



**Addendum 1 to the
RGA Environmental, Inc., May 8, 1992
Health and Safety Plan for the
Harrison Street Garage
Underground Tank Closure Project
Oakland, California**

**August 31, 1992
2680.02**

Prepared for:

**Alvin H. Bacharach and Barbara Jean Borsuk
383 Diablo Road, Suite 100
Danville, California 94526**



LEVINE·FRICKE

CONTENTS

	<u>PAGE</u>
1.0 INTRODUCTION	1
2.0 SOIL STOCKPILING AND SAMPLING	1
3.0 CHEMICALS OF CONCERN	2
4.0 AIR MONITORING PLAN	2
5.0 BASEMENT VENTILATION	2
6.0 PERSONAL PROTECTIVE EQUIPMENT	3
6.1 Purpose	3
6.2 Description of Levels of Protection	3
6.3 Inside the Garage Area	3
6.4 Inside the Basement Area	4
6.5 On the Sidewalk Outside the Garage Area	4
6.6 Action Levels	4
7.0 KEY PERSONNEL AND RESPONSIBILITIES	5
7.1 Levine·Fricke Project Manager	5
7.2 Levine·Fricke Health and Safety Director	6
7.3 Site Safety Officer	6
7.4 Certified Industrial Hygienist (CIH)	7
8.0 SITE SECURITY AND WORK ZONES	8
8.1 Purpose	8
8.2 Control	8
8.3 Field Operations Work Zones	9
8.3.1 Exclusion Zone	9
8.3.2 Contamination Reduction Zone	9
8.3.3 Support Zone	10
8.4 Zone Dimensions	10
8.5 Decontamination Procedures	10
8.5.1 General	10
8.5.2 Decontamination Solutions	11
8.5.3 Personal Decontamination During Medical Emergencies	11
8.6 Site Security	12
9.0 APPROVALS	13
9.1 Levine·Fricke Personnel	13
9.2 Contractor and Subcontractor Personnel	14

CONTENTS
(continued)

TABLE 1: EXPOSURE LIMITS AND SELECTED CHEMICALS OF CONCERN

TABLE 2: AIR MONITORING STRATEGY

APPENDICES:

- A CHEMICAL DESCRIPTIONS OF THE CHEMICALS OF CONCERN
- B HEALTH HAZARDS ASSOCIATED WITH SOIL CONTAINING ELEVATED CONCENTRATIONS OF MERCURY
- C MOLECULAR IONIZATION POTENTIAL
- D NIOSH METHOD 5503

August 31, 1992

2680.02

**ADDENDUM 1 TO THE
RGA ENVIRONMENTAL, INC., MAY 8, 1992
HEALTH AND SAFETY PLAN FOR THE
HARRISON STREET GARAGE
UNDERGROUND TANK CLOSURE PROJECT
OAKLAND, CALIFORNIA**

1.0 INTRODUCTION

This Addendum Number 1 to the May 8, 1992 Health and Safety Plan (HSP), which was prepared by RGA Environmental, Inc., addresses health- and safety-related issues associated with the planned underground tank closure at the Harrison Street Garage in Oakland, California (herein referred to as "the Site"). Specifically, this addendum provides an air monitoring plan, describes precautions to be taken in connection with ventilation during work in the basement area, and stipulates the levels of personal protective equipment (PPE), the site security and work zones, and the responsibilities of health and safety personnel. The Addendum does not address asbestos exposure. A qualified asbestos contractor will remove all accessible pipe before commencement of work addressed in the current HSP and this Addendum.

The current HSP and the Addendum shall be kept on site and made available for reference during all field activities. All site personnel and visitors must read the current HSP and Addendum before accessing the Site. In addition to the procedures and safeguards outlined in the current HSP and this Addendum, Levine-Fricke personnel and contract/subcontract employees shall follow applicable federal, State of California, and local regulations.

2.0 SOIL STOCKPILING AND SAMPLING

Remedial activities to be conducted at the Site will require excavation and stockpiling of soil that is affected and unaffected. Excavated soil will be segregated into affected and unaffected stockpiles to the extent possible, before being removed off site. Affected soils will be stockpiled away from the work area and covered with plastic sheeting. One sample for every 50 cubic yards of soil will be collected from all stockpiles for analysis of the chemicals of concern by a state-certified laboratory. Analytical results will be used

LEVINE·FRICKE

to assess treatment and/or disposal methods. The Levine·Fricke Site Safety Office (see Section 7.0) will monitor soil stockpiling using an organic vapor analyzer (OVA) or photoionization detector (PID). A record of the concentrations detected will be maintained in the project file.

3.0 CHEMICALS OF CONCERN

Table 1 provides the chemicals of concern and their exposure limits for planned field activities at the Site. This includes investigation and analytical data from previous reports prepared by Subsurface Consultants, SCS Engineers, Chromalab, Inc., and RGA Environmental. Appendix A contains chemical descriptions of these chemicals.

Mercury was detected at concentrations of 49.7 parts per million (ppm) to 74.2 ppm in borings in the basement area. The potential health hazard associated with soil containing mercury at these concentrations is addressed in Appendix B. Based on this evaluation, monitoring for heavy metals will not be conducted.

4.0 AIR MONITORING PLAN

Air quality will be monitored inside the garage area and at all access points during removal and/or remediation activities. Monitoring will be conducted by the Levine·Fricke Site Safety Officer (see Section 7.0) or a qualified designee. Air monitoring results will be maintained in an on-site log book, which will be available for review and will become part of the permanent project record. The proper operation and calibration of all monitoring equipment will be in accordance with the manufacturer's instructions.

Table 2 outlines the tasks to be performed, each constituent of concern, the monitoring device that will be used to detect the constituent, and the frequency of sampling.

5.0 BASEMENT VENTILATION

Ventilation in the basement area will include opening the sidewalk vents and removing the "glass bottle" portion of the sidewalk to increase the natural dilution ventilation within the garage. In addition, one or more local fans will be provided in the basement to improve air circulation if

*where will
the exhaust
be?*

necessary. Carbon monoxide concentrations will be continually measured in accordance with Table 2 to check that sufficient air movement is occurring.

6.0 PERSONAL PROTECTIVE EQUIPMENT

6.1 Purpose

The purpose of Personal Protective Equipment (PPE) is to protect employees from hazards and potential hazards they are likely to encounter.

6.2 Description of Levels of Protection

Levels of protection have been defined by the EPA in the EPA Standard Operating Guide, 1984, although there are numerous variations and modifications possible with each level. The levels are defined below.

- Level A requires a totally encapsulated, chemically resistant suit with self-contained breathing apparatus (SCBA).
- Level B requires provision of maximal respiratory protection using supplied air or SCBA, with dermal protection being selected on the basis of anticipated hazards.
- Level C incorporates an air-purifying respirator that is specific to the chemicals or particulates of concern. The degree of dermal protection depends on anticipated hazards.
- Level D is an industrial work uniform, including steel-toed boots, hard hat, and safety glasses.

The type and material of PPE will be modified or upgraded to accommodate the hazards present during each operation as specified by the Site Safety Officer (see Section 7.0).

6.3 Inside the Garage Area

All personnel performing tasks within the exclusion zone inside the garage area (nonbasement area) will wear the following PPE:

- Tyvek coveralls taped at the boot and gloves
- steel-toed boots

- latex inner and nitrile outer gloves
- safety glasses
- hearing protection.

6.4 Inside the Basement Area

All personnel performing tasks within the exclusion zone inside the basement area of the garage will wear the following PPE:

- NIOSH-approved half-face air-purifying respirator (APR) equipped with a Organic Vapor cartridges
- Tyvek coveralls taped at the boot and gloves
- steel-toed boots
- latex inner and nitrile outer gloves
- safety glasses
- hearing protection.

6.5 On the Sidewalk Outside the Garage Area

All personnel performing the tasks within the exclusion zone on the sidewalk outside of the garage area will wear the following PPE:

- Tyvek coveralls taped at the boot and gloves
- steel-toed boots
- latex inner and nitrile outer gloves
- safety glasses
- hearing protection.

6.6 Action Levels

The Site Safety Officer (see Section 7.3) shall impose a temporary stop work and contact the Levine·Fricke Health and Safety Director immediately if the following conditions are observed, or if there is a questions about site conditions:

LEVINE·FRICKE

- uncontrolled dust generation
- indications of heat stress
- changes in the general health profile of on-site personnel, including symptoms discussed in Appendix A and headaches, dizziness, breathing difficulties, irritation to the eyes, nose, throat, and hands
- a lower explosive limit/oxygen reading in excess of 10
- detection of benzene in the breathing zone using the sensidyne pump and tubes.

Action Level for Upgrade to Level C Protection

Detection of ambient air VOC concentrations in the breathing zone at 50 ppm or greater on the PID or OVA will require upgrading to Level C protection.

7.0 KEY PERSONNEL AND RESPONSIBILITIES

John Sturman (Levine·Fricke)	Project Manager
Michael J. Stoll (Levine·Fricke)	Site Safety Officer
Shari A. Samuels (Levine·Fricke)	Health and Safety Director
Dr. M. Joseph Fedoruk	Certified Industrial Hygienist

7.1 Levine·Fricke Project Manager

The Levine·Fricke Project Manager, Mr. John Sturman, has the ultimate responsibility for assuring compliance with the HSP for all personnel on site. As part of his duties, Mr. Sturman will be responsible for the following:

1. informing the Levine·Fricke Health and Safety Director of developments on the project
2. monitoring that all Levine·Fricke personnel on site have received the proper training and have been educated as to the potential hazards anticipated on the Site, as well as the procedures and precautions to be implemented on the job

LEVINE·FRICKE

3. informing all subcontractors and observers as to the hazards expected at the Site and appropriate protective measures (subcontractors and observers also will be given a copy of Levine·Fricke's HSP for review)
4. securing all necessary resources to provide a safe and healthy work environment for all personnel.

7.2 Levine·Fricke Health and Safety Director

The Levine·Fricke Health and Safety Director is Shari A. Samuels. Ms. Samuels is responsible for the following:

1. monitoring the health and safety impacts of this project on personnel performing work at the Site
2. assessing the potential health and safety hazards existing on site
3. recommending appropriate safeguards and procedures
4. modifying the HSP, when necessary
5. approving any changes in safeguards used or operating procedures employed on site.

The Levine·Fricke Health and Safety Director shall have the authority to:

1. require that additional safety precautions or procedures be implemented
2. order an evacuation of portions of the Site or shut down any of the work activities if she believes a health or safety hazard exists
3. deny access to the Site to unauthorized personnel and restrict observers to the Support Zone (see Section 8.3.3)
4. require that any worker obtain immediate medical attention
5. approve or disallow any proposed modifications to safety precautions or working procedures.

7.3 Site Safety Officer

The Site Safety Officer (SSO) designated by Levine·Fricke is Michael J. Stoll, Staff Geotechnical Engineer.

LEVINE·FRICKE

The SSO, or a trained designated alternate, will be present at the Site during work activities. The SSO shall be notified of and approve activities in which persons may be reasonably expected to be exposed to affected soils and/or ground water.

The SSO shall be responsible for the following:

1. monitoring that all Levine·Fricke and subcontractor personnel complying with the requirements of the HSP
2. limiting access to the Contamination Reduction and Exclusion Zones (see Section 8.0) at the Site
3. reporting unusual or potentially hazardous conditions to the Levine·Fricke Health and Safety Director, the Levine·Fricke Project Manager, and Alameda County representatives
4. reporting injuries, exposures, or illnesses to the Levine·Fricke Health and Safety Director, and the Levine·Fricke Project Manager
5. communicating proposed changes in work scope or procedures to the Levine·Fricke Health and Safety Director and Alameda County representatives for approval
6. recommending to the Levine·Fricke Health and Safety Director, the Levine·Fricke Project Manager, and Alameda County representatives additional safety procedures or precautions that might be implemented
7. conducting required air monitoring.

The SSO shall have the authority to:

1. order an evacuation of portions of the Site or shut down any of the work activities if he/she believes a health or safety hazard exists
2. deny site access to unauthorized personnel and restrict observers to the Support Zones (see Section 8.3.3)
3. require that any worker, including the subcontractor's personnel, obtain immediate medical attention.

7.4 Certified Industrial Hygienist (CIH)

Levine·Fricke will subcontract the services of M. Joseph Fedoruk, M.D., Inc. Dr. Fedoruk is a Certified Industrial

Hygienist (CIH). He will work directly with Levine·Fricke's Health and Safety Director to provide his professional expertise to oversee and approve the procedures and safeguards included in the HSP and Addendum.

8.0 SITE SECURITY AND WORK ZONES

8.1 Purpose

Controls must be implemented at the Site to reduce the possibility of exposure to any chemicals of concern present and to limit their transport from the Site by personnel or equipment.

8.2 Control

A control system is required to ensure that personnel and equipment working on hazardous waste sites are subjected to appropriate health and safety surveillance and site access control. The possibility of exposure or translocation of chemicals of concern will be reduced or eliminated in a number of ways, including the following:

- setting security or physical barriers at control points to regulate and/or exclude unnecessary personnel from the general area
- minimizing the number of personnel and equipment on site consistent with effective operations
- establishing work zones within the Site
- conducting operations in a manner that will reduce the exposure of personnel and equipment
- minimizing the airborne dispersion of contaminants (using dust control procedures; vapor suppressing foam or water will be made available, if necessary)
- implementing appropriate decontamination procedures for both personnel and equipment
- spill control and contamination procedures (a vacuum truck will be on call, if needed).

8.3 Field Operations Work Zones

Work zones will be established based on anticipated contamination and projected work activities. Within these zones, prescribed operations will occur using appropriate Personal Protective Equipment (see Section 6.0). Movement between zones will be controlled at checkpoints. The planned zones are as follows:

- Exclusion (contaminate)
- Contamination Reduction
- Support (noncontaminated).

8.3.1 Exclusion Zone

The Exclusion Zone is the innermost area of the three concentric "areas" and is considered to have contaminated materials present. Within this area, the prescribed protection must be worn by personnel. An entry checkpoint is established at the periphery of the exclusion zone to control flow of personnel and equipment between contiguous zones, and to monitor that the procedures established to enter and exit the zones are followed.

The Exclusion Zone boundary will be established initially on the presence of the chemicals of concern within the area. Subsequent to initial operations, the boundary may be readjusted based on observations and/or measurements. The boundary will be physically secured and posted and access will be limited.

8.3.2 Contamination Reduction Zone

Between the Exclusion and the Support Zone is the Contamination Reduction Zone (CRZ). This zone provides an area to prevent or reduce the transfer of chemicals of concern that may have been picked up by personnel or equipment returning from the Exclusion Zone. All decontamination activities occur in this area. The boundary between the Support Zone and the CRZ is the contamination control line. This boundary separates the potentially contaminated area from the clean area. Entry into the CRZ from the clean area will be through an access control point. Personnel entering at this station will be wearing the prescribed PPE for work in the CRZ. Exiting the CRZ to the clean area requires the removal of any suspected or known contaminated PPE, and compliance with the established decontamination procedures.

8.3.3 Support Zone

The Support Zone is the outermost of the three concentric "areas" and is considered decontaminated, or the "Clean Area." It contains the field office Command Post for field operations and other elements necessary to support site activities. Normal street or Level D work clothes are appropriate apparel for this area.

8.4 Zone Dimensions

Considerable judgment balanced with practical work considerations will be used to ensure a safe working area for each zone. Physical and topographical barriers may constrain ideal locations. Zones will be established on site after work areas are determined to allow enough room for all equipment and personnel. When the zones are established, the Alameda County representative will be notified to inspect the work zones. Field/laboratory measurements may assist in establishing the control zone distances. When not working in areas that require the use of chemical-resistant clothing, work zone procedures may still need to limit the movement of personnel and retain adequate site control.

8.5 Decontamination Procedures

8.5.1 General

As part of the system to prevent or reduce the physical transfer of chemicals of concern by people and/or equipment from the Site, procedures will be instituted for decontaminating anything leaving the Exclusion Zone and CRZ. These procedures will include decontamination of personnel, protective equipment, monitoring equipment, cleanup equipment, etc. Unless otherwise demonstrated, everything leaving the Exclusion Zone should be considered contaminated.

Decontamination is addressed in two ways: the physical arrangement and control of contamination zones, and the effective use of decontamination procedures. The decontamination process uses cleaning solutions, followed by rinse solutions. Used solutions, brushes, sponges, and containers must be properly disposed. In general, decontamination at the Site may consist of rinsing equipment, personnel, etc., with a detergent and water solution. Reusable decontaminated PPE will be stored for air drying.

8.5.2 Decontamination Solutions

Description

Usage

3 cups Alconox or
TSP to 5 to 8 gallons of water

Light contamination

Commercial Detergent-
Full strength or diluted

Organic contamination

As with all alkaline cleaners, continuous or repeated contact with the skin should be avoided. If an employee's skin becomes contaminated, he/she will move to the decontamination area and remove contaminated clothing, and wash with a mild soap/detergent and water to remove any contaminant from the skin. He/she will then seek first aid treatment.

A rinse solution will be used to remove the contamination solution and neutralize any excess decontamination solution. All personnel will follow these decontamination procedures:

1. When entering from the Exclusion Zone, remove heavy soil, as necessary, from boots, gloves, and clothing by using a towel or hose before entering the CRZ.
2. At the decontamination area, step into a decontamination tub(s) and brush boots and gloves clean.
3. Remove disposable suit and discard in proper container.
4. Step into a rinse tub(s), then remove boots.
5. Remove outer gloves and properly dispose.
6. Remove respirator and hard hat.
7. Remove inner gloves and dispose of properly.

Decontamination procedures may be modified, if necessary, with the approval of the Health and Safety Director.

8.5.3 Personal Decontamination During Medical Emergencies

In the event of personal injury, first aid personnel must decide if the victim's injuries are potentially the type that would be aggravated by movement. If there is any doubt, or if the victim is unconscious and cannot respond, no attempt should be made to move the victim to the decontamination area.

Only off-site paramedics may move such victims. If the paramedics approve, the victim's PPE will be cut off in the CRZ. If the decision is made not to remove the victim's PPE, he/she will be wrapped in a tarp or similar object to protect the ambulance and crew during transport. If the victim is contaminated with material that threaten to cause additional injury or immediate health hazards, the PPE will be carefully removed and the victim washed appropriately.

8.6 Site Security

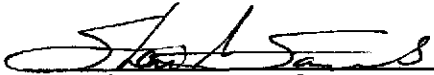
The work will be performed on weekends, when the garage is closed. If it is necessary to continue any work on weekdays, the Alameda County representative will be consulted to determine the extent to which the garage must be shut down. Fencing will be used to secure the gas tank area and prohibit unauthorized access. Trench plates will be used to cover the excavations at the end of each day.

At a minimum, all visitors entering the Exclusion Zone and the CRZ must wear the protective clothing and equipment worn by Levine·Fricke personnel. Permission to enter the work area must be obtained from at least one of the personnel named in Section 7.0. Visitor's name and purpose of visit will be recorded in the field notes.


9.0 APPROVALS

9.1 Levine·Fricke Personnel

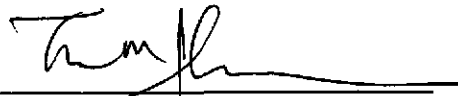
This HSP Addendum 1, covering activities at the Harrison Street Garage Site in Oakland, California, is approved by the following personnel:


Shari A. Samuels
Health and Safety Director

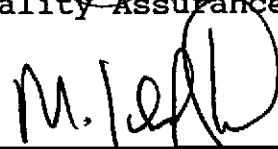
8/31/92
Date


John Sturman, P.E.
Project Manager

8/31/92
Date


Thomas M. Johnson, R.G.
Quality Assurance Reviewer

8/31/92
Date


Dr. M Joseph Fedoruk, CIH
Certified Industrial Hygienist

8.27.92
Date

9.2 Contractor and Subcontractor Personnel

Contractor and Subcontractor Agreement:

1. The Contractor certifies that the following personnel to be employed on the Harrison Street Garage Site have met the requirements of the Federal and California OSHA Hazardous Waste Operations and Emergency Response Standard 29 CFR 1910.120 and GISO 5192.

2. The Contractor certifies that in addition to meeting the OSHA requirements, it has received a copy of the HSP and this Addendum 1, and will ensure that its employees are informed and will comply with both OSHA requirements and the guidelines in this HSP.

3. The Contractor further certifies that its representative has read, understands, and will comply with all provisions of the HSP and this Addendum 1, and it will take full responsibility for the health and safety of its employees.

<u>Contractor</u>	<u>Signature</u>	<u>Date</u>
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____

TABLE 1

**EXPOSURE LIMITS AND
SELECTED CHEMICALS OF CONCERN
HARRISON STREET GARAGE SITE
OAKLAND, CALIFORNIA**

Chemical Compound	OSHA PEL (ppm unless noted)
Barium	0.5*
Benzene	1
Bromodichloromethane	NA
Chloroform	2
Chromium	1*
Ethylbenzene	100
Lead	0.05 *
Mercury	0.01 *
Methylene Chloride	500
PCBs	0.5*
PCE	100
Selenium	0.2 *
TCE	100
Toluene	100
TPH as diesel	NA
TPH as gasoline	300
Xylene	100

Notes:

- PCB - Polychlorinated biphenyls
- PCE - Tetrachloroethene
- TCE - Trichloroethene
- TPH - Total petroleum hydrocarbons
- PEL - Permissible Exposure Limit
- ppm - parts per million
- * - noted in milligrams per cubic meter
- NA - Not Applicable

monitoring
stockpiled soils?

TABLE 2
AIR MONITORING STRATEGY

Task	Constituents of Concern	Instrument	Frequency
Area: Sump and Lift Area/Gasoline Pump Area			
Soil boring sampling and excavation	Benzene, toluene, ethylbenzene, xylenes, bromodichloromethane, PCE, TCE	PID (with appropriate lamp; see Appendix C) and OVA Sensidyne pump and benzene tubes	At start of work and 30 minutes to continuously. Every 4 hours or if PID or OVA detect 50 ppm.
Monitoring well installation	Benzene, toluene, ethylbenzene, xylenes, bromodichloromethane, PCE, TCE	PID/OVA Sensidyne pump and benzene tubes	At start of work and 30 minutes to continuously. Every 4 hours or if PID or OVA detect 50 ppm.
Monitoring well survey	Benzene, toluene, ethylbenzene, xylenes, bromodichloromethane, PCE, TCE	PID/OVA Sensidyne pump and benzene tubes	Start-up of work at each well location. Every 4 hours or if PID or OVA detect 50 ppm.
Monitoring well development	Benzene, toluene, ethylbenzene, xylenes, bromodichloromethane, PCE, TCE	PID/OVA Sensidyne pump and benzene tubes	Start-up of work at each well location. Every 4 hours or if PID or OVA detect 50 ppm.
Ground-water sampling	Benzene, toluene, ethylbenzene, xylenes, bromodichloromethane, PCE, TCE	PID/OVA Sensidyne pump and benzene tubes	Start-up of work at each location. Every 4 hours or if PID or OVA detect 50 ppm.
Excavation activities	PCBs	SKC personal air sampling pump (according to NIOSH Method 5503; see Appendix D)	One 8-hour sample will be collected the first day of activity
Area: Basement			
Soil sampling and excavation	Benzene, toluene, ethylbenzene, xylenes, carbon monoxide, flammable vapors, oxygen levels	PID/OVA, CO meter, and O ₂ meter Sensidyne pump and benzene tubes	At start of work and 30 minutes to continuously. Every 4 hours or if PID or OVA detect 50 ppm.
Monitoring well installation	Benzene, toluene, ethylbenzene, xylenes, carbon monoxide, flammable vapors, oxygen levels	PID/OVA, CO meter, and O ₂ meter Sensidyne pump and benzene tubes	At start of work and 30 minutes to continuously. Every 4 hours or if PID or OVA detect 50 ppm.
Monitoring well survey	Benzene, toluene, ethylbenzene, xylenes, carbon monoxide, flammable vapors, oxygen levels	PID/OVA, CO meter, and O ₂ meter	Start-up of work at each well location

**TABLE 2
AIR MONITORING STRATEGY**

Task	Constituents of Concern	Instrument	Frequency
Monitoring well development	Benzene, toluene, ethylbenzene, xylenes, flammable vapors, oxygen levels	PID/OVA, CO meter, and O ₂ meter	Start-up of work at each well location
Ground-water sampling	Benzene, toluene, ethylbenzene, xylenes, flammable vapors, oxygen levels	PID/OVA, CO meter, and O ₂ meter	Start-up of work at each well location
Excavation activities	PCBs	SKC personal air sampling pump (according to NIOSH Method 5503; see Appendix D)	One 8-hour sample will be collected the first day of activity

PCE - Tetrachloroethene
TCE - Trichloroethene
PCB - Polychlorinated biphenyl
PID - Photo ionization detector
OVA - organic vapor analyzer

APPENDIX A

CHEMICAL DESCRIPTIONS OF THE CHEMICALS OF CONCERN

CHEMICAL DESCRIPTIONS OF THE CHEMICALS OF CONCERN

Barium

The soluble barium salts, such as the chloride and sulfide, are poisonous when ingested. The insoluble sulfate used in radiography is not acutely toxic. The chromate is a human carcinogen. Some salts are skin, eye, and mucous membrane irritants producing dermatitis.

The Permissible Exposure Limit (PEL) for barium is 0.5 mg/m³.

Benzene

Benzene is a clear colorless liquid. Exposure to high concentrations (3,000 parts per million [ppm]) may result in acute poisoning, characterized by the narcotic action of benzene on the central nervous system. Chronic poisoning occurs most commonly through inhalation and dermal absorption. Benzene is also a recognized carcinogen.

The PEL for benzene is 1 ppm.

Bromodichloromethane

Bromodichloromethane is a colorless liquid. Short-term exposure to high concentrations of bromodichloromethane may be narcotic. Bromodichloromethane is classified by the U.S. Environmental Protection Agency as a Group B2, probable human carcinogen.

The PEL for bromodichloromethane is 200 ppm.

Chloroform

Chloroform is a colorless liquid with a pleasant, sweet odor. Short-term exposure to chloroform vapor may cause headaches, drowsiness, vomiting, dizziness, unconsciousness, irregular heart beat, and death. Liver and kidney damage may result from exposure to chloroform vapor.

The PEL for chloroform is 2 ppm.

Chromium

Chromium is a greenish-blue, odorless solid. Exposure to chromium has been associated with lung changes in workers exposed to chromium alloys. Chromium dust exposure may cause minor lung changes.

The PEL for chromium is 1 mg/m³.

Diesel Fuel

Diesel fuel is a gas oil fraction available in various grades as required by different engines. Composition of diesel varies in ratios of predominantly aliphatic, olefinic, cycloparaffinic, and aromatic hydrocarbons, and additives.

Ingestion of diesel can lead to systemic effects such as gastrointestinal irritation, vomiting, diarrhea, and in severe cases, drowsiness and central nervous system depression, progressing to coma and death. Aspiration of diesel fuel can cause hemorrhaging and pulmonary edema, progressing to pneumonitis and renal involvement.

Ethylbenzene

Ethylbenzene is a clear, colorless liquid. Exposure to high concentrations of ethylbenzene vapor may result in irritation of the skin and mucous membranes, dizziness, irritation of the nose and throat, and a sense of constriction of the chest.

The PEL for ethylbenzene is 100 ppm.

Gasoline

Gasoline is produced from the light distillates during petroleum fractionation; its major components include paraffins, olefins, naphthenes, aromatics, and recently ethanol. Gasoline also contains various functional additives as required for different uses, such as antiknock fluids, antioxidants, metal deactivators, corrosion inhibitors, anti-icing agents, pre-ignition preventors, upper-cylinder lubricants, dyes, and decolorizers. Lead additives in particular were widely used in gasoline until the introduction of vehicle catalytic converters.

Mild cases of gasoline ingestion can cause inebriation, vomiting, vertigo, drowsiness, confusion, and fever. Aspiration into the lungs and secondary pneumonia may occur unless prevented. Gasoline can cause hyperemia of the conjunctiva and other eye disturbances. Gasoline is a skin irritant and a possible allergen. Repeated or chronic dermal contact can result in drying of the skin, lesions, and other dermatologic conditions.

The PEL TWA for gasoline is 300 ppm. The PEL STEL is 500 ppm.

Lead

Lead (inorganic) is a bluish-white, silver, or gray odorless solid.

Short-term exposure to lead can cause decreased appetite, insomnia, headache, muscle and joint pain, colic, and constipation.

The PEL for lead is 0.05 mg/m³.

Mercury

Mercury is a silvery, mobile, odorless liquid. Short-term exposure to inhaled mercury vapors may cause headache, cough, chest pains, chest tightness, and difficulty in breathing. In addition, it may cause soreness of the mouth, loss of teeth, nausea, and diarrhea. Liquid mercury may irritate the skin.

The PEL TWA for mercury is 0.1 mg/m³.

Methylene Chloride

Methylene chloride is a colorless liquid with an odor similar to chloroform.

Methylene chloride is an anesthetic. Short-term exposure to methylene chloride can cause mental confusion, light-headedness, nausea, vomiting, and headache. Continued exposure may cause increased light-headedness, staggering, unconsciousness, and death. High vapor concentrations may also cause irritation of the eyes and respiratory tract. Exposure to methylene chloride may make the symptoms of angina worse. Skin exposure to the liquid can cause irritation. If the liquid is held in contact with the skin, it can cause skin burns. Splashes of the liquid into the eye can cause irritation.

Methylene chloride is classified by the U.S. Environmental Protection Agency as a Group B2 probable human carcinogen.

The PEL for methylene chloride is 100 ppm in air.

Perchloroethylene (PCE)

PCE, also known as tetrachloroethylene, is a colorless liquid with an ether-like odor.

Short-term exposure to PCE may cause headaches, nausea, drowsiness, dizziness, incoordination, unconsciousness, irritation of the eyes, nose, and throat, and flushing of the face and neck. In addition, it may cause liver damage with such findings as yellow jaundice and dark urine. Liver damage may become evident several weeks after exposure.

PCE is classified by the U.S. Environmental Protection Agency as a Group B2 probable human carcinogen.

The PEL for PCE is 25 ppm in air.

Polychlorinated Biphenyls (PCBs)

PCBs pale yellow viscous liquids with a mild hydrocarbon odor. Exposure to PCBs may cause irritation of the eyes, nose, and throat, and an acne-like skin rash. It also may injure the liver, resulting in such effects as fatigue, dark urine, and yellow jaundice. Skin irritation may result from repeated skin contact.

The PEL for PCBs is 0.5 mg/m³.

Selenium

Selenium is a black, gray, or red odorless solid.

Prolonged exposure to selenium can cause paleness, coated tongue, stomach disorders, nervousness, metallic taste, and a garlic odor of the breath. Fluid in the abdominal cavity, damage to the liver and spleen, and anemia have been reported in animals.

The PEL TWA for selenium is 0.2 mg/m³.

Trichloroethene (TCE)

TCE is a colorless liquid with a sweet odor similar to chloroform.

Short-term inhalation exposure to TCE can cause drowsiness, dizziness, headache, blurred vision, incoordination, mental confusion, flushed skin, tremors, nausea, vomiting, fatigue, and cardiac arrhythmia. Irritation of the skin, mucous membranes, and eyes also can occur.

TCE is classified by the U.S. Environmental Protection Agency as a Group B2 probable human carcinogen.

The PEL for TCE is 50 ppm in air.

Toluene

Toluene is a colorless liquid with a benzol-like odor. Inhalation of high vapor concentrations may cause impairment of coordination and reaction time, headaches, nausea, eye irritation, loss of appetite, a bad taste, and lassitude.

The PEL for toluene is 100 ppm.

Xylenes

Xylenes are clear, colorless liquids. Exposure to high concentrations of xylene vapor may result in eye and skin irritation. Eye irritation may occur at concentrations of about 200 ppm.

The PEL for total xylene is 100 ppm.

APPENDIX B

**HEALTH HAZARDS ASSOCIATED WITH SOIL CONTAINING
ELEVATED CONCENTRATIONS OF MERCURY**

M. Joseph Fedoruk M.D., Inc.

Diplomate American Board of
Preventive Medicine,
certified in Occupational Medicine
Diplomate American Board of Toxicology
Certified Industrial Hygienist

1401 N. Tustin Avenue
Suite 240
Santa Ana, California 92701
Telephone: (714) 550-7211
FAX: (714) 550-7215

Medicine
Toxicology
Exposure Assessment

June 21, 1991

Ms. Shari Samuels
Levine-Fricke
1900 Powell Street
Emeryville, California 94608

Regarding : mercury exposure potential at Oakland remediation project.

Dear Ms.Samuels:

The purpose of this letter is to provide you with my opinion regarding the potential health hazard that soil containing mercury at concentrations of 70-80 ppm poses to remediation workers at a Levine-Fricke project in Oakland, California.

The potential health hazard of this mercury containing soil to industrial workers can be assessed by determining the airborne concentration of mercury that could be produced from remediation activities at this site which disturb the soil and comparing this predicted concentration to the industrial exposure limit for mercury. To be conservative an assumption will be made that the soil contains 100 ppm of mercury.

Since no specific information is available regarding the form of mercury which is present in the soil, for the purpose of this assessment it will be assumed that the soil contains alkyl mercury compounds. Alkyl mercury compounds have the lowest Threshold Limit Value (TLV) of 0.01 mg/m³ (10 ug/m³) for an eight-hour time-weighted average of all mercury compounds. The Cal/OSHA Permissible Exposure Limit (PEL) for alkyl mercury compounds is also 0.01 mg/m³ for an eight-hour time-weighted average. By contrast the TLV for aryl and inorganic mercury compounds is 100 ug/m³ for an eight-hour time-weighted average and 50 ug/m³ for all other mercury forms.

The first step is to identify the concentration of mercury that is present in 1 mg of soil.

The concentration in the soil is assumed to be 100 ppm, therefore:

100 ppm = 100 mg/kg
100 mg/kg = 100 ug/g
100 ug/g = 0.1 ug/mg

Therefore 1 mg of soil will contain 0.1 ug of mercury assuming the soil contains 100 ppm or 100 mg/kg of mercury.

The next step is to identify what airborne concentration of dust could be produced at this site from

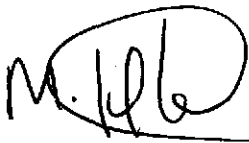
soil disturbance associated with remediation activities. Although there are no published data concerning airborne concentrations of suspended soil at various remediation projects it is extremely unlikely, based upon personal experience, that the ambient dust concentrations could exceed 5 mg/m³. At this ambient dust concentration the airborne concentration of mercury would only be 0.5 ug/m³ which is 1/20 of the TLV or PEL for the species of mercury with the lowest exposure limit. Even if the airborne dust concentrations were unrealistically high, such as 20 mg/m³, the airborne mercury concentration would still only be 1/5 of the TLV or PEL.

There is no evidence to suggest that airborne concentrations of mercury due to airborne suspension of soil at this site would approach the industrial exposure limit for the mercury, even if the soil contained the mercury species with the lowest industrial exposure limit. Therefore based upon information that soil at this site does not contain mercury in excess of 100 ppm, the hazard posed by inhalation of this soil is low and there is no evidence to suggest that airborne concentrations of mercury would exceed any regulated exposure limit.

The site safety plan should ensure that remediation workers utilize adequate dermal protective equipment to prevent inadvertent dermal absorption of mercury as well as other compounds at this site. Similarly although the airborne concentrations of mercury at this site are anticipated to be very low, respiratory protection for other compounds at the site such as volatile organic compounds will likely be required. The site safety plan should include adequate decontamination measures to avoid inadvertent ingestion of any contaminated soil. The exact level of personal protective equipment that would be required should be based upon an evaluation of exposure potential to all compounds.

I hope this information is of use in assessing the magnitude of the industrial hazard that mercury containing soils pose to remediation workers at this site. If you have any further questions please contact me directly.

Respectfully,



M. Joseph Fedoruk, M.D., CIH, DABT
Diplomate, American Board of Preventive Medicine, certified in Occupational Medicine
Certified Industrial Hygienist (Toxicological Aspects)
Diplomate, American Board of Toxicology

APPENDIX C
MOLECULAR IONIZATION POTENTIAL

B. MOLECULAR IONIZATION POTENTIALS

Acetamide	9.71	P.I.	(II)	16.6	E.I.
Acetic acid	10.35	P.I.	(III)	18.	E.I.
Acetic acid-d ₄	10.71	E.I.	Benzene-d ₆	9.251	S.
Acetophenone	9.27	P.I.	Benzonitrile	9.71	P.I.
Acetyl bromide	10.55	P.I.	Benzo(c)phenanthrene	8.40	E.I.
Acetyl chloride	11.02	P.I.	Benzophenone	9.45	P.I.
Acridine	7.78	P.I.	Benzoyl chloride	10.6	E.I.
Acrylonitrile	10.91	P.I.	Benzoyl fluoride	10.6	E.I.
Allyl alcohol	9.67	P.I.	Benzylamine	7.56	P.I.
Allylamine	9.6	E.I.	Benzylmethyl ether	8.85	P.I.
Aluminum monofluoride	9.5	E.I.	Benzyne	9.75	E.I.
Aluminum monoxide	9.5	E.I.	Bicyclo(2.2.1)-heptadiene	8.60	E.I.
Aluminum tribromide	12.2	E.I.	Bis-(<i>n</i> -butyl) amine	7.69	P.I.
Aluminum trichloride	12.8	E.I.	Dis-(2-chloroethyl) ether	9.85	P.I.
α -aminonaphthalene	7.30	P.I.	Biscyclopentadienyl		
β -aminonaphthalene	7.25	P.I.	chromium	6.91	E.I.
4-aminopyridine	8.97	E.I.	Biscyclopentadienyl cobalt	6.2	E.I.
2-aminotropone	9.43	E.I.	Biscyclopentadienyl iron	7.05	E.I.
Ammonia (I)	10.154	P.I.	Biscyclopentadienyl		
(II)	23.5	E.I.	manganese	7.25	E.I.
Ammonia-d ₃	11.47	E.I.	Biscyclopentadienyl nickel	7.06	E.I.
Ammonia-d ₃	11.52	E.I.	Biscyclopentadienyl		
Ammonium hydroxide	10.8	E.I.	vanadium	7.56	E.I.
<i>n</i> -amylamine	9.5	E.I.	Dis(<i>p</i> -methylphenyl) amine	7.8	E.I.
<i>N</i> - <i>n</i> -amylaniline	7.5	U.V.	Bismuth (Bi ₂)	8.	E.I.
Anabasine	8.70	E.I.	Bismuth monosulfide	8.	E.I.
Aniline	7.70	P.I.	Bis-(<i>n</i> -propyl) amine	7.84	P.I.
<i>p</i> -anisidine	7.82	E.I.	Dis(<i>i</i> -propyl) amine	7.73	P.I.
Anisole	8.22	P.I.	Dis(trifluoromethyl)		
Anthracene	7.23	S.	arsine	10.9	E.I.
Anthraquinone	9.34	P.I.	Dis(trifluoromethyl)		
Antimony (Sb ₂)	9.5	E.I.	chloroarsine	11.0	E.I.
Antimony (Sb ₃)	9.1	E.I.	Bis(trifluoromethyl)		
Antimony monochloride	10.9	E.I.	methylarsine	10.5	E.I.
Antimony trichloride	11.4	E.I.	Borazine	10.2	E.I.
Arsenic (As ₂)	11.0	E.I.	Boric oxide	13.2	E.I.
Arsenic (As ₃)	10.8	E.I.	Borine	10.5	E.I.
Arsenic (As ₄)	8.9	E.I.	Boron (B ₂)	12.06	E.I.
Arsenic dichloride	8.4	E.I.	Boron dibromide	7.06	E.I.
Arsenic trichloride	11.7	E.I.	Boron dichloride	7.20	E.I.
Arsenic trimethyl	8.3	E.I.	Boron diethyl	5.98	E.I.
Arsenic triphosphide	10.3	E.I.	Boron dihydride	8.12	E.I.
Arsine	10.6	E.I.	Boron diiodide	7.13	E.I.
Azacyclobutane	8.9	E.I.	Boron dimethyl	6.44	E.I.
Barium oxide	6.0	E.I.	Boron monobromide	9.25	E.I.
Benzaldehyde	9.53	P.I.	Boron monochloride	10.44	E.I.
Benz(a)anthracene	7.53	E.I.	Boron monoethyl	8.73	E.I.
Benzene	9.245	P.I.	Boron monohydride	10.06	E.I.
Benzene-d ₆ (I)	9.44	E.I.	Boron monolodide	8.96	E.I.

B. MOLECULAR IONIZATION POTENTIALS (CONT.)

Boron monomethyl	9.28	E.I.	2-bromothiophene	8.63	P.I.
Boron monoxide	7.0	S.	<i>o</i> -bromotoluene	8.78	P.I.
Boron tribromide	9.7	E.I.	<i>m</i> -bromotoluene	8.81	P.I.
Boron trichloride	12.0	E.I.	<i>p</i> -bromotoluene	8.67	P.I.
Boron triethyl	9.0	E.I.	Bromotrifluoromethane	11.78	P.I.
Boron-trifluoride	15.5	E.I.	1,2-butadiene;	9.57	E.I.
Boron triiodide	9.0	E.I.	1,3-butadiene (<i>cis</i>)	9.07	P.I.
Boron trimethyl	8.8	E.I.	1,3-butadiene (<i>trans</i>)	9.07	P.I.
Boroxine	13.5	E.I.	1,3-butadiyne	10.74	S.
Bromine (I)	10.55	P.I.	<i>n</i> -butanal	9.86	P.I.
(II)	19.5	E.I.	<i>n</i> -butane	10.63	P.I.
Bromine difluoride	11.2	E.I.	2,3-butanedione	9.23	P.I.
Bromine trifluoride	12.9	E.I.	<i>n</i> -butanoic acid	10.16	P.I.
Bromine tetrafluoride	15.6	E.I.	1-butanol	10.04	P.I.
Bromine monochloride	11.1	E.I.	2-butanol	10.1	P.I.
Bromobenzene	8.98	P.I.	Butanone	9.53	P.I.
1-bromo-bicyclo-(2.2.1)-			2-butenal	9.73	P.I.
heptane	9.90	E.I.	1-butene	9.58	P.I.
1-bromo-bicyclo-(2.2.2)-			2-butene (<i>cis</i>)	9.13	P.I.
octane	9.76	E.I.	2-butene (<i>trans</i>)	9.13	P.I.
1-bromobutane	10.13	P.I.	Buteneone	9.91	E.I.
2-bromobutane	9.98	P.I.	<i>n</i> -butylamine	8.71	P.I.
1-bromobutanone	9.54	P.I.	<i>i</i> -butylamine	8.70	P.I.
1-bromo-2-chloroethane	10.63	P.I.	<i>sec</i> -butylamine	8.70	P.I.
Bromochloromethane	10.77	P.I.	<i>i</i> -butylamine	8.64	P.I.
Bromodichloromethane	10.88	E.I.	<i>N</i> - <i>n</i> -butylaniline	7.5	U.V.
Bromodifluoromethane	12.0	E.I.	<i>n</i> -butylbenzene	8.69	P.I.
Bromodurene	8.0	E.I.	<i>i</i> -butylbenzene	8.69	P.I.
Bromoethane	10.24	P.I.	<i>sec</i> -butylbenzene	8.68	P.I.
Bromoethene	9.8	P.I.	<i>i</i> -butylbenzene	8.68	P.I.
1-bromo-4-fluorobenzene	8.99	P.I.	<i>n</i> -butyl ethanoate	10.00	P.I.
Bromoform	10.51	P.I.	<i>i</i> -butyl ethanoate	9.95	P.I.
1-bromo-3-hexanone	9.26	P.I.	<i>sec</i> -butyl ethanoate	9.91	P.I.
Bromomethane	10.53	P.I.	<i>n</i> -butyl methanoate	10.50	P.I.
Bromomethyl ethyl ether	10.08	P.I.	<i>i</i> -butyl methanoate	10.46	P.I.
2-(bromomethyl)-			<i>n</i> -butyl pentanoate	9.57	P.I.
propane	10.15	E.I.	2-butyliothiophene	8.5	E.I.
1-bromo-2-methyl			1-butyne	10.18	P.I.
propane	10.09	P.I.	2-butyne	9.85	P.I.
2-bromo-2-methylpropane	9.89	P.I.	1-butyne-3-ene	9.87	E.I.
1-bromopentane	10.10	P.I.	Calcium monofluoride	5.5	E.I.
<i>p</i> -bromophenol	9.04	E.I.	Carbon (C ₂)	12.0	E.I.
1-bromopropane	10.18	P.I.	Carbon (C ₃)	12.6	E.I.
2-bromopropane	10.08	P.I.	Carbon (C ₄)	12.6	E.I.
1-bromopropene	9.30	P.I.	Carbon (C ₅)	12.5	E.I.
3-bromopropene	9.7	P.I.	Carbon tetrachloride	11.47	P.I.
1-bromopropyne	10.1	E.I.	Carbon tetrafluoride	<15.0	E.I.
2-bromopyridine	9.65	E.I.	Carbon dioxide (I)	13.79	P.I.
4-bromopyridine	9.94	E.I.	(II)	22.6	E.I.

B. MOLECULAR IONIZATION POTENTIALS (CONT.)

Carbon disulfide	10.076	P.I.	<i>p</i> -chlorophenol	9.07	E.I.
Carbon monoxide (I)	14.01	P.I.	Chloroprene	8.8	S.
(II)	27.7	E.I.	1-chloropropane	10.82	P.I.
Carbon monosulfide	11.8	E.I.	2-chloropropane	10.78	P.I.
Carbon suboxide	10.8	E.I.	1-chloropropanone	9.71	P.I.
Carbonyl sulfide	11.17	E.I.	3-chloropropene	10.04	P.I.
Chlorine (I)	11.48	P.I.	1-chloropropyne	9.9	E.I.
(II)	21.0	E.I.	2-chloropyridine	9.91	E.I.
Chlorine difluoride	11.0	E.I.	4-chloropyridine	10.15	E.I.
Chlorine dioxide	11.1	E.I.	2-chlorothophene	8.68	E.I.
Chlorine monoxide	10.4	E.I.	<i>o</i> -chlorotoluene	8.83	P.I.
Chlorine trifluoride	13.0	E.I.	<i>m</i> -chlorotoluene	8.83	P.I.
Chlorine trioxide	11.7	E.I.	<i>p</i> -chlorotoluene	8.69	P.I.
<i>o</i> -chloroaniline	7.9	U.V.	Chlorotrifluoroethene	10.4	E.I.
Chlorobenzene	9.07	P.I.	Chlorotrifluoromethane	12.8	P.I.
1-chloro-2-bromoethane	10.63	P.I.	Chromium hexacarbonyl	8.03	P.I.
Chlorobromomethane	10.77	P.I.	Chromium monoxide	8.2	E.I.
2-chloro-1,3-butadiene	8.79	S.	Chromyl chloride	12.6	E.I.
1-chlorobutane	10.67	P.I.	Chromyl fluoride	14.0	E.I.
2-chlorobutane	10.65	P.I.	Chrysene	7.75	U.V.
1-chlorobutanone	9.54	P.I.	Coronene	7.6	U.V.
Chlorocyanomethane	12.2	P.I.	<i>o</i> -cresol	8.93	E.I.
Chlorocyclopropane	10.10	E.I.	<i>m</i> -cresol	8.98	E.I.
Chlorodibromomethane	10.59	P.I.	<i>p</i> -cresol	8.97	E.I.
1-chloro-1,1-difluoroethane	11.98	P.I.	Cyanoethane	11.84	P.I.
Chlorodifluoromethane	12.45	P.I.	Cyanoethene	10.91	P.I.
Chloroethane	10.97	P.I.	Cyanoethyne	11.6	E.I.
Chloroethene	10.00	P.I.	Cyanogen	13.57	E.I.
1-chloro-3-fluorobenzene	9.155	P.I.	Cyanogen bromide	11.95	E.I.
1-chloro-3-fluorobenzene	9.21	P.I.	Cyanogen chloride	12.49	E.I.
1-chloro-2-fluoroethene (<i>cis</i>)	9.87	P.I.	Cyanogen iodide	10.98	E.I.
1-chloro-2-fluoroethene (<i>trans</i>)	9.87	P.I.	Cyanomethane	12.22	P.I.
Chloroform	11.42	P.I.	1-cyanopropane	11.67	P.I.
<i>o</i> -chloriodobenzene	8.35	P.I.	3-cyanopropane	10.39	P.I.
Chloromethane	11.28	P.I.	Cyclobutane	10.50	P.I.
Chloromethyl ethyl ether	10.08	P.I.	Cycloheptatriene	8.55	E.I.
Chloromethylmethyl ether	10.25	P.I.	<i>N</i> -cycloheptylaniline	7.45	U.V.
1-chloro-2-methylpropane	10.66	P.I.	Cyclohexadiene	8.40	S.
2-chloro-2-methylpropane	10.2	S.	Cyclohexane	9.88	P.I.
<i>o</i> -chlorophenol	9.29	E.I.	Cyclohexanone	9.14	P.I.
			Cyclohexene	8.95	P.I.
			<i>N</i> -cyclohexylaniline	7.45	U.V.
			Cyclooctatetraene	7.99	P.I.
			Cyclopentadiene	8.58	S.
			Cyclopentane	10.52	P.I.
			Cyclopentanone	9.26	P.I.
			Cyclopentene	9.01	P.I.
			<i>N</i> -cyclopentylaniline	7.45	U.V.
			Cyclopropane	11.05	P.I.

B. MOLECULAR IONIZATION POTENTIALS (CONT.)

Cyclopropene	9.95	E.I.	Dichlorodifluoromethane	12.31	P.I.
Cyclopropyl chloride	10.10	E.I.	Dichlorodifluoroethene	10.0	E.I.
Cyclopropyl cyanide	11.2	E.I.	1,2-dichloroethane	11.12	P.I.
Decaborane	10.7	E.I.	1,1-dichloroethene	9.45	S.
Decafluorocyclohexene	11.3	E.I.	1,2-dichloroethene (<i>cis</i>)	9.65	P.I.
Decafluoro- <i>o</i> -xylene	10.6	E.I.	1,2-dichloroethene (<i>trans</i>)	9.96	P.I.
<i>n</i> -decane	10.19	E.I.	Dichloroethyne	13.	E.I.
2-decanone	9.40	P.I.	Dichlorofluoromethane	12.39	E.I.
1-decene	9.51	E.I.	Dichloromethane	11.35	P.I.
<i>N</i> - <i>n</i> -decylaniline	7.5	U.V.	Dichloromethyl methyl ether	10.23	P.I.
Deuterium	15.457	S.	1,2-dichloropropane	10.87	P.I.
Dialuminum monoxide	7.7	E.I.	1,3-dichloropropane	10.85	P.I.
<i>N</i> , <i>N</i> -di- <i>n</i> -amylaniline	7.1	U.V.	1,1-dichloropropanone	9.71	P.I.
Diazirine	10.18	E.I.	2,3-dichloropropene	9.82	P.I.
Diazomethane	9.00	S.	Dicyanoacetylene	11.4	E.
Diborane	11.9	E.I.	Dicyanodiacetylene	11.4	E.
Diborane- <i>d</i> ₂	12.0	E.I.	<i>N</i> , <i>N</i> -di- <i>n</i> -decylaniline	7.1	U.
Diboron dihydride	11.36	E.I.	Diethoxymethane	9.70	P.
Diboron dihydride- <i>d</i> ₂	11.50	E.I.	<i>N</i> , <i>N</i> -diethylacetamide	8.60	P.
Diboron dioxide	13.3	E.I.	Diethylamine	8.01	P.
Diboron monodeuteride	8.7-11.7	E.I.	<i>N</i> , <i>N</i> -diethylaniline	7.15	U.
Diboron monohydride	10.62	E.I.	Diethylbenzene	8.88	E.
Diboron pentahydride	7.86	E.I.	1,2-diethylbenzene	8.91	E.
Diboron pentahydride- <i>d</i> ₂	8.01	E.I.	1,3-diethylbenzene	8.99	E.
Diboron tetrahydride	10.93	E.I.	1,4-diethylbenzene	8.93	E.
Diboron tetrahydride- <i>d</i> ₂	10.90	E.I.	Diethyl ether	9.53	P.
Diboron trihydride	8.79	E.I.	<i>N</i> , <i>N</i> -diethyl formamide	8.89	P.
Diboron trihydride- <i>d</i> ₂	8.81	E.I.	Diethyl sulfide	8.43	P.
1,4-dibromobutane	10.28	E.I.	Diethyl sulfite	9.68	P.
Dibromochloromethane	10.59	P.I.	<i>o</i> -difluorobenzene	9.31	P.
Dibromodifluoromethane	11.07	P.I.	<i>p</i> -difluorobenzene	9.15	P.
1,1-dibromoethane	10.19	P.I.	1,1-difluoro-1-chloroethane	11.98	P.
1,2-dibromoethane	10.30	E.I.	Difluorochloromethane	12.45	P.
1,2-dibromoethene (<i>cis</i>)	9.45	P.I.	Difluorocyanomethane	12.4	I.
1,2-dibromoethene (<i>trans</i>)	9.46	P.I.	1,1-difluoro-1,2-dibromoethane	10.83	I.
Dibromomethane	10.49	P.I.	1,1-difluoroethene	10.30	I.
1,3-dibromopropane	10.07	P.I.	Difluorodibromomethane	11.07	I.
<i>N</i> , <i>N</i> -di- <i>n</i> -butylaniline	7.15	U.V.	Difluorodichloroethene	10.0	I.
Di- <i>n</i> -butyl ether	9.18	P.I.	Difluorodichloromethane	12.31	I.
<i>o</i> -Dichlorobenzene	9.07	P.I.	Difluoromethane	12.55	I.
<i>m</i> -dichlorobenzene	9.12	P.I.	Difluoromethylbenzene	9.45	I.
<i>p</i> -dichlorobenzene	8.94	P.I.			
1,2-dichloro-1,2-bis(trifluoromethyl)-ethene	10.36	P.I.			
Dichlorobromomethane	10.88	E.I.			
Dichlorocyanomethane	12.9	E.I.			
1,1-dichlorocyclopropane	10.30	E.I.			

B. MOLECULAR IONIZATION POTENTIALS (CONT.)

N,N-di-n-hexylaniline	7.1	U.V.	Diphosphorusdarsenide	10.3	E.I.
Dihydropyran	8.34	P.I.	Diphosphorus tetrachloride	9.36	E.I.
Diimide	9.85	E.I.	N,N-di-n-propylaniline	7.15	U.V.
Diiodomethane	9.34	P.I.	Di-n-propyl disulfide	8.27	P.I.
Diketene	9.4	E.I.	Di-n-propyl ether	9.27	P.I.
Dilithium iodide	8.75	E.I.	Di- <i>i</i> -propyl ether	9.20	P.I.
Dilithium oxide	6.8	E.I.	Di-n-propyl sulfide	8.30	P.I.
Dimethoxyborane	4.46	E.I.	Disilicon dioxide	10.0	E.I.
1,1-dimethoxyethane	9.65	P.I.	Disulfur monoxide	10.3	E.I.
Dimethoxymethane	10.00	P.I.	2,3-dithiabutane	8.46	P.I.
N,N-dimethylacetamide	8.81	P.I.	3,4-dithiahexane	8.27	P.I.
Dimethylamine	8.24	P.I.	N-n-dodecylaniline	7.5	U.V.
N,N-dimethylaniline	7.14	P.I.	Durene	8.03	P.I.
Dimethylarsine	9.0	E.I.	3,4-epoxy-1-butene	9.7	E.I.
2,3-dimethylbutadiene	8.72	P.I.	1,2-epoxypropane	9.81	E.I.
2,2-dimethylbutane	10.05	P.I.	Ethanal	10.21	P.I.
2,3-dimethylbutane	10.01	P.I.	Ethane	11.65	P.I.
3,3-dimethylbutanone	9.17	P.I.	Ethane-d ₂	11.70	E.I.
2,3-dimethyl-2-butene	8.30	P.I.	Ethanoic acid	10.35	P.I.
Dimethyl chloroarsine	9.9	E.I.	Ethanoic acid-d ₂	10.71	E.I.
Dimethyl disulfide	8.46	P.I.	Ethanol	10.48	P.I.
Dimethyl ether	10.00	P.I.	Ethanol-d ₂ (OD)	10.45	E.I.
N,N-dimethylformamide	9.12	P.I.	Ethene	10.51	P.I.
2,3-dimethylfuran	8.01	E.I.	Ethene-d ₂	10.52	S.
3,5-dimethyl-4-heptanone	9.04	P.I.	Ethylamine	8.86	P.I.
1,1-dimethylhydrazine	8.12	E.I.	N-ethylaniline	7.5	U.V.
1,2-dimethylhydrazine	7.75	E.I.	Ethylbenzene	8.76	P.I.
Dimethyl mercury	8.90	E.I.	Ethyl boron difluoride	11.8	E.I.
2,2-dimethyl-3-pentanone	8.98	P.I.	Ethyl bromide	10.29	P.I.
2,2-dimethylpropane	10.35	P.I.	Ethyl bromoacetate	10.13	P.I.
Dimethyl sulfide	8.69	P.I.	Ethyl α-bromobutanoate	9.85	P.I.
Dimethyl sulfoxide	8.85	P.I.	2-ethyl-1-butene	9.21	E.I.
Dimethyltrifluoromethyl arsine	9.2	E.I.	Ethyl chloride	10.97	P.I.
Dimethyl zinc	8.86	E.I.	Ethyl chloroacetate	10.20	P.I.
Dinitrogen difluoride	13.1	E.I.	Ethyl decaborane	9.0	E.I.
Dinitrogen tetrafluoride	12.0	E.I.	Ethyl disulfane	9.4	E.I.
N,N-di-n-octylaniline	7.1	U.V.	Ethyleneimine	9.94	E.I.
1,3-dioxane	10.15	E.I.	Ethylene oxide	10.565	P.I.
1,4-dioxane	9.13	P.I.	Ethyl ethanoate	10.10	P.I.
Diphenyl	8.27	P.I.	Ethyl hexanoate	9.67	P.I.
Diphenylamine	7.4	U.V.	Ethyl iodide	9.33	P.I.
Diphenylbutadiene	7.75	U.V.	Ethyl isothiocyanate	9.10	P.I.
Diphenyldecapentaene	7.4	U.V.	Ethyl mercaptan	9.29	P.I.
Diphenylhexadiene	8.2	U.V.	Ethyl methanoate	10.61	P.I.
Diphenylhexatriene	7.6	U.V.	Ethyl nitrate	11.22	P.I.
Diphenyloctatetraene	7.5	U.V.	Ethyl propanoate	10.00	P.I.
Diphosphine	8.7	E.I.	2-ethylthiophene	8.8	E.I.
			Ethyl thiocyanate	9.89	P.I.

Ethyl... 12.3

B. MOLECULAR IONIZATION POTENTIALS (CONT.)

Ethyl trichloroacetate	10.44	P.I.	Hexafluoroacetone	11.81
Ethyne	11.41	P.I.	Hexafluorobenzene	9.39
Ethyne-d ₂	11.39	E.I.	Hexafluoropropene	10.3
Ethynylbenzene	8.82	P.I.	Hexamethylbenzene	7.85
Ferrous chloride (monomer)	11.5	E.I.	Hexamethylenimine	8.76
Ferrous chloride (dimer)	10.5	E.I.	n-hexane	10.17
Fluorene	8.63	E.I.	2-hexanone	9.34
Fluorine	15.7	P.I.	1,3,5-hexatriene	8.26
<i>o</i> -fluoroaniline	7.95	P.I.	1-hexene	9.46
<i>m</i> -fluoroaniline	7.90	P.I.	2-hexene (<i>trans</i>)	9.16
<i>p</i> -fluoroaniline	7.82	P.I.	3-hexene (<i>trans</i>)	9.12
Fluorobenzene	9.20	P.I.	3-hexene-1,5-diyne	9.46
Fluorocyanomethane	13.0	E.I.	N-n-hexylaniline	7.5
1-fluoro-1, 2-dibromoethane	10.75	P.I.	Hydrazine	9.00
Fluoroethane	12.00	E.I.	Hydrazoic acid	10.1
Fluoroethene	10.37	P.I.	Hydrogen	15.427
Fluoroform	13.84	S.	Hydrogen bromide (I)	11.62
Fluoromethane	11.4	P.I.	Hydrogen bromide (II)	21.6
Fluoromethane	12.80	S.	Hydrogen chloride (I)	12.74
<i>o</i> -fluorophenol	8.66	P.I.	Hydrogen chloride (II)	22.9
<i>o</i> -fluorotoluene	8.91	P.I.	Hydrogen cyanide (I)	13.73
<i>m</i> -fluorotoluene	8.91	P.I.	Hydrogen cyanide (II)	26.3
<i>p</i> -fluorotoluene	8.78	P.I.	Hydrogen disulfide	10.2
Fluorotribromomethane	10.67	P.I.	Hydrogen fluoride	15.77
Fluorotrifluoromethylbenzene	9.12	P.I.	Hydrogen iodide (I)	10.38
Formamide	10.20	P.I.	Hydrogen iodide (II)	19.6
Formic acid	11.05	P.I.	Hydrogen peroxide	10.92
Formic acid-d ₂	11.57	E.I.	Hydrogen selenide	9.88
Furan	8.89	P.I.	Hydrogen selenide-d ₂	9.88
Furfural	9.21	P.I.	Hydrogen sulfide	10.46
<i>β</i> -galactose	9.1	E.I.	Hydrogen sulfide-d ₂	10.47
Germane	12.3	E.I.	Hydrogen telluride	9.138
Germanium tetrachloride	11.90	E.I.	Hydrogen telluride-d ₂	9.14
Germanium tetramethyl	9.2	E.I.	4-hydroxypyridine	9.70
<i>d</i> -glucose	8.8	E.I.	Indene	8.81
Glycine	9.5	E.I.	Iodine	9.28
<i>n</i> -heptane	10.07	P.I.	Iodine difluoride	10.7
2-heptanone	9.33	P.I.	Iodine monobromide	9.98
4-heptanone	9.12	P.I.	Iodine monochloride	10.31
1-heptene	9.54	E.I.	Iodine pentafluoride	13.5
N-n-heptylaniline	7.5	U.V.	Iodine tetrafluoride	14.5
1,5-hexadiene	9.51	E.I.	Iodine trifluoride	9.7
2,4-hexadiene	10.65	S.	Iodobenzene	8.73

R₂

2

ethyl isobutyl ketone

dimethyl sulfate
EP unknown
Ted A.
oesn't have an
estimate

B. MOLECULAR IONIZATION POTENTIALS (CONT.)

N,N-di-n-hexylaniline	7.1	U.V.	Diphosphorusdiarsenide	10.3	E.I.
Dihydropyran	8.34	P.I.	Diphosphorus tetrachloride	9.36	E.I.
Diimide	9.85	E.I.	N,N-di-n-propylaniline	7.15	U.V.
Diiodomethane	9.34	P.I.	Di-n-propyl disulfide	8.27	P.I.
Diketene	9.4	E.I.	Di-n-propyl ether	9.27	P.I.
Dilithium iodide	8.75	E.I.	Di-t-propyl ether	9.20	P.I.
Dilithium oxide	6.8	E.I.	Di-n-propyl sulfide	8.30	P.I.
Dimethoxyborane	4.46	E.I.	Disilicon dioxide	10.0	E.I.
1,1-dimethoxyethane	9.65	P.I.	Disulfur monoxide	10.3	E.I.
Dimethoxymethane	10.00	P.I.	2,3-dithiabutane	8.46	P.I.
N,N-dimethylacetamide	8.81	P.I.	3,4-dithiahexane	8.27	P.I.
Dimethylamine	8.24	P.I.	N-n-dodecylaniline	7.5	U.V.
N,N-dimethylaniline	7.14	P.I.	Durgene	8.03	E.I.
Dimethylarsine	9.0	E.I.	Epichlorohydrine	10.6	E.I.
2,3-dimethylbutadiene	8.72	P.I.	3,4-epoxy-1-butene	9.7	E.I.
2,2-dimethylbutane	10.05	P.I.	1,2-epoxypropane	9.81	E.I.
2,3-dimethylbutane	10.01	P.I.	Ethanal	10.21	P.I.
3,3-dimethylbutanone	9.17	P.I.	Ethane	11.65	P.I.
2,3-dimethyl-2-butene	8.30	P.I.	Ethane-d ₁	11.70	E.I.
Dimethyl chloroarsine	9.9	E.I.	Ethanoic acid	10.35	P.I.
Dimethyl disulfide	8.46	P.I.	Ethanoic acid-d ₁	10.71	E.I.
Dimethyl ether	10.00	P.I.	Ethanol	10.48	P.I.
N,N-dimethylformamide	9.12	P.I.	Ethanol-d ₁ (OD)	10.45	E.I.
2,3-dimethylfuran	8.01	E.I.	Ethene	10.51	P.I.
3,5-dimethyl-4-heptanone	9.04	P.I.	Ethene-d ₁	10.52	S.
1,1-dimethylhydrazine	8.12	E.I.	Ethylamine	8.86	P.I.
1,2-dimethylhydrazine	7.75	E.I.	N-ethylaniline	7.5	U.V.
Dimethyl mercury	8.90	E.I.	Ethylbenzene	8.76	P.I.
2,2-dimethyl-3-pentanone	8.98	P.I.	Ethyl boron difluoride	11.8	E.I.
2,2-dimethylpropane	10.35	P.I.	Ethyl bromide	10.29	P.I.
Dimethyl sulfide	8.69	P.I.	Ethyl bromoacetate	10.13	P.I.
Dimethyl sulfoxide	8.85	P.I.	Ethyl α -bromobutanoate	9.85	P.I.
Dimethyltrifluoromethylarsine	9.2	E.I.	2-ethyl-1-butene	9.21	E.I.
Dimethyl zinc	8.86	E.I.	Ethyl chloride	10.97	P.I.
Dinitrogen difluoride	13.1	E.I.	Ethyl chloroacetate	10.20	P.I.
Dinitrogen tetrafluoride	12.0	E.I.	Ethyl decaborane	9.0	E.I.
N,N-di-n-octylaniline	7.1	U.V.	Ethyl disulfane	9.4	E.I.
1,3-dioxane	10.15	E.I.	Ethyleneimine	9.94	E.I.
1,4-dioxane	9.13	P.I.	Ethylene oxide	10.565	P.I.
Diphenyl	8.27	P.I.	Ethyl ethanoate	10.10	P.I.
Diphenylamine	7.4	U.V.	Ethyl hexanoate	9.67	P.I.
Diphenylbutadiene	7.75	U.V.	Ethyl iodide	9.33	P.I.
Diphenyldecapentaene	7.4	U.V.	Ethyl isothiocyanate	9.10	P.I.
Diphenylhexadiene	8.2	U.V.	Ethyl mercaptan	9.29	P.I.
Diphenylhexatriene	7.6	U.V.	Ethyl methanoate	10.61	P.I.
Diphenyloctatetraene	7.5	U.V.	Ethyl nitrate	11.22	P.I.
Diphosphine	8.7	E.I.	Ethyl propanoate	10.00	P.I.
			2-ethylthiophene	8.8	E.I.
			Ethyl thiocyanate	9.89	P.I.
			Ethyl α -glycolate	10.3	

B. MOLECULAR IONIZATION POTENTIALS (CONT.)

Ethyl trichloroacetate	10.44	P.I.	Hexafluoroacetone	11.81
Ethyne	11.41	P.I.	Hexafluorobenzene	9.39
Ethyne-d ₂	11.39	E.I.	Hexafluoropropene	10.3
Ethynylbenzene	8.82	P.I.	Hexamethylbenzene	7.85
Ferrous chloride (monomer)	11.5	E.I.	Hexamethylenimine	8.76
Ferrous chloride (dimer)	10.5	E.I.	n-hexane	10.17
Fluorene	8.63	E.I.	2-hexanone	9.34
Fluorine	15.7	P.I.	1,3,5-hexatriene	8.26
o-fluoroaniline	7.95	P.I.	1-hexene	9.46
m-fluoroaniline	7.90	P.I.	2-hexene (trans)	9.16
p-fluoroaniline	7.82	P.I.	3-hexene (trans)	9.12
Fluorobenzene	9.20	P.I.	3-hexene-1,5-diyne	9.46
Fluorocyanomethane	13.0	E.I.	N-n-hexylaniline	7.5
1-fluoro-1,2-dibromoethane	10.75	P.I.	Hydrazine	9.00
Fluoroethane	12.00	E.I.	Hydrazoic acid	10.3
Fluoroethene	10.37	P.I.	Hydrogen	15.427
Fluoroform	13.84	S.	Hydrogen bromide (I)	11.62
Fluoromethanal	11.4	P.I.	(II)	21.6
Fluoromethane	12.80	S.	Hydrogen chloride (I)	12.74
o-fluorophenol	8.66	P.I.	(II)	22.9
o-fluorotoluene	8.91	P.I.	Hydrogen cyanide (I)	13.73
m-fluorotoluene	8.91	P.I.	(II)	26.3
p-fluorotoluene	8.78	P.I.	Hydrogen disulfide	10.2
Fluorotribromomethane	10.67	P.I.	Hydrogen fluoride	15.77
Fluorotrichloromethane	11.77	P.I.	Hydrogen iodide (I)	10.38
Fluorotrifluoromethylbenzene	9.12	P.I.	(II)	19.6
Formamide	10.20	P.I.	Hydrogen peroxide	10.92
Formic acid	11.05	P.I.	Hydrogen selenide	9.88
Formic acid-d ₁	11.57	E.I.	Hydrogen selenide-d ₂	9.88
Furan	8.89	P.I.	Hydrogen sulfide	10.46
Furfural	9.21	P.I.	Hydrogen sulfide-d ₂	10.47
Formaldehyde	10.9	E.I.	Hydrogen telluride	9.138
D-galactose	9.1	E.I.	Hydrogen telluride-d ₂	9.14
Germane	12.3	E.I.	4-hydroxypyridine	9.70
Germanium tetrachloride	11.90	E.I.	Indene	8.81
Germanium tetramethyl	9.2	E.I.	Iodine	9.28
d-glucose	8.8	E.I.	Iodine difluoride	10.7
Glycine	9.5	E.I.	Iodine monobromide	9.98
n-heptane	10.07	P.I.	Iodine monochloride	10.31
2-heptanone	9.33	P.I.	Iodine pentafluoride	13.5
4-heptanone	9.12	P.I.	Iodine tetrafluoride	14.5
1-heptene	9.54	E.I.	Iodine trifluoride	9.7
N-n-heptylaniline	7.5	U.V.	Iodobenzene	8.73
1,5-hexadiene	9.51	E.I.	1-iodobutane	9.21
2,4-hexadiene	10.65	S.	2-iodobutane	9.09
			Iodoethane	9.31
			Iodomethane	9.54
			1-iodo-2-methylpropane	9.18
			2-iodo-2-methylpropane	9.02

11
CC
ethyl isobutyl ketone

dimethyl sulfide
IP unknown
Ted A.
oesn't have an estimate

B. MOLECULAR IONIZATION POTENTIALS (CONT.)

Iodopentaborane	11.1	E.I.	Methyl bromide	10.53	P.I.
1-iodopentane	9.19	P.I.	2-methyl-1,3-butadiene	8.85	P.I.
1-iodopropane	9.26	P.I.	2-methylbutanal	9.71	P.I.
2-iodopropane	9.17	P.I.	3-methylbutanal	9.92	E.I.
<i>o</i> -iodotoluene	8.62	P.I.	2-methylbutane	10.31	P.I.
<i>m</i> -iodotoluene	8.61	P.I.	Methyl <i>n</i> -butanoate	10.07	P.I.
<i>p</i> -iodotoluene	8.50	P.I.	Methyl <i>i</i> -butanoate	9.98	P.I.
Iron pentacarbonyl	7.95	P.I.	3-methyl-2-butanone	9.32	P.I.
Isoleucine	9.5	E.I.	2-methyl-1-butene	9.12	P.I.
Isoprene	8.845	P.I.	3-methyl-1-butane	9.51	P.I.
Isothiocyanic acid	10.4	E.I.	2-methyl-2-butene	8.68	P.I.
Ketene	9.61	S.	3-methyl-1-butyne	10.35	E.I.
Lanthanum monoxide	4.8	E.I.	Methyl chloride	11.28	P.I.
Lead tetramethyl	8.0	E.I.	Methyl chloroacetate	10.35	P.I.
Lithium (diatomic)	4.96	S.	Methylcyclohexane	9.85	P.I.
Lithium iodide	8.55	E.I.	4-methylcyclohexene	8.91	P.I.
Lithium oxide	6.8	E.I.	Methylcyclopentane	10.45	E.I.
2,3-lutidine	8.85	P.I.	Methylcyclopropane	9.88	E.I.
2,4-lutidine	8.85	P.I.	Methyl dichloroacetate	10.44	P.I.
2,6-lutidine	8.85	P.I.	Methyldichloroarsine	10.4	E.I.
Magnesium dicyclo-			Methyl disulfane	8.8	E.I.
pentadienide	7.76	E.I.	Methylene chloride	11.35	P.I.
Maleic anhydride	9.9	P.I.	Methyl ethanoate	10.27	P.I.
Mercuric chloride	12.1	E.I.	Methyl ethyl ether	9.81	E.I.
Mercury dimethyl	8.90	E.I.	Methyl ethyl sulfide	8.55	P.I.
Metaboric acid	12.6	E.I.	Methyl fluoride	12.80	S.
Methanal	10.87	E.I.	<i>N</i> -methylformamide	9.25	P.I.
Methanal- <i>d</i> ₁	10.83	E.I.	2-methylfuran	8.39	P.I.
Methanal dimer	10.51	P.I.	Methyl iodide	9.54	P.I.
Methane	12.98	P.I.	Methyl isothiocyanate	9.13	E.I.
Methane- <i>d</i> ₁	13.12	E.I.	Methyl mercaptan	9.44	P.I.
Methane- <i>d</i> ₂	13.14	E.I.	Methyl methanoate	10.82	P.I.
Methane- <i>d</i> ₃	13.18	E.I.	α -methylnaphthalene	7.96	P.I.
Methane- <i>d</i> ₄	13.19	E.I.	β -methylnaphthalene	7.955	P.I.
Methanoic acid	11.05	P.I.	Methyl nitrile	10.7	E.I.
Methanoic acid- <i>d</i> ₁	11.57	E.I.	2-methylpentane	10.11	P.I.
Methanol	10.85	P.I.	3-methylpentane	10.07	P.I.
Methanol- <i>d</i> ₁ (OD)	11.04	E.I.	Methyl pentanoate	9.87	P.I.
Methionine	9.5	E.I.	4-Methyl-2-pentanone	9.30	P.I.
<i>N</i> -methylacetamide	8.90	P.I.	2-methyl-2-pentene-4-one	9.08	E.I.
<i>N</i> -methylaniline	7.35	P.I.	<i>p</i> -methylphenylamine	8.2	E.I.
Methylamine	8.97	P.I.	2-methylpropane	10.56	P.I.
<i>p</i> -methylaniline	8.14	E.I.	2-methylpropanal	9.74	P.I.
Methylarsine	9.7	E.I.	Methyl propanoate	10.15	P.I.
Methyl azide	9.5	E.I.	2-methylpropanoic acid	10.02	P.I.
Methyl benzoate	10.0	E.I.	2-methyl-2-propanol	9.7	P.I.
Methyl boron			2-methylpropene	9.23	P.I.
difluoride	12.54	E.I.	Methyl <i>i</i> -propyl sulfide	8.7	E.I.
			Methyl <i>n</i> -propyl sulfide	8.80	E.I.

methyl acrylate - 10.72

B. MOLECULAR IONIZATION POTENTIALS (CONT.)

<i>N</i> -methylpyrrolidine	8.06	E.I.	Nitritomethane	10.7
α -methylstyrene	8.35	P.I.	<i>o</i> -nitroaniline	8.68
3-methyl-2-thiabutane	8.7	E.I.	<i>m</i> -nitroaniline	8.80
Methyl thiocyanate	10.065	P.I.	<i>p</i> -nitroaniline	8.85
Molybdenum dioxide	9.4	E.I.	Nitrobenzene	9.92
Molybdenum			Nitroethane	10.88
hexacarbonyl	8.12	P.I.	Nitrogen (I)	15.576
Molybdenum monoxide	8.0	E.I.	(II)	27.8
Molybdenum trioxide	12.0	E.I.	Nitrogen difluoride	11.4
Monoaluminum oxide	9.5	E.I.	Nitrogen dioxide	9.78
Monobromobenzene	8.98	P.I.	Nitrogen monofluoride	12.0
Monobromodifluoro-			Nitrogen trifluoride	12.9
methane	12.0	E.I.	Nitromethane	11.08
Monobromoethane	10.29	P.I.	<i>p</i> -nitrophenol	9.52
Monobromoethene	9.80	P.I.	1-nitropropane	10.81
Monobromomethane	10.53	P.I.	2-nitropropane	10.71
Monobromotrifluoro-			<i>p</i> -nitrotoluene	9.82
methane	11.78	P.I.	Nitrous oxide	12.89
Monochlorobenzene	9.07	P.I.	<i>n</i> -nonane	10.21
Monochlorocyclopropane			5-nonanone	9.10
	10.10	E.I.	<i>N</i> - <i>n</i> -nonylaniline	7.5
Monochloroethane	10.97	P.I.	Nornicotine	9.30
Monochloroethene	10.00	P.I.	Octafluoroacetophenone	11.25
Monochloromethane	11.28	P.I.	Octafluorotoluene	10.4
Monochlorotrifluoromethane			<i>n</i> -octane	10.24
	12.8	P.I.	3-octanone	9.19
Monofluorobenzene	9.20	P.I.	4-octanone	9.10
Monofluorodichloromethane			1,3,5,7-octatetraene	7.8
	13.06	E.I.	1-octene	9.52
Monofluoroethane	12.00	E.I.	2-octene	9.11
Monofluoroethene	10.37	P.I.	<i>N</i> - <i>n</i> -octylaniline	7.5
Monofluoromethane	12.80	S.	Osmium tetroxide	12.6
Monoiodobenzene	8.73	P.I.	Osmium trioxide	12.3
Monoiodoethane	9.33	P.I.	Oxacyclobutane	9.85
Monoiodomethane	9.54	P.I.	Oxygen	12.075
Monolithium oxide	9.0	E.I.	Oxygen difluoride	13.7
Monomethylarsine	9.7	E.I.	Ozone	12.80
Monomethylhydrazine	8.63	E.I.		
Naphthalene (I)	8.12	P.I.	Pentaborane	10.8
(II)	14.7	E.I.	1,2-pentadiene	9.42
(III)	17.2	E.I.	1,3-pentadiene	8.68
1-naphthylamine	7.30	P.I.	1,4-pentadiene	9.58
2-naphthylamine	7.25	P.I.	2,3-pentadiene	9.26
Nickel chloride	11.2	E.I.	Pentafluorobenzene	9.84
Nickel tetracarbonyl	8.28	P.I.	Pentamethylbenzene	7.92
Nicotine	8.01	E.I.	<i>n</i> -pentanal	9.82
Nitric oxide (I)	9.25	P.I.	<i>n</i> -pentane	10.34
(II)	30.6	E.I.	2,4-pentanedione	8.87
Nitric sulfide	8.8	P.I.	<i>n</i> -pentanoic acid	10.12

Methyl isopropyl ketone

B. MOLECULAR IONIZATION POTENTIALS (CONT.)

2-pentanone	9.39	P.I.	Propane	11.07	P.I.
3-pentanone	9.32	P.I.	Propadiene	10.19	P.T.
1-pentene	9.30	P.I.	Propanoic acid	10.24	P.I.
2-pentene (<i>cis</i>)	9.11	E.I.	1-Propanol	10.17	P.I.
2-pentene (<i>trans</i>)	9.06	E.I.	2-Propanol	10.17	P.I.
<i>n</i> -pentyl ethanoate	9.92	P.I.	Propanone	9.69	P.I.
1-pentyne	10.39	E.I.	Propenal	10.10	P.I.
Perchloryl fluoride	13.6	E.I.	Propene	9.73	P.I.
Perfluoroheptane	12.5	E.I.	Prop-1-ene-2-ol	8.2	P.I.
Perfluoro-1-heptene	10.48	P.I.	Prop-2-ene-1-ol	9.67	P.I.
(<i>n</i> -perfluoropropyl)-chloromethane	11.84	P.I.	Propenoic acid	10.90	E.I.
<i>n</i> -perfluoropropyl iodide	10.36	P.I.	Propiolactone	9.70	P.I.
(<i>n</i> -perfluoropropyl)-iodomethane	9.96	P.I.	<i>n</i> -propylamine	8.78	P.I.
(<i>n</i> -perfluoropropyl)-methyl ketone	10.58	P.I.	<i>i</i> -propylamine	8.72	P.I.
Perylene	7.15	U.V.	<i>N</i> - <i>n</i> -propylaniline	7.5	U.V.
Phenanthrene	7.8	S.	<i>N</i> - <i>i</i> -propylaniline	7.5	U.V.
Phenetole	8.13	P.I.	1-propylbenzene	8.72	P.I.
Phenol	8.50	P.I.	2-propylbenzene	8.69	P.I.
Phenylacetylene	8.82	P.I.	Propylene oxide	9.81	E.I.
<i>o</i> -Phenylenediamine	8.00	E.I.	Propylene sulfide	8.6	E.I.
<i>m</i> -Phenylenediamine	7.96	E.I.	<i>n</i> -propyl ethanoate	10.04	P.I.
<i>p</i> -Phenylenediamine	7.58	E.I.	<i>i</i> -propyl ethanoate	9.99	P.I.
Phenyldiazine	7.64	P.I.	<i>i</i> -propyl isothiocyanate	9.4	E.I.
Phenyl isocyanate	8.77	P.I.	<i>n</i> -propyl methanoate	10.54	P.T.
Phenyl isothiocyanate	8.52	P.I.	<i>n</i> -propyl nitrate	11.07	P.I.
Phosgene	11.78	S.	2-propyl thiophene	8.6	E.I.
Phosphine	10.1	E.I.	Propyne	10.36	P.I.
Phosphorous acid	12.6	E.I.	Pyrazine	10.00	E.I.
Phosphorus (P ₂)	11.1	E.I.	Pyrene	7.72	E.I.
Phosphorus (P ₃)	11.2	E.I.	Pyridazine	9.86	E.I.
Phosphorus (P ₄)	9.0	E.I.	Pyridine	9.266	S.
Phosphorus arsenide	11.2	E.I.	2-pyridinecarboxaldehyde	9.75	E.I.
Phosphorus dichloride	9.0	E.I.	4-pyridinecarboxaldehyde	10.12	E.I.
Phosphorus monoarsenide	11.2	E.I.	Pyrimidine	9.91	E.T.
Phosphorus monochloride	9.6	E.I.	Pyrrrole	8.20	P.I.
Phosphorus triarsenide	10.0	E.I.	Quadracyclene	8.70	E.I.
Phosphorus trichloride	10.75	E.I.	Quinoline	8.30	P.I.
2-picoline	9.02	P.I.	Quinone	9.68	P.I.
3-picoline	9.04	P.I.	Selenium dioxide	11.94	E.I.
4-picoline	9.04	P.I.	Selenium dioxide difluoride	13.15	E.I.
Piperidine	8.49	E.I.	Selenium oxydifluoride	12.50	E.I.
Polymethylene	10.15	E.I.	Silane	12.2	E.I.
Potassium (K ₂)	4.09	S.	Silicon carbide	9.3	E.I.
Potassium iodide	8.3	E.I.	Silicon dichloride	11.8	E.I.
Propanal	9.98	P.I.	Silicon dioxide	11.7	E.I.
			Silicon monofluoride	7.26	P.I.
			Silicon monoxide	10.8	E.I.
			Silicon tetrachloride	12.06	E.I.


B. MOLECULAR IONIZATION POTENTIALS (CONT.)

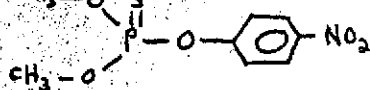
Silicon tetrafluoride	15.4	E.I.	Thiacyclobutane	8.9
Silicon tetramethyl	9.80	E.I.	Thiacyclohexane	8.36
Sodium (Na ₂)	4.87	S.	Thiacyclopentane	8.48
Sodium azide	11.7	E.I.	Thiacyclopropane	8.87
Sodium hydroxide	9.	E.I.	Thiadioxane	8.50
Sodium iodide	8.8	E.I.	4-thiaheptane	8.30
Stannane	11.7	E.I.	2-thiapentane	8.80
Stibine	9.58	P.I.	3-thiapentane	8.43
Stilbene	7.95	U.V.	4-thia-1-pentane	8.70
Styrene	8.47	P.I.	2-thiapropene	8.69
Sulfur (S ₂)	9.9	E.I.	Thioanisole	8.9
Sulfur (S ₃)	10.5	E.I.	1-thiobutanol	9.14
Sulfur (S ₄)	10.4	E.I.	<i>i</i> -thiobutanol	8.79
Sulfur (S ₅)	9.9	E.I.	Thioethanoic acid	10.00
Sulfur (S ₆)	9.4	E.I.	Thioethanol	9.29
Sulfur (S ₇)	9.2	E.I.	Thiomethanol	9.44
Sulfur (S ₈)	8.9	E.I.	Thiophene	8.86
Sulfur dioxide	12.34	S.	Thiophenol	8.33
Sulfur hexafluoride	19.3	E.I.	1-thiopropanol	9.20
Sulfur monoxide	12.1	E.I.	Tin tetramethyl	8.25
Tetracene	8.88	P.I.	Titanium tetrachloride	11.7
1,1,2,2-tetrachloroethane	11.10	E.I.	Titanium trichloride	13.0
Tetrachloroethene	9.32	P.I.	Toluene (I)	8.82
Tetrachloromethane	11.47	P.I.	(II)	15.3
1,2,3,4-tetrafluoro-benzene	9.61	P.I.	(III)	17.5
1,2,3,5-tetrafluoro-benzene	9.55	P.I.	<i>o</i> -toluidine	7.75
1,2,4,5-tetrafluoro-benzene	9.39	P.I.	<i>m</i> -toluidine	7.50
Tetrafluoroethene	10.12	P.I.	<i>p</i> -toluidine	7.50
Tetrafluoromethane	< 15.0	E.I.	<i>p</i> -tolunitrile	9.76
Tetrahydrofuran	9.45	E.I.	Triazene	9.6
Tetrahydropyran	9.26	P.I.	<i>s</i> -triazine	10.07
Tetrahydropyrrole	8.60	E.I.	Tribromoethene	9.27
2,3,5,6-tetramethyl-aniline	7.7	E.I.	Tribromofluoromethane	10.67
1,2,4,5-tetramethyl-benzene	8.03	P.I.	Tribromomethane	10.51
2,2,3,3-tetramethyl-butane	9.79	E.I.	1,1,1-trichlorobutanone	9.54
Tetramethyl germanium	9.2	E.I.	Trichlorofluoromethane	11.77
Tetramethyl hydrazine	7.76	E.I.	Trichloroethene	9.45
Tetramethyl lead	8.0	E.I.	Trichloromethane	11.42
2,2,4,4-tetramethyl-3-pentanone	8.65	P.I.	Trichloromethyl ethyl ether	10.08
Tetramethyl silane	9.80	E.I.	Trichlorovinylsilane	10.79
Tetramethyl tin	8.25	E.I.	Triethylamine	7.50
2-thiabutane	8.55	P.I.	Triethylphosphine	8.27
			Trifluoroacetophenone	10.25
			1,2,4-trifluorobenzene	9.37
			1,3,5-trifluorobenzene	9.3
			Trifluorochloromethane	12.91
			Trifluoroethane	10.4
			Trifluoroethene	10.14
			trichloroethylene	9.2

B. MOLECULAR IONIZATION POTENTIALS (CONT.)

1,1,1-trifluoro-2-iodoethane	10.00	P.I.	Uranium trioxide	10.4	E.I.
Trifluoroiodomethane	10.40	P.I.	Vinyl acetate	9.19	P.I.
Trifluoromethane	13.84	S.	Vinyl benzene	8.47	P.I.
Trifluoromethylbenzene	9.68	P.I.	Vinyl boron difluoride	11.06	E.I.
Trifluoromethyl-cyclohexane	10.46	P.I.	Vinyl bromide	9.80	P.I.
1,1,1-trifluoropropene	10.9	P.I.	Vinyl chloride	10.00	P.I.
1,1,1-trifluoro-2,2,2-trichloroethane	11.78	P.I.	4-vinylcyclohexene	8.93	P.I.
1,1,2-trifluoro-1,2,2-trichloroethane	11.99	P.I.	Vinyl ethanoate	9.19	P.I.
Trimethoxyborane	8.9	E.I.	Vinyl fluoride	10.37	P.I.
Trimethylamine	7.82	P.I.	Vinyl methyl ether	8.93	P.I.
2,4,6-trimethylaniline	7.7	E.I.	Water (I)	12.59	P.I.
Trimethyl arsine	8.3	E.I.	(II)	16.7	S.
1,2,3-trimethylbenzene	8.48	P.I.	(III)	24.2	S.
1,2,4-trimethylbenzene	8.27	P.I.	(IV)	33.4	S.
1,3,5-trimethylbenzene	8.39	P.I.	Water-d ₁	12.58	E.I.
2,2,3-trimethylbutane	10.09	E.I.	Water-d ₂	12.60	E.I.
Trifmethylen oxide	9.85	E.I.	Xenon difluoride	11.5	S.
Trimethyl hydrazine	7.93	E.I.	Xenon tetrafluoride	12.9	E.I.
2,2,4-trimethylpentane	9.85	P.I.	o-xylene	8.56	P.I.
2,2,4-trimethyl-3-pentanone	8.82	P.I.	m-xylene	8.56	P.I.
Trimethylphosphine	8.60	E.I.	p-xylene	8.445	P.I.
Trimethylsilane	9.8	E.I.	Zinc chloride	12.9	E.I.
Triphenylamine	7.6	E.I.	Zinc dimethyl	8.86	E.I.
Triphenylene	7.8	U.V.	Zinc phthalocyanine	7.	U.V.
Tris-(p-methylphenyl)-amine	7.4	E.I.			
Tris-(perfluoroethyl)-amine	11.7	P.I.			
Tris(n-propyl) amine	7.23	P.I.			
Tris (trifluoromethyl)-amine	11.0	E.I.			
Tris(trifluoromethyl)-phosphorus	11.3	E.I.			
2,3,4-trithiapentane	8.80	E.I.			
Tropolone	9.83	E.I.			
Tropone	9.68	E.I.			
Tungsten dioxide	9.9	E.I.			
Tungsten hexacarbonyl	8.18	P.I.			
Tungsten monoxide	9.1	E.I.			
Tungsten trioxide	11.7	E.I.			
Uranium dioxide	4.3	E.I.			
Uranium hexafluoride	15.0	E.I.			
Uranium monoxide	4.7	E.I.			
Uranium tetrachloride	11.5	E.I.			

PCBs - less than 10.2 but
no IP's listed, only
relative sensitivities.

methyl parathion - < 10.2 because of
its large size and presence of 



C. RADICAL IONIZATION POTENTIALS

Acetyl	7.90	E.I.	EthyleniminyI	7.6
Allyl	8.16	E.I.	Fluorenyl	7.07
Amino	11.3	E.I.	m-fluorobenzyl	8.18
Aminocyclopentadienyl	7.55	E.I.	p-fluorobenzyl	7.78
Anilino	8.26	E.I.	Fluorocyclopentadienyl	8.82
Azido	11.6	E.I.	Fluoroimino	12.0
Benzoyl	7.40	E.I.	Fluoromethynyl	13.81
Benzyl	7.76	E.I.	Fluorophenyl	10.86
Bromocyclopentadienyl	8.85	E.I.	Fluoroxy	13.0
Bromomethynyl	10.43	E.I.	Formyl	9.43
2-buten-1-yl	7.71	E.I.	Formyl-d ₁	9.82
n-butyl	8.64	E.I.	Hydrazyl	11.53
i-butyl	8.35	E.I.	Hydroperoxy	10.50
sec-butyl	7.93	E.I.	Hydrosulfonyl	6.20
t-butyl	7.42	E.I.	Hydroxyl	13.53
p-chlorobenzyl	7.95	E.I.	Imino	13.10
Chlorodioxo	11.1	E.I.	Indenyl	8.35
Chlorocyclopentadienyl	8.78	E.I.	Isothiocyanato	< 10.4
Chloromethynyl	12.9	E.I.	Methenyl	10.39
Chlorotrioxo	11.7	E.I.	Methoxy	10.7
Chloroxy	10.4	E.I.	p-methoxybenzyl	6.82
m-cyanobenzyl	8.58	E.I.	Methyl	9.83
p-cyanobenzyl	8.36	E.I.	Methyl-d ₁	9.83
Cyanocyclopentadienyl	9.44	E.I.	Methylcyclopentadienyl	8.54
1-cyanoethyl	9.76	E.I.	Methylhydrazyl	5.12
2-cyano-1-ethyl	9.85	E.I.	Methylnitrosyl	8.2
Cyanomethyl	10.87	E.I.	2-methyl-1-propen-1-yl	8.03
2-(2-cyanopropyl)	9.15	E.I.	Methylsilyl	9.3
Cyclobutyl	7.88	E.I.	Methynyl	11.13
Cycloheptatrienyl	6.24	S.	Monobromomethyl	8.34
Cyclohexyl	7.66	E.I.	Monochloromethyl	8.70
Cyclopentadienyl	8.69	E.I.	Monofluoromethyl	9.35
Cyclopentyl	7.79	E.I.	Nitrile	14.2
Cyclopropyl	8.05	E.I.	m-nitrobenzyl	8.56
Dibromomethynyl	10.11	E.I.	Pentafluorophenyl	10.6
Dibromomethyl	8.13	E.I.	2-pentyl	7.73
Dichloromethynyl	13.10	E.I.	3-pentyl	7.86
Dichloromethyl	8.67	E.I.	neo-pentyl	8.33
Difluoroamino	11.4	E.I.	t-pentyl	7.12
Difluoromethynyl	13.30	E.I.	Phenyl	9.89
Difluoromethyl	9.45	E.I.	Propargyl	8.23
Dimethylhydrazyl	5.29	E.I.	Propionyl	7.66
Dimethylsilyl	7.1	E.I.	1-propyl	7.37
Diphenylmethyl	7.32	E.I.	2-propyl	7.21
Dithiomethylperoxy	9.4	E.I.	p-(l-propyl)benzyl	7.42
Ethenyl	9.45	E.I.	2-pyridylmethyl	8.17
Ethoxy	10.30	E.I.	3-pyridylmethyl	7.92
Ethyl	8.30	E.I.		

C. RADICAL IONIZATION POTENTIALS (CONT.)

4-pyridylmethyl	8.40	E.I.
Thioethoxy	8.15	E.I.
Thiomethoxy	8.06	E.I.
Thiophenoxy	8.63	E.I.
Trichloromethyl	8.78	E.I.
Trifluoromethyl	10.10	E.I.
Trimethylgermanyl	8.0	E.I.
Trimethylstanyl	7.6	E.I.
Trimethylplumbyl	7.5	E.I.
Trimethylsilyl	7.8	E.I.
Tropylium	6.24	S.
Vinyl	9.45	E.I.
Vinylcyclopentadienyl	8.44	E.I.
<i>o</i> -xylyl	7.61	E.I.
<i>m</i> -xylyl	7.65	E.I.
<i>p</i> -xylyl	7.46	E.I.

APPENDIX V

GENERAL BIBLIOGRAPHY

- Applied Mass Spectrometry*, Report of a conference organized by the spectroscopy panel of the Institute of Petroleum, London, Oct. 2 1953, The Institute of Petroleum, London, 1954, 333 pp.
- F. W. Aston, *Mass Spectra and Isotopes*, second edition, Edward A and Company, London, 1942, 276 pp.
- G. P. Barnard, *Modern Mass Spectrometry*, The Institute of Physics, London, 1953, 326 pp.
- C. E. Berry and J. K. Walker, "Industrial Applications (Mass Spectrometry)," in *Annual Reviews of Nuclear Physics*, Vol. 5, J. G. Beck M. D. Kamen, and L. I. Schiff (eds.), Annual Reviews, Inc., San Calif., 1955, pp. 197-211.
- J. H. Beynon, *Mass Spectrometry and Its Applications to Organic Chemistry*, Elsevier Publishing Company, Amsterdam, 1960, 640 pp.
- J. H. Beynon, and A. E. Williams, *Mass and Abundance Tables for Mass Spectrometry*, Elsevier Publishing Company, Amsterdam, 570 pp.
- K. Biemann, *Mass Spectrometry: Applications to Organic Chemistry*, Graw-Hill Book Company, New York, 1962, 370 pp.
- K. Biemann, "Mass Spectrometry," in *Annual Reviews of Biochemistry*,

Photoionization Detector Sensitivity of Organic Compounds*

Marsha L. Langhorst

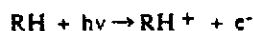
The Dow Chemical Company, USA, Analytical Laboratory, 574 Building, Midland, Michigan 48640

Abstract

Using a gas chromatograph equipped with a high temperature photoionization detector, a wide variety of organic compounds was analyzed. Relative detector sensitivities were determined on a molar basis and on a weight basis and were normalized against the detector response for benzene. By analyzing sets of organic compounds of like functionality but different numbers of carbons, several conclusions were derived relating PID sensitivity to molecular structure. In general, relative PID sensitivities should be compared on a molar basis rather than on a weight basis. PID sensitivity depends primarily upon carbon number, functional groups, and bonding type.

Introduction

The photoionization detector (PID) is designed to detect species in the effluent from a gas chromatograph by utilizing the principle of photoionization. Photoionization occurs when the absorption of a photon by a molecule leads to ionization via the reaction:



where RH is an ionizable molecule and $h\nu$ is a photon with an energy \geq the ionization potential (IP) of the molecule.

With the development of a stable PID with a sealed UV source (HNU Systems, Inc., Newton Upper Falls, Massachusetts), interest in the detector has increased. The development and performance of the detector have been documented (1-5), as well as a number of diverse applications (6-12). By utilizing UV lamps with different photon energies, the detector can be easily modified for almost universal or quite select detection of compounds.

If the ionization potential of the compound is less than the lamp energy, then the photoionization detector will respond to

that molecule. As a result, tables of IPs can be used to determine whether or not the detector may be useful (6). However, these parameters of lamp energy and IP do not indicate the relative detector sensitivity for various compounds. This lack of information for concisely defining the factors affecting PID sensitivity has limited its acceptance.

Some instrumental parameters effecting PID sensitivity include: (A) lamp intensity, (B) lamp seal, and (C) flow rate through the detector. The lamp intensity is adjustable with a dial on the HNU Systems electrometer/power supply unit. The intensity can be diminished if the detector window becomes dirty or coated with material from column bleed or samples. The lamp seal is optimized at the time the UV lamp is installed in the detector. The sensitivity increases (almost exponentially) as flow rate decreases (5). With high efficiency, packed gas chromatography columns' flow rates between 8-12 cc/min can be normally used for high sensitivity.

Logically, the detector sensitivity also depends upon ionization efficiency, a parameter related to the tightness with which electrons are held to a molecule. By investigating detector response for a wide variety of organic compounds, general rules have been derived for predicting PID sensitivity based upon organic compound structure.

Experimental

The HNU Systems, Inc. high-temperature photoionization detector, Model PI-51-02, was installed on a Hewlett-Packard (Palo Alto, California) 5700 gas chromatograph (GC). Using a 10.2 eV lamp, a wide variety of organic compounds was analyzed on several different GC columns. Peak areas were integrated with a Spectra-Physics (Arlington Heights, Illinois) Systems I computing integrator. Relative detector sensitivities were determined on a molar basis and on a weight basis and were normalized against the detector response for benzene. Using the data obtained from analyzing sets of compounds of like functionality but different numbers of carbons, conclusions were derived that related PID sensitivity to molecular structure.

The chemical standards were obtained from Supelco, Inc., (Bellefonte, Pennsylvania) (PolyScience Corp. analytical standards kits, Niles, Illinois). The chemical purities were all > 95%.

*This paper was presented at the 1980 Pittsburgh Conference on March 12, 1980, in Atlantic City, New Jersey (paper number 415).

Calculations

The molar sensitivity relative to benzene is calculated using the following equation:

$$SM = \frac{A}{A_{(BZ)}} \times \frac{B_{(BZ)}}{B} \quad \text{Eq. 1}$$

where A is the peak area of compound of interest, $A_{(BZ)}$ is the peak area of the benzene peak, B is the molar concentration of the compound of interest (nmoles/ml), and $B_{(BZ)}$ is the molar concentration of the benzene standard solution (nmoles/ml).

The relative sensitivity normalized to benzene on a weight basis is calculated using the following equation:

$$S = \frac{A}{A_{(BZ)}} \times \frac{C_{(BZ)}}{C} \quad \text{Eq. 2}$$

where C is the concentration of compound of interest ($\mu\text{g/ml}$) and $C_{(BZ)}$ is the concentration of benzene in standard solution ($\mu\text{g/ml}$).

Results and Discussion

The detector response relative to benzene on a molar basis for a large number of organic compounds is detailed in Table I. From these data, it can be concluded that PID sensitivity depends upon the following chemical structure parameters: (A) carbon number, (B) functional groups (e.g., -OH, -COOR, etc.), and (C) bonding type (e.g., double bonds, aromatic, etc.). More specific conclusions are listed in Table II.

Table I. Sensitivity of Compound Relative to Benzene on a Molar Basis (Benzene = 1.0)

Compound	SM (Bz)	Compound	SM (Bz)	Compound	SM (Bz)
n-ALKANES		ALDEHYDES			
Heptane	0.032	1-Hexadecene	0.99	Butanal	0.30
Octane	0.080	1-Heptadecene	1.06	Pentanal	0.36
n-Nonane	0.14	1-Octadecene	1.10	Hexanal	0.41
n-Decane	0.23	1-Nonadecene	1.17	Heptanal	0.45
Undecane	0.30			Octanal	0.49
Dodecane	0.37	ALKENES, DIENES, ALKYNES		Nonanal	0.53
n-Tridecane	0.46	2-Heptene	0.51		
n-Tetradecane	0.53	3-Heptene	0.58	ALCOHOLS	
n-Pentadecane	0.59	3-Methyl-1-butene	0.52	1-Butanol	0.023
Hexadecane	0.71	1,9-Decadiene	1.07	1-Pentanol	0.053
Heptadecane	0.72	2-Octyne	2.75	1-Hexanol	0.086
n-Octadecane	0.79			1-Heptanol	0.12
n-Nonadecane	0.86	KETONES		1-Octanol	0.16
Eicosane	0.93	Acetone	0.35	1-Nonanol	0.20
Heneicosane	1.03	2-Butanone	0.40	1-Decanol	0.25
n-Docosane	1.13	2-Pentanone	0.45	1-Undecanol	0.29
ALKANES: BRANCHED & CYCLIC		2-Hexanone	0.52	1-Dodecanol	0.36
2-Dimethylbutane	0.037	2-Heptanone	0.59	Isobutanol	0.029
2,3-Dimethylbutane	0.032	2-Octanone	0.71		
2-Methylpentane	0.011	2-Nonanone	0.78	ESTERS	
Methylpentane	0.027	3-Pentanone	0.54	Methyl propionate	0.010
4-Dimethylpentane	0.080	3-Heptanone	0.68	Methyl butanoate	0.039
Methylhexane	0.075	3-Octanone	0.73	Methyl pentanoate	0.082
2,3-Dimethylpentane	0.10	4-Heptanone	0.70	Methyl hexanoate	0.096
2,2,4-Trimethylpentane	0.21	5-Nonanone	0.82	Methyl heptanoate	0.14
4- & 2,5-Dimethylhexane	0.15			Methyl octanoate	0.15
3,4-Trimethylpentane	0.22	KETONES: BRANCHED & CYCLIC		Methyl nonanoate	0.26
3-Methylheptane	0.13	3-Methyl-2-butanone	0.58	Methyl decanoate	0.33
2,2,5-Trimethylhexane	0.26	3-Methyl-2-pentanone	0.60	Methyl dodecanoate	0.48
Cyclohexane	0.18	4-Methyl-2-hexanone	0.62	Methyl tetradecanoate	0.66
Methylcyclohexane	0.28	3-Methyl-2-heptanone	0.72	Methyl hexadecanoate	0.82
Decahydronaphthalene	1.04	2-Methyl-3-pentanone	0.62	Ethyl acetate	0.020
1-ALKENES		5-Methyl-2-hexanone	0.65	Ethyl butanoate	0.15
Heptene	0.54	5-Methyl-3-heptanone	0.75	Ethyl hexanoate	0.24
1-Octene	0.55	3,3-Dimethyl-2-butanone	0.65	Ethyl octanoate	0.32
1-Nonene	0.58	2,4-Dimethyl-3-pentanone	0.70	Ethyl decanoate	0.51
Decene	0.67	2,6-Dimethyl-4-heptanone	0.81	Ethyl dodecanoate	0.70
Undecene	0.70	Cyclopentanone	0.57	Propyl acetate	0.025
Dodecene	0.73	Cyclohexanone	0.62	Propyl butanoate	0.21
1-Tridecene	0.81	2-Methylcyclohexanone	0.66	Butyl acetate	0.044
1-Tetradecene	0.87	3-Methylcyclohexanone	0.66		
Pentadecene	0.92	4-Methylcyclohexanone	0.63	AROMATIC HYDROCARBONS	
		2,3-Butanedione	0.45	Toluene	1.09

(continued on next page)

Table I. (continued)

Compound	SM (Bz)	Compound	SM (Bz)	Compound	SM (Bz)
<u>(Aromatic Hydrocarbons)</u>		1,3,5-Trichlorobenzene	1.26	<u>Phthalates</u>	
Ethylbenzene	1.16	1,2,4-Trichlorobenzene	1.20	bis(Methyl)phthalate	0.56
n-Propylbenzene	1.21	1,2,3-Trichlorobenzene	1.44	bis(Ethyl)phthalate	0.87
n-Butylbenzene	1.27	1,2,4,5-Tetrachlorobenzene	1.28	bis(n-Butyl)phthalate	1.06
n-Hexylbenzene	1.29	1,2,3,4-Tetrachlorobenzene	1.40	bis(2-Ethylhexyl)phthalate	1.78
n-Octylbenzene	1.52	Pentachlorobenzene	1.32	Butylbenzylphthalate	1.78
n-Decylbenzene	1.69	Hexachlorobenzene	1.25		
o-Xylene	1.14	Chlorobenzenes average = 1.30		<u>Halogenated</u>	
m-Xylene	1.15	<u>Chlorophenols</u>		Monochlorobenzene	1.30
p-Xylene	1.20	2-Chlorophenol	1.19	Bromobenzene	1.82
Cumene	1.22	3-Chlorophenol	1.32	Iodobenzene	2.50
p-Cymene	1.27	4-Chlorophenol	1.30	1-Chloro-2-fluorobenzene	0.98
Mesitylene	1.27	2,3-Dichlorophenol	1.34	1-Fluoro-4-nitrobenzene	0.15
<u>PAHs/PNAs</u>		2,4-Dichlorophenol	1.34	<u>Mixed Functionality</u>	
Naphthalene	1.97	2,5-Dichlorophenol	1.34	p-Cresol	1.07
Anthracene	2.44	2,6-Dichlorophenol	1.33	2,4-Dimethylphenol	1.10
Phenanthrene	2.50	3,4-Dichlorophenol	1.37	2-Chloro-5-hydroxy toluene	1.20
1,2-Benzanthracene	2.46	3,5-Dichlorophenol	1.35	2,4-Dinitrotoluene	0.062
Chrysene	2.96	2,3,4-Trichlorophenol	1.28	4-Nitrophenol	0.29
Pyrene	3.02	2,3,5-Trichlorophenol	1.28	2,4-Dinitrophenol	0.094
Triphenylene	3.08	2,3,6-Trichlorophenol	1.47	Diphenyl oxide	2.10
Fluorene	2.08	2,4,5-Trichlorophenol	1.32	Dibenzofuran	0.86
Fluoranthene	2.85	2,4,6-Trichlorophenol	1.30	Dibenzo-p-dioxin	0.93
Acenaphthene	3.06	3,4,5-Trichlorophenol	1.20	Dibenzothiophene	1.31
Biphenyl	1.88	2,3,4,5-Tetrachlorophenol	1.14	4-Bromodiphenyl oxide	3.30
p-Terphenyl	2.20	2,3,4,6-Tetrachlorophenol	1.43	2-Chloronaphthalene	2.04
<u>SUBSTITUTED BENZENES</u>		2,3,5,6-Tetrachlorophenol	1.38	<u>MISCELLANEOUS</u>	
<u>Ring Activators</u>		Pentachlorophenol	1.18	3-Hexene-1-ol	0.46
Phenol	1.05	Chlorophenols average = 1.32		Hexachlorocyclohexane	0.027
Aniline	1.13	<u>Polychlorinated Biphenyls</u>		Hexachlorocyclopentadiene	0.88
1,2-Dimethoxybenzene	1.19	2,3-Dichlorobiphenyl	2.18	Hexachloro-1,3-butadiene	1.34
<u>Ring Deactivators</u>		4,4'-Dichlorobiphenyl	2.47	Mesityl oxide	0.511
Nitrobenzene	0.29	2,3,4-Trichlorobiphenyl	2.40	1-Bromobutane	0.066
Benzoic acid	0.50	2,2',5,5'-Tetrachlorobiphenyl	2.43	1-Iodobutane	1.93
Benzaldehyde	0.96	2,3',4',5'-Tetrachlorobiphenyl	2.39	1,2-Dibromobutane	0.081
Acetophenone	0.94	3,3',4',4'-Tetrachlorobiphenyl	2.96	Diethyl ether	0.36
<u>Chlorobenzenes</u>		2,2',4,5,5'-Pentachlorobiphenyl	2.45	Tetrahydrofuran	0.39
1,3-Dichlorobenzene	1.42	2,2',3,4,5'-Pentachlorobiphenyl	2.80	Pyridine	0.50
1,4-Dichlorobenzene	1.39	2,2',3,4,5,6'-Hexachlorobiphenyl	2.55	Isopentanol	0.057
1,2-Dichlorobenzene	1.30	2,2',4,4',5,5'-Hexachlorobiphenyl	2.60	tert-Pentanol	0.054
		PCBs average = 2.53		1,4-Butanediol	0.10

Table II. Conclusions on a Molar Basis

- Sensitivity increases as carbon number increases.
- For n-alkanes, $SM = 0.0715n - 0.457$ where SM = molar sensitivity relative to benzene (Benzene = 1.0) and n = carbon number
- Sensitivity for alkanes < alkenes < aromatics.
- Sensitivity of alkanes < alcohols < esters < aldehydes < ketones
- Sensitivity of cyclic compounds > noncyclic compounds.
- Sensitivity of branched compounds > nonbranched compounds.
- Sensitivity of fluorine-substituted < chlorine-substituted < bromine-substituted < iodine-substituted compounds
- For substituted benzenes, ring activators (electron-releasing groups), increase sensitivity and ring deactivators (electron-withdrawing groups) decrease sensitivity (exception: halogenated benzenes).

In general, sensitivity increases as carbon number increases. For n-alkanes, molar sensitivity is linearly related to carbon number by the relationship:

$$SM = 0.715n - 0.475$$

where SM is the molar sensitivity relative to benzene and n is the carbon number (see Figure 1). This line was drawn for C₇ through C₂₂ n-alkanes. C₁ through C₆ alkanes were excluded because they have ionization potentials greater than or equal to 10.2 eV and therefore give little or no response when the PID is equipped with a 10.2-eV lamp. Figure 2 shows relative sensitivities normalized to benzene on a weight basis for n-alkanes and 1-alkenes. For alkanes, the relationship is nearly linear at low carbon numbers. It was concluded that PID sensitivities could be better compared on a molar basis

rather than on a weight basis.

Series of 1-alkenes, alcohols, aldehydes, ketones, and esters were also analyzed. For these compounds, functional groups

and bonding structure also affect detector sensitivity as well as carbon number (see Figures 1 and 3-4). At low carbon numbers, the bonding type or functional group is the primary

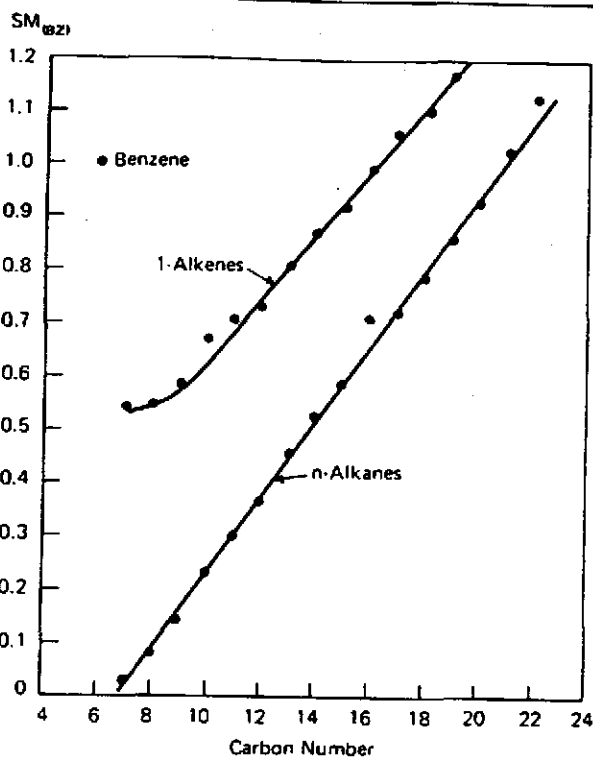


Figure 1. Molar sensitivity relative to benzene vs. carbon number for n-alkanes and 1-alkenes.

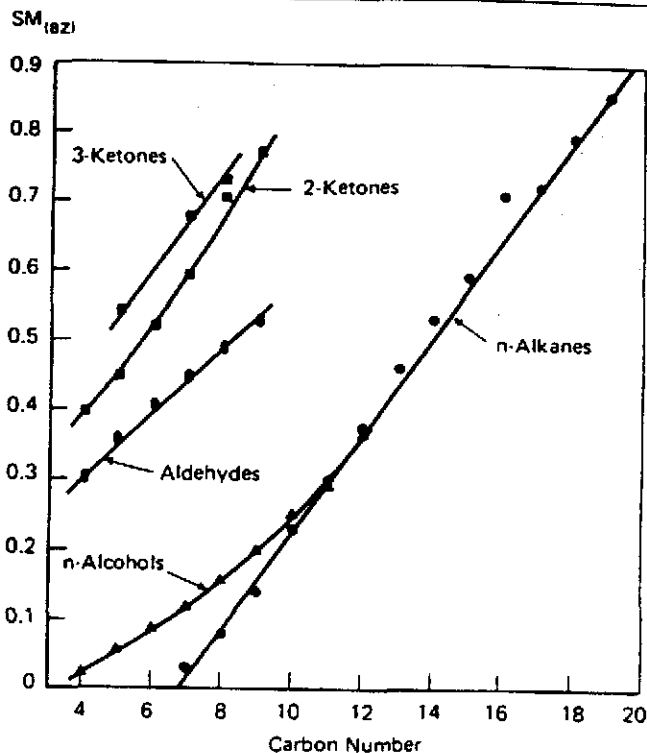


Figure 3. Molar sensitivity relative to benzene vs. carbon number for n-alcohols, aldehydes, and ketones.

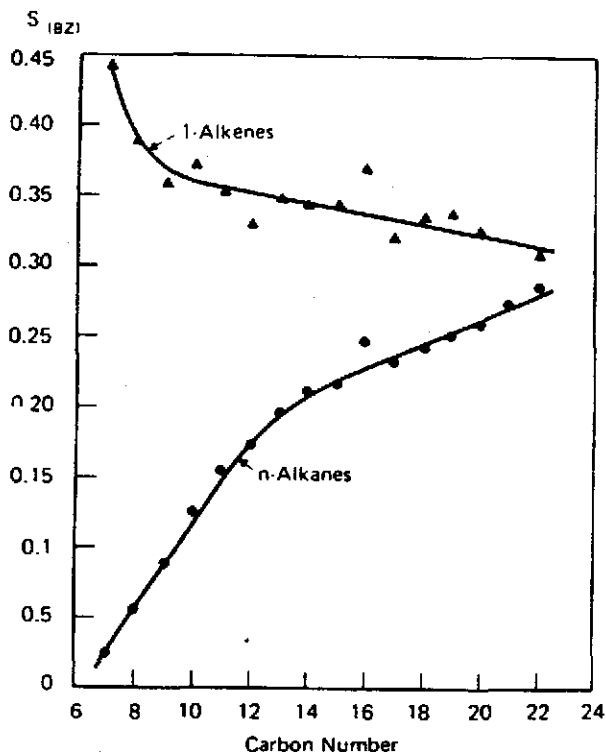


Figure 2. Sensitivity relative to benzene on a weight basis vs. carbon number for n-alkanes and 1-alkenes.

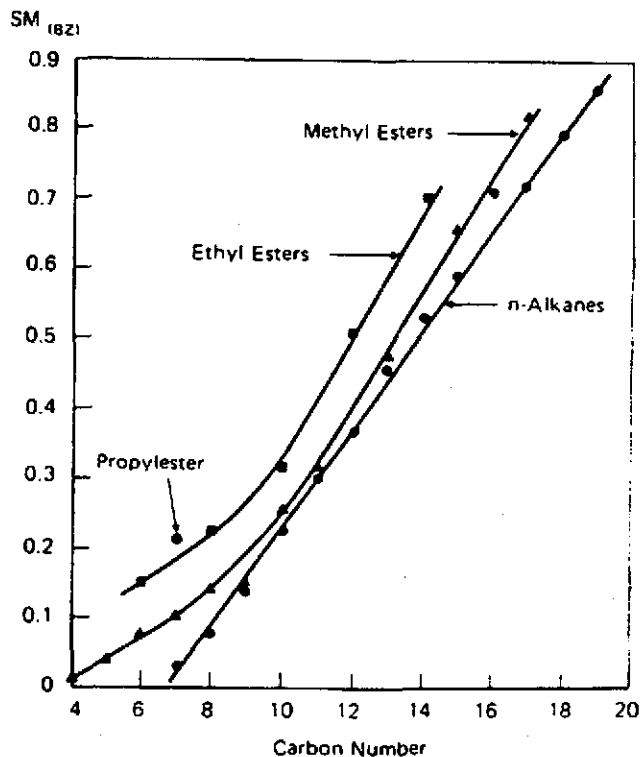


Figure 4. Molar sensitivity relative to benzene vs. carbon number for methyl, ethyl, and propyl esters.

factor affecting sensitivity. At high carbon number, the plot of SM vs. carbon number tends to parallel or meet the line for n -alkanes. That is, carbon number is then the predominant factor affecting response. In general, the sensitivity of n -alkanes $<$ 1-alcohols $<$ esters $<$ aldehydes $<$ ketones of the same carbon number.

From the data in Table I a number of other conclusions can be drawn. Sensitivity of alkanes $<$ alkenes $<$ aromatics. Figure 5 shows that branched compounds are generally more sensitive than nonbranched compounds. This figure compares alkanes with one, two, or three branching methyl groups attached.

Table III shows data to support the conclusion that cyclic compounds are more sensitive than their noncyclic analogs. For halogenated compounds, sensitivity increases in the order fluorine-substituted compounds $<$ chlorine-substituted compounds $<$ bromine-substituted compounds $<$ iodine-substituted compounds. This is illustrated in Figure 6 with halogenated benzenes.

For substituted benzenes, electron-releasing groups (ring activators) increase sensitivity, and electron-withdrawing groups (ring deactivators) decrease sensitivity relative to benzene itself. Figure 7 lists activating and deactivating groups and shows how these substituents affect molar sensitivity relative to benzene. For alkyl benzenes and phthalates sensi-

tivity increases as the carbon number of the alkyl chain increases (see Figure 8).

These general conclusions should increase the utility of the PID by giving the analyst a better understanding of its applicability and performance.

References

1. J.N. Driscoll and F.F. Spaziani. PID development gives new performance levels. *Res./Dev.* 27: 50-54 (1976).
2. J.N. Driscoll. Applications of a photoionization detector in gas chromatography. *Am. Lab.* 9: 71-74 (1976).

Table III. Comparison of Molar Sensitivity of Cyclic and Noncyclic Compounds

Noncyclic Compound	SM (Bz)	Cyclic Compound	SM (Bz)
Hexane	<0.032	Cyclohexane	0.18
3-Methylhexane	0.075	Methylcyclohexane	0.18
2-Pentanone	0.45	Cyclopentanone	0.57
3-Pentanone	0.54		
2-Hexanone	0.52	Cyclohexanone	0.62
4-Methylhexanone	0.62	2-Methylcyclohexanone	0.66
		3-Methylcyclohexanone	0.66
		4-Methylcyclohexanone	0.63
Decane	0.23	Decahydronaphthalene	1.04
Diethyl ether	0.36	Tetrahydrofuran	0.39

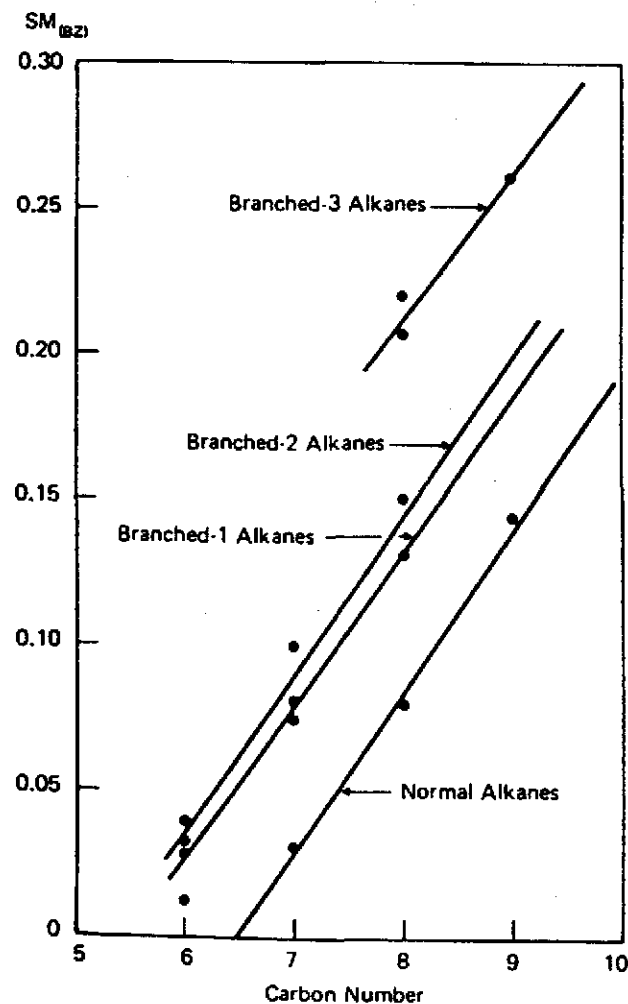


Figure 5. SM vs. carbon number for straight chain vs. branched hydrocarbons.

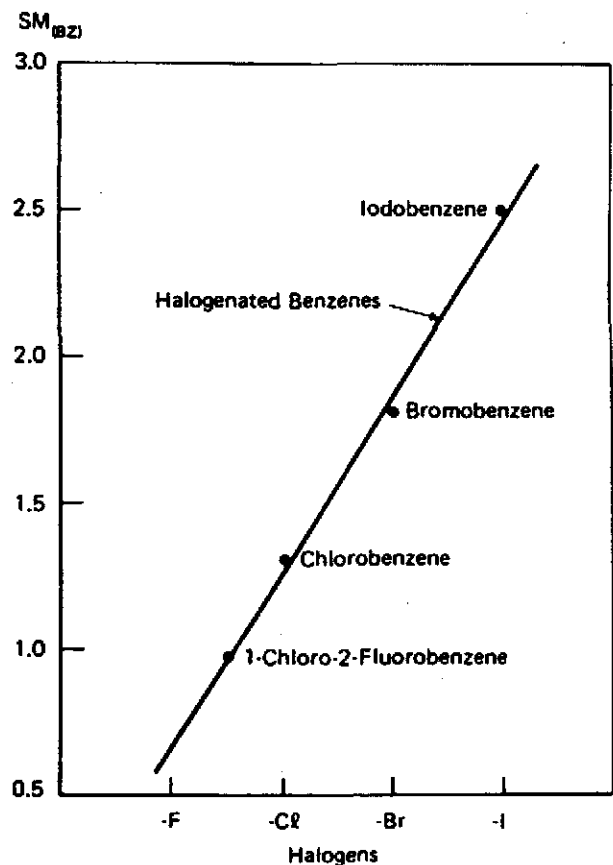


Figure 6. SM vs. halogen for halogenated benzenes.

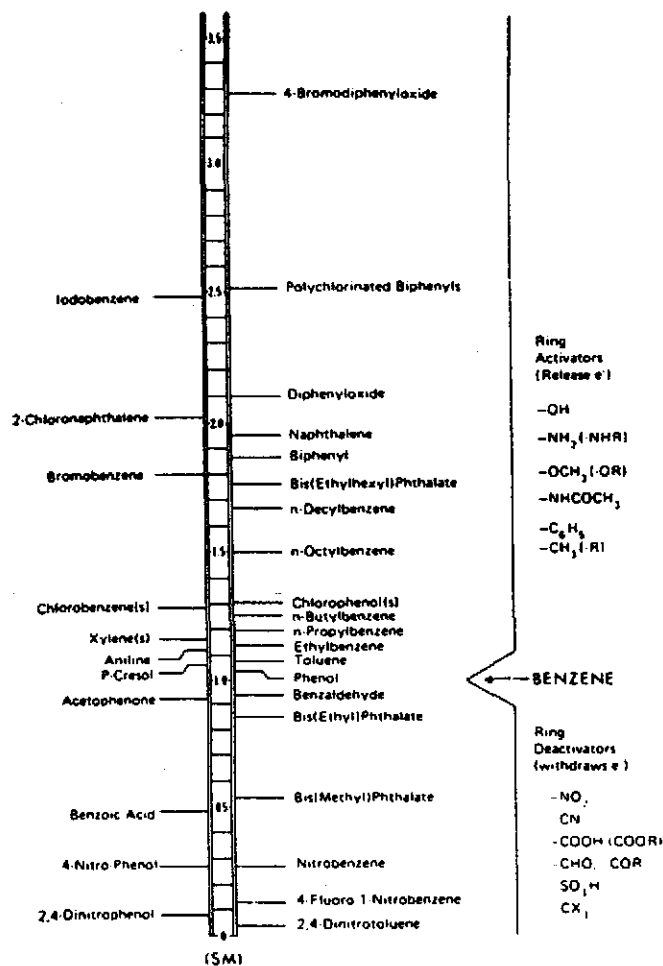


Figure 7. Molar sensitivity relative to benzene for substituted benzenes.

- J.N. Driscoll. Evaluation of a new photoionization detector for organic compounds. *J. Chromatogr.* 134: 49-55 (1977).
- J.N. Driscoll, F. Ford, L.F. Jaramillo, J.H. Becker, G. Hewitt, J.K. Marshall, and F. Onishuk. Developments and applications of the photoionization detector in gas chromatography. *Am. Lab.* 10: 137-44 (1978).
- Instruction Manual for PI-51-02 Photoionization Detector.* HNU Systems, Inc., Newton Upper Falls, Massachusetts, 1976.
- J.N. Driscoll, J. Ford, L.F. Jaramillo, and E.T. Gruber. Gas chromatographic detection and identification of aromatic and aliphatic hydrocarbons in complex mixtures by coupling photoionization and flame ionization detectors. *J. Chromatogr.* 158: 171-80 (1978).
- A.R. Oyler, D.L. Bodenner, K.J. Welch, R.J. Liukkonen, R.M. Carlson, H.L. Kopperman, and R. Caple. Determination of aqueous chlorination reaction products of polynuclear aromatic hydrocarbons by reversed phase high performance liquid chromatography-gas chromatography. *Anal. Chem.* 50: 837 (1978).
- D.B. Smith and L.A. Krause. Analysis of charcoal tube samples for carbon disulfide using a photoionization detector. *Am. Ind. Hyg. Assoc. J.* 39: 939-44 (1978).
- N.E. Hester and R.A. Meyer. A sensitive technique for measurement of benzene and alkylbenzenes in air. *Environ. Sci. Technol.* 13: 107-09 (1979).
- W.G. Jennings, S.G. Wyllie, and S. Alves. Photoionization detection in a high resolution glass capillary system. *Chromatographia.* 10: 426-29 (1977).
- R.S. Mehta, M.S. Dresselhaus, G. Dresselhaus, and J.K. Zeiger. On the possible magnetic field dependence of the nickel carbonylation rate. *Surface Sci.* 78: L681-88 (1978).
- M.L. Langhorst and T.J. Nestrick. Determination of chlorobenzenes in air and biological samples by gas chromatography with photoionization detection. *Anal. Chem.* 51: 2018-25 (1979).

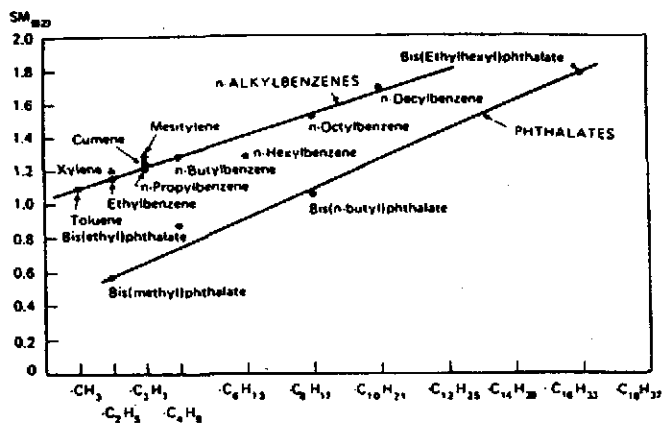


Figure 8. SM vs. carbon number of alkyl group for alkylbenzenes and phthalates.

Manuscript received April 18, 1980;
revision received August 18, 1980.

APPENDIX D
NIOSH METHOD 5503

FORMULA: mixture: $C_{12}H_{10-x}Cl_x$
 [where $x = 1$ to 10]
 M.W.: ca. 258 (42% Cl ; $C_{12}H_7Cl_2$);
 ca. 326 (54% Cl ; $C_{12}H_5Cl_5$)

POLYCHLOROBIPHENYLS

METHOD: 5503
 ISSUED: 2/15/84
 REVISION #1: 8/15/87

OSHA: 1 mg/m ³ (42% Cl); 0.5 mg/m ³ (54% Cl)	PROPERTIES:	42% Cl: BP 325 to 366 °C; MP -19 °C; d 1.38 g/mL @ 25 °C; VP 0.01 Pa (8 x 10 ⁻⁵ mm Hg; 1 mg/m ³) @ 20 °C [3]
NIOSH: 0.001 mg/m ³ [1,2]		54% Cl: BP 365 to 390 °C; MP 10 °C; d 1.54 g/mL @ 25 °C; VP 0.0004 Pa (3 x 10 ⁻⁶ mm Hg; 0.05 mg/m ³) @ 20 °C [3,4]
ACGIH: 1 mg/m ³ (42% Cl); STEL 2 mg/m ³ 0.5 mg/m ³ (54% Cl); STEL 1 mg/m ³ (skin)		

SYNONYMS: PCB; CAS #1336-36-3; 1,1'-biphenyl chloro (CAS #27323-18-8); chlorodiphenyl, 42% Cl (Aroclor 1242; CAS #53469-21-9), and 54% Cl (Aroclor 1254; CAS #11097-69-1)

SAMPLING	MEASUREMENT
SAMPLER: FILTER + SOLID SORBENT (13-mm glass fiber + Florisil, 100 mg/50 mg)	! TECHNIQUE: GAS CHROMATOGRAPHY, ECD (⁶³ Ni)
FLOW RATE: 0.05 to 0.2 L/min or less	! ANALYTE: polychlorobiphenyls
VOL-MIN: 1 L @ 0.5 mg/m ³ -MAX: 50 L	! DESORPTION: filter + front section, 5 mL hexane; back section, 2 mL hexane
SHIPMENT: transfer filters to glass vials after sampling	! INJECTION VOLUME: 4 µL with 1-µL backflush
SAMPLE STABILITY: unknown for filters; 2 months for Florisil tubes [5]	! TEMPERATURE-INJECTION: 250 - 300 °C -DETECTOR: 300 - 325 °C -COLUMN: 180 °C
BLANKS: 10% of samples	! CARRIER GAS: N ₂ , 40 mL/min
	! COLUMN: glass, 1.8 m x 2 mm ID, 1.5% OV-17/1.95% QF-1 on 80/100 mesh Chromosorb MHP
	! CALIBRATION: standard PCB mixture in hexane
	! RANGE: 0.4 to 4 µg per sample [6]
	! ESTIMATED LOD: 0.03 µg per sample [6]
	! PRECISION (s _r): 0.044 [5]
	!
APPLICABILITY: The working range is 0.01 to 10 mg/m ³ for a 40-L air sample [5]. With modifications, surface wipe samples may be analyzed [7,8].	
INTERFERENCES: Chlorinated pesticides, such as DDT and DDE, may interfere with quantitation of PCB. Sulfur-containing compounds in petroleum products also interfere [9].	
OTHER METHODS: This method revises Methods S120 [10], 5503 (dated 2/15/84), and P&CAM 244 [5]. Methods S121 [11] and P&CAM 253 [12] for PCB have not been revised.	

REAGENTS:

1. Hexane, pesticide quality.
2. Florisil, 30/48 mesh sieved from 30/60 mesh. After sieving, dry at 105 °C for 45 min. Mix the cooled Florisil with 3% (w/w) distilled water.
3. Nitrogen, purified.
4. Stock standard solution of the PCB in methanol or isooctane (commercially available).*

*See SPECIAL PRECAUTIONS.

EQUIPMENT:

1. Sampler: 13-mm glass fiber filter without binders in a Swinnex cassette (Cat. No. SX 0001300, Millipore Corp.) followed by a glass tube, 7 cm long, 6 mm OD, 4 mm ID containing two sections of 30/48 mesh deactivated Florisil. The front section is preceded by glass wool and contains 100 mg and the backup section contains 50 mg; urethane foam between sections and behind the backup section. Join the cassette and Florisil tube with PVC tubing, 3/8" L x 9/32" OD x 5/32" ID, on the outlet of the cassette and with another piece of PVC tubing, 3/4" L x 5/16" OD x 3/16" ID, complete the union.
2. Personal sampling pump, 0.05 to 0.2 L/min, with flexible connecting tubing.
3. Tweezers.
4. Vials, glass, 4- and 7-mL, with aluminum or PTFE-lined caps.
5. Gas chromatograph, electron capture detection (⁶³Ni), integrator and column (page 5503-1).
6. Volumetric flasks, 10-mL and other convenient sizes for preparing standards.
7. Syringe, 10- μ L.

SPECIAL PRECAUTIONS: Avoid prolonged or repeated contact of skin with PCB and prolonged or repeated breathing of the vapor [1,2,13].

SAMPLING:

1. Calibrate each personal sampling pump with a representative sampler in line.
2. Break the ends of the Florisil tube immediately before sampling. Connect Florisil tube to Swinnex cassette and attach sampler to personal sampling pump with flexible tubing.
3. Sample at an accurately known flow rate between 0.05 and 0.2 L/min for a total sample size of 1 to 50 L.

NOTE: At low PCB concentrations, the sampler was found to be efficient when operated at flow rates up to 1 L/min, for 24 hours [8]. Under these conditions, the limit of detection was 0.02 μ g/m³.

4. Transfer the glass fiber filters to 7-mL vials. Cap the Florisil tubes with plastic (not rubber) caps and pack securely for shipment.

SAMPLE PREPARATION:

5. Place the glass wool and 100-mg Florisil bed in the same 7-mL vial in which the filter was stored. Add 5.0 mL hexane.
NOTE: For surface wipe samples, extract each gauze pad with 25 mL hexane [7].
6. In a 4 mL vial, place the 50-mg Florisil bed including the two urethane plugs. Add 2.0 mL hexane.
7. Allow to stand 20 min with occasional agitation.

CALIBRATION AND QUALITY CONTROL:

8. Calibrate daily with at least five working standards over the range 10 to 500 ng PCB/mL.
 - a. Add known amounts of stock standard solution to hexane in 10-mL volumetric flasks and dilute to the mark.
 - b. Analyze together with samples and blanks (steps 11 and 12).
 - c. Prepare calibration graph (sum of areas of selected peaks vs. ng PCB/mL).
9. Determine desorption efficiency (DE) at least once for each lot of glass fiber filters and Florisil used for sampling in the calibration range (step 8). Prepare three tubes at each of five levels plus three media blanks.
 - a. Remove and discard back sorbent section of a media blank Florisil tube.
 - b. Inject known amounts of stock standard solution directly onto front sorbent section and onto a media blank filter with a microliter syringe.
 - c. Cap the tube. Allow to stand overnight.
 - d. Desorb (steps 5 through 7) and analyze together with working standards (steps 11 and 12).
 - e. Prepare a graph of DE vs. μg PCB recovered.
10. Analyze three quality control blind spikes and three analyst spikes to ensure 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 5503-1. Inject sample aliquot manually using solvent flush technique or with autosampler.

NOTE 1: Where individual identification of PCB is needed, a procedure using a capillary column may be used [14].

NOTE 2: If peak area is above the linear range of the working standards, dilute with hexane, reanalyze and apply the appropriate dilution factor in calculations.
12. Sum the areas for five or more selected peaks.

CALCULATIONS:

13. Determine the mass, ng (corrected for DE) of PCB found on the glass fiber filter (w) and in the Florisil front (W_f) and back (W_b) sorbent sections, and in the average media blank filter (B) and 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 PCB in the air volume sampled, V (L):

$$C = \frac{(W + W_f + W_b - B - B_f - B_b) \cdot 10^{-9}}{V}, \text{ mg/m}^3.$$

EVALUATION OF METHOD:

This method uses 13-mm glass fiber filters which have not been evaluated for collecting PCB. In Method S120, however, Aroclor 1242 was completely recovered from 37-mm glass fiber filters using 15 mL isoctane [12,15,16]. With 5 mL of hexane, Aroclor 1016 was also completely recovered from 100-mg Florisil beds after one-day storage [5]. Thus, with no adsorption effect likely on glass fiber filters for PCB, 5 mL hexane should be adequate to completely extract PCB from combined filters and front sorbent sections. Sample stability on glass fiber filters has not been investigated. Breakthrough volume was >48 L for the Florisil tube at 75% RH in an atmosphere containing 10 mg/m^3 Aroclor 1016 [5].

REFERENCES:

- [1] Criteria for a Recommended Standard...Occupational Exposure to Polychlorinated Biphenyls, U.S. Department of Health, Education, and Welfare, Publ. (NIOSH) 77-225 (1977).

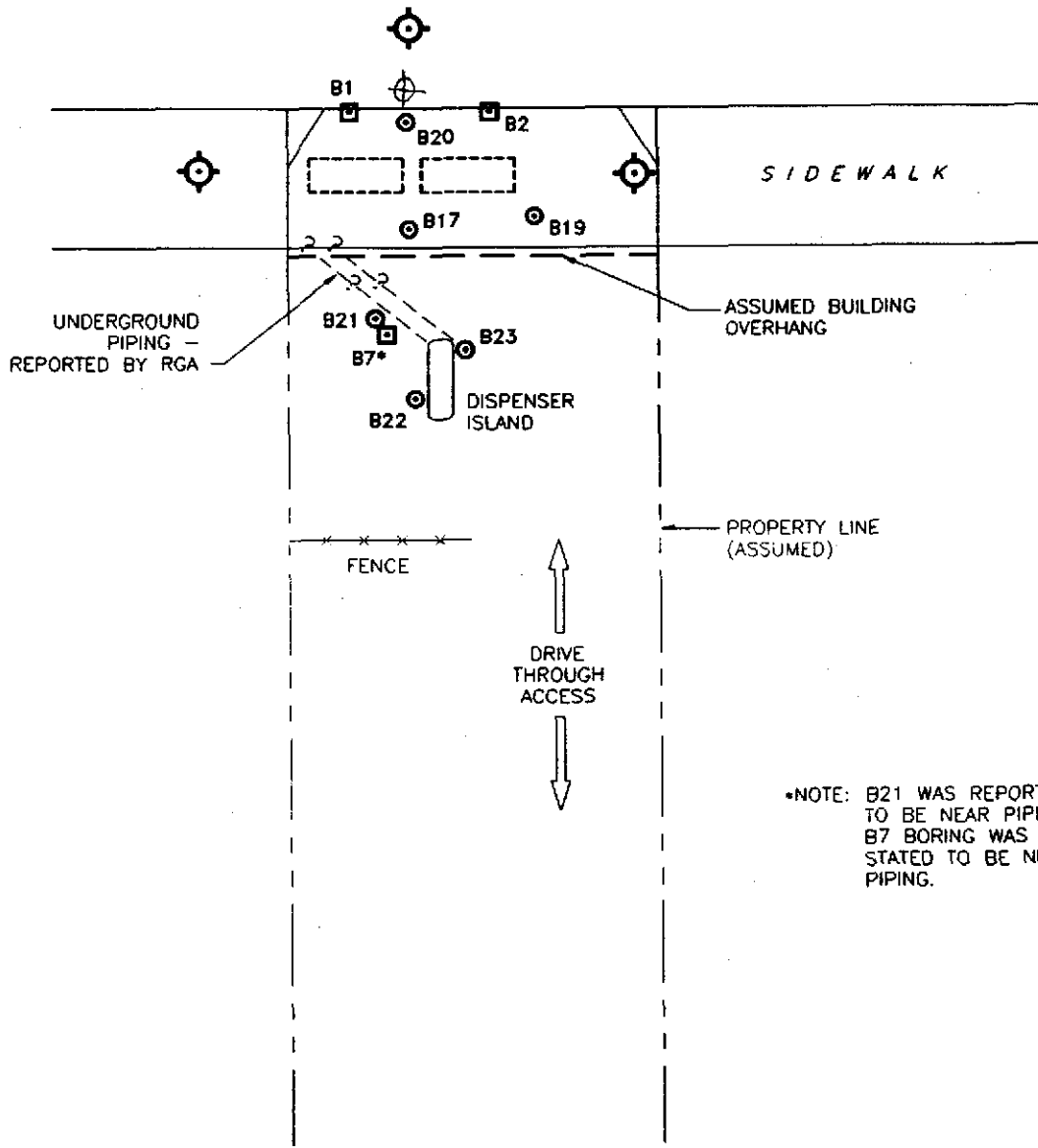
- [2] Current Intelligence Bulletin 7, Polychlorinated Biphenyls (PCBs), U.S. Department of Health and Human Services, Publ. (NIOSH) 78-127 (1975).
- [3] Hutzinger, O. S. Safe and V. Zitko. The Chemistry of PCBs, CRC Press, Inc., Cleveland, OH (1974).
- [4] Foreman, W. T., and T. F. Bidleman, "Vapor Pressure Estimates of Individual Polychlorinated Biphenyls and Commercial Fluids Using Gas Chromatographic Retention Data," J. Chromatogr. 330: 203-216 (1985).
- [5] NIOSH Manual of Analytical Methods, 2nd. ed., V. 1, P&CAM 244, U.S. Department of Health, Education, and Welfare, Publ. (NIOSH) 77-157-A (1977).
- [6] User check, Southern Research Institute, NIOSH Sequence #4121-U (unpublished, January 25, 1984).
- [7] Kominsky, J. Applied Ind. Hyg. 1 (4): R-6 (1986).
- [8] NIOSH Health Hazard Evaluation Report, HETA 85-289-1738 (unpublished, 1986).
- [9] Hofstader, R. A., C. A. Bache, and D. J. Lisk. Bull. Environ. Contam. Toxicol., 11:136 (1974).
- [10] NIOSH Manual of Analytical Methods, 2nd ed., V. 4, S120, U.S. Department of Health, Education, and Welfare, Publ. (NIOSH) 78-175 (1978).
- [11] *Ibid.*, V. 2, S121, U.S. Department of Health, Education, and Welfare, Publ. (NIOSH) 77-157-B (1977).
- [12] *Ibid.*, Vol. 1, P&CAM 253.
- [13] Occupational Diseases, A Guide to Their Recognition, revised ed., 255-256, U.S. Department of Health, Education, and Welfare, Publ. (NIOSH) 77-181 (1978).
- [14] Dunker, J. C. and M. T. J. Hillebrand. Characterization of PCB Components in Clophen Formulations by Capillary GC-MS and GC-ECD Techniques, Environ. Sci. Technol., 17 (8), 449-456 (1983).
- [15] Backup Data Report for S120, prepared under NIOSH Contract 210-76-0123, available as "Ten NIOSH Analytical Methods, Set 2," Order No. Pb 271-464 from NTIS, Springfield, VA 22161.
- [16] NIOSH Research Report-Development and Validation of Methods for Sampling and Analysis of Workplace Toxic Substances, U.S. Department of Health and Human Services, Publ. (NIOSH) 80-133 (1980).

METHOD REVISED BY: James E. Arnold, NIOSH/DPSE; S120 originally validated under NIOSH Contract 210-76-0123.

Table 1. Composition of some Aroclors [3].

Major Components	Aroclor 1016	Aroclor 1242	Aroclor 1254
Biphenyl	0.1%	<0.1%	<0.1%
Monochlorobiphenyls	1	1	<0.1
Dichlorobiphenyls	20	16	0.5
Trichlorobiphenyls	57	49	1
Tetrachlorobiphenyls	21	25	21
Pentachlorobiphenyls	1	8	48
Hexachlorobiphenyls	<0.1	1	23
Heptachlorobiphenyls	none detected	<0.1	6
Octachlorobiphenyls	none detected	none detected	none detected

HARRISON STREET *actual SBs (only 2 SBs)*



*NOTE: B21 WAS REPORTED TO BE NEAR PIPING. B7 BORING WAS NOT STATED TO BE NEAR PIPING.

- EXPLANATION**
- ⊙ RGA borings
 - ⊠ SCI borings
 - ⊕ Proposed boring location
 - ⎓ Underground storage tank

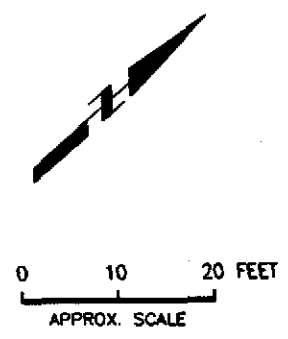


Figure 2: SITE PLAN SHOWING UNDERGROUND STORAGE TANKS IN HARRISON STREET SIDEWALK AND PROPOSED BORING LOCATIONS