 96, TO MGMT 14 MAR 96
PHASE: Protocol Review

INSPECT ON 15 MAR 96, TO STUDY DIR 15 MAR 96, TO MGMT 15 MAR 96
PHASE: Preparation of S9 mixture

INSPECT ON 02 APR 96, TO STUDY DIR 02 APR 96, TO MGMT 02 APR 96
PHASE: Entering plate counts into Ames program

INSPECT ON 10 APR 96, TO STUDY DIR 10 APR 96, TO MGMT 11 APR 96
PHASE: Final Report

This report describes the methods and procedures used in the study and the reported results accurately reflect the raw data of the study.

Diane B. Madsen
QUALITY ASSURANCE

4-11-96
DATE

SALMONELLA PREINCUBATION MUTAGENICITY ASSAY FOR A PETROLEUM EXTRACT

FINAL REPORT

Sponsor: **Harland Bartholomew & Associates, Inc.**
400 Woods Mill Road South, Suite 330
Chesterfield, MO 63017

Authorized Representative: **Bruce Cox, Parsons Engineering**

Performing Laboratory: **Microbiological Associates, Inc. (MA)**
9900 Blackwell Road and 9630 Medical Center Drive
Rockville, Maryland 20850

Test Article Identification	MA Study Number	Test Article Lot Number	Test Article Description	Test Article Storage Condition*
TD71	G96AG87.505	Not provided	yellow liquid	2-8°C
TD72	G96AG88.505	Not provided	yellow liquid	2-8°C

* Protected from exposure to light

Sponsor Project No.: **728715**

Test Article Receipt: **02/21/96**

Study Initiation: **03/13/96**

Associate Study Director: Richard H.C. San, Ph.D.

Study Director: Valentine O. Wagner, III 4/11/96
Valentine O. Wagner, III, M.S. Date

TABLE OF CONTENTS

SUMMARY

The dimethylsulfoxide extract of each test article was tested in the bacterial reverse mutation assay using *S. typhimurium* tester strain TA98 in the presence of Aroclor-induced hamster liver S9. The assay was performed using the preincubation method. The mutagenicity assay was used to evaluate the mutagenic potential of the test article for the ability of its extract (and/or metabolites) to induce reverse mutations at a selected locus of *S. typhimurium* tester strain TA98. This test system, modified to test petroleum extracts, has been shown to be a reliable indicator of the carcinogenic potential of high boiling-point ($\geq 500°F$) oils.

Dimethylsulfoxide was selected as the solvent of choice based on the methods of Blackburn *et al.* (1984) and compatibility with the target cells. The maximum dose level tested in the mutagenicity assay was 60 μl of undiluted test article extract per plate. Subsequent dose levels were prepared by diluting the test article extracts in dimethylsulfoxide. These dilutions were soluble at approximately 0.83 ml/ml, the most concentrated dilution prepared.

The results of the *Salmonella* Preincubation Mutagenicity Assay for a Petroleum Extract indicate that under the conditions of this study no positive response was observed. Neither of the test articles caused a positive response with tester strain TA98 in the presence of Aroclor-induced hamster liver S9. Neither precipitate nor appreciable toxicity was observed. The overall evaluations are as follows:

Summary of Results			
Test Article ID	MA Study No.	Mutagenicity Result[a] (Maximum fold increase)	Mutagenicity Index[b]
TD71	G96AG87.505	-	0
TD72	G96AG88.505	-	0
HC235	positive control oil	3.1	0.9

[a] For a test material to be considered positive, its extract must cause at least a dose-responsive doubling in the mean revertants per plate.

[b] The mutagenicity index (MI) for positive materials is calculated by performing a robust, nonlinear regression analysis of the assay data. It has been successfully used to rank samples as to their carcinogenic potency. A correlation between the MI and number of tumors *in vivo* has been established and MI values ≥ 2 are considered biologically significant. In the absence of a statistically significant dose response, an MI of zero is assigned. If a statistically significant dose response is observed but the maximum increase in revertant colony count is less than 2-fold above the vehicle control, the test article is assigned an MI of less than one but greater than zero.

PURPOSE

The purpose of this study is to evaluate the mutagenic potential of the test article (or its metabolites) by measuring the ability of its extract to induce back mutations at a selected locus of *Salmonella typhimurium* TA98 in the presence of aroclor induced 80% hamster microsomal enzymes. This test system has been shown to be predictive of the carcinogenicity of certain oils.

CHARACTERIZATION OF TEST AND CONTROL ARTICLES

The test article was received by Microbiological Associates, Inc. on 02/21/96 and was characterized as shown on page 4. The dosing solutions were not adjusted to compensate for the purity of the test article. Aliquots of dosing solution preparations were retained for chemical analysis by the Sponsor.

To extract test article, a 1.0 g aliquot of test article was placed in a conical glass centrifuge tube (with a Teflon-lined screw cap). For test articles that are extremely viscous, a 3.0 ml aliquot of cyclohexane (CAS# 110-82-7, Aldrich Chemical Co.) was added and the mixture was vortexed until homogeneous prior to the addition of dimethylsulfoxide (DMSO, CAS# 67-68-5, Fisher Scientific). A 5.0 ml aliquot of DMSO was added and the test article/cyclohexane/DMSO mixture was again vortexed until homogeneous. This mixture was allowed to sit for 5 minutes and was once again vortexed. This vortex-sitting procedure was repeated for a total of six cycles. The mixture was then centrifuged at 1000 rpm for 10 minutes at room temperature in a centrifuge, using a swinging-bucket rotor. The DMSO layer was carefully removed by pipetting from beneath the oil/cyclohexane layer, taking care not to cross-contaminate the DMSO extract with cyclohexane. For each extract in which cyclohexane was used, the extract was heated in an open tube at 37±2°C for 30 minutes before blowing with N_2 for 1 to 2 minutes. In this study, since the test articles were not extremely viscous, cyclohexane was not used in the extraction process.

Aliquots of dosing solution preparations were returned to the Sponsor for chemical analysis.

Positive controls plated concurrently with the assay are listed below:

Strain	S9 Activation	Positive Control	Concentration (per plate)
TA98	+	benzo[a]pyrene	10 μg
		HC 235	See data table
Source and Grade benzo[a]pyrene (CAS #50-32-8), Aldrich Chemical Co., 98% pure HC 235, crude distillate			

To determine the sterility of the test article extract, the highest dose level of extract used in the mutagenicity assay was plated on selective agar with an aliquot volume equal to that used in the assay.

MATERIALS AND METHODS

Test System

The tester strain used was the *Salmonella typhimurium* histidine auxotroph TA98 described by Ames *et al.* (1975). This tester strain was received on 11/10/92 directly from Dr. Bruce Ames, University of California, Berkeley.

Tester strains TA98 is reverted from histidine dependence (auxotrophy) to histidine independence (prototrophy) by frameshift mutagens.

Overnight cultures were prepared by inoculating from the appropriate master plate or from the appropriate frozen permanent stock into a vessel containing ~25 ml of culture medium. To assure that cultures were harvested in late log phase, the length of incubation was controlled and monitored. Following inoculation, the flask was placed in a shaker/incubator programmed to begin shaking at approximately 100 rpm at 37±2°C 16 hours before the anticipated time of harvest. The overnight culture was subcultured by using 2.0 ml of the 16-hour culture to inoculate 8.0 ml of fresh broth. The inoculated flask was then placed in a shaker/incubator for 3 hours at approximately 100 rpm and 37±2°C. At the end of the 3 hour incubation, each culture was monitored spectrophotometrically for turbidity and was harvested at a percent transmittance yielding a titer of approximately 10^9 cells per milliliter. If it was necessary to inoculate multiple flasks to have sufficient volume of culture for the studies, they were combined before use. The actual titers were determined by viable count assays on nutrient agar plates.

Metabolic Activation System

Aroclor 1254-induced hamster liver S9 was used as the metabolic activation system. The S9 was prepared from male Syrian Golden hamsters induced with a single intraperitoneal injection of Aroclor 1254, 500 mg/kg, five days prior to sacrifice. The S9 batch was prepared 10/06/95 and stored at $\leq$-70°C until used. Each bulk preparation of S9 was assayed for its ability to metabolize 2-aminoanthracene and 7,12-dimethylbenz(a)anthracene to forms mutagenic to *Salmonella typhimurium* TA100.

The S9 mix was prepared immediately before its use and contained 80% S9, 5 mM glucose-6-phosphate, 8 mM β-nicotinamide-adenine dinucleotide phosphate, 8 mM $MgCl_2$ and 33 mM KCl in a 100 mM phosphate buffer at pH 7.4. To confirm the sterility of the S9 mix, a 0.5 ml aliquot of was plated on selective agar.

Mutagenicity Assay

The mutagenicity assay was used to evaluate the mutagenic potential of the test article. A minimum of eight dose levels of each test article extract along with appropriate vehicle and positive controls were plated with tester strain TA98 in the presence of 80% hamster liver S9 activation. All dose levels of test article, vehicle controls and positive controls were plated in triplicate.

Plating and Scoring Procedures

The test system was exposed to the test article extract via the modification of the preincubation methodology (Yahagi *et al.* 1977) developed specifically for oils by Blackburn *et al.* (1984).

On the day of its use, minimal top agar, containing 0.8 % agar (W/V) and 0.5 % NaCl (W/V), was melted and supplemented with L-histidine, D-biotin and L-tryptophan solution to a final concentration of 50 μM each. Top agar not used with S9 was supplemented with 25 ml of water for each 100 ml of minimal top agar. For the preparation of media and reagents, all references to water imply sterile, deionized water produced by the Milli-Q Reagent Water System. Bottom agar was Vogel-Bonner minimal medium E (Vogel and Bonner, 1956) containing 1.5 % (W/V) agar. Nutrient bottom agar was Vogel-Bonner minimal medium E containing 1.5 % (W/V) agar and supplemented with 2.5 % (W/V) Oxoid Nutrient Broth No. 2 (dry powder). Nutrient Broth was Vogel-Bonner salt solution supplemented with 2.5 % (W/V) Oxoid Nutrient Broth No. 2 (dry powder).

Each plate was labeled with a code system that identified the test article, test phase, dose level, tester strain, and activation, as described in detail in Microbiological Associates, Inc.'s Standard Operating Procedures.

The test article extract dilutions were prepared immediately before use. A 500 μl aliquot of S9 mix was added to 13 X 100 mm glass culture tubes pre-heated to

37±2°C. To these tubes were added 100 µl of appropriate tester strain and either 60 µl of vehicle, test article extract or positive control oil extract. When plating the positive controls, the test article extract aliquot was replaced by a 50 µl aliquot of appropriate positive control. After vortexing, these mixtures were incubated without shaking for 20±2 minutes at 37±2°C. Following the preincubation, 2.0 ml of selective top agar was added to each tube and the mixture was vortexed and overlaid onto the surface of 25 ml of minimal bottom agar. After the overlay had solidified, the plates were inverted and incubated for approximately 48 to 72 hours at 37±2°C. Plates that were not counted immediately following the incubation period were stored at 4±2°C until colony counting could be conducted.

The condition of the bacterial background lawn was evaluated for evidence of test article toxicity and precipitate by using a dissecting microscope. Toxicity and degree of precipitation were scored relative to the vehicle control plate using the codes shown below.

Code	Description	Characteristics
1	Normal	Distinguished by a healthy microcolony lawn.
2	Slightly Reduced	Distinguished by a noticeable thinning of the microcolony lawn and possibly a slight increase in the size of the microcolonies compared to the vehicle control plate.
3	Moderately Reduced	Distinguished by a marked thinning of the microcolony lawn resulting in a pronounced increase in the size of the microcolonies compared to the vehicle control plate.
4	Severely Reduced	Distinguished by an extreme thinning of the microcolony lawn resulting in an increase in the size of the microcolonies compared to the vehicle control plate such that the microcolony lawn is visible to the unaided eye as isolated colonies.
5	Absent	Distinguished by a complete lack of any microcolony lawn over ≥90% of the plate.
6	Obscured by Precipitate	The background bacterial lawn cannot be accurately evaluated due to microscopic test article precipitate.
SP	Slight Precipitate	Distinguished by noticeable precipitate on the plate, either macro or microscopically; however, any precipitate particles detected by the automated colony counter must total less than 10% of the revertant colony count (e.g., ≤3 particles on a plate with 30 revertants.)
MP	Moderate Precipitate	Distinguished by a marked amount of precipitate on the plate such that the number of precipitate particles detected by the automated colony counter exceeds 10% of the revertant colony count (e.g., >3 particles on a plate with 30 revertants).
HP	Heavy Precipitate	Distinguished by a large amount of precipitate on the plate, making the revertant colonies difficult to distinguish from the precipitate.

Revertant colonies for a given tester strain and activation condition were counted either entirely by automated colony counter or entirely by hand unless the assay was the preliminary toxicity assay or the plate exhibited toxicity. Plates with sufficient test article precipitate to interfere with automated colony counting were counted manually.

Evaluation of Results

For each replicate plating, the mean and standard deviation of the number of revertants per plate were calculated and are reported.

For a test article extract to be considered positive, it must cause at least a doubling in the mean revertants per plate. This increase in the mean number of revertants per plate must be accompanied by a dose response to increasing concentrations of the test article extract.

On each positive data set a robust, nonlinear regression was calculated as described by Myers *et al.* (1981). This regression analysis generates a slope value that is identified as the Mutagenicity Index (MI) and it has been successfully used to rank samples as to their carcinogenic potency. A correlation between the MI and number of tumors *in vivo* has been established and MI values ≥ 2 are considered biologically significant. In the absence of a statistically significant dose response, an MI of zero is assigned. If a statistically significant dose response is observed but the maximum increase in revertant colony count is less than 2-fold above the vehicle control, the test article is assigned an MI of less than one but greater than zero. If the standard model does not fit the curve, Blackburn recommends the use of a linear model to determine the slope of the dose response curve when the maximum fold increase is at least two-fold. If these data are found to have a significant linear relationship, then the MI is the slope of the predicted dose-response curve.

Criteria for a Valid Test

The following criteria must be met for the mutagenicity assay to be considered valid. All tester strain cultures must demonstrate the presence of the deep rough mutation (*rfa*), the presence of the pKM101 plasmid R-factor and the deletion in the *uvr*B gene. All cultures must demonstrate the characteristic mean number of spontaneous revertants (20 - 60) in the vehicle controls. To ensure that appropriate numbers of bacteria are plated, tester strain culture titers must be greater than or equal to 0.3×10^9 cells/ml. The mean of each positive control must exhibit at least a three-fold increase in the number of revertants over the mean value of the respective vehicle control. A minimum of three non-toxic dose levels are required to evaluate assay data. A dose level is considered toxic if one or both of the following criteria are met: (1) A >50 % reduction in the mean number of revertants per plate as compared to the mean vehicle control value. This reduction must be accompanied by an abrupt dose-dependent drop in the revertant count. (2) A reduction in the background lawn.

Archives

Upon completion of the final report, all raw data and reports will be maintained by the Quality Assurance Unit of Microbiological Associates, Rockville, MD in accordance with the relevant Good Laboratory Practices Regulations.

RESULTS AND DISCUSSION

Solubility Test

Dimethylsulfoxide was selected as the solvent of choice based on the methods of Blackburn *et al.* (1984) and compatibility with the target cells. The maximum dose level tested in the mutagenicity assay was 60 μl of undiluted test article extract per plate. Subsequent dose levels were prepared by diluting the test article extracts in dimethylsulfoxide. These dilutions were soluble at approximately 0.83 ml/ml, the most concentrated dilution prepared.

Mutagenicity Assay

The results of the mutagenicity assay are presented in Tables 1 through 3 and summarized in Table 4. These data were generated in Experiment B2. Neither precipitate nor appreciable toxicity was observed.

In Experiment B1, the assay was not evaluated due to unacceptable vehicle control values but was repeated in Experiment B2.

In Experiment B2, no positive responses were observed with any of the tester strains in the presence and absence of S9 activation.

CONCLUSION

All criteria for a valid study were met as described in the protocol. The results of the *Salmonella* Preincubation Mutagenicity Assay for a Petroleum Extract indicate that under the conditions of this study, extracts of test articles did not cause a positive response with tester strain TA98 in the presence of Aroclor-induced hamster liver S9.

Summary of Results			
Test Article ID	MA Study No.	Mutagenicity Result[a] (Maximum fold increase)	Mutagenicity Index[b]
TD71	G96AG87.505	-	0
TD72	G96AG88.505	-	0
HC-235	Positive Control Oil	3.1	0.9

[a] For a test material to be considered positive, its extract must cause at least a dose-responsive doubling in the mean revertants per plate.

[b] The mutagenicity index (MI) for positive materials is calculated by performing a robust, nonlinear regression analysis of the assay data. It has been successfully used to rank samples as to their carcinogenic potency. A correlation between the MI and number of tumors *in vivo* has been established and MI values ≥ 2 are considered biologically significant. In the absence of a statistically significant dose response, an MI of zero is assigned. If a statistically significant dose response is observed but the maximum increase in revertant colony count is less than 2-fold above the vehicle control, the test article is assigned an MI of less than one but greater than zero.

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Blackburn, G.R., R.A. Deitch, C.A. Schreiner, M.A. Mehlman, and C.R. Mackerer (1984) Estimation of the Dermal Carcinogenic Activity of Petroleum Fractions using a Modified Ames Assay. Cell Biology and Toxicology, 1:40-48.

Myers, L.E., N.H. Sexton, L.I. Southerland, and T.J. Wolff (1981) Regression Analysis of Ames Test Data. Environmental Mutagenesis, 3:575-586.

Vogel, H.J. and D.M. Bonner (1956) Acetylornithinase of *E. coli*: Partial Purification and Some Properties, J. Biol. Chem., 218:97-106.

Yahagi, M., Y. Nagao, T. Seino, T. Sugimura and M. Okada (1977) Mutagenicities of N-nitrosamines on *Salmonella*, Mutation Research 48:121-130.

Salmonella Mutagenicity Assay

Table 1

Test Article Id	: TD71		
Study Number	: G96AG87.505	Experiment No	: B2
Strain	: TA98	Cells Seeded	: 8.2×10^8
Liver Microsomes	: Hamster liver S9	Date Plated	: 03/29/96
Vehicle	: dimethylsulfoxide (DMSO)		
Plating Aliquot	: 60 µl	Counted by	: hand

Concentration µl per plate	Plate Number	Revertants per plate	Background Code[a]	Average Revertants	Standard Deviation
Vehicle	01	27	1		
	02	27	1		
	03	24	1	26	2
5.0	01	27	1		
	02	33	1		
	03	45	1	35	9
10	01	18	1		
	02	23	1		
	03	35	1	25	9
15	01	27	1		
	02	33	1		
	03	38	1	33	6
20	01	24	1		
	02	29	1		
	03	24	1	26	3
30	01	25	1		
	02	31	1		
	03	38	1	31	7
40	01	23	1		
	02	26	1		
	03	29	1	26	3
50	01	23	1		
	02	27	1		
	03	18	1	23	5
60	01	26	1		
	02	23	1		
	03	24	1	24	2
Positive Control benzo[a]pyrene 10.0 µg per plate[b]					
	01	94	1		
	02	81	1		
	03	103	1	93	11

[a]Background bacterial evaluation code
1=Normal 2=Slightly reduced 3=Moderately reduced
4=Extremely reduced 5=Absent 6=Obscured by precipitate
SP=Slight precipitate MP=Moderate precipitate HP=Heavy precipitate

[b]Positive control plates were machine counted

Salmonella Mutagenicity Assay

Table 2

Test Article Id	: TD72		
Study Number	: G96AG88.505	Experiment No	: B2
Strain	: TA98	Cells Seeded	: 8.2 X 10^8
Liver Microsomes	: Hamster liver S9	Date Plated	: 03/29/96
Vehicle	: dimethylsulfoxide (DMSO)		
Plating Aliquot	: 60 µl	Counted by	: hand

Concentration µl per plate	Plate Number	Revertants per plate	Background Code[a]	Average Revertants	Standard Deviation
Vehicle	01	27	1		
	02	27	1		
	03	24	1	26	2
5.0	01	21	1		
	02	32	1		
	03	33	1	29	7
10	01	28	1		
	02	28	1		
	03	25	1	27	2
15	01	18	1		
	02	22	1		
	03	29	1	23	6
20	01	25	1		
	02	29	1		
	03	24	1	26	3
30	01	31	1		
	02	23	1		
	03	24	1	26	4
40	01	22	1		
	02	24	1		
	03	27	1	24	3
50	01	17	1		
	02	25	1		
	03	25	1	22	5
60	01	32	1		
	02	29	1		
	03	29	1	30	2
Positive Control benzo[a]pyrene 10.0 µg per plate[b]					
	01	94	1		
	02	81	1		
	03	103	1	93	11

[a]Background bacterial evaluation code
1=Normal 2=Slightly reduced 3=Moderately reduced
4=Extremely reduced 5=Absent 6=Obscured by precipitate
SP=Slight precipitate MP=Moderate precipitate HP=Heavy precipitate

[b]Positive control plates were machine counted

Salmonella Mutagenicity Assay

Table 3

Test Article Id	: HC-235	Experiment No	: B2
Strain	: TA98	Cells Seeded	: 8.2 X 10^8
Liver Microsomes	: Hamster liver S9	Date Plated	: 03/29/96
Vehicle	: dimethylsulfoxide (DMSO)		
Plating Aliquot	: 60 µl	Counted by	: hand

Concentration µl per plate	Plate Number	Revertants per plate	Background Code[a]	Average Revertants	Standard Deviation
Vehicle	01	27	1		
	02	27	1		
	03	24	1	26	2
5.0	01	36	1		
	02	35	1		
	03	28	1	33	4
10	01	29	1		
	02	29	1		
	03	19	1	26	6
15	01	29	1		
	02	22	1		
	03	30	1	27	4
20	01	55	1		
	02	37	1		
	03	48	1	47	9
30	01	53	1		
	02	43	1		
	03	60	1	52	9
40	01	56	1		
	02	61	1		
	03	65	1	61	5
50	01	77	1		
	02	78	1		
	03	85	1	80	4
60	01	61	1		
	02	52	1		
	03	64	1	59	6
Positive Control benzo[a]pyrene 10.0 µg per plate[b]					
	01	94	1		
	02	81	1		
	03	103	1	93	11

[a]Background bacterial evaluation code
1=Normal 2=Slightly reduced 3=Moderately reduced
4=Extremely reduced 5=Absent 6=Obscured by precipitate
SP=Slight precipitate MP=Moderate precipitate HP=Heavy precipitate

[b]Positive control plates were machine counted

Salmonella Mutagenicity Assay
Summary of Results

Table 4

Test Article Id : TD71
Study Number : G96AG87.505 Experiment No : B2

Average Revertants Per Plate ± Standard Deviation
Liver Microsomes: Hamster liver S9

Dose (μl)	G96AG87	G96AG88	HC-235
0.0	26 ± 2	26 ± 2	26 ± 2
5.0	35 ± 9	29 ± 7	33 ± 4
10	25 ± 9	27 ± 2	26 ± 6
15	33 ± 6	23 ± 6	27 ± 4
20	26 ± 3	26 ± 3	47 ± 9
30	31 ± 7	26 ± 4	52 ± 9
40	26 ± 3	24 ± 3	61 ± 5
50	23 ± 5	22 ± 5	80 ± 4
60	24 ± 2	30 ± 2	59 ± 6
Pos	93 ± 11	93 ± 11	93 ± 11

0.0 = Vehicle plating aliquot of 60 μl
Pos = Positive Control concentrations as specified in Materials and Methods section.

APPENDIX I

Historical Control Data

Historical Vehicle and Positive Control Values
1993 - 1995

revertants per plate

Strain	Control	Activation			
		None			
		Mean	SD	Min	Max
TA98	DMSO	36	10	16	63
	BAP	449	133	224	940
	HC235	208	67	36	416
	MI	6	1	5	7

SD = standard deviation; Min = minimum value; Max = maximum value;
DMSO = dimethylsulfoxide; BAP = benzo[a]pyrene;
HC235 = crude oil distillate;
MI = mutagenicity index for HC235

APPENDIX II

Study Protocol

dom 4-11-96 QA APPROVED

PROTOCOL AMENDMENT I

SPONSOR: **Harland Bartholomew & Associates, Inc.**

TEST ARTICLE I.D.: **TD71 and TD72**

MA STUDY NO: **G96AG87-88.505**

SPONSOR PROJECT NO.: **728715**

PROTOCOL TITLE: ***Salmonella* Preincubation Mutagenicity Assay for a Petroleum Extract**

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1. **LOCATION:** Page 2, §4.2; Address

AMENDMENT: Add the following to line 1 of the address
" and 9630 Medical Center Drive"

REASON FOR THE AMENDMENT: The assay was completed after relocation of the laboratory to the testing facility's new address.

APPROVALS:

Valentin O. Wagner, III — STUDY DIRECTOR — 4/11/96 — DATE

Bruce A. Cox — SPONSOR REPRESENTATIVE — 4/11/96 — DATE

MICROBIOLOGICAL ASSOCIATES, INC.

DOM 3-14-96 QA APPROVED

Received by RA/QA 3-13-96

MA Study Number: G96AG87-8.505

SALMONELLA PREINCUBATION MUTAGENICITY ASSAY FOR A PETROLEUM EXTRACT

1.0 PURPOSE

The purpose of this study is to evaluate the mutagenic potential of the test article (or its metabolites) by measuring the ability of its extract to induce back mutations at selected locus of *Salmonella typhimurium* TA98 in the presence of aroclor induced 80% hamster microsomal enzymes. This test system has been shown to be predictive of the carcinogenicity of certain oils.

2.0 SPONSOR

2.1 Name: **Harland Bartholomew & Associates, Inc.**
Woods ①

2.2 Address: 400 Mill Road South, Suite 330
Chesterfield, MO 63017

2.3 Representative: Bruce Cox
Parsons Engineering

2.4 Sponsor Project #: 728715

3.0 IDENTIFICATION OF TEST AND CONTROL SUBSTANCES

3.1 Test Article: **TD71 and TD72**

3.2 Controls: Positive: benzo[a]pyrene
HC-235
Negative: Vehicle controls

3.3 Determination of Strength, Purity, etc.

The Sponsor will be directly responsible for determination and documentation of the analytical purity and composition of the test article and the stability and strength of the dosing solutions.

3.4 Test Article Retention Sample

The retention of a reserve sample of the test article will be the responsibility of the Sponsor.

4.0 TESTING FACILITY AND KEY PERSONNEL

4.1 Name: Genetic and Cellular Toxicology Division
Microbiological Associates, Inc.

4.2 Address: 9900 Blackwell Road
Rockville, MD 20850

4.3 Study Director: Valentine O. Wagner, III, M.S.

4.4 Associate Study Director: Richard H. C. San, Ph.D.

5.0 TEST SCHEDULE

5.1 Proposed Experimental Initiation Date: 03/15/96

5.2 Proposed Experimental Completion Date: 04/12/96

5.3 Proposed Report Date: 04/26/96

6.0 TEST SYSTEM

The Ames Test has been shown to be a sensitive, rapid, accurate indicator of the mutagenic activity of a wide range of chemical classes.

The tester strain to be used will be the *Salmonella typhimurium* histidine auxotroph TA98 as described by Ames *et al.* (1975).

Genotype of the Strains Used for Mutagen Testing

Histidine Mutation	Additional Mutations		
hisD3052	LPS	Repair	R-factor
TA98	*rfa*	ΔuvrB	+R

This tester strain contains, in addition to a mutation in the histidine operon, two additional mutations that enhance its sensitivity to some mutagenic compounds. The *rfa* mutation causes a loss of one of the enzymes responsible for the synthesis of part of the lipopolysaccharide layer of the cell wall. The resulting cell wall deficiency increases the permeability of the cell to certain classes of chemicals such as those containing large ring systems that would otherwise be excluded by a normal intact cell wall. The second mutation is a deletion in the *uvr*B gene that results in a deficient DNA excision-repair system, and consequently, greatly enhanced sensitivity to some mutagens. Since the *uvr*B deletion extends through the *bio* gene, TA98 requires the vitamin biotin for growth. Finally, tester strain TA98 also contains the pKM101 plasmid (carrying the R-factor) that further increases the sensitivity of this strain to some mutagens. The mechanism by which this plasmid increases sensitivity to mutagens has been suggested to be by modifying an existing bacterial DNA repair polymerase complex involved with the mis-match repair process. TA98 is reverted from histidine dependence (auxotrophy) to histidine independence (prototrophy) by frameshift mutagens.

The tester strain was received directly from Dr. Bruce Ames, Department of Biochemistry, University of California, Berkeley.

7.0 EXPERIMENTAL DESIGN AND METHODOLOGY

An extract of the test article and the positive control oil HC 235 will be tested at a minimum of eight dose levels along with appropriate vehicle and positive controls with tester strain TA98 in the presence of an aroclor induced 80% hamster liver S9 mix, as described by Blackburn *et al.* (1984). All dose levels of test article extract, vehicle controls and positive controls will be plated in triplicate.

The dose levels to be used in the mutagenicity assay will be 60, 50, 40, 30, 20, 15, 10 and 5 µl of extract per plate, unless there is a limitation due to excessive toxicity or precipitate.

7.1 Frequency and Route of Administration

The test system will be exposed to an extract of the test article based on the preincubation modification of the Ames Test modified for petroleum extracts by Blackburn *et al.* (1984) and the Standard Test Method for Determining Carcinogenic Potential of Virgin Base Oils in Metalworking Fluids (ASTM Method E 1687-95).

7.2 Controls

7.2.1 Positive Controls

Positive controls plated concurrently with the assay are as follows:

Positive Controls

Strain	S9 Activation	Positive Control	Concentration (per plate)
TA98	+	benzo[a]pyrene	10 µg
		HC 235	See §7.0

A single set of positive controls will be used for all concurrently tested test articles.

7.2.2 Vehicle Control

The vehicle to be used in this study will be dimethylsulfoxide. A single set of vehicle controls will be used for all concurrently tested test articles.

7.2.3 Sterility Controls

The most concentrated test article extract dilution and S9 mix will be checked for sterility.

7.3 Exogenous Metabolic Activation

Aroclor 1254-induced hamster liver S9 will be used as the metabolic activation system. The S9 homogenate will be prepared from male Syrian Golden hamsters with a single intraperitoneal injection of Aroclor 1254, 500 mg/kg, five days prior to sacrifice. The S9 will be batch prepared and stored frozen at approximately -70°C until used. Each batch of S9 homogenate will be assayed for its ability to metabolize 2-aminoanthracene and 7,12-dimethylbenzanthracene to forms mutagenic to *S. typhimurium* TA100.

Immediately prior to use, the S9 will be thawed and mixed with a cofactor pool to contain 80% S9 homogenate, 5 mM glucose-6-phosphate, 8 mM β-nicotinamide-adenine dinucleotide phosphate, 8 mM $MgCl_2$ and 33 mM KCl in a 100 mM phosphate buffer at pH 7.4.

7.4 Preparation of Tester Strain

Overnight cultures will be prepared by transferring a colony of the tester strain from a Master Plate to a flask containing 25 ml of culture medium. To assure that cultures were harvested in late log phase, the length of incubation is controlled and monitored. At the end of the working day, the inoculated flask is placed in a resting shaker/incubator at room temperature. The shaker/incubator is programed to begin shaking at approximately 100 rpm at 37±2°C approximately 16 hours before the anticipated time of harvest. Cultures will be harvested by spectrophotometric monitoring of culture turbidity rather than by duration of incubation. A 2.0 ml aliquot of the 16-hour culture will be used to inoculate 8.0 ml of fresh medium. To have sufficient volume of culture for the study, it may be necessary to inoculate multiple flasks. The inoculated flasks will be placed in a shaker/incubator for 3 hours at approximately 100 rpm and 37±2°C. At the end of the 3 hour incubation, the flasks will be pooled if necessary, the culture characterized and then used in the assay.

7.5 Test System Identification

Each plate will be labeled with a code system that identifies the test article, test phase, dose level, tester strain and activation type as described in Microbiological Associates' Microbial Mutagenesis Standard Operating Procedures.

7.6 Test Article Extraction

One (1.0) grams of the test article and 1.5 ml of cyclohexane will be mixed in a conical glass centrifuge tube and vortexed until uniformly suspended. If the test article is not extremely viscous, the use of cyclohexane will be excluded. Five (5) milliliters of DMSO will then added and the mixture will again be vortexed. The mixture will be allowed to stand at room temperature for 5 minutes at which time it will again be vortexed. This vortex/standing

procedure will be repeated 5 additional times at 5 minute intervals. The mixture will then be centrifuged for 10 minutes at 1000 rpm and the DMSO layer will be removed. For each extract in which cyclohexane is used, the extract will be heated in an open tube at 37±2°C for 30 minutes before blowing with N_2 for 1 to 2 minutes. The extract may be stored at 4±2°C until needed. Unless specified otherwise, test article extract dilutions will be prepared immediately prior to use. All test article dosing will be at room temperature under yellow light.

7.7 Treatment of Test System

One-half (0.5) milliliter of S9 mix will be added to pre-heated 13 x 100 mm glass culture tubes. To these tubes will be added 100 µl of tester strain and 50 µl of vehicle, test article extract dilution or positive control. After vortexing, the mixture will be allowed to incubate for 20±2 minutes at 37±2°C with shaking. Two milliliters of selective top agar will then be added to each tube and the mixture will be overlaid onto the surface of 25 ml of minimal bottom agar. After the overlay has solidified, the plates will be inverted and incubated for approximately 48 to 72 hours at 37±2°C. When necessary to achieve the target concentration, aliquots of other than 50 µl of test article extract/vehicle/positive control will be plated. Plates that are not counted immediately following the incubation period will be stored at 4±2°C.

7.8 Colony Counting

The condition of the bacterial background lawn will be evaluated for evidence of test article toxicity and precipitate. Evidence of toxicity will be scored relative to the vehicle control plate and recorded along with the revertant count for that plate.

7.9 Tester Strain Verification

On the day of use in the mutagenicity assay, tester strain culture will be checked for the following genetic markers:

The presence of the *rfa* wall mutation will be confirmed by demonstrating sensitivity to crystal violet. The presence of the *uvr*B mutation will be confirmed by demonstrating sensitivity to ultraviolet light. The presence of the pKM101 plasmid will be confirmed by demonstrating resistance to ampicillin.

8.0 CRITERIA FOR DETERMINATION OF A VALID TEST

The following criteria must be met for the mutagenicity assay to be considered valid:

8.1 Tester Strain Integrity

To demonstrate the presence of the *rfa* mutation, the tester strain culture must exhibit sensitivity to crystal violet. To demonstrate the presence of the *uvr*B mutation, the tester strain culture must exhibit sensitivity to ultraviolet light. To demonstrate the presence of the pKM101 plasmid R-factor, the tester strain culture must exhibit resistance to ampicillin.

8.2 Spontaneous Revertant Background Frequency

Based on historical control data, the tester strain culture must exhibit the characteristic number of spontaneous revertants per plate in the vehicle controls. The mean revertants per plate must be within the inclusive range of 20 - 60.

8.3 Tester Strain Titers

To ensure that appropriate numbers of bacteria are plated, the tester strain culture titer must be equal to or greater than 0.3×10^9 cells per milliliter.

8.4 Positive Control Values

Each mean positive control value must exhibit at least a three fold increase over the respective mean vehicle control value for each tester strain.

8.5 Toxicity

A minimum of three non-toxic dose levels will be required to evaluate assay data. A dose level is considered toxic if it causes a >50% reduction in the mean number of revertants per plate relative to the mean vehicle control value (this reduction must be accompanied by an abrupt dose-dependent drop in the revertant count) or a reduction in the background lawn. In the event that fewer than three non-toxic dose levels are achieved, the affected portion of the assay will be repeated with an appropriate change in dose levels.

9.0 EVALUATION OF TEST RESULTS

For a test article to be evaluated positive, it must cause a dose-related increase in the mean revertants per plate of at least one tester strain with a minimum of two increasing concentrations of test article. Data sets will be judged positive if the increase in mean revertants at the peak of the dose response is equal to or greater than two times the mean vehicle control value.

In addition, on each positive data set a robust nonlinear regression will be performed as described by Myers *et al.* (1981). This regression analysis generates a slope value that is identified as the Mutagenicity Index (MI) and it has been successfully used to rank samples as to their carcinogenic potency. A correlation between the MI and number of tumors *in vivo* has been established and MI values

≥2 are considered biologically significant. In the absence of a statistically significant dose response, an MI of zero is assigned. If a statistically significant dose response is observed but the maximum increase in revertant colony count is less than two-fold above the vehicle control, the test article is assigned an MI of less than one but greater than zero. If the standard model does not fit the curve, Blackburn recommends the use of a linear model to determine the slope of the dose response curve when the maximum fold increase is at least two-fold. If these data are found to have a significant linear relationship, then the MI is the slope of the predicted dose-response curve.

10.0 REPORT

A report of the results of this study will be prepared by the Testing Laboratory and will accurately describe all methods used in the generation and analysis of data. Results presented will include:

- bacterial tester strain description
- test conditions, including dose levels and rationale for selection, number of plates per test point, toxicity, media, type and composition of metabolic activation system, treatment procedures, positive and negative controls.
- individual plate counts
- mean and standard deviation of revertant colonies per plate
- dose response relationship, if applicable
- evaluation of results
- historical control values

11.0 RECORDS AND ARCHIVES

Upon completion of the final report, all raw data and reports will be maintained by the Regulatory Affairs Unit of Microbiological Associates in accordance with the relevant Good Laboratory Practice Regulations.

12.0 REGULATORY REQUIREMENTS/GOOD LABORATORY PRACTICE

This study will be performed in compliance with the provisions of the Good Laboratory Practice Regulations for Nonclinical Laboratory Studies.

Will this study be submitted to a regulatory agency? No If so, to which agency or agencies? _____

Unless arrangements are made to the contrary, unused dosing solutions will be disposed of following administration to the test system and all residual test article will be disposed of following finalization of the report.

13.0 REFERENCES

Ames, B.N., McCann, J. and Yamasaki, E. (1975). Methods for detecting carcinogens and mutagens with the *Salmonella*/mammalian-microsome mutagenicity test. *Mutation Research* 31:347-364.

Blackburn, G.R., Deitch, R.A., Schreiner, C.A., Mehlman, M.A. and Mackerer, C.R. (1984). Estimation of the dermal carcinogenic activity of petroleum fractions using a modified Ames assay. *Cell Biology and Toxicology* 1:40-48.

Myers, L.E., Sexton, N.H., Southerland, L.I. and Wolff, T.J. (1981). Regression Analysis of Ames Test Data. *Environmental Mutagenesis* 3:575-586.

Yahagi, T., Nagao, M., Seino, Y., Matsushima, T., Sugimura, T. and Okada, M. (1977). Mutagenicities of N-nitrosamines on *Salmonella*. *Mutation Research*, 48:121-130.

14.0 APPROVAL

Bruce A. Cox — 3/4/96
SPONSOR REPRESENTATIVE — DATE

BRUCE A. COX
(Print or Type Name)

Valentine O. Wagner, III — 3/13/96
STUDY DIRECTOR — DATE

APPENDIX III

Statistical Analysis Data

Non-Linear Model

```
DATA COUNTS;
INFILE 'D:\SAS\7~.DTA';
INPUT X Y;
RUN;
PROC PRINT DATA=COUNTS;
LABEL X='Concentration'
      Y='Revertants';
PROC NLIN ITER=30 NOHALVE;
PARMS B=50 S=10 T=.001;
BOUNDS B>0, S>0, T>0;
C=.11; D=1.62;
E=EXP(-T*X); U=B+S*X; MEAN=U*E;
VAR = C*MEAN**D;
A=1000;
STDRES = (Y-MEAN)/SQRT(VAR);
PSI=-A*(STDRES<-A)+STDRES*(-A<=STDRES<=A)+A*(STDRES>A);
IF STDRES NE 0 THEN _WEIGHT_ = PSI/(STDRES*VAR);
ELSE _WEIGHT_ = 1/VAR;
MODEL Y=MEAN;
DER.B = E;
DER.S = X*E;
DER.T = -MEAN*X;
OUTPUT PREDICTED = YHAT PARMS=B S T;
PROC PRINT;
PROC PLOT;
PLOT YHAT*X='*' Y*X/OVERLAY;
RUN;
```

Linear Model

```
OPTIONS NODATE PAGESIZE=60 LINESIZE=78;
DATA COUNTS;
INFILE 'D:\SAS\7~.DTA';
INPUT TA $ DOSE REV;
PROC PRINT DATA=COUNTS;
 TITLE 'SAS Linear Analysis';
PROC GLM;
 BY TA;
 MODEL REV=DOSE / SS1;
RUN;
```

SAS Non-Linear Analysis

OBS	TA	DOSE	REV
1	AG87	60	26
2	AG87	60	23
3	AG87	60	24
4	AG87	50	23
5	AG87	50	27
6	AG87	50	18
7	AG87	40	23
8	AG87	40	26
9	AG87	40	29
10	AG87	30	25
11	AG87	30	31
12	AG87	30	38
13	AG87	20	24
14	AG87	20	29
15	AG87	20	24
16	AG87	15	27
17	AG87	15	33
18	AG87	15	38
19	AG87	10	18
20	AG87	10	23
21	AG87	10	35
22	AG87	5	27
23	AG87	5	33
24	AG87	5	45
25	AG87	0	27
26	AG87	0	27
27	AG87	0	24
28	AG87A	60	61
29	AG87A	60	52
30	AG87A	60	64
31	AG87A	50	77
32	AG87A	50	78
33	AG87A	50	85
34	AG87A	40	56
35	AG87A	40	61
36	AG87A	40	65
37	AG87A	30	53
38	AG87A	30	43
39	AG87A	30	60
40	AG87A	20	55
41	AG87A	20	37
42	AG87A	20	48
43	AG87A	15	29
44	AG87A	15	22
45	AG87A	15	30
46	AG87A	10	29
47	AG87A	10	29
48	AG87A	10	19
49	AG87A	5	36
50	AG87A	5	35
51	AG87A	5	28
52	AG87A	0	27
53	AG87A	0	27
54	AG87A	0	24
55	AG88	60	32
56	AG88	60	29

57	AG88	60	29
58	AG88	50	17
59	AG88	50	25
60	AG88	50	25
61	AG88	40	22
62	AG88	40	24
63	AG88	40	27
64	AG88	30	31
65	AG88	30	23
66	AG88	30	24
67	AG88	20	25
68	AG88	20	29
69	AG88	20	24
70	AG88	15	18
71	AG88	15	22
72	AG88	15	29
73	AG88	10	28
74	AG88	10	28
75	AG88	10	25
76	AG88	5	21
77	AG88	5	32
78	AG88	5	33
79	AG88	0	27
80	AG88	0	27
81	AG88	0	24

SAS Non-Linear Analysis

---------- TA=AG87A ----------

Non-Linear Least Squares Iterative Phase
Dependent Variable REV Method: Gauss-Newton

Iter	B	S	T	Weighted SS
0	50.000000	10.000000	0.001000	1367.010725
1	26.066768	0.580595	0.000476	74.262597
2	23.659931	1.040676	0.003622	44.486326
3	24.619076	0.819137	0.000184	43.060033
4	24.313624	0.872277	0.000715	42.648388
5	24.407228	0.853201	0.000449	42.647818
6	24.378567	0.858550	0.000518	42.640202
7	24.387038	0.856922	0.000496	42.641512
8	24.384510	0.857403	0.000503	42.641047
9	24.385261	0.857260	0.000501	42.641178
10	24.385038	0.857302	0.000501	42.641139
11	24.385104	0.857289	0.000501	42.641150
12	24.385084	0.857293	0.000501	42.641147
13	24.385090	0.857292	0.000501	42.641148
14	24.385088	0.857292	0.000501	42.641147

NOTE: Convergence criterion met.

Non-Linear Least Squares Summary Statistics Dependent Variable REV

Source	DF	Weighted SS	Weighted MS
Regression	3	1032.0977921	344.0325974
Residual	24	42.6411475	1.7767145
Uncorrected Total	27	1074.7389396	
(Corrected Total)	26	162.0158588	

Parameter	Estimate	Asymptotic Std. Error	Asymptotic 95 % Confidence Interval Lower	Upper
B	24.38508847	2.8037889278	18.598399140	30.171777810
S	0.85729241	0.4772841105	-0.127765649	1.842350464
T	0.00050109	0.0068555374	-0.013647928	0.014650112

Asymptotic Correlation Matrix

Corr	B	S	T
B	1	-0.692247933	-0.587193914
S	-0.692247933	1	0.976765853
T	-0.587193914	0.976765853	1

SAS Linear Analysis

---------- TA=AG87 ----------

General Linear Models Procedure

Number of observations in by group = 27

Dependent Variable: REV

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	110.9400000	110.9400000	3.18	0.0865
Error	25	871.0600000	34.8424000		
Corrected Total	26	982.0000000			

R-Square	C.V.	Root MSE	REV Mean
0.112974	21.33522	5.902745	27.6666667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
DOSE	1	110.9400000	110.9400000	3.18	0.0865

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	30.30400000	16.26	0.0001	1.86412143
DOSE	-0.10320000	-1.78	0.0865	0.05783485

SAS Linear Analysis

---------- TA=AG88 ----------

General Linear Models Procedure

Number of observations in by group = 27

Dependent Variable: REV

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.18491852	0.18491852	0.01	0.9176
Error	25	423.66693333	16.94667733		
Corrected Total	26	423.85185185			

R-Square	C.V.	Root MSE	REV Mean
0.000436	15.87845	4.116634	25.9259259

Source	DF	Type I SS	Mean Square	F Value	Pr > F
DOSE	1	0.18491852	0.18491852	0.01	0.9176

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	26.03360000	20.02	0.0001	1.30005716
DOSE	-0.00421333	-0.10	0.9176	0.04033461

Appendix D

PARSONS ENGINEERING SCIENCE, INC.

INTEROFFICE CORRESPONDENCE

TO: Bruce Cox, St. Louis **DATE:** 03/18/95

FROM: Barb Percoulis BP **PHONE:** (810) 433-2700 **LOCATION:** Detroit (051)

SUBJECT: Review of Fog Oil Smoke Data - VOCs/PAHs Blank Corrections Only.

The VOCs results were qualified due to trip blank contamination. There was no method blank provided for VOCs.

The PAH results were qualified due to field and lab blank contamination.

For both sets of data, values were "struck out" if they were less than five times the value in the associated blank. Since no PRLs (Project Reporting Limit) were provided, no values could be put in for the non-detects. Please note that the non-detects are not considered to be "zero" (0).

cc: Bill Bradford, Syracuse

VOC

Table 7. Summary Information for Canister Sampling For Tests #1 and #2

Sample Description	Sample ID	Comments
BG Test 1, Reference	90-015	Grab sample collected
Test 1, 200+ meters	88-001	Grab sample collected
Test 1, 200+ meters	91-002	Grab sample collected
Test 1, 25 meters	91-003	No sample collected - vacuum still at 30" Hg
Test 1, 25 meters	91-033	No sample collected - vacuum still at 30" Hg
Test 1, 11 meters	88-013	Grab sample collected
Test 1, 11 meters	88-014	Grab sample collected
BG Test 2, Reference	90-016	Grab sample collected
Test 2, 100 meters	91-045	Grab sample collected
Test 2, 100 meters	91-026	Grab sample collected
Test 2, 11 meters	91-012	Grab sample collected
Test 2, 11 meters	91-069	Grab sample collected
Test 2, < 1 meter	88-058	Grab sample collected
Test 2, < 1 meter	88-029	Grab sample collected
Trip Blank	88-019	Filled with zero air upon return

VOC

Table 10. Concentrations of Volatile Organic Compounds For Tests #1 and #2 (ug/m3).

Test #1

Peak ID and Compound	Sampling Location and Canister ID				
	reference 90-015	200+ m 88-001	200+ m 91-002	11 m 88-013	11 m 88-014
Peak 1 -- C3-ene	1	2	2	191	199
Peak 2 -- C4-ene	0	1	0	62	71
Peak 3 -- 1,3-butadiene	0	1	0	48	65
Peak 4 -- isobutane	8	6	5	29	35
Peak 5 -- 1,2-dimethyl cyclopropane (z)	0	1	0	26	42
Peak 6 -- 1,2-dimethyl cyclopropane (e)	0	0	0	8	17
Peak 7 -- 1-hexene	2	1	0	27	31
Peak 8 -- benzene	✗	✗	✗	36	34
Peak 9 -- cyclohexene/C6-ol	3	2	0	8	8
Peak 10 -- 1-heptene	✗	✗	✗	15	18
Peak 11 -- methyl cyclohexane	0	0	0	13	14
Peak 12 -- toluene	2	2	2	16	15
Peak 13 -- 1-octene	0	0	0	12	12
Peak 14 -- ethyl cyclohexane	0	0	0	13	12
Peak 15 -- m,p-xylene	0	1	1	25	30
Peak 16 -- 1-nonene/o-xylene	0	1	1	16	19
Peak 17 -- unknown a	0	0	0	13	13
Peak 18 -- 4-ethyltoluene	0	0	0	14	14
Peak 19 -- 1,2,4-trimethylbenzene	✗	✗	✗	30	35
Peak 20 -- diethylbenzene	0	0	0	28	31
Peak 21 -- methyl, propylbenzene	1	0	0	22	14
Peak 22 -- tetramethylbenzene	0	0	0	60	38
Peak 23 -- ethyl, dimethylbenzene	0	0	0	45	18
Peak 24 -- unknown b	0	0	0	28	18
Peak 25 -- unknown c	0	0	0	19	21
Peak 26 -- dimethyl adamantane	0	0	0	32	33
Peak 27 -- unknown d	0	0	0	45	23
Peak 28 -- unknown e	0	0	0	45	38
Peak 29 -- dimethyl adamantane	0	0	0	19	25
Peak 30 -- dimethyl adamantane	0	0	0	26	14

"Strike out" results (✗) indicate values qualified non-detect due to trip blank contamination. Project reporting limits are to be determined by the St. Louis office. Non-detect values are not considered to be "zero."

B. Pericoulis

VOC

Table 10 Continued. Concentrations of Volatile Organic Compounds For Tests #1 and #2 (ug/m3).

trip blank

Peak ID and Compound	Sampling Location and Canister ID: reference 90-016	100 m 91-045	100 m 91-026	11 m 91-012	11 m 91-069	<1 m 88-058	<1 m 88-029	blank 88-019
Peak 1 -- propyne	0	75	80	2730	643	87536	70126	0
Peak 2 -- C4-ene	0	24	25	965	226	17260	15486	0
Peak 3 -- C4-ene	0	22	22	944	195	27487	23170	0
Peak 4 -- 1,3-butadiene	0	0	0	0	0	12587	10565	0
Peak 5 -- 2-butene (z)	0	4	4	165	31	3059	2698	0
Peak 6 -- 2-butene (e)	0	1	1	67	15	1252	1092	0
Peak 7 -- 3-methyl-1-butene	0	2	2	69	17	2149	1801	0
Peak 8 -- 1,2-dimethyl cyclopropane (z)	0	6	6	229	56	7041	5950	0
Peak 9 -- 1,2-dimethyl cyclopropane (e)	2	3	4	124	29	3806	3217	0
Peak 10 -- 2-methyl-1,3-butadiene	0	6	6	181	44	5659	4855	0
Peak 11 -- 2-pentene (z)	1	2	2	65	16	2209	1896	0
Peak 12 -- 2-pentene (e)	0	1	1	50	10	1360	1167	0
Peak 13 -- C5-ene	0	4	4	88	22	2907	2500	0
Peak 14 -- 3-penten-1-yne	0	7	7	280	65	8566	7462	0
Peak 15 -- 1,3-pentadiene	0	2	2	71	16	2496	2177	0
Peak 16 -- cyclopentene	0	1	1	59	14	1807	1529	0
Peak 17 -- 4-methyl-1-pentene	0	0	1	50	12	1646	1377	0
Peak 18 -- 1-hexene	1	6	7	250	58	7413	6216	0
Peak 19 -- 1,4-cyclohexadiene	0	1	2	111	23	3330	2852	0
Peak 20 -- 1,4-cyclohexadiene	0	1	1	70	13	2091	1848	0
Peak 21 -- benzene	~~4~~	~~12~~	~~12~~	414	100	12105	10563	(3)
Peak 22 -- cyclohexadiene	0	2	3	66	26	3272	3403	0
Peak 23 -- cyclohexene	~~3~~	~~5~~	~~4~~	43	12	1369	1148	(2)
Peak 24 -- 1-heptene	~~1~~	~~3~~	~~3~~	114	25	3481	2910	(1)
Peak 25 -- toluene	2	8	7	216	47	6194	5433	0
Peak 26 -- 1-octene	0	1	2	58	12	1766	1495	0
Peak 27 -- ethylbenzene	1	2	2	73	17	2089	1895	0
Peak 28 -- m,p-xylene	1	2	3	77	19	2147	1943	0
Peak 29 -- styrene	0	2	2	77	17	2175	2034	0
Peak 30 -- 1-nonene	0	3	2	71	17	2258	2073	0
Peak 31 -- 4-ethyltoluene	0	1	1	26	6	585	583	0
Peak 32 -- 1,3,5-trimethylbenzene	0	0	0	12	3	325	321	0
Peak 33 -- 1,2,4-trimethylbenzene	~~1~~	~~3~~	~~2~~	82	18	1482	1532	(1)

Reference = background air samples

Table 8. Summary Information For XAD-2 Sampling For Tests #1 and #2

Sample Description	Sample ID	Volume Sampled (Liters) Rotameter	Volume Sampled (Liters) Corrected[b]	Sampling Time (Min)	Comments
Test 1, Reference	#5	77.3	70.3	15	
Test 1, 200+ meters	#2	97.9	89.1	22	Moved station from 300 meters to 200 meters within first 5 min
Test 1, 200+ meters	#15	102.4	93.2	23	Moved station from 300 meters to 200 meters within first 5 min
Test 1, 25 meters	#10	101.7	92.5	21	
Test 1, 25 meters	#13	25.5	23.2	5	
Test 1, 11 meters	#7	78.8	71.7	17	
Test 1, 11 meters	#8[a]	75.0	68.3	16	
Test 2, Reference	#9	83.8	76.3	20	
Test 2, 100 meters	#3	236.4	215.1	46	
Test 2, 100 meters	#16	213.7	194.5	46	
Test 2, 11 meters	#6	90.0	81.9	20	
Test 2, 11 meters	#12	88.0	80.1	20	
Test 2, <1 meter	#4[a]	6.8	6.2	1-2	Total sampled volume could be ±2.0 L of listed value
Test 2, < 1 meter	#1	12.1	11.0	3-4	Total sampled volume could be ±2.0 L of listed value
Laboratory Blank	#17	-	-	-	
Field Blank	#14	-	-	-	

(a) 50 µl of spiking solution DY29 was spiked to all XAD-2 samples prior to extraction except for samples #4 and #8.
(b) Volume corrected to 25°C, 1 atm.

Table 12. Concentrations of PAHs For Tests #1 and #2

Client/Field ID:	Sample #17, Laboratory Matrix Blank^		Sample #17, Laboratory Matrix Blank^		Sample #14, Field Blank		Sample #14, Field Blank		North Slope Crude	
BOS Sample ID:	TD70		TD70		TD67		TD67		TW07NSC	
Batch ID:	96-033		96-033		96-033		96-033		96-033	
Matrix:	Oil		Oil		Oil		Oil		Oil	
Sample Weight (wg, oil weight)	1.00		1.00		1.00		1.00		5.09	
Sample Volume (L)	83.8		83.8		83.8		83.8		NA	
Dilution:	1.01		1.01		1.01		1.01		1.00	
Reporting Unit:	mg/kg oil		ug/m3*		mg/kg oil		ug/m3*		mg/kg oil	
Reporting Limit:	5 mg/kg				5 mg/kg				5 mg/kg	
Decalin	39	B	0.47	B	31	B	~~0.37~~	B	670	
C1-decalins	52	B	0.62	B	ND		ND		1100	
C2-decalins	ND		ND		ND		ND		1400	
C3-decalins	ND		ND		ND		ND		800	
C4-decalins	ND		ND		ND		ND		320	
Benzo[b]thiophene	ND		ND		ND		ND		ND	
C1-benzo[b]thiophenes	ND		ND		ND		ND		ND	
C2-benzo[b]thiophenes	ND		ND		ND		ND		ND	
C3-benzo[b]thiophenes	ND		ND		ND		ND		ND	
C4-benzo[b]thiophenes	ND		ND		ND		ND		ND	
Naphthalene	76	B	0.91	B	66	B	~~0.79~~	B	770	
C1-naphthalenes	21	B	0.25	B	16	B	~~0.19~~	B	1500	
C2-naphthalenes	18	B	0.22	B	ND		ND		1700	
C3-naphthalenes	ND		ND		ND		ND		1100	
C4-naphthalenes	ND		ND		ND		ND		580	
Biphenyl	ND		ND		ND		ND		210	
Acenaphthylene	ND		ND		ND		ND		ND	
Acenaphthene	ND		ND		ND		ND		14	
Dibenzofuran	11	B	0.13	B	ND		ND		62	
Fluorene	10	B	0.12	B	ND		ND		100	
C1-fluorenes	ND		ND		ND		ND		230	
C2-fluorenes	ND		ND		ND		ND		300	
C3-fluorenes	ND		ND		ND		ND		320	
Anthracene	ND		ND		ND		ND		14	
Phenanthrene	47	B	0.56	B	32	B	~~0.39~~	B	290	
C1-phenanthrenes/anthracenes	ND		ND		ND		ND		630	
C2-phenanthrenes/anthracenes	ND		ND		ND		ND		700	
C3-phenanthrenes/anthracenes	ND		ND		ND		ND		460	
C4-phenanthrenes/anthracenes	ND		ND		ND		ND		230	
Dibenzothiophene	ND		ND		ND		ND		220	
C1-dibenzothiophenes	ND		ND		ND		ND		390	
C2-dibenzothiophenes	ND		ND		ND		ND		480	
C3-dibenzothiophenes	ND		ND		ND		ND		440	
Fluoranthene	ND		ND		ND		ND		3.8	J
Pyrene	ND		ND		ND		ND		11	
C1-fluoranthenes/pyrenes	ND		ND		ND		ND		66	
C2-fluoranthenes/pyrenes	ND		ND		ND		ND		120	
C3-fluoranthenes/pyrenes	ND		ND		ND		ND		140	
Benz(a)anthracene	ND		ND		ND		ND		ND	
Chrysene	ND		ND		ND		ND		22	
C1-chrysenes	ND		ND		ND		ND		85	
C2-chrysenes	ND		ND		ND		ND		120	
C3-chrysenes	ND		ND		ND		ND		77	
C4-chrysenes	ND		ND		ND		ND		41	
Benzo(b)fluoranthene	ND		ND		ND		ND		6.7	
Benzo(k)fluoranthene	ND		ND		ND		ND		ND	
Benzo(e)pyrene	ND		ND		ND		ND		12	
Benzo(a)pyrene	ND		ND		ND		ND		ND	
Perylene	ND		ND		ND		ND		ND	
Indeno(1,2,3-c,d)pyrene	ND		ND		ND		ND		ND	
Dibenz(a,h)anthracene	ND		ND		ND		ND		ND	
Benzo(g,h,i)perylene	ND		ND		ND		ND		3.5	J
Total PAH	270		3.3		140		1.7		16000	
2-methylnaphthalene	21	B	0.25	B	15	B	~~0.18~~	B	NM	
1-methylnaphthalene	10	B	0.12	B	8.3	B	~~0.099~~	B	NM	
2,6-dimethylnaphthalene	5.4	B	0.064	B	ND		ND		NM	
2,3,5-trimethylnaphthalene	ND		ND		ND		ND		NM	
1-methylphenanthrene	ND		ND		ND		ND		NM	

^ Assume oil weight of 1.00 mg.
* Average of 14 sample volumes = 83.8 cubic meters.
B, Laboratory/XAD-2 contaminant is major contributor to analyte concentration.
J, concentration below reporting limit (5 mg/kg).
NM, not measured in sample.

Only the ug/m³ samples were blank corrected for all PAHs- B. Bercaw

Table 12. Continued, Concentrations of PAHs For Tests #1 and #2

Client/Field ID:	Test 1 Dec. 13, 1995		Sample #5, Reference for Test #1		Sample #5, Reference for Test #1	
BOS Sample ID:	TD71-1		TD59		TD59	
Batch ID:	96-027		96-033		96-033	
Matrix:	Oil		Oil		Oil	
Sample Weight (mg, oil weight)	55.20		1.10		1.10	
Sample Volume (L)	NA		70.3		70.3	
Dilution:	10.00		1.01		1.01	
Reporting Unit:	mg/kg oil		mg/kg oil		ug/m3	
Reporting Limit:	5 mg/kg		5 mg/kg			
Decalin	6.6		22	B	~~0.34~~	B
C1-decalins	19		24	B	~~0.99~~	B
C2-decalins	78		ND		ND	
C3-decalins	160		ND		ND	
C4-decalins	140		ND		ND	
Benzo[b]thiophene	1.7	J	ND		ND	
C1-benzo[b]thiophenes	2.5	J	ND		ND	
C2-benzo[b]thiophenes	12		ND		ND	
C3-benzo[b]thiophenes	26		ND		ND	
C4-benzo[b]thiophenes	58		ND		ND	
Naphthalene	41		71	B	~~1.1~~	B
C1-naphthalenes	75		18	B	~~0.28~~	B
C2-naphthalenes	240		14	B	~~0.22~~	B
C3-naphthalenes	370		ND		ND	
C4-naphthalenes	430		ND		ND	
Biphenyl	5.9		4.6	J	0.073	
Acenaphthylene	ND		ND		ND	
Acenaphthene	4.8	J	5.5	B	0.087	B
Dibenzofuran	1.7	J	9.8	B	~~0.16~~	B
Fluorene	17		14		~~0.21~~	
C1-fluorenes	89		ND		ND	
C2-fluorenes	490		ND		ND	
C3-fluorenes	1100		ND		ND	
Anthracene	ND		ND		ND	
Phenanthrene	89		60	B	~~0.95~~	B
C1-phenanthrenes/anthracenes	520		10		0.16	
C2-phenanthrenes/anthracenes	1000		ND		ND	
C3-phenanthrenes/anthracenes	1100		ND		ND	
C4-phenanthrenes/anthracenes	640		ND		ND	
Dibenzothiophene	150		6.4		0.10	
C1-dibenzothiophenes	970		ND		ND	
C2-dibenzothiophenes	2400		ND		ND	
C3-dibenzothiophenes	2800		ND		ND	
Fluoranthene	7.0		17		0.27	
Pyrene	14		4.6	J	0.072	
C1-fluoranthenes/pyrenes	84		ND		ND	
C2-fluoranthenes/pyrenes	200		ND		ND	
C3-fluoranthenes/pyrenes	290		ND		ND	
Benz(a)anthracene	ND		ND		ND	
Chrysene	48		ND		ND	
C1-chrysenes	81		ND		ND	
C2-chrysenes	120		ND		ND	
C3-chrysenes	81		ND		ND	
C4-chrysenes	ND		ND		ND	
Benzo(b)fluoranthene	6.7		ND		ND	
Benzo(k)fluoranthene	ND		ND		ND	
Benzo(e)pyrene	6.3		ND		ND	
Benzo(a)pyrene	ND		ND		ND	
Perylene	ND		ND		ND	
Indeno(1,2,3-c,d)pyrene	ND		ND		ND	
Dibenz(a,h)anthracene	ND		ND		ND	
Benzo(g,h,i)perylene	ND		ND		ND	
Total PAH	14000		280		4.4	
2-methylnaphthalene	86		19	B	~~0.30~~	B
1-methylnaphthalene	68		11	B	~~0.18~~	B
2,6-dimethylnaphthalene	48		5.2	B	~~0.081~~	B
2,3,5-trimethylnaphthalene	69		ND		ND	
1-methylphenanthrene	140		1.8	J	0.029	

B, Laboratory/XAD-2 contaminant is major contributor to analyte concentration.

The total PAH values were not updated to reflect blank corrected values.

Table 12. Continued, Concentrations of PAHs For Tests #1 and #2

Client/Field ID:	Sample #7, Test #1, 11 m		Sample #7, Test #1, 11 m	Sample #8, Test #1, 11 m		Sample #8, Test #1, 11 m
BOS Sample ID:	TD61		TD61	TD62		TD62
Batch ID:	96-033		96-033	96-033		96-033
Matrix:	Oil		Oil	Oil		Oil
Sample Weight (mg, oil weight)	48.40		48.40	48.40		48.40
Sample Volume (L)	71.7		71.7	68.3		68.3
Dilution:	1.01		1.01	1.01		1.01
Reporting Unit:	mg/kg oil		ug/m3	mg/kg oil		ug/m3
Reporting Limit:	5 mg/kg			5 mg/kg		
Decalin	11		7.7	7.8		5.5
C1-decalins	28		19	21		15
C2-decalins	140		95	98		69
C3-decalins	230		160	190		130
C4-decalins	210		140	170		120
Benzo[b]thiophene	2.1	J	1.4	2.6	J	1.9
C1-benzo[b]thiophenes	4.3	J	2.9	ND		ND
C2-benzo[b]thiophenes	15		9.8	13		9.0
C3-benzo[b]thiophenes	47		32	33		24
C4-benzo[b]thiophenes	63		43	88		62
Naphthalene	65		44	42		30
C1-naphthalenes	110		76	74		52
C2-naphthalenes	320		220	260		180
C3-naphthalenes	540		360	440		310
C4-naphthalenes	460		310	550		390
Biphenyl	8.7		5.9	6.3		4.4
Acenaphthylene	ND		ND	0.64	J	0.45
Acenaphthene	6.7		4.5	5.1		3.6
Dibenzofuran	3.3	J	2.2	2.3	J	1.6
Fluorene	22		15	21		15
C1-fluorenes	85		57	110		78
C2-fluorenes	320		220	410		290
C3-fluorenes	890		600	970		690
Anthracene	ND		ND	95		67
Phenanthrene	120		79	89		63
C1-phenanthrenes/anthracenes	470		310	380		270
C2-phenanthrenes/anthracenes	1100		740	720		510
C3-phenanthrenes/anthracenes	900		610	820		580
C4-phenanthrenes/anthracenes	520		350	500		350
Dibenzothiophene	180		120	170		120
C1-dibenzothiophenes	860		580	650		460
C2-dibenzothiophenes	2600		1800	1700		1200
C3-dibenzothiophenes	2500		1700	1800		1300
Fluoranthene	ND		ND	ND		ND
Pyrene	ND		ND	ND		ND
C1-fluoranthenes/pyrenes	110		71	85		60
C2-fluoranthenes/pyrenes	180		120	130		89
C3-fluoranthenes/pyrenes	270		180	170		120
Benz(a)anthracene	ND		ND	ND		ND
Chrysene	43		29	29		20
C1-chrysenes	72		48	43		30
C2-chrysenes	120		78	57		40
C3-chrysenes	100		67	51		36
C4-chrysenes	31		21	ND		ND
Benzo(b)fluoranthene	8.1		5.5	2.7	J	1.9
Benzo(k)fluoranthene	ND		ND	ND		ND
Benzo(e)pyrene	8.3		5.6	2.6	J	1.8
Benzo(a)pyrene	ND		ND	ND		ND
Perylene	ND		ND	ND		ND
Indeno(1,2,3-c,d)pyrene	ND		ND	ND		ND
Dibenz(a,h)anthracene	ND		ND	ND		ND
Benzo(g,h,i)perylene	1.6	J	1.1	ND		ND
Total PAH	14000		9300	11000		7800
2-methylnaphthalene	100		67	65		46
1-methylnaphthalene	100		69	66		47
2,6-dimethylnaphthalene	77		52	58		41
2,3,5-trimethylnaphthalene	82		56	88		62
1-methylphenanthrene	85		57	92		65

B, Laboratory/XAD-2 contaminant is major contributor to analyte concentration.

Table 12. Continued, Concentrations of PAHs For Tests #1 and #2

Client/Field ID:	Sample #10, Test #1, 25 m		Sample #10, Test #1, 25 m		Sample #13, Test #1, 25 m		Sample #13, Test #1, 25 m		Sample #15, Test #1, 200+ m	
BOS Sample ID:	TD64		TD64		TD66		TD66		TD68	
Batch ID:	96-033		96-033		96-033		96-033		96-033	
Matrix:	Oil		Oil		Oil		Oil		Oil	
Sample Weight (mg, oil weight)	3.60		3.60		0.70		0.70		0.20	
Sample Volume (L)	92.5		92.5		23.2		23.2		93.2	
Dilution:	1.01		1.01		1.01		1.01		1.01	
Reporting Unit:	mg/kg oil		ug/m3		mg/kg oil		ug/m3		mg/kg oil	
Reporting Limit:	5 mg/kg				5 mg/kg				5 mg/kg	
Decalin	14	B	~~0.59~~	B	69	B	~~2.1~~	B	ND	
C1-decalins	27	B	~~1.0~~	B	99	B	~~3.0~~	B	ND	
C2-decalins	140		5.5		ND		ND		ND	
C3-decalins	200		7.8		ND		ND		ND	
C4-decalins	200		7.9		ND		ND		ND	
Benzo[b]thiophene	ND		ND		ND		ND		ND	
C1-benzo[b]thiophenes	7.1		0.28		22		0.65		ND	
C2-benzo[b]thiophenes	11		0.44		ND		ND		ND	
C3-benzo[b]thiophenes	25		0.96		27		0.83		ND	
C4-benzo[b]thiophenes	66		2.6		65		2.0		ND	
Naphthalene	67		~~2.6~~		180	B	5.3	B	280	B
C1-naphthalenes	88		3.4		100		3.0		120	B
C2-naphthalenes	210		8.2		160		4.9		200	
C3-naphthalenes	380		15		290		8.6		190	
C4-naphthalenes	470		18		530		16		150	
Biphenyl	7.2		0.28		11		0.33		ND	
Acenaphthylene	ND		ND		ND		ND		ND	
Acenaphthene	6.2		0.24		14	B	0.42	B	ND	
Dibenzofuran	4.9	J	~~0.19~~		14	B	~~0.42~~	B	ND	
Fluorene	21		0.83		23		0.71		ND	
C1-fluorenes	100		4.0		120		3.5		33	
C2-fluorenes	570		22		570		17		230	
C3-fluorenes	1200		46		1500		45		610	
Anthracene	ND		ND		ND		ND		ND	
Phenanthrene	110		4.4		160	B	4.9	B	190	B
C1-phenanthrenes/anthracenes	520		20		710		21		270	
C2-phenanthrenes/anthracenes	1100		43		1500		45		590	
C3-phenanthrenes/anthracenes	1100		44		1300		40		690	
C4-phenanthrenes/anthracenes	650		25		820		25		400	
Dibenzothiophene	150		6.0		180		5.3		48	
C1-dibenzothiophenes	1000		40		1200		37		320	
C2-dibenzothiophenes	2600		99		3300		98		1300	
C3-dibenzothiophenes	3000		120		3600		110		1600	
Fluoranthene	11		0.42		36		1.1		ND	
Pyrene	19		0.73		27		0.8		ND	
C1-fluoranthenes/pyrenes	97		3.8		120		3.7		ND	
C2-fluoranthenes/pyrenes	210		8.1		280		8.5		ND	
C3-fluoranthenes/pyrenes	270		10		330		10		ND	
Benz(a)anthracene	ND		ND		ND		ND		ND	
Chrysene	39		1.5		40		1.2		ND	
C1-chrysenes	58		2.3		79		2.4		ND	
C2-chrysenes	87		3.4		110		3.4		ND	
C3-chrysenes	63		2.5		ND		ND		ND	
C4-chrysenes	ND		ND		ND		ND		ND	
Benzo(b)fluoranthene	4.9	J	0.19		ND		ND		ND	
Benzo(k)fluoranthene	ND		ND		ND		ND		ND	
Benzo(e)pyrene	5.0		0.20		ND		ND		ND	
Benzo(a)pyrene	ND		ND		ND		ND		ND	
Perylene	1.8	J	0.068		ND		ND		ND	
Indeno(1,2,3-c,d)pyrene	ND		ND		ND		ND		ND	
Dibenz(a,h)anthracene	ND		ND		ND		ND		ND	
Benzo(g,h,i)perylene	ND		ND		ND		ND		ND	
Total PAH	15000		580		18000		530		7700	
2-methylnaphthalene	80		3.1		99		3.0		120	
1-methylnaphthalene	75		2.9		79		2.4		83	
2,6-dimethylnaphthalene	48		1.9		37		1.1		55	
2,3,5-trimethylnaphthalene	68		2.6		58		1.7		34	
1-methylphenanthrene	170		6.6		220		6.5		63	

B, Laboratory/XAD-2 contaminant is major contributor to analyte concentration.

Table 12. Continued, Concentrations of PAHs For Tests #1 and #2

Client/Field ID:	Sample #15, Test #1, 200+ m		Sample #2, Test #1, 200+ m		Sample #2, Test #1, 200+ m		Test 2 Dec. 14, 1995		Sample #9, Reference for Test #2	
BOS Sample ID:	TD68		TD56		TD56		TD72-1		TD63	
Batch ID:	96-033		96-033		96-033		96-027		96-033	
Matrix:	Oil		Oil		Oil		Oil		Oil	
Sample Weight (mg, oil weight)	0.20		0.20		0.20		51.20		0.80	
Sample Volume (L)	93.2		89.1		89.1		NA		76.3	
Dilution:	1.01		1.01		1.01		10.00		1.01	
Reporting Unit:	ug/m3		mg/kg oil		ug/m3		mg/kg oil		mg/kg oil	
Reporting Limit:			5 mg/kg				5 mg/kg		5 mg/kg	
Decalin	ND		91	B	~~0.20~~	B	7.4		ND	
C1-decalins	ND		ND		ND		24		ND	
C2-decalins	ND		ND		ND		93		ND	
C3-decalins	ND		ND		ND		140		ND	
C4-decalins	ND		ND		ND		150		ND	
Benzo[b]thiophene	ND		ND		ND		1.7	J	ND	
C1-benzo[b]thiophenes	ND		ND		ND		5.1		7.4	
C1-benzo[b]thiophenes	ND		ND		ND		11		ND	
C1-benzo[b]thiophenes	ND		ND		ND		26		ND	
C1-benzo[b]thiophenes	ND		ND		ND		58		ND	
Naphthalene	~~0.82~~	B	340	B	~~0.77~~	B	42		83	B
C1-naphthalenes	~~0.27~~	B	130	B	~~0.39~~	B	76		23	B
C2-naphthalenes	~~0.42~~		180		~~0.92~~		250		31	B
C3-naphthalenes	0.41		110		0.24		390		ND	
C4-naphthalenes	0.33		100		0.23		470		ND	
Biphenyl	ND		22		0.049		6.0		ND	
Acenaphthylene	ND		ND		ND		ND		ND	
Acenaphthene	ND		24		0.054		5.1		11	
Dibenzofuran	ND		41	B	~~0.092~~	B	1.6	J	13	B
Fluorene	ND		46	B	~~0.10~~	B	18		14	B
C1-fluorenes	0.071		33		0.074		93		ND	
C2-fluorenes	0.49		180		0.40		490		ND	
C3-fluorenes	1.3		570		1.3		1200		ND	
Anthracene	ND		ND		ND		ND		ND	
Phenanthrene	~~0.40~~	B	220	B	~~0.30~~	B	98		61	B
C1-phenanthrenes/anthracenes	0.59		240		0.53		530		ND	
C2-phenanthrenes/anthracenes	2.1		740		1.7		1100		ND	
C3-phenanthrenes/anthracenes	1.5		480		1.1		1100		ND	
C4-phenanthrenes/anthracenes	0.86		290		0.64		710		ND	
Dibenzothiophene	0.10		54		0.12		150		ND	
C1-dibenzothiophenes	0.70		310		0.69		960		ND	
C2-dibenzothiophenes	2.8		1000		2.3		2400		ND	
C3-dibenzothiophenes	3.4		1200		2.7		2700		ND	
Fluoranthene	ND		96		0.22		5.7		13	
Pyrene	ND		32		0.073		18		ND	
C1-fluoranthenes/pyrenes	ND		ND		ND		100		ND	
C2-fluoranthenes/pyrenes	ND		ND		ND		200		ND	
C3-fluoranthenes/pyrenes	ND		ND		ND		280		ND	
Benz(a)anthracene	ND		ND		ND		ND		ND	
Chrysene	ND		ND		ND		50		ND	
C1-chrysenes	ND		ND		ND		90		ND	
C2-chrysenes	ND		ND		ND		120		ND	
C3-chrysenes	ND		ND		ND		99		ND	
C4-chrysenes	ND		ND		ND		ND		ND	
Benzo(b)fluoranthene	ND		ND		ND		8.3		ND	
Benzo(k)fluoranthene	ND		ND		ND		ND		ND	
Benzo(e)pyrene	ND		ND		0		11		ND	
Benzo(a)pyrene	ND		ND		0		ND		ND	
Perylene	ND		ND		ND		ND		ND	
Indeno(1,2,3-c,d)pyrene	ND		ND		ND		ND		ND	
Dibenz(a,h)anthracene	ND		ND		ND		ND		ND	
Benzo(g,h,i)perylene	ND		ND		ND		ND		ND	
Total PAH	17		6500		15		14000		260	
2-methylnaphthalene	~~0.30~~		120		~~0.27~~		68		26	
1-methylnaphthalene	~~0.18~~		75		~~0.17~~		69		16	
2,6-dimethylnaphthalene	~~0.12~~		42		~~0.094~~		52		9.7	
2,3,5-trimethylnaphthalene	0.073		23		0.053		71		ND	
1-methylphenanthrene	0.14		61		0.14		150		ND	

B, Laboratory/XAD-2 contaminant is major contributor to analyte concentration.

Table 12. Continued, Concentrations of PAHs For Tests #1 and #2

Client/Field ID:	Sample #9, Reference for Test #2		Sample #1, Test #2, 1/2 m	Sample #1, Test #2, 1/2 m	Sample #4, Test #2, 1/2 m	Sample #4, Test #2, 1/2 m
BOS Sample ID:	TD63		TD55-D	TD55-D	TD58-D	TD58-D
Batch ID:	96-033		96-033	96-033	96-033	96-033
Matrix:	Oil		Oil	Oil	Oil	Oil
Sample Weight (mg, oil weight)	0.80		84.60	84.60	85.60	85.60
Sample Volume (L)	76.3		11.0	11.0	6.2	6.2
Dilution:	1.01		20.00	20.00	20.00	20.00
Reporting Unit:	ug/m3		mg/kg oil	ug/m3	mg/kg oil	ug/m3
Reporting Limit:			5 mg/kg		5 mg/kg	
Decalin	ND		16	130	35	420
C1-decalins	ND		31	240	79	1100
C2-decalins	ND		120	890	140	1900
C3-decalins	ND		190	1500	130	1800
C4-decalins	ND		160	1200	120	1700
Benzo[b]thiophene	ND		6.1	47	5.6	77
C1-benzo[b]thiophenes	0.078		17	130	16	220
C2-benzo[b]thiophenes	ND		28	210	24	330
C3-benzo[b]thiophenes	ND		45	350	40	560
C4-benzo[b]thiophenes	ND		95	730	75	1000
Naphthalene	~~0.87~~	B	140	1100	160	2200
C1-naphthalenes	~~0.34~~	B	150	1100	150	2100
C2-naphthalenes	~~0.55~~	B	300	2300	250	3500
C3-naphthalenes	ND		440	3600	460	6200
Biphenyl	ND		9.7	75	9.5	130
Acenaphthylene	ND		45	340	43	600
Acenaphthene	0.12		13	100	12	160
Dibenzofuran	~~0.14~~	B	5.4	42	5.0	69
Fluorene	~~0.15~~	B	66	510	55	760
C1-fluorenes	ND		180	1400	150	2100
C2-fluorenes	ND		660	5000	560	7800
C3-fluorenes	ND		1500	12000	1300	17000
Anthracene	ND		31	240	33	460
Phenanthrene	~~0.64~~	B	170	1300	160	2200
C1-phenanthrenes/anthracenes	ND		750	5800	650	8900
C2-phenanthrenes/anthracenes	ND		1200	9400	1100	15000
C3-phenanthrenes/anthracenes	ND		1300	10000	1200	16000
C4-phenanthrenes/anthracenes	ND		760	5800	700	9600
Dibenzothiophene	ND		220	1700	180	2500
C1-dibenzothiophenes	ND		1300	9600	1100	15000
C2-dibenzothiophenes	ND		2800	22000	2400	34000
C3-dibenzothiophenes	ND		3500	27000	3000	41000
Fluoranthene	0.14		23	180	20	280
Pyrene	ND		48	370	39	540
C1-fluoranthenes/pyrenes	ND		130	980	180	2500
C2-fluoranthenes/pyrenes	ND		280	2100	250	3500
C3-fluoranthenes/pyrenes	ND		360	2700	350	4800
Benz(a)anthracene	ND		9.6	74	25	340
Chrysene	ND		48	370	63	870
C1-chrysenes	ND		79	610	110	1500
C2-chrysenes	ND		110	850	130	1800
C3-chrysenes	ND		85	660	120	1600
C4-chrysenes	ND		ND	ND	ND	ND
Benzo(b)fluoranthene	ND		7.6	59	7.9	110
Benzo(k)fluoranthene	ND		ND	ND	ND	ND
Benzo(e)pyrene	ND		5.6	43	8.8	120
Benzo(a)pyrene	ND		ND	ND	ND J	ND
Perylene	ND		ND	ND	ND	ND
Indeno(1,2,3-c,d)pyrene	ND		ND	ND	ND	ND
Dibenz(a,h)anthracene	ND		ND	ND	ND	ND
Benzo(g,h,i)perylene	ND		ND	ND	ND	ND
Total PAH	2.7		18000	140000	16000	220000
2-methylnaphthalene	~~0.27~~		130	990	130	1800
1-methylnaphthalene	~~0.19~~		140	1100	140	1900
2,6-dimethylnaphthalene	~~0.10~~		62	470	47	650
2,3,5-trimethylnaphthalene	ND		64	490	61	840
1-methylphenanthrene	ND		210	1600	180	2500

B, Laboratory/XAD-2 contaminant is major contributor to analyte concentration.

Table 12. Continued, Concentrations of PAHs For Tests #1 and #2

Client/Field ID:	Sample #12, Test #2, 11 m		Sample #12, Test #2, 11 m	Sample #6, Test #2, 11 m	Sample #6, Test #2, 11 m	Sample #16, Test #2, 100 m	
BOS Sample ID:	TD65		TD65	TD60	TD60	TD69	
Batch ID:	96-033		96-033	96-033	96-033	96-033	
Matrix:	Oil		Oil	Oil	Oil	Oil	
Sample Weight (mg, oil weight)	6.70		6.70	5.80	5.80	1.40	
Sample Volume (L)	80.1		80.1	81.9	81.9	194.5	
Dilution:	1.01		1.01	1.01	1.01	1.01	
Reporting Unit:	mg/kg oil		ug/m3	mg/kg oil	ug/m3	mg/kg oil	
Reporting Limit:	5 mg/kg			5 mg/kg		5 mg/kg	
Decalin	14		~~1.2~~	15	~~1.3~~	32	B
C1-decalins	45		3.8	56	3.9	66	B
C2-decalins	150		13	160	12	190	
C3-decalins	220		18	220	16	130	
C4-decalins	170		14	180	13	230	
Benzo[b]thiophene	6.5		0.55	6.5	0.46	6.9	
C1-benzo[b]thiophenes	19		1.6	17	1.2	23	
C2-benzo[b]thiophenes	27		2.3	27	1.9	27	
C3-benzo[b]thiophenes	46		3.8	43	3.1	46	
C4-benzo[b]thiophenes	75		6.3	74	5.2	61	
Naphthalene	180		15	200	14	260	
C1-naphthalenes	180		15	190	14	190	
C2-naphthalenes	320		27	320	23	300	
C3-naphthalenes	460		38	440	31	400	
C4-naphthalenes	490		41	510	36	430	
Biphenyl	13		1.1	13	0.89	15	
Acenaphthylene	41		3.4	41	2.9	33	
Acenaphthene	13		1.1	13	0.90	14	
Dibenzofuran	6.4		~~0.56~~	5.9	~~0.42~~	9.2	B
Fluorene	52		4.3	54	3.8	44	
C1-fluorenes	130		11	150	10	120	
C2-fluorenes	580		49	650	46	470	
C3-fluorenes	1300		110	1400	100	1200	
Anthracene	19		1.6	19	1.3	22	
Phenanthrene	140		11	140	9.9	150	
C1-phenanthrenes/anthracenes	580		48	620	44	600	
C2-phenanthrenes/anthracenes	1100		88	1100	80	1200	
C3-phenanthrenes/anthracenes	1100		92	1200	82	1200	
C4-phenanthrenes/anthracenes	640		53	610	44	680	
Dibenzothiophene	170		14	180	12	160	
C1-dibenzothiophenes	1000		86	1100	75	970	
C2-dibenzothiophenes	2500		200	2700	190	2600	
C3-dibenzothiophenes	2900		250	3100	220	3000	
Fluoranthene	19		1.6	23	1.6	30	
Pyrene	29		2.5	26	1.8	25	
C1-fluoranthenes/pyrenes	130		11	120	8.7	130	
C2-fluoranthenes/pyrenes	210		18	230	16	220	
C3-fluoranthenes/pyrenes	280		23	300	21	300	
Benz(a)anthracene	ND		ND	ND	ND	ND	
Chrysene	39		3.2	44	3.1	ND	
C1-chrysenes	66		5.5	63	4.5	71	
C2-chrysenes	92		7.7	90	6.4	93	
C3-chrysenes	68		5.7	64	4.5	71	
C4-chrysenes	ND		ND	ND	ND	ND	
Benzo(b)fluoranthene	6.7		0.56	5.5	0.39	5.9	
Benzo(k)fluoranthene	ND		ND	ND	ND	ND	
Benzo(e)pyrene	4.7	J	0.40	6.1	0.43	ND	
Benzo(a)pyrene	ND		ND	ND	ND	ND	
Perylene	ND		ND	ND	ND	ND	
Indeno(1,2,3-c,d)pyrene	ND		ND	ND	ND	ND	
Dibenz(a,h)anthracene	ND		ND	ND	ND	ND	
Benzo(g,h,i)perylene	ND		ND	ND	ND	ND	
Total PAH	16000		1300	17000	1200	16000	
2-methylnaphthalene	160		14	170	12	170	
1-methylnaphthalene	170		14	170	12	170	
2,6-dimethylnaphthalene	63		5.3	73	5.1	60	
2,3,5-trimethylnaphthalene	76		6.3	64	4.5	52	
1-methylphenanthrene	210		18	210	15	190	

B, Laboratory/XAD-2 contaminant is major contributor to analytic concentration.

Table 12. Continued, Concentrations of PAHs For Tests #1 and #2

Client/Field ID:	Sample #16, Test #2, 100 m		Sample #3, Test #2, 100 m		Sample #3, Test #2, 100 m	
BOS Sample ID:	TD69		TD57		TD57	
Batch ID:	96-033		96-033		96-033	
Matrix:	Oil		Oil		Oil	
Sample Weight (mg, oil weight)	1.40		1.30		1.30	
Sample Volume (L)	194.5		215.1		215.1	
Dilution:	1.01		1.01		1.01	
Reporting Unit:	ug/m3		mg/kg oil		ug/m3	
Reporting Limit:			5 mg/kg			
Decalin	~~0.23~~	B	91		~~0.55~~	
C1-decalins	~~0.47~~	B	110		~~0.67~~	
C2-decalins	1.4		320		1.9	
C3-decalins	0.91		540		3.3	
C4-decalins	1.7		470		2.8	
Benzo[b]thiophene	0.049		10		0.062	
C1-benzo[b]thiophenes	0.17		27		0.16	
C1-benzo[b]thiophenes	0.19		32		0.20	
C1-benzo[b]thiophenes	0.33		49		0.29	
C1-benzo[b]thiophenes	0.44		72		0.44	
Naphthalene	~~1.0~~		380		~~2.3~~	
C1-naphthalenes	1.4		250		1.5	
C2-naphthalenes	2.2		370		2.2	
C3-naphthalenes	2.9		450		2.7	
C4-naphthalenes	3.1		450		2.7	
Biphenyl	0.11		20		0.12	
Acenaphthylene	0.24		43		0.26	
Acenaphthene	0.10		20		0.12	
Dibenzofuran	~~0.066~~	B	15	B	~~0.091~~	B
Fluorene	~~0.32~~		58		~~0.35~~	
C1-fluorenes	0.89		140		0.84	
C2-fluorenes	3.4		650		3.9	
C3-fluorenes	8.8		1500		8.9	
Anthracene	0.16		28		0.17	
Phenanthrene	~~1.0~~		230		~~1.4~~	
C1-phenanthrenes/anthracenes	4.3		750		4.5	
C2-phenanthrenes/anthracenes	8.7		1400		8.4	
C3-phenanthrenes/anthracenes	8.5		1300		7.8	
C4-phenanthrenes/anthracenes	4.9		830		5	
Dibenzothiophene	1.1		180		1.1	
C1-dibenzothiophenes	6.9		1300		7.7	
C2-dibenzothiophenes	19		2900		18	
C3-dibenzothiophenes	21		3600		21	
Pyrene	0.18		35		0.21	
C1-fluoranthenes/pyrenes	0.95		140		0.82	
C2-fluoranthenes/pyrenes	1.6		320		1.9	
C3-fluoranthenes/pyrenes	2.2		310		1.9	
Benz(a)anthracene	ND		ND		ND	
Chrysene	ND		50		0.3	
C1-chrysenes	0.51		79		0.48	
C2-chrysenes	0.67		110		0.66	
C3-chrysenes	0.51		89		0.54	
C4-chrysenes	ND		ND		ND	
Benzo(b)fluoranthene	0.042		8.4		0.051	
Benzo(k)fluoranthene	ND		ND		ND	
Benzo(e)pyrene	ND		7.5		0.045	
Benzo(a)pyrene	ND		ND		ND	
Perylene	ND		ND		ND	
Indeno(1,2,3-c,d)pyrene	ND		ND		ND	
Dibenz(a,h)anthracene	ND		ND		ND	
Benzo(g,h,i)perylene	ND		ND		ND	
Total PAH	110		20000		120	
2-methylnaphthalene	1.3		240		1.4	
1-methylnaphthalene	1.2		220		1.3	
2,6-dimethylnaphthalene	0.43		78		0.47	
2,3,5-trimethylnaphthalene	0.37		81		0.49	
1-methylphenanthrene	1.4		240		1.4	

B, Laboratory/XAD-2 contaminant is major contributor to analyte concentration.

Appendix E

EVALUATION OF POTENTIAL HUMAN HEALTH EFFECTS FROM EXPOSURE TO FOG OIL SMOKE AND LIQUID FOG OIL

A LITERATURE REVIEW

SECTION 1 - INTRODUCTION

Recommendations of the Defense Base Closure and Realignment Commission, made in conformance with the provisions of the 1990 Base Realignment and Closure Act, require the closing of Fort McClellan in Alabama and realignment of essential missions to other installations. Pursuant to the National Environmental Policy Act of 1969 (NEPA) and its implementing regulations, the Army is required to prepare an Environmental Impact Statement (EIS) to address the environmental and socioeconomic impacts of realigning the U.S. Army Military Police School and U.S. Army Chemical School, and several associated support units, from Fort McClellan, Alabama to Fort Leonard Wood, Missouri.

One of the missions to be transferred to Fort Leonard Wood is obscurant smoke training with fog oil. The following literature review of the human health effects associated with fog oil obscurant training, has been conducted to support the overall EIS for this base realignment action and will serve to update fog oil health evaluations by Liss-Suter et al. (1978); Palmer (1990); and Driver et al. (1993).

Initial reviews of the human health literature revealed an absence of information on hydrocarbon constituents in smoke generated from SGF-2 (Smoke Generator Fuel) oils manufactured under recent military specifications. Therefore, as part of the EIS process and to advance the state-of-knowledge of fog oil health effects, samples of fog oil smoke were monitored for individual hydrocarbon compounds. Analytical results will be used to further assess health risks beyond this literature evaluation.

SECTION 2 - BACKGROUND

2.1 HISTORY OF FOG OIL

The generation of obscurant smoke for concealment purposes has been a part of military tactics prior to World War I (Driver et al., 1993). The current use of white fog oil to generate smoke dates back to World War II and the Korean conflict. Tactically, smoke may be employed in offensive operations to neutralize firepower and reduce mobility, or for defensive operations to deter enemy observation and aimed enemy fire (Wimer et al., 1987).

Industrial oil burners were initially adapted by the military to produce smoke in years past; however, specially designed smoke generators have now been developed. Over time, improvements to smoke generating systems have made them lighter, more mobile, and increasingly capable of producing larger clouds of optimum particle size fog (Liss-Suter and Villaume, 1978).

Many different types of fog oil and other petroleum products have been used to generate smoke including SGF-1 and SGF-2, diesel fuel, jet fuel (JP-4), and kerosene. SGF-1 has not been supplied to the U.S. Army since the mid-1970s. SGF-2 is currently used for year-round obscurant applications (Liss-Suter and Villaume, 1978).

Prior to 1986, military manufacturing specifications for SGF-2 were written to control the physical attributes of fog oil (e.g., boiling point range, pour point, and viscosity) for optimum production of smoke by generators. To address human health concerns, manufacturing specifications for SGF-2 fog oil were modified in 1986 (MIL-F-12070C, Amendment 2) to require certification by manufacturers that no carcinogenic or potentially carcinogenic constituents were present in fog oil (U.S. Army, 1986). The 1986 manufacturing specification added considerably to the health protection of individuals exposed to fog oil smoke during training or actual combat missions.

2.2 PHYSICAL AND CHEMICAL PROPERTIES OF FOG OIL

2.2.1 Physical Properties of Fog Oil

The physical characteristics of SGF-2 fog oil are currently defined under military specification, MIL-F-12070D or NATO Code No. F-62 (U.S. Army, 1992). SGF-2 fog oil is a middle distillate product of crude oil, which is drawn from stocks of a raw industrial lubricating oil (Driver et al., 1993). It is a pale colored liquid, and has a viscosity similar to that of SAE 20 motor oil. The military specifications require: 320 °F minimum flash point; a Kinematic viscosity (cSt) at 212 °F of 3.40 minimum and 4.17 maximum; 0.2% maximum Ramsbottom

Carbon; 0.1 maximum neutralization number; and -40 °F maximum pour point. The density of SGF-2 fog oil is approximately 0.92 g/cm^3 (U.S. Army, 1992). Because crude oil compositions and distillation procedures differ, and a range of acceptable manufacturing specifications exist, individual batches of SGF-2 may be different in both appearance and composition (Driver et al., 1993). The physical specifications of SGF-2 have remained unchanged for over thirteen years.

While smoke is usually generated using pure SGF-2 fog oil, it may be necessary to blend the oil with kerosene, diesel fuel, or JP-8 to improve the flow of the resultant oil at temperatures below 32 °F. The recommended volume concentration of the added fuel is 0% above 32 °F, 25% between 32 °F and 0 °F, 40% between 0 °F and -25 °F, and 50% between -25 °F and -40 °F (Driver et al., 1993).

2.2.2 Chemical Properties of Fog Oil

Before manufacturing specifications were modified in 1986 to remove carcinogens and potential carcinogens, SGF-2 fog oil contained high concentrations of mononuclear and polynuclear aromatic hydrocarbons (PAHs), complex cyclic aliphatics, oxygenated aromatics and nitrogen based organic compounds. Three SGF-2 fog oils produced prior to 1980 by different manufacturers, were analyzed by Katz et al. (1980) and found to contain nearly equal amounts of aliphatic and aromatic compounds. These two fractions made up 95-99% of the total hydrocarbon content of the SGF-2 oils tested. The remaining fractions in the oils consisted of alcohols, acids, and esters.

In the pre-1980 SGF-2 fog oils tested by Katz, a number of aromatic compounds were identified, including substituted benzenes, naphthalenes, anthracenes, phenanthrenes dihydrophenanthrenes, fluorenes, acenaphthalenes, biphenyls, indanes, phenalenes, and ionols, as well as cyclic compounds. The aliphatic fractions contained straight and branched chain saturated hydrocarbons in the C_{14}-C_{22} range. A considerable number of nitrogen base materials were also identified in the oils, including quinoline, benzoquinoline, and indole derivatives. The 200 plus hydrocarbon species which could be identified, represented only a small fraction of the total number of hydrocarbons present, many of which could not be identified or detected in appreciable amounts.

SGF-2 fog oil manufactured under the 1986 military specification has a significantly altered hydrocarbon composition due to rigorous oil refinement to remove toxic aromatic hydrocarbons, some of which are known or potential carcinogens. Removal of the aromatic compounds has required manufacturers to either severely hydrotreat oils or subject them to solvent refining (Palmer, 1990).

Once the aromatic fraction is removed, low-toxicity aliphatics comprise the greatest percent of the SGF-2 oil (Palmer, 1990 and Rabe and Dorsey, 1994). Several SGF-2 fog oil samples were analyzed in 1995 and found to consist predominantly of aliphatics, and did not detect the presence of PAHs or mono-aromatics such as benzene (3D Environmental, 1995).

An aliquot of SGF-2 fog oil, sampled from drums stored at the U.S. Army Combat Maneuver Training Center (CMTC) at Hohenfels, Germany, was analyzed by gas chromotography/mass spectroscopy (GC/MS). Because the sample consisted of thousands of organic compounds, the chromatographic system used was not capable of resolving most of the constituents. The chromatogram consisted of a large, bell-shaped curve upon which many sharp peaks were superimposed. With this type of chromatogram, only those compounds in sufficient quantity to appear as a separate peak superimposed on the curve could be identified. Long chain aliphatic hydrocarbons dominated the sample, which also had substituted forms of indenes, pentadecane, dodecane, and cyclohexane (Brubaker et al., 1992).

Trace metals were analyzed in three different SGF-2 fog oils, manufactured prior to 1980 (Katz et al., 1980). Of the 14 different metal species analyzed by atomic absorption, 12 were not detected, and two metals, copper (Cu) and zinc (Zn), were detected in low parts per billion (ppb) concentrations. Results of the analyses are shown in Table 2.1.

Table 2.1: Results of Trace Metal Speciation in SGF-2 Fog Oil (from Katz et al., 1980)

Metal	Oil #1 (PPB)	Oil #2 (PPB)	Oil #3 (PPB)	Detection Limit (PPB)
Cadmium (Cd)	ND	ND	ND	9
Chromium (Cr)	ND	ND	ND	9
Cobalt (Co)	ND	ND	ND	9
Copper (Cu)	46 (± 25%)	46	48	
Lead (Pb)	ND	ND	ND	93
Manganese (Mn)	ND	ND	ND	9
Molybdenum	ND	ND	ND	95
(Mo)	ND	ND	ND	9
Nickel (Ni)	ND	ND	ND	9
Strontium (Sr)	ND	ND	ND	93
Tin (Sn)	ND	ND	ND	95
Vanadium (V)	55 (± 25%)	19	104	
Zinc (Zn)	ND	ND	ND	95
Arsenic (As)	ND	ND	ND	2
Mercury (Hg)				

ND - Not Detected, PPB - Parts Per Billion

Metal analyses on SGF-2 fog oils manufactured under current specifications specifications have not been performed. However, there is no reason to expect significant differences, particularly since present specifications require more rigorous oil refinement than the processing techniques used prior to 1986. Additionally, specifications dating back to 1984, and perhaps earlier, prohibit the use of re-refined oil in the manufacturing of fog oil (U.S. Army, 1984).

It is not unusual for re-refined oil such as used lubricating oils, to contain high metals concentrations, particularly used engine oil (Rabe and Dorsey, 1994). Because used lubricating oils cannot be re-refined for production of SGF-2, the probability of high metal concentrations in fog oil manufactured under current specifications is further reduced.

2.2.3 Proposed Specification Changes

The U.S. Army is currently in the process of approving the latest revision of the fog oil specification, MIL-F-12070E (U.S. Army, 1995a). The primary difference is the requirement of new tests to be conducted by the manufacturer to demonstrate the absence of "any toxic effect or carcinogenic or potentially carcinogenic effects." Required manufacturer certification tests include:

- Carcinogenicity test. A mouse skin paint test, as outlined in the National Toxicity Program, will be performed on the oil delivered to the Army or on previous batches of mineral oil produced by the same refinement process. The oil will be certified if the test does not produce an excess of malignant tumors when compared to the control group at the same application site (U.S. Army, 1995a).

- Mutagenicity test. An *in vitro* genotoxicity test in accordance with the Modified Ames test will be performed on the batch of oil only if results of the carcinogenicity test are unavailable. The fog oil can be certified with a Mutagenicity Index equal to or less than 1.0 (U.S. Army, 1995a).

- FDA White Oil Purity test. An analytical FDA white oil purity test to estimate aromaticity, will be performed only if results from the carcinogenicity test are unavailable. If the FDA absorbance value at 280 to 290 nanometers (nm) is less than 200 units, then the fog oil can be certified not toxic (U.S. Army, 1995a).

2.3 PHYSICAL AND CHEMICAL PROPERTIES OF FOG OIL SMOKE

2.3.1 Physical Properties of Fog Oil Smoke

Fog oil smoke generators used by the military produce smoke by heating liquid fog oil until it vaporizes, then propelling the vaporized oil into the atmosphere. As the fog oil vapor reaches the cooler atmosphere, it condenses into small oil droplets, 0.6-5.0 micrometers (μm) in diameter, which collectively form a fog-like cloud (Driver et al., 1993).

The particle size distribution has been measured in several studies. Aerodynamic mass median particle diameter (AMMD) ranged between 0.6 μm-1.3 μm (Ballou, 1981), and 0.2 μm-0.29μm (Aranyi et al., 1992), when measurements were made in inhalation aerosol chambers. Cataldo et al. (1989) measured fog oil smoke particle size in a wind tunnel and found droplet size to range between 1.6 μm and 3.1 μm. Using a similar (inertial) sampling technique, Katz measured mass median diameters of fog oil smoke droplets between 0.7 μm and 1.7 μm (Katz et al., 1980).

Because fog oil particles are spherical liquid droplets, their aerodynamic sizes and behavior can be calculated. Calculated estimates agree well with actual measurements made in the laboratory and field (Driver et al., 1993).

Aerodynamic particle size distributions of fog oil aerosols will vary based upon: generation method; viscosity and chemical composition of the fog oil; internal temperature of the generator; and feed rate of SGF-2 oil to the generator (U.S

Army, 1995b; Driver et al., 1993; and Katz et. al., 1980). For example, the M157 generator will produce larger oil droplets with lower internal temperature and high SGF-2 feed rate, and increasingly smaller oil droplets as internal temperature is increased and SGF-2 feed rate is decreased (U.S. Army, 1995b).

The size distribution of oil particles making up a smoke cloud, is very important to achieving optimum obscuration. Smoke clouds with smaller sized particles are unstable in light wind and tend to rapidly elevate a short distance from the generator. Smoke with larger particles sink rapidly to the ground and therefore, it does not provide enough vertical or horizontal obscurant cover.

2.3.2 Chemical Properties of Fog Oil Smoke

The Katz et al. (1980) studies represent the only indepth characterization of fog oil smoke for hydrocarbon compounds of biologic significance, and *were performed on fog oil manufactured prior to 1986.* Military manufacturing specifications were changed in 1986 to require the elimination of carcinogens and potential carcinogens from the oil. This modification is significant because a change in the hydrocarbon composition of the parent oil will also cause commensurate changes in the chemical composition of smoke generated from the oil. Studies were initiated in 1995 to document hydrocarbon compositional changes of the smoke generated with SGF-2 that had been manufactured after 1986. Final results are anticipated by the summer of 1996 (Parsons ES, 1996).

Katz analyzed smoke produced from three different SGF-2 oils using three different gasoline powered M3-A3 generators. The physical appearances of the three oils varied from clear light amber to dark black-brown. Varying the generators had little effect on either the physical or chemical properties of the smoke; additionally, the physical properties of the smokes were not greatly altered from one oil to the next.

Initially the fog oil smoke samples were separated into class fractions of aliphatics, aromatics, alcohols, acids, and esters. The aliphatic and aromatic fractions comprised 95-99% of the oils by weight in all three oils tested, as well as the smokes generated from them. In general, the aliphatic and ester fractions in the fog oil smoke samples were similar to the parent SGF-2 oil composition. There was, however, a slight increase in aromatic content of smokes when compared to parent SGF-2 oils (Katz et al., 1980). This finding indicates that removal of toxics and carcinogens in the parent oil will likely eliminate the same compounds in smoke generated from the oil.

The complete complement of hydrocarbons present in smoke produced by fog oil generators includes: hydrocarbons from vaporized and subsequent condensed fog oil; and the exhaust gases from the combustion of fuel used to

operate smoke generators. The hydrocarbon composition of the fuel exhaust gas will depend on such factors as the type of fuel used to power the generator (e.g., gasoline, No. 1 or No. 2 diesel, JP-4, etc.); the completeness of combustion as controlled by air/fuel ratios; temperatures, pressures and configuration of the combustion chamber; and methods of fuel injection into the chamber.

Depending on the type of generator, exhaust gases could be a source of toxic and carcinogenic hydrocarbons to the fog oil cloud because fuel consumption rates are different. For example, the M157 burns 2.5 gallons per hour [gph] of diesel fuel and uses 40 gph of fog oil (U.S. Army, 1995b). Again, results of tests conducted by Parsons ES are expected to contribute needed information on the hydrocarbons (aliphatics and aromatics) found in smoke produced by the M157 and M56 generators (Parsons ES, 1996).

2.4 FOG OIL SMOKE GENERATORS

2.4.1 Operational Guidance

In general, there are three types of systems for producing smoke: projected, self-defense, and generated smoke systems. This review will focus upon generated smoke systems, and more specifically, smoke generated from the mobile smoke generator systems anticipated for use in obscurant training conducted by the chemical school at Fort Leonard Wood.

Generators are designed to produce large amounts of smoke for a considerable length of time (60 to 90 minutes). Their ideal battlefield applications include screening, protecting, and sustaining obscuring smoke (U.S. Army, 1995b). Given the number of people and duration of concealment by smoke, this type of obscuring operation will provide the greatest exposure to the soldiers in the field.

2.4.2 Current Smoke Generation Equipment

The U.S. Army's primary generator is the M157 pulse-jet smoke generator. In addition, the Army is developing the M56 turbine-jet generator, which is scheduled for production in fiscal year (FY) 1997.

2.4.2.1 M157 Pulse-Jet Smoke Generator

The M157 pulse-jet smoke generator is a gasoline powered generator which is capable of vaporizing 0.67 gpm of fog oil (40 gallons per hour [gph]). The M157 is currently undergoing a retrofitting which will allow it to operate with multiple fuels, at a rate of 2.5 gph, in place of gasoline. Designated the M157A2, this will satisfy the DOD directive 4140.43 for fuel standardization, and should be

available for full deployment in FY97 (U.S. Army, 1995b). It can be mounted on either the M113 APC (armored personnel carrier) or the M1037 HMMWV (High Mobility Multipurpose Wheeled Vehicle or "Hum-Vee").

START Mode

Before starting the generator, a preheating operation is required if the ambient temperature is below 45 °F. To preheat the combustion chamber, a 150 watt glow plug and a 650 watt band heater are run for two minutes. At the end of this time period, or if the temperature is above 45 °F, the control switch is held in the "START" position.

When the generator is in the start mode, the primary fuel (diesel, JP-8, etc.) is pumped from the 5-gallon fuel tanks to the nozzle assemblies along with air from the air compressor. The fuel and air is mixed at the fuel/air mix manifold, and fed into the combustion chamber where a spark from the ignitor, which only fires once in the generation process, causes the fuel/air mixture to explode. The pressure created by the explosion closes the engine valve and forces the gases through the engine tube. At the same time, the vacuum which is created allows external air at atmospheric pressure to enter the combustion chamber, fuel is again added, and the combustion process repeats itself at a rate of 60 times per second.

When the exhaust gas has reached the proper operating temperature of 1475-1575 °F (verified by a thermocouple in the exhaust stream), the generator is then switched to its RUN mode and the SGF-2 is fed to the generator. This stops the ignitor spark and flow of compressed air.

RUN Mode

Once in the RUN mode, the flow of primary fuel (diesel, JP-8, etc.) is not stopped, therefore the final obscurant smoke that is generated is actually a mixture of exhaust gas from ignition of the primary fuel and vaporized SGF-2 fog oil.

After the primary fuel is ignited, the exhaust gas travels through a pipe, molded in the shape of a trombone, past the first 180° turn, where is passes over a thermocouple. If the temperature of this gas is between 1475-1575 °F, the fog oil pump assembly draws SGF-2 oil from a storage tank and pumps it into the exhaust gas stream. Vaporization occurs as the SGF-2 is mixed with the exhaust gases, and then forced into the atmosphere through one of three exhaust jets, where it cools and condenses into very small liquid droplets (approximately 5 μm in diameter). The small recondensed oil droplets, along

with partially combusted fuel exhaust, form a white smoke cloud. The temperature of the smoke when it reaches the atmosphere is between 900-1100 °F. Because the SGF-2 actually operates as the coolant for the generator, adjusting the flow of oil with the "FOG OIL FLOW" control knob will raise or lower the temperature in the generator. According to the "SMOKE TEMP" indicator on the control panel, the nominal operating range for the M157 generator is 650-900 °F. It must be noted, however, that the thermocouple inside the generator actually governs whether or not smoke will be produced, not the SMOKE TEMP indicator (U.S. Army, 1995b).

2.4.2.2 Turbine Smoke Generator

The turbine smoke generator, the first new smoke generator technology since the 1940s (U.S. Army, 1995b), can provide not only large area visual smoke capability, but also IR (infrared) smoke obscuration (through the use of graphite flakes). This new turbine smoke generator has two designations. When it is mounted on the M1097 HMMWV, it is designated M56, and when mounted on the M113 APC, it is designated the M58. The sampling conducted by Parsons ES in 1995, was of smoke produced by the M56 variant of the turbine smoke generator. The M56 utilizes a turbine engine, powered by either diesel or JP-8 fuel with a rate of 15 gph, which will generate exhaust gas for vaporizing SGF-2 fog oil to provide visual smoke, bleed air to propel the IR graphite smoke, and electrical power to operate the system (U.S. Army, 1995b).

When producing visual smoke, the M56 can consume 1.33 gallons of SGF-2 per minute (80 gallons/hour) by pumping the fog oil from its two, 45-gallon tanks. Currently it can generate smoke for up to 60 minutes, and a material change program (MCP) will be conducted in FY96 to increase the generation time to 90 minutes (U.S. Army, 1995b). Full-scale production of the M56 generators should begin in FY97.

Producing Smoke

The M56 generates smoke by shooting SGF-2 oil through a small injector which is in the exhaust nozzle, approximately 5 inches from the ignition chamber. Fog oil flow is controlled by a thermocouple also located in the exhaust nozzle. Heat from the turbine exhaust vaporizes the oil into droplets. Given the force of the exhaust, and the 1050 °F exhaust gas temperature, the smoke cloud begins to form several feet from the generator.

SECTION 3 - HUMAN HEALTH EFFECTS

3.1 EXPOSURE LEVELS TO FOG OIL SMOKE

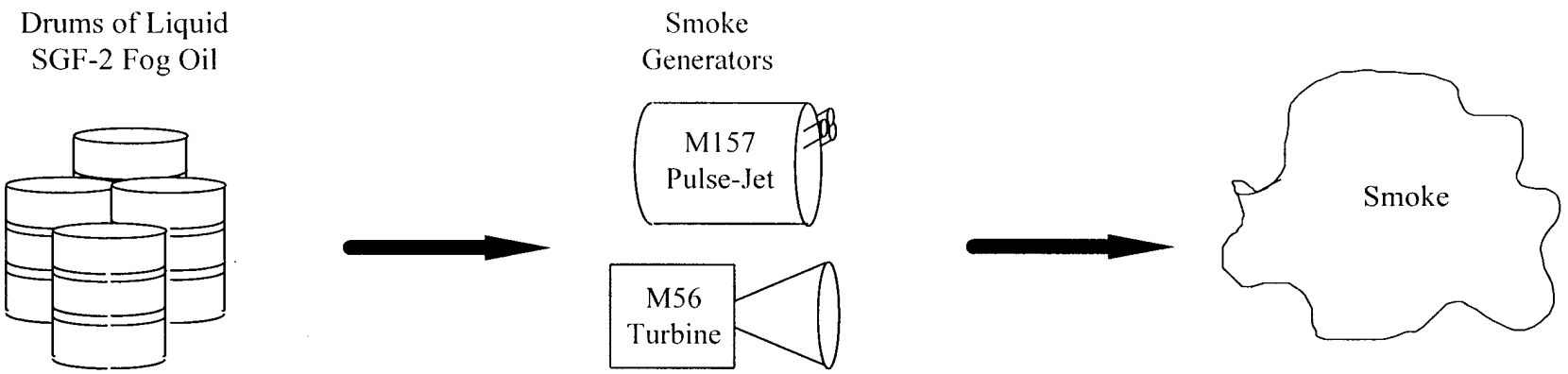
The importance of understanding the fate of chemicals in the environment cannot be underestimated as it relates directly to the types of exposures to which humans and the environment are subjected. In the case of fog oil obscurant training, the level and duration of the exposures, in combination with the toxicity of the substance(s) making up the exposure, are directly correlated to the potential environmental and human health effects. The source term exposures for the SGF-2 oil can be broken into three categories: windborne smoke (inhalation and visibility effects), deposition of materials (dermal exposures), and the potential release of potentially large quantities of bulk liquid fog oil from normal transportation and handling (including the filling and draining of the smoke generator tanks) or accidental spills of the liquid SGF-2 oil (Driver et al., 1993).

3.1.1 Potentially Exposed Personnel

As with the source term exposures, the exposed groups can also be broken into three categories: those who are exposed only to the liquid SGF-2; those who are only exposed to the smoke; and those that can be exposed to both the liquid fog oil and the smoke.

Support personnel are most likely to only be exposed to the liquid SGF-2 oil. Such exposures would most likely be from accidental spills relating to the transportation and handling of the oil. Those likely to be exposed only to the smoke are the soldiers in the field that are being obscured by the smoke during training or actual combat. While there is a chance of dermal exposure through the settling of the droplets on the exposed skin, it is not expected to be an appreciable amount. The group that faces exposure to both the liquid oil and the obscurant is the generator operators. They will be exposed to the liquid oil while filling and draining the generator tanks and performing maintenance on the generators. While in the field, they could be exposed to the smoke under several conditions such as a sudden wind change or malfunction of the generator. Figure 3.1 summarizes the relationship of the source term exposures.

Figure 3.1: Potential Source Term Exposures



Group Exposed: Support Personnel, Generator Operators

Primary Exposure Type: Dermal

From: Transportation and Handling, Accidental Spills

Group Exposed: Generator Operators

Primary Exposure Type: Dermal

From: Filling and Draining of Tanks, Accidental Spills

Secondary Exposure Type: Inhalation

From: Smoke Generated from SGF-2 Oil

Group Exposed: Soldiers

Primary Exposure Type: Inhalation

From: Smoke Generated from SGF-2 Oil

Secondary Exposure Type: Dermal

From: Droplets from Smoke Settling on Exposed Skin

3.1.2 Environmental Exposures to Fog Oil Smoke

The airborne fog oil droplets are deposited on the ground and other surfaces in relation to the atmospheric conditions at the time the fog is generated. Although the weather and surface conditions will be different for each fogging scenario, there are several general conditions that are consistent with the smoke generation. First, the droplets are small enough that they will always travel downwind. Second, the concentration of the settled droplets will decrease as the distance from the generating source increases. Finally, once fog oil droplets deposit, they will be less likely than other smoked materials (such as the graphite flakes used for IR obscuration) to be redistributed during wind storm and other atmospheric conditions. Therefore, the environmental exposures to the droplets will occur at the location of initial deposition (Driver et al., 1993).

Soil deposition modeling using a Gaussian dispersion model (Hanna et al., 1982) estimated soil deposition, depending on atmospheric conditions, to range between 30 to 300 milligrams per square meter (mg/m^2) 1 km downwind to less than 0.001 to 0.3 mg/m^2 at 40 km downwind. The modeling also estimated deposition concentrations to be less than 10 mg/m^2 at distances greater than 2 km downwind for any atmospheric condition (Driver et al.,1993).

Actual field results from testing conducted in 1985 by Liljegren et al., suggest that the model results may even be too conservative and best suited as a worst case estimate. Their testing resulted in non-dectable levels for fog oil on neither horizontal (to simulate ground cover) nor vertical (to simulate shrubs and blades of grass) surfaces. Therefore, they concluded the deposition of fog oil smoke from settling, diffusion, or impaction, is insignificant at distances greater than 25 m downwind (Liljegren et al., 1988). Although the chemical, photochemical, and microbial degradation of the fog oil is site dependent, given the small amounts that will be deposited, long term soil contamination is not expected (Driver et al., 1993).

Extensive air modeling has been conducted in an attempt to characterize the dissemination of the droplets in the atmosphere. In order to assess the potential impacts of tests and training activities on the environment, several variables must be identified. Among these are deposition rates, air concentration, and plume dispersion (Driver et al., 1993). The first model used to quantify these unknowns was a Gaussian plume dispersion model, selected because it is the most basic and commonly used dispersion model (Hanna et al., 1982).

3.1.3 Estimated Airborne Concentrations Using the Gaussian Dispersion Model

The model developed by Hanna et al. is a plume dispersion model which provides an estimate of the downwind concentrations of fog oil in a three-coordinate system, where x is the downwind coordinate, y is the crosswind coordinate, and z is the vertical coordinate. The input parameters of the model are based upon the mass rate of fog oil generation, the mean velocity of the wind, height of the plume at the point of release, settling velocity of fog oil droplets in the plume, deposition velocity of fog oil droplets, the length of time the generator is run, and an atmospheric stability condition (ASC; Hanna et al., 1982). The ASC is a qualitative characterization of atmospheric turbulence, based upon surface wind speed and insolation level (Driver et al., 1993). Table 3-1 provides the criteria for characterizing the six ASCs.

Table 3.1: Meteorological Conditions Defining Turbulence Types (Driver et al., 1993)

	Daytime Insolation			Nighttime Conditions	
Surface Wind Speed (m/s)	Strong	Medium	Slight	Thin Overcast or > 4/8 Low Cloud	≤ 3/8 Cloud
<2	A	A-B	B	-	-
2	A-B	B	C	E	F
4	B	B-C	C	D	E
6	C	C-D	D	D	D
>6	C	D	D	D	D

ASCs: A = extremely unstable; B = moderately unstable; C = slightly unstable; D = neutral; E = slightly stable; and F = moderately stable.

Driver et al. ran six test cases using this model and the M56 smoke generator in a variety of ASCs in order to estimate plume dispersion and deposition for the SGF-2 oil. In each of their test cases the following assumptions were made: the generator consumed fog oil at a rate of 77 grams per second (g/s, or 80 gal/h), the plume height was 5 m (Case 6 used a plume height of 10 m), and wind speed was assumed to be in the range of 2-5 m/s. Although different ASCs were selected to optimize test results, it was determined that ASCs A and B provide poor obscuration but good mixing, D may provide good obscuration, and E and F are very uncommon (Driver et al., 1993). Settling velocity was assumed to be 0.02 cm/s, and the deposition velocity was assumed to be 0.06 cm/s for a wind speed of 2 m/s, and 0.6 cm/s with a wind speed of 5 m/s (Cataldo et al., 1990). Finally, the smoke generation time was set to 30 minutes.

3.1.3.1. Results of the Gaussian Dispersion Model

In each of the six tests, two concentrations were determined: Cm, the concentration of the fog oil in the air assuming no surface reflection (all of the oil droplets settle on the ground at impact); and Cm*, the concentration of the fog oil in the air assuming 100 percent surface reflection (none of the oil droplets settle on the ground). Both are estimated to be the concentrations at 1 m above the ground. In each of the test cases, the crosswind distance was held at a constant (0 km) while the downwind distance was varied (0.1-40 km), and then the downwind distance was held constant (1 km) while the crosswind distance was varied (0.1-0.4 km). Table 3.2 provides the assumption that were used in each model, and Table 3.3 provides the results of the model.

Predicted fog oil concentrations decrease from a range of 14-120 mg/m^3 at 0.1 km downwind to 0.002-0.27 mg/m^3 at 40 km downwind. The highest concentration for both Cm and Cm* occurs in Case 4 at a distance of 0.2 km. This range, 110-140 mg/m^3, is over ten times the short-term exposure limit (STEL) of 10 mg/m^3 which has been established by the American Conference of Governemental Industrial Hygienists (ACGIH).

In addition, at all points greater than 0.3 km, the model produces concentrations higher than the STEL. This would indicate that respiratory protection would be needed for most generator operations, and in the event that a smoke is generated in conditions similar to those modeled in Case 4, respiratory protection would still be needed over 1 km from the generator source.

This model, however, is highly idealistic. The assumptions, for example, are very conservative, and do not necessarily simulate actual field conditions found when generating smoke. First, the first set of results in Table 3.3 are produced assuming a the smoke will not laterally disperse during generation, which is highly unlikely based upon real world observations. As the model indicates, concentrations are significantly reduced as one moves laterally from the generator. For example, in Case A, the concentration at 1 km downwind and perfectly in line with in the generator is 0.15 mg/m^3; at 0.2 km from the centerline, the concentration is 0.092 mg/m^3; and at 0.4 km from the centerline, the concentration is 0.024 mg/m^3.

Second, model results indicated the air and surface concentrations steadily decrease as the downwind distance increases. Actual field surveys indicate that fog oil concentrations may actually have maxima and minima based upon site-specific characteristics. Finally, the wind vector that is used must be kept constant in direction and time, and field tests show that constant wind changes

greatly affect the intensity of the plume. These real-world conditions invalidate many model results.

Testing conducted in 1992 by the U.S. Army Chemical School would indicate that actual concentrations may not be as high as the model would indicate. Smoke was generated for 8-hours in order to compare exposures to the 8-hour threshold limit values (TLVs) established by the ACGIH and the personal exposure limit (PEL) established by the Occupational Safety and Health Administration (OSHA). The results indicate personal exposure levels of 0.0-1.98 mg/m^3, which are considerably lower than the TLV and PEL of 5 mg/m^3 (Skrutskie et al., 1993). In addition, modeling shows a decrease in air concentration of fog oil due to volatilization of 30-40% within a 1 hour period, and approximately 80-90% within one week of smoke generation (Driver et al., 1993).

While the Gaussian model results may not be completely accurate, they could be used to represent the worst-case exposure scenario. Because the assumptions used are highly conservative, using this model to predict the worst possible exposure level would be plausible. In recent years, two new models, the Industrial Source Complex Dispersion Model (Wackter and Foster, 1986) and the Real-Time Volume Source Dispersion Model (Bjorklund, 1990), have been developed which more accurately reflect the changing atmspheric conditions and terrain conditions. These models have become widely accepted, and the Bjorklund model is currently used by the Meteorolgy Division of the U.S. Army at Dugway Proving Grounds, Utah (Driver, et al., 1993).

3.2 DERMAL EXPOSURE

Fog oils are generally classed in the category of oils known as mineral oils, which are derived from petroleum hydrocarbons. Historically, mineral oils have been produced by a number of refinery processes and from a wide range of parent oils. The hydrocarbon composition of mineral oil will differ depending on the method of production and the base oil used to prepare it (Palmer, 1990, and Driver et al., 1993). Toxicity of a particular mineral oil is directly correlated with the types hydrocarbons contained in the oil.

Mineral oil exposures to workers are particularly high in certain industries such as metal fabrication and machining; printing press operations; jute and cotton spinning; and refining (Selgrade, et al. 1990). Considerable evidence has correlated skin cancer of the hand, arm and scrotum to exposures to minerals oil previously used in these and other industries (Cruickshank and Squire, 1950; Bingham et al., 1980; International Agency for Research on Cancer [IARC], 1984; and Palmer, 1980). PAHs in mineral oils were identified as the main class of hydrocarbon compounds causing cancer and toxicity in humans (Bingham et al., 1980, and Hermann, et al., 1980).

Table 3.2: Assumptions Used in the Gaussian Model

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
SGF-2 Flow Rate (g/s)	77	77	77	77	77	77
Wind Speed (m/s)	2	2	5	2	5	2
ASC	A	C	D	F	C	C
Time (min)	30	30	30	30	30	30
Vertical Coordinate [z] (m)	1	1	1	1	1	1
Settling Velocity (cm/s)	0.02	0.02	0.02	0.02	0.02	0.02
Deposition Velocity (cm/s)	0.06	0.06	0.06	0.06	0.06	0.06

Table 3.3: Results of the Six Test Cases Using the Gaussian Model

		Case 1		Case 2		Case 3		Case 4		Case 5		Case 6	
x (km)	y (km)	Cm (mg/m^3)	Cm* (mg/m^3)	Cm (mg/m^3)	Cm* (mg/m^3)	Cm (mg/m^3)	Cm* (mg/m^3)	Cm (mg/m^3)	Cm* (mg/m^3)	Cm (mg/m^3)	Cm* (mg/m^3)	Cm (mg/m^3)	Cm* (mg/m^3)
0.1	0	1.4E+01	2.7E+01	6.2E+01	1.2E+02	4.2E+01	7.3E+01	3.7E+01	3.7E+01	2.5E+01	4.6E+01	3.7E+01	6.4E+01
0.2	0	3.5E+00	7.0E+00	1.7E+01	3.4E+01	1.3E+01	2.6E+01	1.1E+02	1.4E+02	6.8E+00	1.3E+01	1.5E+01	2.9E+01
0.4	0	8.8E-01	1.8E+00	4.5E+00	9.0E+00	3.9E+00	7.7E+00	5.3E+01	9.3E+01	1.8E+00	3.6E+00	4.4E+00	8.7E+00
0.7	0	2.9E-01	5.9E-01	1.6E+00	3.1E+00	1.5E+00	2.9E+00	2.2E+01	4.2E+01	6.1E-01	1.2E+00	1.5E+00	3.1E+00
1	0	1.5-01	2.9E-01	7.9E-01	1.6E+00	8.0E-01	1.6E+00	1.3E+01	2.4E+01	3.1E-01	6.2E-01	7.9E-01	1.6E+00
2	0	3.8E-02	7.6E-02	2.2E-01	4.5E-01	2.6E-01	5.2E-01	4.0E+00	7.9E+00	8.6E-02	1.7E-01	2.2E-01	4.5E-01
4	0	1.0E-02			1.4E-01	9.1E-02	1.8E-01	2.0E-02	6.8E-02	2.6E-02	5.2E-02	6.8E-02	1.4E-01
7	0	3.7E-03	7.4E-03	2.8E-02	5.6E-02	4.1E-02	8.2E-02	7.3E-01	1.5E+00	1.1E-02	2.2E-02	2.8E-02	5.7E-02
10	0	2.0E-03	3.9E-03	1.7E-02	3.4E-02	2.5E-02	5.0E-02	4.9E-01	9.8E-01	6.4E-03	1.3E-02	1.7E-02	3.4E-02
20	0	-----	------	6.6E-03	1.3E-02	1.0E-02	2.0E-02	2.5E-01	5.0E-01	2.5E-03	5.0E-03	6.6E-03	1.3E-02
40	0	-----	-----	2.9E-03	5.7E-03	4.3E-03	8.7E-03	1.4E-01	2.7E-01	1.1E-03	2.1E-03	2.9E-03	5.7E-03
1	0.1	1.3E-01	2.6E-01	5.0E-01	1.0E+00	3.4E-01	6.8E-01	3.9E-01	7.6E-01	2.0E-01	3.9E-01	5.0E-01	1.0E+00
1	0.2	9.2E-02	1.8E-01	1.3E-01	2.6E-01	2.6E-02	5/1E-02	1.3E-05	2.5E-05	5.0E-02	1.0E-01	1.3E-01	2.6E-01
1	0.4	2.4E-02	4.7E-02	5.5E-04	1.1E-03	8.6E-07	1.7E-06	1.6E-23	3.1E-23	2.1E-04	4.3E-04	5.5E-04	1.1E-03

In general, short-term dermal contact with conventionally refined mineral oils (with higher aromatic content), can cause mild erythema; however, repeated contact over prolonged periods can cause inflammation, dermatitis, folliculitis, acne, eczema, contact sensitivity and cancer (Palmer, 1990). The lipid solubility of aliphatic and aromatic hydrocarbons allows their absorption through the respiratory epithelium, mucous membranes, gastrointestinal tract and epidermis. Normal aliphatics can be represented by octadecane and hexadecane for purposes of studying absorption, and in a study with guinea pigs, 20% of the hexadecane dose applied to the skin was absorbed. Aromatic hydrocarbons are absorbed slowly through the skin (Liss-Suter et al., 1978).

IARC evaluated human health literature on the carcinogenic effects of mineral oils, manufactured by different types of processes (IARC, 1984). The production of skin tumors caused by dermal application of different mineral oils in laboratory animals, was used to judge carcinogenic potency. The SGF-2 fog oil manufactured by current military specifications is equivalent to a mineral oil which has been either severely hydrotreated, severely acid-treated or severely solvent-treated and would therefore demonstrate no evidence of carcinogenicity. A summary of the IARC evaluation is depicted in Table 3.4.

Table 3.4: IARC Evaluation of Carcinogenic Risk of Mineral Oils (IARC, 1984)

Type of Oil	Carcinogenicity to Experimental Animals from Dermal Exposures
Vacuum distillates	Sufficient evidence
Severely solvent-refined	No evidence
Mildly solvent-refined	Sufficient evidence
Severely hydrotreated	Inadequate evidence
Mildly hydrotreated	Sufficient evidence
Severely (oleum) acid-treated	No evidence
Mildly acid-treated	Sufficient evidence
Aromatic distillate extracts	Sufficient evidence
White oils	No evidence

Dermal exposure to SGF-2 fog oil manufactured according to specifications instituted in 1986, does not elicit the same strong reactions typical of mineral oils containing high PAHs. Severe hydrotreatment and/or solvent refinement of SGF-2 oil in accordance with 1986 military specifications, serves to reduce PAH concentration in oils such that they do not exhibit carcinogenic effects and have reduced dermal toxicity (Federal Register, 1985; MSDS, 1989; Mackerer, 1989; Herman et al, 1980; and Hans et al., 1964). SGF-2 fog oil currently used by the military is not considered by IARC to be carcinogenic upon repeated or prolonged exposure to skin because of the severe refining process used to significantly reduce carcinogenic compounds (OSHA, 1985; ACGIH, 1993).

The material safety data sheet (Industrial Oils Unlimited, 1989) classes SGF-2 fog oil as a non-hazardous, hydrotreated heavy napthenic distillate and further states, "prolonged or repeated exposure to liquid or mist may cause dry skin, irritation, and oil acne." Special protection recommended in the MSDS includes the wearing of impervious gloves; the use of face shield and goggles for eye protection; and specifies standard work clothing which can be washed with soap and water for reuse. SGF-2 fog oils are not considered to be skin sensitizers or eye irritants (Mathei et al., 1980, and Mayhew et al., 1986).

3.3 INHALATION

3.3.1 Inhalation Effects of SGF-2 Fog Oil

Inhalation of smoke produced by generators using SGF-2 fog oil, is considered to be the most important of the different types of direct exposures (e.g., inhalation, dermal contact, ingestion) to military troops during training exercises or combat missions. Smoke generators produce small fog oil droplets in the 0.6 to 3 μm size range that can effectively penetrate to the gas-exchange, or alveolar regions of the lungs (Driver et al., 1993 ; and ACGIH, 1985).

Dispersion modeling of fog oil droplets (which comprise the smoke cloud) indicates windborne fog oil concentrations will generally decrease from between 7 and 140 mg/m^3 at downwind distances between about 0.1 and 0.2 km, to between less than 0.003 and 0.3 mg/m^3 at a distance of 40 km (Driver et al., 1993). Actual personnel monitoring during an 8-hour field training exercise, demonstrated personnel exposure levels between 0.0-1.98 mg/m^3 (Skrutskie, et al., 1993). This exposure level was considerably lower than the Threshold Limit Value (TLV) and Personal Exposure Level (PEL) of 5 mg/m^3, established by ACGIH and OSHA, respectively. Young et al. (1989) collected breathing zone samples from soldiers and Cadre involved in both field, and generator operation and maintenance training ("static training"). Fog oil exposures during field training were generally under the 5 mg/m^3 TLV-TWA for mineral oil. However, exposures of personnel in close proximity to generators was greater during

static training where more than 50 percent of the Cadre and students alike, experienced exposures in excess of the TLV-TWA of 5 mg/m^3 when one hour exposures were averaged over an 8-hour period.

The studies of Grose et al. (1986), Selgrade et al. (1987 and 1990), and Aranyi et al. (1991 and 1992) represent the most rigorous research investigations of the inhalatory effects of SGF-2 fog oil to laboratory test animals. This review will therefore provide more indepth reporting of those inhalation studies on SGF-2 and will examine, to a lesser extent, the literature on inhalation effects of oil mists from other mineral oils.

The fog oil currently used for military smoke application is heavily hydrotreated or solvent refined to eliminate carcinogens or potential carcinogens. Therfore, it is important to distinguish the fog oil inhalation studies performed using SGF-2 processed to eliminate carcinogenicity (i.e., severely hydrotreated to reduce PAHs), from studies performed with fog oils which have high PAH content and presumably exhibit carcinogenicity and more toxicity.

The Aranyi studies were conducted with SGF-2 fog oil containing low PAHs, but the timing of the Grose and Selgrade studies would indicate they were conducted with fog oil processed before 1986. Because the same SGF-2 oil was used in both studies by Selgrade and results of the earlier study were published in 1987, it is likely the SGF-2 oil was manufactured under pre-1986 military specifications. A draft report of the results of studies by Grose was complete in 1985, therefore the SGF-2 oil used must have been produced before 1986.

High, acute inhalatory exposures are necessary to elicite lethal effects to laboratory animals. Rats exposed for 3.5 hours to smoke generated with pre-1986 SGF-2, produced an LC_{50} of 5.19 mg/l (5190 mg/m^3, Selgrade et al., 1987). An LC_{50} is the dose resulting in 50% mortality of the test population. Most mortality occurred between the 4.2 and 5.9 mg/l concentrations.

Minimal systemic and pulmonary changes were noted when rats were repeatedly exposed (3.5 hours/day, 4 days/week for 4 to 13 weeks) at concentrations below 500 mg/m^3 (Grose et al., 1985 and 1986). Selgrade et al., (1987) exposed rats in the laboratory to SGF-2 fog oil smoke for 3.5 hours per day and 4 days per week for 4 weeks. Exposure concentrations were 1.5, 0.5, or 0.0 mg/l (1500, 500 and 0 mg/m^3). The oil droplet size making up the smoke, was approximately 1 μm. Samples of respiratory tissues were taken for histopathologic analysis, lavage fluid samples were collected, and pulmonary function measurements were made the day after the last exposure.

When compared to the control group of rats, exposures at the 1.5 mg/l level resulted in accumulation of macrophages within the alveolar lumen, increased lavage fluid protein content, and elevated total cell content in lavage fluid due to an influx of polymorphonuclear leukocytes. For the 1.5 mg/l exposure group there was also an increase in lung wet and dry weight; an increase in end-expiratory volume; and pneumonitis was observed histopathologically in 4 of 10 male rats. Pneumonitis was not observed among six female rats examined. Oil fog had no effect on total lung capacity, residual volume, vital capacity, lung compliance, or the distribution of ventilated air within the lung. Effects from the 0.5 mg/l exposure were limited to slight accumulation of macrophages in the alveolar lumen and an increase in the total number of cells in lavage fluid. Although the SGF-2 oil used in these experiments likely contained toxic and carcinogenic concentrations of aromatics, few effects were noted at the 500 mg/m^3 chronic exposure concentration (Selgrade et al., 1987).

In another inhalation study, Selgrade et al. (1990) exposed rats for 3.5 hours per day, 4 days per week for 13 weeks to oil mists created by flash vaporization and subsequent condensation of fog oil. Males were exposed at concentrations of 1.5, 0.5, 0.2 and 0.0 mg/l (1500, 500, 200, and 0 mg/m^3) at a particle size of approximately 1 μm. Biological endpoints were assessed the day after the last exposure and in some cases, after a 4 week recovery period.

Effects were concentration dependent. Histologic effects observed one day and 4 weeks post-exposure, were similar. Minimal histological and minimal lavage fluid protein increase were the only changes observed at the 0.2 mg/l exposure. Increases in lavage fluid protein, percent lavagable polymorphonuclear leukocytes and lung wet and dry weight were observed for the 0.5 and 1.5 mg/l exposures. Increased lung weight was evident in rats exposed at 1.5 mg/l, 4 weeks after exposure. Pulmonary functions including total lung capacity, vital capacity, residual volume, diffusing capacity to carbon monoxide, compliance, and end expiratory volume (EEV), were unaffected by exposures, except EEV in male rats exposed at 1.5 mg/l. By comparison to controls, the incidence of multi-focal pneumonia was low and was not increased when exposures were extended from 4 weeks to 14 weeks (Selgrade et al., 1987).

Aranyi et al. (1991) chronically exposed rats to flash-vaporized and subsequently condensed aerosols of SGF-2 fog oil at 100 mg/m^3 for 4 hours per day, 4 days per week for four weeks; and 200 mg/m^3 for 1 hour per day, 2 days per week for 4 weeks. In a parallel study, Aranyi et al. (1992) extended exposures to 13 weeks and monitored recovery 3 and 6 weeks after exposure.

There were no mortalities or significant exposure-related clinical signs. Effects included decreased body weight gain and food consumption early in the exposure

period; increased lung/body weight ratio; hyperplasia of the goblet cells of the respiratory epithelium of the nose; and hyperplasia of the epithelium of the lung. Complete recovery was seen for the goblet cell hyperplasia. Mild inflammatory lesions were detected in 4 and 13 week exposures which failed to resolve after 3 and 6 week recovery periods. Pulmonary function tests demonstrated a mild restrictive lesion characterized by decreased respiratory system compliance and a reduction in static and dynamic lung volumes after the 4 and 13 week exposures. The restrictive lesion, as measured by functional parameters, showed no signs of recovery (Aranyi et al.,1992).

In summary, the results of actual fog oil inhalation studies with rats, in controled laboratory experiments, were consistent and demonstrated dose response relationships. A very high inhalation concentrations of 5,190 mg/m^3, administered for 3.5 hours, was necessary to elicite acute mortality to rats (Segrade et al., 1987). This concentration would only be found within a few feet of a fog oil smoke generator (Parsons, 1996).

For studies involving chronic, long-term exposures of fog oil to rats, oil mist concentrations ranged from 100 mg/m^3 to 1500 mg/m^3. Duration and frequency of chronic exposures ranged from 4 to 13 weeks, 3.5 to 4 hours per day, and 4 days per week (Selgrade et al., 1987; Selgrade et al., 1990, Aranyi et al., 1991; and Aranyi et al., 1992). Results were similar in each of the reasearch studies. Chronic exposure concentrations below 200 mg/m^3 elicited minimal effects such as slight accumulation of macrophages in the alveolar lumen and slight increases of cells in the lavage fluid protein. No impacts to respiratory function were seen at the 200 mg/m^3 exposure concentration. Chronic exposure concentrations as high as 1,500 mg/m^3, demonstrated only slight elevations in lavage fluid proteins and cells, some evidence of pneumonitis in male rats only, and minimal effects on pulmonary function.

Concentrations of fog oil measured in the field, are commonly less than 200 mg/m^3 at 50 meters downwind of a generator (Liljegren et al., 1988). Personnel involved in training generally occupy areas upwind of generators, thus limiting the time they would be exposed to 200 mg/m^3 concentrations. Skrutskie et al., (1993) monitored military personnel in the field and determined the Threshold Limit Value-Time Welghted Average (TLV-TWA) of 5mg/m^3 would not be exceeded while conducting obscurant training. Results of fog oil inhalation studies with laboratory animals, indicate much higher exposures at greater frequency and duration than those received during oil fog obscurant training, would be neccessary to elicite deleterious respiratory effects in military personnel.

In general, inhalation studies with laboratory animals exposed to SGF fog oil, whether manufactured prior to or after 1986, demonstrated minimal effects, even

considering the exposure concentrations, and frequency and durations of the exposure, were many time higher than soldiers encounter during obscurant training.

3.3.2 Inhalation Effects of Other Oils

Inhalation of mineral oil mists, generated at industrial workplaces, can cause two types of lipoid pneumonia. The first is lipoid granuloma or paraffinoma (a circumscribed lesion within a lobe of the lung and easily mistaken for a tumor), and the second is diffuse pneumonitis in which oil droplets are disseminated throughout one or more lobes of the lung (Palmer, 1990). In some cases lipoid pneumonia is asymptomatic while in others, symptoms are manifested as occassional to severe cough, dyspnea and/or pulmonary illness leading to death.

There is little research evidence to indicate that occupational exposure to oil mists produces significant deleterious effects on the pulmonary system (Jarvholm et al., 1982). Industrial oil mist exposures as high as 50 mg/m^3, over many years, have not been attributed to many cases of respiratory illness (Liss-Suter et al., 1978).

Extensive reviews of the literature revealed no evidence to suggest a relationship between oil mist and lung cancer; however, prolonged exposure to oil mists from poorly refined oils, sometimes leads to skin cancer (Hendricks et al., 1962). In a study by Jarvholm and Lavneius (1987) of workers exposed to cutting fluids, mortality from lung cancer was less than expected, and urinary bladder and gastrointestinal tract cancers were not elevated.

Hendricks et al.(1962) found that a sizable population of workers from many industries, are exposed to oil mists and that average exposure levels are less than 15 mg/m^3. He concluded that pulmonary irritations would be minimized by a maximum allowable exposure level of 5 mg/m^3.

3.4 INHALATION EXPOSURE STANDARDS

The American Conference of Governmental Industrial Hygienists (ACGIH, 1994) set the Toxic Limit Value for chronic, time weighted average (TLV-TWA) industrial exposure to oil mists from white oils, severely hydrotreated, severely solvent-treated and severely acid-treated mineral oils, at 5 mg/m^3. The TLV refers to airborne concentrations of substances and represents conditions under which it is believed that nearly all workers may be repeatedly exposed daily (8 hour work-day and 40 hour work-week), without adverse health effects. In order to assign a TLV, the ACGIH considers all available information from industrial experience and experimental studies with animals and humans.

ACGIH has established a TLV Short-Term Exposure Limit (TLV-STEL) for mineral oil mists of 10 mg/m^3. The STEL is the concentration to which workers can be exposed continuously for a short period of time without suffering from irritation, chronic or irreversible tissue damage or narcosis. In general, STEL exposure periods should not exceed 15 minutes nor be repeated more than four times per day (ACGIH, 1992). The STEL also provides that the TLV-TWA is not exceeded.

The Occupational Safety and Health Administration (OSHA, 1989) established a Permissible Exposure Limit - Time Weighted Average (PEL-TWA) for mineral oil mists of 5 mg/m^3. The National Institute for Occupational Safety and Health (NIOSH) Recommended Exposure Limit-Time Weighted Average (REL-TWA) and STEL of 5 mg/m^3 and 10 mg/m^3, respectively, thus concurring with OSHA's proposed PEL. NIOSH found no evidence of an Immediate Danger To Life and Health (IDLH) value for mineral oil mists (AIH, 1993).

The exposure limits recommended by ACGIH are for mineral oils that have been severely hydrotreated, severely acid-treated, or severely solvent-treated, and white oils. The ACGIH standards do not apply those mineral oils which have been only mildly treated, or produced by vacuum distillation. The OSHA and NIOSH standards are for all mineral oils, regardless of how they are processed, or the types of additives they contain (ACGIH, 1993). Exposure standards established by other nations for mineral oil mists are shown in Table 3.5 (ACGIH, 1993).

Table 3.5: Mineral Oil Exposure Standards in Other Nations

Country	TLV-TWA	TLV-STEL
Australia	5 mg/m^3	10 mg/m^3
Sweden	3 mg/m^3	5 mg/m^3
United Kingdom	5 mg/m^3	10 mg/m^3

Concentrations of fog oil smoke may reach potentially harmful levels (i.e., $\geq$ 10 mg/m^3) within 2 km downwind of a smoke generator during training exercises; if weather conditions favor a shallow mixing depth. With greater mixing depth, harmful levels are limited to 0.4 km from a generator, based on modeling analysis (Driver et al., 1993). Young et al. (1989) determined exposure concentrations up to 130 mg/m^3 for military personnel in proximity to the generators during gererator operation and maintenance training (i.e. static training) and that the safe TLV is often exceeded. However, when exposures were averaged over an 8 hour period, at least 50% of the individuals were not exposed to concentrations > 5 mg/m^3. In another personnel monitoring program of exposures received during a field training

fog oil obscurant exercise, Skrutskie et al. (1993) determined 8-hour time weighted average exposures of 0.00-1.98 mg/m^3.

3.5 INGESTION

Simple ingestion, without aspiration, of mineral oils with high aromatic content will irritate the mucous membranes of the mouth, throat, and upper gastrointestinal tract. The danger of ingestion of is that aspiration and resultant chemical pneumonitis almost always follow due to coughing or gagging caused by the fuel (Liss-Suter and Villaume, 1978).

The acute toxicity from ingestion of SGF-2 fog oil manufactured after 1986 (i.e., with low PAH) is 0.47 to 0.94 liters, LC_{50}, and is therefore considered practically non-toxic (MSDS, 1989). Very unusual circumstances would have to occur for a person to ingest this amount of fog oil. Ingestion of highly refined mineral oils over prolonged periods is not known to cause cancer in animals (Palmer, 1990). When rats were fed 2 percent liquid paraffin in their diet for 500 days, no tumors were induced (Schmal and Reiter, 1953).

The effects of ingestion of fuel oils, kerosene, diesel, and mineral oils, which contain high concentrations of PAHs, have been documented in the fog oil/human health reviews of Liss-Suter et al., Palmer, and Driver et al. Their findings are not summarized because SGF-2 fog oil used today has none of the chemical characteristics of fuel oils and high PAH mineral oils.

SECTION 4 - CONCLUSIONS AND RECOMMENDATIONS

The preponderance of evidence in the literature on the health effects of smoke generated with SGF-2 fog oil manufactured after 1986 by military specification, MIL-F-12070C, Amendment 2 and specifications thereafter, indicate there is limited potential for adverse effects to humans. Toxicological research documented in the literature demonstrates that currently used SGF-2 has low toxicity when ingested, presents minimal toxicity from dermal exposure, and has limited potential for pulmonary effects unless the Threshold Limit Value-Time Weighted Average (TLV-TWA) of 5 mg/m^3 is exceeded for prolonged periods of time.

The TLV-TWA standard of 5 mg/m^3 was established by the Occupational Safety and Health Administration (OSHA), the American Conference of Governmental Industrial Hygienists (ACGIH), and other national and international health organizations to protect workers in industrial settings from harmful exposures to mineral oil mists in the air. The TLV-TWA is considered a safe concentration when workers are repeatedly exposed for up

to 8 hours per day and 5 days per week. This health protective standard was for mineral oils which are severely acid treated, severely hydrotreated or severely solvent treated to reduce the content of carcinogens and other toxic compounds.

To meet the 1986 manufacturing specifications, fog oil is severely treated to remove carcinogens and therefore represents the type of mineral oil upon which the OSHA/ACGIH standard was based. Hydrotreating (the most common method for production of mineral oils used in industry and fog oil used by the military) involves low-pressure, catalytic reduction of carbon-carbon double bonds, whereby aromatics are converted to saturated cycloparaffins (naphthenes) and heterocyclic aromatics rings are opened by chemical removal of bound sulfur, nitrogen and oxygen (Palmer, 1990).

Fog oils produced before 1986 typically had high concentrations of toxic and carcinogenic compounds (Katz et al., 1980), and posed a potential health threat to exposed individuals. In 1986, military manufacturing specifications for SGF-2, were altered to required manufacturers to remove carcinogens and potential carcinogens from the oil. Carcinogenicity of the oil is attributed primarily to certain volatile organic carbon and semivolatile organic carbon constituents in petroleum stocks from which lubricating oil and fog oils are refined. Also, the toxicity of petroleum derived fuels and mineral oils is mostly due to the aromatic fraction (includes PAH) as opposed to the aliphatic fraction (Neff, 1979).

Recently proposed modifications to the 1986 specification require manufacturers to certify the carcinogenic nature of the oil by conducting modified Ames tests, mouse skin tests, and a DMSO extraction procedure for measuring PAH content (U.S. Army, 1995). The proposed 1995 specification, designated MIL-F-12070E, does not require altered physical or chemical properties of fog oil when compared to 1986 specification. It does, however, change the requirement of "no carcinogenic or potential carcinogenic constituents" (U.S. Army, 1986) to "fog oil shall not demonstrate any toxic effects or carcinogenic or potentially carcinogenic effects when tested..." (U.S. Army, 1995). Therefore, under the newly proposed changes, manufacturers must perform tests to certify no effects rather than certify that the oil contains no carcinogenic constituents as required under current specifications. The 1995 proposed specification, when implemented, will provide further assurance of human health protection by requiring actual documentation, through testing, of each batch of fog oil manufactured.

Absent from the scientific literature on fog oil were analyses of smoke produced from low-aromatic fog oil, for individual PAHs. Although SGF-2 fog oil manufactured after 1986 is processed to significantly reduce or remove PAHs, there is a potential for alteration of aliphatic hydrocarbons (and other non-PAH compounds) by combustion heat within the generator as fog oil smoke is produced. The smoke generators planned for use at Fort

Leonard Wood, are the M157 (pulse jet) and the M56 (turbine), and temperatures within these generators, for smoke production, are 1400° F and 1050° F, respectively (U.S. Army, 1995). Katz et al.(1980) found slight enrichments of PAHs in fog oil smoke as compared to parent fog oil, thus indicating the potential of hydrocarbon transformation during smoke generation. Existing scientific literature contains a number of studies documenting increases in toxic compounds and carcinogenic PAHs when relatively non-toxic lubricating oils are combusted or subjected to high heat (Neff, 1979; Grimmer, 1981; Grimmer et al., 1981; and Carmichael et al., 1990 and 1991).

As part of this health evaluation, fog oil and smoke generated from it, will be analyzed for individual aromatic and aliphatic hydrocarbons. Results of this monitoring, will be evaluated by performing a preliminary human health risk evaluation, using EPA methods. The risk evaluation findings will provide additional weight-of-evidence for evaluating the potential for health effects from breathing fog oil smoke.

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