CTEH CENTER FOR TOXICOLOGY AND ENVIRONMENTAL HEALTH, LLC

CR-91 Event

Birmingham, AL

Air Sampling and Analysis Plan

Version 1.1

Prepared On Behalf Of:

Colonial Pipeline

Prepared By:

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Version 1.1			
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Project:	Colonial Pipeline Gasoline Response
Location:	Birmingham, AL
Client:	Colonial Pipeline
Version History:	V 1.1

Introduction and Purpose

The Center for Toxicology and Environmental Health CTEH® was contracted by Colonial Pipeline, LP (Colonial) to conduct real-time air monitoring and analytical air sampling at the site of the CR-91 Event and potentially within the local communities. Based on an absence of air monitoring data, CTEH will be conducting initial air monitoring to determine if workers performing certain job tasks may be exposed to gasoline-related hydrocarbons, including benzene, at levels approaching their applicable occupational exposure guidelines (OELs) as outlined in this Plan.

The objective of the Sampling and Analysis Plan is to provide guidance for the action levels for airborne constituents of gasoline for response and remediation workers working in the area of the release site and other locations where worker exposure to gasoline vapor is likely. Unless otherwise indicated by data, this formal plan will be implemented at the release site only; however, periodic personnel air sampling and continuous real-time air monitoring will continue to be performed for remediation workers actively involved in clean-up operations throughout the response site.

CTEH® Site-Specific Action Levels

The following chemicals were determined to have the greatest potential for human health impacts based on the relative levels in air of volatile organics emitted from gasoline, together with published information regarding health-based worker exposure guidelines. Site specific action levels are to be employed in all monitoring locations (i.e. excavation, pipeline repair site, product recovery sites, and in nearby residential areas) to provide information for corrective action to limit chemical exposure. These levels are intended to be a concentration limit that triggers a course of action to better address worker and community member safety before regulatory or guideline exposure limits are reached. Real-time air monitoring for all analytes will be conducted on a 24-hour continuous basis with discrete readings recorded periodically. In addition, real-time air monitoring for site characterization may be conducted upon request. Readings collected for site characterization may be recorded directly above pooled product, or other areas not representative of the breathing zone. Based on the data collected, real-time air monitoring for some analytes may be reduced or discontinued. CTEH® will also collect analytical air samples at residential or commercial locations upwind and downwind of remediation operations. Details of this analytical sampling are provided in the pages below.

Plan/Assignment: **WORK AREA (Including Excavation, Pipeline Repair Site, and Product Recovery Sites)**

Objective: Report air levels before they reach those requiring respiratory protection or other precautionary actions. More information regarding worker exposure sampling is provided in **Appendix A**.

Analyte	Action Level	Basis	Action to be Taken
Total VOCs	30 ppm	1/10 ACGIH® TLV-TWA for gasoline - Reading sustained for 15 minutes	Report reading to Site Management. Conduct specific monitoring for benzene.
	300 ppm	ACGIH® TLV-TWA – for gasoline Reading sustained for 15 minutes	Don respirator or evacuate area; report reading to Site Management.
Benzene	0.5 ppm	ACGIH® TLV-TWA - Reading sustained for 15 minutes	Don Air purifying respirator or evacuate area; report reading to Site Management.
	2.5 ppm	ACGIH® STEL Reading sustained for 5 minutes	Don Air purifying respirator or evacuate area; report reading to Site Management.
Gasoline	30 ppm	ACGIH® TLV-TWA - Reading sustained for 15 minutes	Don Air purifying respirator or evacuate area; report reading to Site Management.
Toluene	20 ppm	ACGIH® TLV-TWA Reading sustained for 15 minutes	Don Air purifying respirator or evacuate area; report reading to Site Management.
Xylene	100 ppm	ACGIH® TLV-TWA – Reading sustained for 15 minutes	Don Air purifying respirator or evacuate area; report reading to Site Management.
Hexane	50 ppm	ACGIH® TLV-TWA (n-hexane) Reading sustained for 15 minutes	Don Air purifying respirator or evacuate area; report reading to Site Management.
Naphthalene	10 ppm	ACGIH® TLV-TWA - Reading sustained for 15 minutes	Don Air purifying respirator or evacuate area; report reading to Site Management.

Plan/Assignment: **COMMUNITY (Residential Areas near the Excavation & Pipeline Repair & Product Recovery Sites)**

Objective: Report levels that minimize nuisance odor in the community and evaluate

Analyte	Action Level	Basis	Action to be Taken
Total VOCs	0.2 ppm	Reading Sustained for 15 minutes. Gasoline Odor Threshold; Colonial Air Monitoring Protocol	Report reading to Site Management. Assess the presence of benzene.
	100 ppm	Reading sustained for 30 minutes*. ½ Gasoline-specific Emergency Response Planning Guidelines (ERPG)-1** value	Report reading to Site Management.
Benzene	0.05 ppm	Reading sustained for 15 minutes. Colonial Air Monitoring Protocol.	Report reading to Site Management.

*If VOCs are detected at or above 100 ppm in the community, air monitoring personnel will remain at the site of detection and collect multiple readings throughout a 30 minute period.

**ERPG-1: The maximum concentration in air below which it is believed nearly all individuals could be exposed for up to one hour without experiencing other than mild transient adverse health effects or perceiving a clearly defined objectionable odor. ERPGs are developed by the Emergency Response Planning Committee of the American Industrial Hygiene Association (AIHA).

Plan/Assignment: **SITE CHARACTERIZATION**

Objective: Report air levels before they reach those precautionary actions.

Analyte	Action Level	Basis	Action to be Taken
Total VOCs	NA	NA	Report reading to Site Management.
Benzene	NA	NA	Report reading to Site Management.
Toluene	NA	NA	Report reading to Site Management.
Xylene	NA	NA	Report reading to Site Management.
Hexane	NA	NA	Report reading to Site Management.
Naphthalene	NA	NA	Report reading to Site Management

Site characterization readings are not indicative of worker exposures (i.e., not taken at breathing level, no work activity, directly above product, etc.). As such, no occupational action levels are established for site characterization. All site characterization readings are noted and reported to site management.

Plan: **All – FLAMMABILITY**

Objective: Report areas where flammability is most likely.

Analyte	Instrument Reading	Corrected Value	Correction Factor	Basis	Action to be Taken
LEL	3 %	10 %	2.6 for gasoline LEL	10% LEL	Egress and Notify Site Management
VOCs	1,444 ppm	1,300 ppm	0.9 for gasoline PID	10% LEL	Egress and Notify Site Management

Methods

Real-Time Monitoring Methods					
Chemical	Instrument	Detection Limit*	Tube#/Lamp	Notes	Correction Factor
Gasoline (as VOC)	MultiRAE/ AreaRAE	0.09 ppm	PID 10.6 eV lamp	Measuring Range: 0.1 – 4,500 ppm	0.9
Gasoline	Colorimetric	5 ppm	Gastec tube #101L	Measuring Range: 30 – 1,000 ppm	NA
Benzene	UltraRAE	0.05 ppm	PID 9.8 eV lamp	Change SEP tube frequently (Ben. Cal Gas)	NA
	MultiRAE/ AreaRAE	0.05 ppm	PID 10.6 eV lamp	Measuring Range: 0.1 – 2,350 ppm	0.47
	Colorimetric	0.05 ppm	Gastec tube #121L	Range: 0.1 to 65 ppm	Var.
Toluene	MultiRAE/ AreaRAE	0.05 ppm	PID 10.6 eV lamp	Measuring Range: 0.1 – 2,250 ppm	0.45
	Colorimetric	0.5 ppm	Gastec tube #122L	Range: 1 to 100 ppm	Var.
Xylene	MultiRAE/ AreaRAE	0.5 ppm	PID 10.6 eV lamp	Measuring Range: 0.1 – 5,000 ppm	0.44
	Colorimetric	1 ppm	Gastec tube #123L	Measuring Range: 2 – 200 ppm	Var.
Hexane	MultiRAE/ AreaRAE	0.5 ppm	PID 10.6 eV lamp	Measuring Range: 0.1 – 5,000 ppm	4.3
	Colorimetric	1 ppm	Gastec tube #102L	Range: 4 to 1200 ppm	Var.
LEL	MultiRAE/ AreaRAE	2.6 %	Sensor	Measuring range: 1 – 100%	2.6
Naphthalene	Colorimetric	0.5 ppm	Gastec tube #60	Range: 0.5 – 14 ppm	1

*For electronic instruments, the detection limit is listed as the resolution adjusted by the correction factor.

Analytical Methods			
Analyte	Media/Can	Method	Notes
VOCs	1 L Minican	TO-15 + TICS	Minicans will be regulated for an 8 or 24 hour sampling period.
BTEX (+Hexane)	3M® 3520	NIOSH 1501	Passive sampling badges will be utilized for personnel sampling, if needed.
BTEX (+ Hexane)	226-01	NIOSH 1501	Charcoal Tubes to be used for STEL Sampling, if needed
Gasoline	3M® 3520	NIOSH 1550	Passive sampling badges will be utilized for personnel sampling, if needed.

General Information on Procedures (Assessment Techniques) Used

Procedure	Description
Handheld Survey	CTEH® staff members will utilize handheld instruments (e.g. MultiRAE Plus/Pro; UltraRAE, Gastec colorimetric detector tubes, etc.) to measure airborne chemical concentrations. CTEH® will use these hand-held instruments primarily to measure the air within breathing zone. Additionally, measurements may be made at grade level, as well as in elevated workspaces, as indicated by chemical properties or site conditions. When readings are collected outside of the breathing zone, they may be classified as Site Characterization or will be noted in the reading comments. Real-time air monitoring readings may be collected at indoor commercial and residential buildings, if requested (e.g. prior to reopening).
Analytical sampling	Analytical sampling will be used to validate the handheld data monitoring data, or to provide data beyond the scope of the real-time instruments. Analytical samples will be collected on specific collection media and sent to an off-site laboratory for further chemical analysis. If deemed necessary by the results of real-time air monitoring, CTEH® will conduct personal exposure sampling on response personnel involved in excavation, pipeline repair, or product recovery operations.
Guardian Network	A Guardian network may be established with AreaRAEs equipped with electrochemical sensors at locations around the work zone perimeter. The AreaRAEs will be telemetering instantaneous data at 15-second intervals to a computer console. MultiRAE Pros may also be used in the network. The data will be visible in real-time at the computer console and will be monitored 24 hours per day by CTEH personnel.

Quality Assurance/Quality Control Procedures

Method	Procedure
Real-time	• Real time instruments will be calibrated once per day which exceeds the manufacturer's recommendations. o At a minimum whenever indicated by site conditions or instrument readings. • Lot numbers and expiration dates will be recorded with use of Gastec colorimetric tubes.
Analytical	• Chain of custody documents will be completed and documented for each sample. • Level II data verification may be performed on all samples. • Level IV data validation may be performed on 10% of total samples. • Sample Nomenclature may contain: o Badge Serial Number (Badge Sampling)

Data Management	• Real-Time Monitoring data will be collected through the Mobile Data Studio Software, and QA/QC'ed by air monitoring personnel for accuracy and consistency.
	  o Real-time Data may Include:
	  ▪ GPS Coordinates
	  ▪ Location Description
	  ▪ Comments
	  ▪ Reading of equipment
	  ▪ Serial Number of equipment
	  ▪ Unique Environmental Conditions (i.e. humidity, dust, etc.)
	• Data will be databased using Microsoft Access Software and may be provided using the EPA SCRIBE software as needed.
	• QA/QC'ed data and final report will be made after the demobilization of CTEH® from site.

Change from version 1.0 to 1.1

- *Oxygen (O_2) monitoring was briefly implemented on September 14, 2016 with the onset of nitrogen purging into the pipeline. Oxygen monitoring was performed to ensure oxygen levels in work areas remained within optimal conditions (19.5% - 23.5%). Oxygen monitoring was discontinued on September 17, 2016.*
- *Introduction and Purpose Section has been added.*
- *In the section titled: Site Characterization*
  - Sentences were added discussing why action levels were not utilized.
- *In the section titled: Methods*
  - "Real-Time Methods" was renames "Real-Time Monitoring Methods"
- *In the section titled: Methods*
  - Data Management Section has been added.
- *Glossary Section has been added.*

	Name/Organization	Signature	Date Signed
Revised by:			

APPENDIX A

CR-91 Glossary

Acronym	Definition
3M®	Manufacturer of scientific equipment including diffusion badges
ACGIH	American Conference of Governmental Industrial Hygienists
Ben.	Benzene
BTEX	Benzene, Toluene, Ethylbenzene, Xylene
Cal	Calibration
CTEH	Center for Toxicology and Environmental Health
eV	electron-volts
FOSC	Federal On-Scene Coordinator
GC/FID	Gas Chromatography/Flame-Ionization Detector
IC	Incident Commander
L	Liter
LEL	Lower Explosive Limit
LOSC	Local On-Scene Coordinator
NA	Not Applicable
NIOSH	National Institute of Occupational Safety and Health
OEL	Occupational Exposure Limit
OSHA	Occupational Safety and Health Administration
OVM	Organic Vapor Monitoring
PEL	Permissible Exposure Limit
PID	Photo-Ionization Detector
ppm	parts per million
SEG	Similar Exposure Groups
SEP	RaeSEP tubes provided by RAE Systems for use in a RAE Systems UltraRAE 3000
SOSC	State On-Scene Coordinator
STEL	Short-Term Exposure Limit
TICs	Tentatively Identified Compounds
TLV	Threshold Limit Value
TO	EPA TO-15 - Determination of VOCs in Air Collected in Specially-Prepared Canisters and Analyzed by Gas Chromatography/Mass Spectrometry
TWA	Time Weighted Average
Var.	Variable
VOC	Volatile Organic Compounds

APPENDIX B

Worker Exposure Sampling Plan

Introduction and Purpose

This Worker Exposure Assessment Plan is an amendment pursuant to the Incident Air Sampling and Monitoring Work plan, titled: *"Preliminary Air Sampling and Analysis Work Plan Vs 1.1"*.

Center for Toxicology and Environmental Health CTEH® was contracted by Colonial Pipeline, LP (Colonial) to conduct real-time air monitoring and analytical air sampling at the site of the CR-91 Event and within the local communities. Based on an absence of air monitoring data, CTEH will be conducting initial air monitoring to determine if workers performing certain job tasks may be exposed to gasoline-related hydrocarbons, including benzene, at levels approaching their applicable occupational exposure guidelines (OELs) as outlined in this Plan.

The objective of this Worker Exposure Assessment Plan is to provide guidance for the collection of worker exposure samples for response and remediation workers working in the area of the release site and other locations where worker exposure to gasoline vapor is likely. Unless otherwise indicated by data, this formal plan will be implemented at the release site only; however, periodic personnel air sampling and continuous real-time air monitoring will continue to be performed for remediation workers actively involved in clean-up operations throughout the response site. The samples are collected from the breathing zone to represent the full-shift exposure over the duration of the work activity.

Basic Characterization of Operations and Identification of Similar Exposure Groups.

This section is a basic characterization of the response work operations and remediation activities intending to describe: work tasks, work environments, potential chemical hazards, and similar exposure groups (SEGs). The work operations data were collected from site observations, work area surveys, and operational briefings at incident command.

CTEH® is currently providing real-time air monitoring and analytical air sampling designed to assess worker and community exposure to potential inhalation hazards associated with airborne constituents of gasoline. In addition to real-time air monitoring, CTEH® field staff may focus exposure sampling on workers in the pipeline breach area performing the following general tasks:

1. Backhoe/trackhoe operation – These individuals are involved in operating excavation equipment to excavate gasoline-impacted soil and remove it to roll-off containers.
2. Field supervisors – These individuals are often located in the work area, near critical operations, performing task leadership roles. Field supervisors may be located in close proximity to the excavation activity, vac operations, and pipeline repair activities.
3. Vacuum truck operation – These individuals are involved in driving and operating vacuum trucks to remove free product from the ground/trenches in the vicinity of the pipeline breach. This workgroup includes workers handling vacuum hoses and truck-mounted pumps to move free product from the pipeline breach site soil into the vacuum truck storage tank.

4. Roll-off box truck operation – These individuals are involved in driving and operating roll-off box trucks to deliver and retrieve roll-off boxes before and after gasoline-impacted soil is dumped into the roll-off boxes by back hoe and/or track how operations..
5. Pipeline repair – These individuals are involved in the repair and/or replacement of pipeline segments in the excavated trench in the vicinity of the breached pipeline segment.
6. Environmental Monitoring – These individuals are involved in the collection of environmental samples (e.g. air and soil) to monitor gasoline impact in the pipeline breach and repair worksite.

Within these general work tasks, CTEH® has identified 6 similar exposure groups (SEG). These are listed in Table 2.1, on the following page.

Table 2.1 Similar Exposure Groups

SEG	Description
Environmental Field Specialists	*Workers collecting environmental and occupational air and soil samples at the pipeline breach site. Continuous presence at the pipeline breach site, with infrequent short-duration handling of potentially contaminated material while donning appropriate PPE.*
	Tasks: • Environmental Sampling-Air • Environmental Sampling-Soil
Excavation Equipment and Truck Operators	*Workers with continuous presence in the vicinity of the excavated trench pipeline breach work area. Excavation equipment operators will be predominately in enclosed cabs. Vacuum and roll-off box truck drivers will also be predominantly in enclosed truck cabs, with intermittent movement outside of the equipment or truck cab.*
	Tasks: • Equipment/truck operation and driving • Enter/Exit cabs of equipment/vehicles on an as-needed basis
Field Supervisors	*Workers with continuous presence at the pipeline breach site in the vicinity of the roll-off boxes containing excavated soil containing gasoline. Also working near the pipeline repair activities with brief excursions into the excavation area for inspection.*
	Tasks: • Lead dig efforts. • Inspect pipe • Oversee pipeline repair • General site leadership duties
Roll-Off Box Workers	*Workers with continuous presence at the pipeline breach site in the vicinity of the roll-off boxes containing excavated soil containing gasoline.*
	Tasks: • Cover and secure roll-off boxes that have been filled with gasoline-containing soil excavated from around the breached pipeline segment.
Drainage Culvert Cleanup Workers	*Workers with continuous presence at the downhill opening of the storm water drainage through which gasoline flowed from the breached pipeline section.*
	Tasks: • Insert and operate high-pressure water devices to dislodge gasoline from the inside of the storm drainage culvert. • Apply vacuum hoses to remove gasoline that emanates from the culvert.
Pipeline Repair Technicians	*Workers with continuous presence in the pipeline trench removing/repairing segments of damaged pipeline.*
	Tasks: • Removal of damaged pipeline segment(s) • Installation of replacement pipeline components

Identification of Potential Occupational Exposures

This Worker Exposure Assessment plan provides guidance for the chemical constituents of gasoline which may include, but is not limited to: 1) gasoline as hydrocarbon (as VOCs), and benzene, toluene, ethylbenzene, xylenes (BTEX) and n-hexane. The ACGIH® has established a TLV for gasoline; however, it should not be used exclusively to determine worker exposure due to the potential for BTEX concentrations above their respective OELs when gasoline concentrations are below its TLV. Instead, it is recommended that air sampling for individual constituents of gasoline be performed to assess an individual's exposure. Table 3.1 shows the gasoline-representative chemicals of interest for this response and their corresponding occupational exposure limits.

Table 3.1 Occupational Exposure Standards and Guidelines*

Chemical	OSHA			ACGIH®	
	PEL-TWA[a]	PEL-STEL[b] (ppm)	PEL-Ceiling[c] (ppm)	TLV-TWA[d] (ppm)	TLV-STEL[e] (ppm)
Benzene	1 ppm	5 ppm	NE	0.5 ppm	2.5 ppm
Toluene	200 ppm	NE	300 ppm; 500 ppm**	20 ppm	NE
Ethyl Benzene	100 ppm	NE	NE	20 ppm	125 ppm
Xylene	100 ppm	NE	NE	100 ppm	150 ppm
n-hexane	500 ppm	--	--	50 ppm	--
Naphthalene	10 ppm	NE	NE	10 ppm	15 ppm

*(ACGIH, 2015)

** 10 minute peak per 8 hr. shift.

NE = Not Established

a. *OSHA PEL-TWA = The permissible concentration in air of a substance that shall not be exceeded in an 8-hour work shift or a 40-hour work week (OSHA 29 CFR: 1910.1028).*

b. *OSHA PEL-STEL = The time-weighted average exposure that should not be exceeded for any 15-minute period (OSHA 29 CFR: 1910.1028).*

c. *PEL-Ceiling = OSHA PEL-Ceiling = The exposure limit that shall at no time be exceeded. If instantaneous monitoring is not feasible, then the ceiling shall be assessed as a 15-minute time-weighted average (TWA) exposure, which shall not be exceeded at any time during the working day.*

d. *ACGIH TLV-TWA = The Threshold Limit Value-TWA is the concentration for a normal 8-hour workday and a 40-hour workweek, to which nearly all workers may be repeatedly exposed, day after day, without adverse effect.*

e. *ACGIH TLV-STEL = The STEL exposure limit is a 15 minute time weighted exposure that should not be exceeded at any time during a work day.*

Sampling Methods

Worker exposure to BTEX and n-hexane will be evaluated using the Assay N556 organic vapor monitoring (OVM) badges placed in the worker's breathing zone. The N556 OVM badges sample according to the principle of diffusion whereas airborne hydrocarbons diffuse through the permeation membrane and onto the activated charcoal media at flowrate consistent with a worker's average breathing rate under normal working conditions. These OVM badges will be sent an AIHA accredited laboratory and analyzed using a gas chromatography flame ionization detector (GC/FID) in accordance with the National Institute for Occupational Safety and Health (NIOSH) air sampling method 1500/1501 (Appendix A-1).

Each day, CTEH® will evaluate the number of workers and their assigned tasks to identify the sample population selected to represent each similar exposure group. Generally, CTEH® will target 10% of the moderate and maximum risk exposure groups. The action levels published in this plan represent a 8-hr exposure limit, however, CTEH anticipates that workers will likely work extended shifts up to and possibly in excess of 12 hours. Therefore, CTEH will address extended shifts using two available methods, which are: 1) collection of a single 8-hour sample representing the worst 8-hour period of their shift only if CTEH can define a clear and present reduction in exposure during the extended periods of the work shift; and 2) collection of consecutive samples that cover the full extended shift and are later combined and time weighted to represent the 8-hour TWA exposure. The sample results will be compared to the ACGIH® TLV-TWA and OSHA PEL-TWA occupational exposure limits.

Quality Control

With each sample delivery group, one field blank sample will be submitted to the laboratory. The results of the quality control testing can be found along with laboratory reports supplied by Galson Laboratories laboratory reports.

Appendix A-1

NIOSH Method 1500/1501

HYDROCARBONS, BP 36°-216 °C

1500

FORMULA: Table 1 | MW: Table 1 | CAS: Table 1 | RTECS: Table 1

METHOD: 1500, Issue 3 | **EVALUATION: PARTIAL** | **Issue 1: 15 August 1990**
Issue 3: 15 March 2003

OSHA: Table 2
NIOSH: Table 2
ACGIH: Table 2

PROPERTIES: Table 1

COMPOUNDS:
(Synonyms in Table 1)

cyclohexane	**n-heptane**	**n-octane**
cyclohexene	**n-hexane**	**n-pentane**
n-decane	**methylcyclohexane**	**n-undecane**
n-dodecane	**n-nonane**	

SAMPLING

SAMPLER: SOLID SORBENT TUBE [1] (coconut shell charcoal, 100 mg/50 mg)

FLOW RATE: Table 3

VOL-MIN: Table 3
-MAX: Table 3

SHIPMENT: Routine

SAMPLE STABILITY: 30 days @ 5 °C

BLANKS: 10% of samples

ACCURACY

RANGE STUDIED: Table 3

BIAS: Table 3

OVERALL PRECISION ($\hat{S}_{rT}$): Table 3

ACCURACY: Table 3

MEASUREMENT

TECHNIQUE: GAS CHROMATOGRAPHY, FID [1]

ANALYTE: Hydrocarbons listed above

DESORPTION: 1 mL CS_2; stand 30 min

INJECTION VOLUME: 1 µL

TEMPERATURES
-INJECTION: 250 °C
-DETECTOR: 300 °C
-COLUMN: 35 °C (8 min) - 230 °C (1 min) ramp (7.5 °C /min)

CARRIER GAS: Helium, 1 mL/min

COLUMN: Capillary, fused silica, 30 m x 0.32-mm ID; 3.00-µm film 100% dimethyl polysiloxane

CALIBRATION: Solutions of analytes in CS_2

RANGE: Table 4

ESTIMATED LOD: Table 4

PRECISION ($\bar{S}_r$): Table 4

APPLICABILITY: This method may be used for simultaneous measurements; however, interactions between analytes may reduce breakthrough volumes and alter analyte recovery.

INTERFERENCES: At high humidity, the breakthrough volumes may be reduced. Other volatile organic solvents such as alcohols, ketones, ethers, and halogenated hydrocarbons are potential interferences.

OTHER METHODS: This method is an update for NMAM 1500 issued on August 15, 1994 [2] which was based on methods from the 2nd edition of the NIOSH Manual of Analytical Methods: S28, cyclohexane [3]; S82, cyclohexene [3]; S89, heptane [3]; S90, hexane [3]; S94, methylcyclohexane [3]; S378, octane [4]; and S379, pentane [4].

REAGENTS:

1. Eluent: Carbon disulfide *, low benzene, chromatographic quality.
2. Analytes, reagent grade.*
3. Helium, prepurified and filtered.
4. Hydrogen, prepurified and filtered.
5. Air, prepurified and filtered.

* See SPECIAL PRECAUTIONS

EQUIPMENT:

1. Sampler: glass tube, 7 cm long, 6-mm OD, 4-mm ID, flame-sealed ends, containing two sections of activated coconut shell charcoal (front = 100 mg, back = 50 mg) separated by a 2-mm urethane foam plug. A silylated glass wool plug precedes the front section, and a 3-mm urethane foam plug follows the back section. Tubes are commercially available.
2. Personal sampling pumps (0.01 to 1.0 L/min, Table 3) with flexible tubing.
3. Gas chromatograph, FID, integrator, and a Rtx-1 or equivalent capillary column (page 1500-1).
4. Glass autosampler vials (2-mL) with PTFE-lined caps.
5. Pipettes (1-mL) and pipette bulb.
6. Syringes (10, 25, 100, and 250 µL).
7. Volumetric flasks (10-mL).

SPECIAL PRECAUTIONS: Carbon disulfide is toxic and extremely flammable (flash point = -30°C). Prepare samples and standards in a well-ventilated hood.

SAMPLING:

1. Calibrate each personal sampling pump with a representative sampler in line.
2. Break the ends of the sampler immediately before sampling. Attach the sampler to a personal sampling pump with flexible tubing.
3. Sample at an accurately known flow rate between 0.01 and 0.2 L/min (0.01 to 0.05 L/min for n-pentane) for a total sample size as shown in Table 3.
4. Cap the samplers with plastic (not rubber) caps and pack securely for shipment.

SAMPLE PREPARATION:

5. Place the front and back sorbent sections of the sampler tube in separate vials. Include the glass wool plug in the vial with the front sorbent section. Discard the foam plugs.
6. Add 1.0 mL carbon disulfide to each vial. Attach crimp cap to each vial immediately.
7. Allow to stand at least 30 min with occasional agitation.

CALIBRATION AND QUALITY CONTROL:

8. Calibrate daily with at least six working standards from below the LOD to 10 times the LOQ. Additional standards may be added to extend the calibration curve if necessary.
   a. Add known amounts of analytes to carbon disulfide in 10-mL volumetric flasks and dilute to the mark. Prepare additional standards by serial dilution in 10-mL volumetric flasks.
   b. Analyze with samples and blanks (steps 11 and 12).
   c. Prepare a calibration graph (peak area of analyte vs. µg of analyte per sample).
9. Determine the desorption efficiency (DE) at least once for each batch of charcoal used for sampling in the calibration range (step 8).
   a. Prepare three tubes at each of five levels plus three media blanks.
   b. Remove and discard the back sorbent section of a media blank sampler.

c. Inject a known amount of stock solution (5 to 25 µL) directly onto the front sorbent section with a microliter syringe.
d. Allow the tubes to air equilibrate for several minutes, then cap the tubes and allow to stand overnight.
e. Desorb (steps 5 through 7) and analyze with standards and blanks (steps 11and 12).
f. Prepare a graph of DE vs. µg analyte recovered.

10. Analyze at least three quality control blind spikes and three analyst spikes to insure that the calibration graph and DE graph are in control.

MEASUREMENT:

11. Set the gas chromatograph according to the manufacturer's recommendations and to the conditions given on page 1500-1. Inject a 1-µL aliquot manually using a solvent flushing technique or with an autosampler.
NOTE: If the peak area is above the linear range of the working standards, dilute with solvent, reanalyze and apply the appropriate dilution factor in the calculations.

Analyte	Approximate Retention Time (min)
n-pentane	7.5
solvent (CS_2)	9.6
n-hexane	13.0
cyclohexane	16.1
cyclohexene	16.8
n-heptane	17.7
methylcyclohexane	18.9
n-octane	21.6
n-nonane	24.9
n-decane	27.8
n-undecane	30.5
n-dodecane	32.9

NOTE: Retention times may vary slightly due to column manufacturer and age of column, and be influenced by other GC instrumental parameters.

12. Measure the peak area.

CALCULATIONS:

13. Determine the mass, µg (corrected for DE), of analyte found in the sample front (W_f) and back (W_b) sorbent sections, and in the average media blank front (B_f) and back (B_b) sorbent sections.
NOTE: If $W_b > W_f / 10$, report breakthrough and possible sample loss.
14. Calculate the concentration, C, of analyte in the air volume, V(L), sampled:

$$C = \frac{(W_f + W_b - B_f - B_b)}{V}, mg / m^3$$

NOTE: µg/L = mg/m^3

EVALUATION OF METHOD:

Issues 1 and 2:

Precisions and biases (Table 3) were determined by analyzing generated atmospheres containing one-half, one, and two times the OSHA standard. Table 3 does not contain data for n-decane, n-dodecane and n-heptane since they were not evaluated previously. Generated concentrations were independently verified. Breakthrough capacities were determined in dry air. Storage stability was assessed at 7, 14, and 30 days. Measurement precisions (Table 4) were determined by spiking sampling media with amounts corresponding to one-half, one, and two times the OSHA standard for nominal air volumes. Desorption efficiencies for spiked samplers containing only one compound exceeded 75% [2,3,4,8].

Issue 3:

The desorption efficiency, at levels ranging from 10 times the LOQ to 0.1 times the REL, was determined by spiking known amounts of analytes (in CS_2) on coconut shell charcoal tubes. All analytes exhibited acceptable desorption efficiency recovery results at six levels evaluated.

Each analyte was evaluated for its storage stability. Sorbent tubes were spiked at approximately 100 µg and stored in a drawer for 7 days, then transferred to a refrigerator at 5° C. Samples were analyzed after 7, 14, and 30 days. All analytes had acceptable recoveries (>90%), except cyclohexene, which had a 30 day recovery of 85% [1].

REFERENCES:

[1] Pendergrass SM and May L, Backup Data Report, ACS/CEMB/DART/NIOSH (1999).
[2] NIOSH[1994]. Hydrocarbons, BP 36-136°C. In: Eller PM, ed. NIOSH Manual of Analytical Methods, 4th rev. ed. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 94-113.
[3] NIOSH Manual of Analytical Methods, 2nd. ed., V. 2, S28, S82, S89, S90, S94, U.S. Department of Health, Education, and Welfare, Publ. (NIOSH) 77-157-B (1977).
[4] NIOSH Manual of Analytical Methods, 2nd. ed., V. 3., S378, S379, U.S. Department of Health, Education, and Welfare, Publ. (NIOSH) 77-157-C (1977).
[5] Code of Federal Regulations; Title 29 (Labor), Parts 1900 to 1910; U.S. Government Printing Office, Washington, (1989); 29 CFR 1910.1000.
[6] NIOSH Recommendations for Occupational Safety and Health. U.S. Department of Health and Human Services, DHHS (NIOSH) Publication No. 92-100 (1992).
[7] 1993 Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices. ACGIH, Cincinnati, OH (1993).
[8] Documentation of the NIOSH Validation Tests, S28, S82, S89, S90, S94, S378, S379, U.S. Department of Health, Education, and Welfare, Publ. (NIOSH) 77-185 (1977).

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Issues 1 and 2:

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Issue 3:

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TABLE 1. SYNONYMS, FORMULA, MOLECULAR WEIGHT, PROPERTIES

Name/ Synonyms	Empirical Formula	Molecular Weight	Boiling Point (°C)	Vapor Pressure @ 25°C (mm Hg)	Vapor Pressure @ 25°C (kPa)	Density @ 25°C (g/mL)
cyclohexane hexahydrobenzene CAS # 110-82-7 RTECS GU6300000	C_6H_{12}	84.16	80.7	97.6	13.0	0.779
cyclohexene tetrahydrobenzene CAS # 110-83-8 RTECS GW2500000	C_6H_{10}	82.15	83.0	88.8	11.8	0.811
n-decane CAS # 124-18-5 RTECS HD6550000	$C_{10}H_{22}$	142.28	174	NA	NA	0.730
n-dodecane CAS # 112-40-3 RTECS JR2125000	$C_{12}H_{26}$	170.34	216.2	NA	NA	0.750
n-heptane CAS # 142-82-5 RTECS MI7700000	C_7H_{16}	100.21	98.4	45.8	6.1	0.684
n-hexane CAS # 110-54-3 RTECS MN9275000	C_6H_{14}	86.18	68.7	151.3	20.2	0.659
methylcyclohexane CAS # 108-87-2 RTECS GV6125000	C_7H_{14}	98.19	100.9	46.3	6.2	0.769
n-nonane CAS # 111-84-2 RTECS RA6115000	C_9H_{20}	128.26	151	NA	NA	0.718
n-octane CAS # 111-65-9 RTECS RG8400000	C_8H_{18}	114.23	125.7	14.0	1.9	0.703
n-pentane CAS # 109-66-0 RTECS RZ9450000	C_5H_{12}	72.15	36.1	512.5	68.3	0.626
n-undecane hendecane CAS # 1120-21-4 RTECS YQ1525000	$C_{11}H_{24}$	156.31	196	NA	NA	0.740

TABLE 2. EXPOSURE LIMITS, PPM [5-7]

	OSHA		NIOSH		ACGIH		mg/m^3
Substance	TWA	PEAK	TWA	C	TLV	STEL	per ppm
cyclohexane	300		300		300		3.44
cyclohexene	300		300		300		3.36
n-decane	none		none		none		5.82
n-dodecane	none		none		none		6.97
n-heptane	500		85	440	400	500	4.10
n-hexane [a]	500		50		50		3.52
methylcyclohexane	500		400		400		4.01
n-nonane	none		200		200		5.25
n-octane	500		75	385	300	375	4.67
n-pentane	1000		120	610	600	750	2.95
n-undecane	none		none		none		6.39

[a] The ACGIH recommendation for other hexane isomers is: TLV 500, STEL 1000.

TABLE 3. SAMPLING FLOWRATE[a], VOLUME, CAPACITY, RANGE, OVERALL BIAS AND PRECISION [3, 4, 8]

Substance	Sampling Flowrate (L/min)	Sampling Volume (L) MIN	Sampling Volume (L) MAX[b]	Breakthrough Volume Vol (L)	Breakthrough Volume Concentration (mg/m^3)	Range of Generated Samples (mg/m^3)	Overall Bias (%)	Overall Precision ($\hat{S}_{rT}$)	Accuracy (%)
cyclohexane	0.01- 0.2	2.5	5	7.6	1650	510-2010	1.1	0.060[c]	±11.5
cyclohexene	0.01- 0.2	5	7	10.4	2002	510-2030	10.6	0.073	±20.7
n-hexane	0.01- 0.2	not	studied	-	-	-	-	-	-
methylcyclohexane	0.01- 0.2	4	4	6.1	4060	968-4060	-6.5	0.056	±15.0
n-nonane	0.01- 0.2	4	4	5.9	3679	877-3679	-1.8	0.062	±12.5
n-octane	0.01- 0.2	4	4	6.1	3941	940-3941	6.1	0.052	±15.2
n-pentane	0.01-0.2	4	4	6.5	4612	1050-4403	-2.0	0.060	±12.1
n-undecane	0.01-0.05	2	2	3.1	5640	1476-6190	-8.4	0.055	±16.6

[a] Minimum recommended flow is 0.01 L/min.
[b] Approximately two-thirds the breakthrough volume.
[c] Corrected value calculated from data in Ref. 3

TABLE 4. MEASUREMENT RANGE AND PRECISION [1, 3, 4, 8]

Substance	LOD (µg/sample)	Measurement Range (µg)	Measurement Precision ($\hat{S}_r$)
cyclohexane [a]	0.1	4 - 5300	0.012
cyclohexene [a]	0.08	3 - 9700	0.014
n-decane	0.06	2 - 584	0.020
n-dodecane	0.05	2 - 600	0.027
n-heptane	0.06	2 - 16300	0.014
n-hexane	0.4	10 - 14500	0.011
methylcyclohexane	0.1	4 - 16100	0.013
n-nonane	0.04	1 - 574	0.018
n-octane	0.3	11 - 18900	0.022
n-pentane	0.6	19 - 11800	0.012
n-undecane	0.05	2 - 592	0.024

[a] Corrected value, calculated from the data in [1,8].

HYDROCARBONS, AROMATIC 1501

FORMULA: Table 1 MW: Table 1 CAS: Table 1 RTECS: Table 1

METHOD: 1501, Issue 3 **EVALUATION: Full** **Issue 1: 15 August 1990**
Issue 3: 15 March 2003

OSHA: Table 2
NIOSH: Table 2
ACGIH: Table 2

PROPERTIES: Table 1

SYNONYMS: (Synonyms in Table 1)
Group A: benzene, toluene, ethylbenzene, o-xylene, m-xylene, p-xylene
Group B: cumene, p-tert-butyltoluene, α-methylstyrene, β-methylstyrene, styrene

SAMPLING

SAMPLER: SOLID SORBENT TUBE (coconut shell charcoal, 100 mg/50 mg)

FLOW RATE: Table 3

VOL-MIN: Table 3
-MAX: Table 3

SHIPMENT: Routine

SAMPLE STABILITY: 30 days @ 5°C

BLANKS: 10% of samples

ACCURACY

RANGE STUDIED: Table 3

BIAS: Table 3

OVERALL PRECISION ($\hat{S}_{r,T}$): Table 3

ACCURACY: Table 3

MEASUREMENT

TECHNIQUE: GAS CHROMATOGRAPHY, FID

ANALYTE: Hydrocarbons listed above

DESORPTION: 1 mL CS_2, stand 30 min with agitation

INJECTION VOLUME: 1 µL (Group A: split 5:1; Group B: split 1:1)

TEMPERATURE
-INJECTION: 250 °C
-DETECTOR: 300 °C
-COLUMN: Group A: 40 °C (10 min) to 230°C (10 °C/min)
Group B: 35°C (8 min) to 225°C (10°C/min)

CARRIER GAS: He @ 2.6 mL/min

COLUMN: Capillary, fused silica
Group A: 30m x 0.32-mm ID; 1-µm film 100% PEG or equivalent
Group B: 30m x 0.53-mm ID; 3-µm film crossbonded® 35% diphenyl 65% dimethyl polysiloxane or equivalent

CALIBRATION: Solutions of analytes in CS_2

RANGE: Table 4

ESTIMATED LOD: Table 4

PRECISION ($\hat{S}_r$): Table 4

APPLICABILITY: This method is for peak, ceiling, and TWA determinations of aromatic hydrocarbons. Interactions between analytes may reduce breakthrough volumes and affect desorption efficiencies. Naphthalene, originally validated in S292 [4], failed to meet acceptable desorption efficiency recovery and storage stability criteria at the levels evaluated in this study. However, the application of this method to naphthalene levels at or near the REL/PEL continues to meet acceptable recovery criteria. Styrene failed to meet acceptable recovery criteria at the two lowest levels evaluated in this study (highest level to meet the criteria was 181 µg/sample).

INTERFERENCES: Under conditions of high humidity, the breakthrough volumes may be reduced. Other volatile organic compounds such as alcohols, ketones, ethers, and halogenated hydrocarbons are potential analytical interferences.

OTHER METHODS: This method updates NMAM 1501 issued on August 15, 1994 [1] which was based upon P&CAM 127 (benzene, styrene, toluene, and xylene) [2]; S22 (p-tert-butyltoluene) [3]; S23 (cumene) [3]; S29 (ethylbenzene) [3] ; S26 (α-methylstyrene) [3]; S30 (styrene); S311 (benzene) [4]; S343 (toluene) [4]; and S318 (xylenes) [4].

REAGENTS:

1. Carbon disulfide*, low benzene, chromatographic quality.
2. Analytes, reagent grade.
3. Helium, prepurified and filtered.
4. Hydrogen, prepurified and filtered.
5. Air, prepurified and filtered.

* See SPECIAL PRECAUTIONS

EQUIPMENT:

1. Sampler: glass tube, 7 cm long, 6-mm OD, 4-mm ID, flame-sealed ends, containing two sections of activated coconut shell charcoal (front = 100 mg, back = 50 mg) separated by a 2-mm urethane foam plug. A silylated glass wool plug precedes the front section and a 3-mm urethane foam plug follows the back section. Tubes are commercially available.
2. Personal sampling pump, 0.01 to 1.0 L/min (Table 3), with flexible connecting tubing.
3. Gas chromatograph, FID, integrator, and columns (page 1501-1).
4. Autosampler vials, glass, 1.8 mL, with PTFE-lined caps.
5. Pipets, 1-mL, and pipet bulb.
6. Syringes, 10-µL, 25-µL, and 250-µL.
7. Volumetric flasks, 10-mL.

SPECIAL PRECAUTIONS: Carbon disulfide is toxic and extremely flammable (flash point = -30°C), benzene is a suspect carcinogen. Prepare standards and samples in a well ventilated hood.

SAMPLING:

1. Calibrate each personal sampling pump with a representative sampler in line.
2. Break the ends of the sampler immediately before sampling. Attach sampler to personal sampling pump with flexible tubing.
3. Sample at an accurately known flow rate between 0.01 and 0.2 L/min for a total sample size as shown in Table 3.
4. Cap the samplers with plastic (not rubber) caps and pack securely for shipment.

SAMPLE PREPARATION:

5. Place the front and back sorbent sections of the sampler tube in separate vials. Include the glass wool plug in the vial along with the front sorbent section.
6. Add 1.0 mL eluent to each vial. Attach crimp cap to each vial immediately.
7. Allow to stand at least 30 min with occasional agitation.

CALIBRATION AND QUALITY CONTROL:

8. Calibrate daily with at least six working standards from below the LOD to 10 times the LOQ. If necessary, additional standards may be added to extend the calibration curve.
   a. Add known amounts of analytes to carbon disulfide solvent in 10-mL volumetric flasks and dilute to the mark. Prepare additional standards by serial dilution in 10-mL volumetric flasks.
   b. Analyze together with samples and blanks (steps 11 through 12).
   c. Prepare calibration graph (peak area of analyte vs. µg analyte per sample).

9. Determine desorption efficiency (DE) at least once for each batch of charcoal used for sampling in the calibration range (step 8).
   a. Prepare three tubes at each of five levels plus three media blanks.
   b. Inject a known amount of DE stock solution (5 to 25 µL) directly onto front sorbent section of each charcoal tube with a microliter syringe.
   c. Allow the tubes to air equilibrate for several minutes, then cap the ends of each tube and allow to stand overnight.
   d. Desorb (steps 5 through 7) and analyze together with standards and blanks (steps 11 and 12).
   e. Prepare a graph of DE vs. µg analyte recovered.
10. Analyze a minimum of three quality control blind spikes and three analyst spikes to insure that the calibration graph and DE graph are in control.

MEASUREMENT:

11. Set gas chromatograph according to manufacturer's recommendations and to conditions given on page 1501-1. Inject a 1-µL sample aliquot manually using the solvent flush technique or with an autosampler.
    Note: If peak area is above the linear range of the working standards, dilute with solvent, reanalyze, and apply the appropriate dilution factor in the calculations.

Analyte	Approximate Retention Time (min)
benzene[a]	3.52
toluene[a]	6.13
ethylbenzene[a]	10.65
o-xylene[a]	12.92
m-xylene[a]	11.33
p-xylene[a]	11.04
cumene[b]	18.61
p-tert-butyltoluene[b]	21.45
α-methylstyrene[b]	19.99
β-methylstyrene[b]	20.82
styrene[b]	18.33

[a] Separation achieved using a 30-m Stabilwax fused silica capillary colum.
[b] Separation achieved using a 30-m Rtx-35 fused silica capillary column.

12. Measure peak areas.

CALCULATIONS:

13. Determine the mass, µg (corrected for DE) of analyte found in the sample front (W_f) and back (W_b) sorbent sections, and in the average media blank front (B_f) and back (B_b) sorbent sections.
    NOTE: If $W_b > W_f/10$, report breakthrough and possible sample loss.
14. Calculate concentration, C, of analyte in the air volume sampled, V (L):

$$C = \frac{(W_f + W_b - B_f - B_b)}{V}, mg/m^3$$

NOTE: µg/L = mg/m^3

EVALUATION OF METHOD:

The desorption efficiency, at levels ranging from 5 times the LOQ to 0.1x the REL, was determined for each analyte by spiking known amounts (in CS_2) on coconut shell charcoal tubes. Both groups of analytes (A and B) were spiked together on the charcoal sorbent tubes. All analytes, with the exception of styrene and naphthalene, exhibited acceptable desorption efficiency recovery results at all five levels evaluated. Styrene failed to meet the 75% recovery criteria at the 18.1 µg and 90.6 µg levels. Naphthalene failed to meet the 75% criteria at all levels evaluated ranging from 48.8 µg to 976.0 µg.

Each analyte, at a level approximately 0.05x REL/PEL, was evaluated for its storage stability @ 5°C after 7, 14, and 30 days. All analytes, with the exception of naphthalene, had acceptable recoveries after 30 days storage.

REFERENCES:

[1] NIOSH [1984]. Hydrocarbons, Aromatic: Method 1501. In: Eller PM, ed. NIOSH Manual of Analytical Methods. 4th rev. ed. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 94-113.

[2] NIOSH [1977]. NIOSH Manual of Analytical Methods, 2nd. ed., V. 1, P&CAM 127, U.S. Department of Health, Education, and Welfare, Publ. (NIOSH) 77-157-A.

[3] Ibid, V. 2, S22, S23, S25, S26, S29, S30, U.S. Department of Health, Education, and Welfare, Publ. (NIOSH) 77-157-B (1977).

[4] Ibid, V. 3, S292, S311, S318, S343, U.S. Department of Health, Education, and Welfare, Publ. (NIOSH) 77-157-C (1977).

[5] NIOSH [1977]. Documentation of the NIOSH Validation Tests, S22, S23, S25, S26, S29, S30, S292, S311, S318, S343, U.S. Department of Health, Education, and Welfare; Publ. (NIOSH) 77-185.

METHOD WRITTEN BY:

Stephanie M. Pendergrass, NIOSH/DART

TABLE 1. SYNONYMS, FORMULA, MOLECULAR WEIGHT, PROPERTIES

Name/Synonyms	Empirical Formula	Molecular Weight	Boiling Point (°C)	Vapor Pressure @ 25 °C (mm Hg)	(kPa)	Density @ 20 °C (g/mL)
benzene CAS #71-43-2 RTECS CY1400000	C_6H_6	78.11	80.1	95.2	12.7	0.879
p-tert-butyltoluene CAS #98-51-1 RTECS XS8400000 1-tert-butyl-4-methylbenzene	$C_{11}H_{16}$	148.25	192.8	0.7	0.09	0.861
cumene CAS #98-82-8 RTECS GR8575000 isopropylbenzene	C_9H_{12}	120.20	152.4	4.7	0.63	0.862
ethylbenzene CAS #100-41-4 RTECS DA0700000	C_8H_{10}	106.17	136.2	9.6	1.28	0.867
α-methylstyrene CAS #98-83-9 RTECS WL5075300 isopropenylbenzene (1-methylethenyl)-benzene	C_9H_{10}	118.18	165.4	2.5	0.33	0.909
β-methylstyrene CAS #873-66-5 RTECS DA8400500	C_9H_{10}	118.18	175.0	—	—	0.911
toluene CAS #108-88-3 RTECS XS5250000 methylbenzene	C_7H_8	92.14	110.6	28.4	3.79	0.867
xylene[c] CAS #1330-20-7 RTECS ZE2100000 dimethylbenzene (p-xylene)	C_8H_{10} (ortho) (meta) (para)	106.17	 144.4 139.1 138.4	 6.7 8.4 8.8	 0.89 1.12 1.18	 0.880 0.864 0.861
styrene CAS #100-42-5 RTECS WL3675000 vinylbenzene	C_8H_8	104.15	145.2	6.1	0.81	0.906

TABLE 2. PERMISSIBLE EXPOSURE LIMITS, PPM

Substance	OSHA TWA	NIOSH TWA	NIOSH C	NIOSH STEL	ACGIH TLV	ACGIH STEL	mg/m³ per ppm
benzene	1	0.1[a]	1		10[b]		3.19
p-tert-butyltoluene	10	10		20	1		6.06
cumene	50 (skin)	50 (skin)			50 (skin)		4.91
ethylbenzene	100	100		125	100	125	4.34
α-methylstyrene	100	50		100	50	100	4.83
β-methylstyrene	100	50		100	50	100	4.83
toluene	200	100		150	50 (skin)		3.77
o-xylene	100	100[c]		150	100	150	4.34
m-xylene	100	100			100	150	4.34
p-xylene	100	100			100	150	4.34
styrene	100	50		100	50	100 (skin)	4.26

[a] Potential carcinogen
[b] Suspect carcinogen
[c] Group I Pesticide

TABLE 3. SAMPLING FLOWRATE[a], VOLUME, CAPACITY, RANGE, OVERALL BIAS AND PRECISION

Substance	Sampling Flowrate (L/min)	Sampling Volume[b] (L) MIN	Sampling Volume[b] (L) MAX	Breakthrough Volume @ Concentration (L)	Breakthrough Volume @ Concentration (mg/m³)	Range at VOL-MIN (mg/m³)	Overall Bias (%)	Overall Precision ($\hat{S}_r$)	Accuracy (±%)
benzene	≤0.20	5	30	>45	149	42 - 165	-0.4	0.059	11.4
p-tert-butyltoluene	≤0.20	1	29	44	112	29 - 119	-10.3	0.071[c]	20.7
cumene	≤0.20	1	30	>45	480	120 - 480	5.6	0.059	15.2
ethylbenzene	≤0.20	1	24	35	917	222 - 884	-7.6	0.089[c]	17.1
α-methylstyrene	≤0.20	1	30	>45	940	236 - 943	-7.6	0.061[c]	16.9
β-methylstyrene	≤0.20	1	30	>45	940	236 - 943	-7.6	0.061	16.9
toluene	≤0.20	1	8	12	2294	548 - 2190	1.6	0.052	10.9
xylene (o-,m-,p-)	≤0.20	2	23	35	870	218 - 870	-1.2	0.060	12.2
styrene	<1.00	1	14	21	1710	426 - 1710	-7.9	0.058[c]	16.7

[a] Minimum recommended flow is 0.01 L/min.
[b] V_{Min} = minimum sample volume @ OSHA TWA;
V_{Max} = maximum sample volume @ OSHA TWA
[c] Corrected value, calculated from data in Reference 5.

TABLE 4. MEASUREMENT RANGE AND PRECISION[a]

Substance	LOD (µg/sample)	Measurement Range (mg)	Measurement Precision ($\hat{S}_r$)
benzene	0.5	0.004-0.35	0.013
p-tert-butyltoluene	1.1	0.013-1.09	0.017[a]
cumene	0.6	0.039-3.46	0.017
ethylbenzene	0.5	0.045-8.67	0.015
α-methylstyrene	0.6	0.036-3.57	0.014
β-methylstyrene	0.6	0.036-0.728	0.014
toluene	0.7	0.024-4.51	0.022
o-xylene	0.8	0.044-10.4	0.014
m-xylene	0.8	0.043-0.864	0.013
p-xylene	0.7	0.043-0.861	0.015
styrene	0.4	0.181-8.49	0.014

[a] Corrected value, calculated from data in [5].