



# **A Literature Review of Wipe Sampling Methods for Chemical Warfare Agents and Toxic Industrial Chemicals**



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## **Abstract**

Wipe sampling is an important technique for the estimation of contaminant deposition in buildings, homes, or outdoor surfaces as a source of possible human exposure. Numerous methods of wipe sampling exist, and each method has its own specification for the type of wipe, wetting solvent, and determinative step to be used, depending upon the contaminant of concern. The objective of this report is to concisely summarize the findings of a literature review that was conducted to identify the state-of-the-art wipe sampling techniques for a target list of compounds. This report describes the methods used to perform the literature review; a brief review of wipe sampling techniques in general; an analysis of physical and chemical properties of each target analyte; an analysis of wipe sampling techniques for the target analyte list; and a summary of the wipe sampling techniques for the target analyte list, including existing data gaps.

In general, no overwhelming consensus can be drawn from the current literature on how to collect a wipe sample for the chemical warfare agents, organophosphate pesticides, and other toxic industrial chemicals of interest to this study. Different methods, media, and wetting solvents have been recommended and used by various groups and different studies. For many of the compounds of interest, no specific wipe sampling methodology has been established for their collection. Before a wipe sampling method (or methods) can be established for the compounds discussed in this report, two steps must be taken: (1) conduct investigative research to fill in the gaps in wipe sampling knowledge, and (2) conduct method validation to optimize the methods.



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## Abbreviations, Acronyms, and Symbols

ASTM	American Society for Testing and Materials
CBIAC	Chemical and Biological Defense Information Analysis Center
CHEERS	Children's Environmental Exposure Research Study
cm	centimeter
cm <sup>2</sup>	square centimeter
cm/s	centimeter per second
CTEPP	Children's Total Exposure to Persistent Pesticides and Other Persistent Organic Pollutants
CWA	chemical warfare agent
DCM	dichloromethane
EPA	U.S. Environmental Protection Agency
FPD	flame photometric detector
ft <sup>2</sup>	square foot
GC	gas chromatography
HPLC	high-performance liquid chromatography
HVS3	High Volume Small Surface Sampler
IPA	isopropyl alcohol
LC	liquid chromatography
m <sup>2</sup>	square meter
mL	milliliter
mm	millimeter
MS	mass spectrometry
MSDS	material safety data sheet
NERL	National Exposure Research Laboratory
NHEXAS	National Human Exposure Assessment Survey
NHSRC	National Homeland Security Research Center
NIOSH	National Institute for Occupational Safety and Health
OP	organophosphate pesticide
OPCW	Organisation for the Prohibition of Chemical Weapons
OSHA	Occupational Safety and Health Agency
PBDE	polybrominated diphenyl ether
PBS	phosphate buffered saline
PBT	phosphate buffer with Tween
PCB	polychlorinated biphenyl
PCP	phencyclidine
PUF	polyurethane foam
SSP	swab sample processing
TEPP	tetraethyl pyrophosphate
TIC	toxic industrial chemical
TSA	Transportation Security Administration
USDA	U.S. Department of Agriculture



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## **Chapter 1**

### **Introduction**

Collection of contaminants from surfaces, referred to as “wipe sampling”, is an important technique for the estimation of contaminant deposition on a variety of surfaces, including those in buildings, homes, outdoor areas, and hands (dermal wipes). Wipe sampling techniques are used for environmental sampling, industrial hygiene monitoring, monitoring of remedial processes, security monitoring, compliance monitoring, and various other related applications. Examples of wipe sampling applications include testing of household surfaces for lead; airport luggage screening for explosives; post-remediation sampling of methamphetamine houses; dermal wipe sampling techniques for personal exposure to pesticides; post-decontamination sampling; and spill clean-up verification of environmental contaminants. These are just a few of the many applications of wipe sampling techniques that are applied by government agencies and the private sector on any given day.

Procedures for the collection of contaminants from surfaces have several components in common, including the wipe sampling media, the wetting solvent, and the collection technique. However, wipe sampling procedures can vary widely, depending on the contaminant(s) of interest and the surface to be sampled. Reliability of the sample results begins with accurate collection of a sample for analysis. Thus, the wipe sampling procedures used for a particular analyte on a given surface, including the proper combination of the wipe sampling components described above, are an integral aspect of whether or not the results generated will be representative of the contamination.

The objective of this report is to concisely summarize the findings of a literature review that was conducted to identify the state-of-the-art wipe sampling techniques for a target list of compounds. This report describes the methods used to perform the literature review; a historical review of wipe sampling techniques in general; a review of chemical and physical properties of each target analyte; an analysis of wipe sampling techniques for the target analyte list; and a summary of the findings, including data gaps.



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## Chapter 2

### Literature Search Methods

#### 2.1 Literature Review

In the first task of this project, a two-phased approach was used to conduct a literature review to determine what is already known about wipe sampling techniques for a target list of analytes. First, a broad search was conducted that explored what general information was available on wipe sampling (i.e., how different organizations are using wipe sampling). This search did not focus on the specific compounds of interest for this project, but instead focused on what wipe sampling procedures could be found for various government agencies or other groups. Extensive internet searching was used as the primary tool for this phase of the review process. Various government agency websites were also searched using the available search options on that site using keywords such as “wipes(s)” or “wiping” and “sample(s)”. The following government agency websites were included in the search: Drug Enforcement Administration, Federal Transit Administration, Occupational Safety and Health Administration (OSHA), National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control and Prevention, Bureau of Alcohol, Tobacco and Firearms, Coast Guard, Consumer Product Safety Commission, U. S. Department of Agriculture (USDA), U.S. Department of Defense, U.S. Department of Homeland Security, U.S. Department on the Interior, Agency for Toxic Substances and Disease Registry, Federal Aviation Administration, Transportation Security Administration (TSA), Federal Bureau of Investigation, Food and Drug Administration, National Aeronautics and Space Administration, National Institute of Standards and Technology, the U.S. Army Corp of Engineers, and the U.S. Environmental Protection Agency (EPA). These agencies and departments were selected because they seemed most likely to conduct wipe sampling for some branch of their operations. In spite of this effort, only limited information was obtained from this search process.

As a subset to this search, the Federal Register was explored to see if any further information could be obtained on the agencies listed above. It was determined that this approach was not productive as little practical information was found.

In the second phase of the literature search, information was sought on wipe sampling as it relates to the compounds of interest. These focused searches were conducted by using databases available through a regular library system as well as by the Chemical and Biological Defense Information Analysis Center (CBIAC), which has special access to documents related to chemical, biological, radiological, and nuclear technology information. Searches were conducted using keywords similar to the following:

**wipe OR wipes OR wiping AND sample OR sampling AND compound**

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Each compound being investigated was included in individual searches. CBIAC searches focused on the chemical warfare agents (CWAs) and related compounds; the library database searches focused on the remaining compounds (pesticides and other toxic industrial chemicals (TICs)). These searches yielded more than 140 references. The references were reviewed further for information regarding wipe sampling methodology, covering areas such as wipe material, wetting solvent, wipe procedure, and sampling surface. As a result of this further examination, only 39 citations were deemed relevant to this study and are included as references in this report.

As part of the overall reference collection effort, knowledgeable experts in the field of wipe sampling were contacted and relevant references were gathered based on their suggestions and input.

## **2.2 Search of Physical and Chemical Properties of Compounds**

Part of the literature review also included gathering physical and chemical property information on each of the compounds of interest. Specifically, material safety data sheets (MSDSs) were collected from various publicly available internet sites as shown in Table 1. Information from the MSDSs was compiled into tables in Chapter 4. When the information contained on the MSDS seemed sparse, physical property information for a particular compound was cross-checked using CHEMINFO (through the Canadian Centre for Occupational Health and Safety (CCOHS)) and Ecotoxnet (<http://extoxnet.orst.edu/>). MSDS information from a subscription service (OHS at [www.ohsworks.com](http://www.ohsworks.com)) was also used. For the CWAs, information on chemical and physical properties was also obtained from two literature sources (1,2), in which detailed information on these compounds had been collected and summarized. The chemical structures for each of the compounds of interest are provided in Appendix A.

**Table 1. Summary of Resources for MSDS Information for Compounds of Interest**

<b>Compound</b>	<b>CAS No.</b>	<b>Resource</b>
Chloropicrin	76-06-2	<a href="http://www.e1.greatlakes.com/common/msdspdf/00026.pdf">www.e1.greatlakes.com/common/msdspdf/00026.pdf</a>
Dichlorvos	62-73-7	<a href="http://www.cdc.gov/niosh/ipcsneng/neng0690.html">http://www.cdc.gov/niosh/ipcsneng/neng0690.html</a>
Dicrotophos	141-66-2	<a href="http://pmep.cce.cornell.edu/profiles/extoxnet/carbaryl-dicrotophos/dicrotophos-ext.html">http://pmep.cce.cornell.edu/profiles/extoxnet/carbaryl-dicrotophos/dicrotophos-ext.html</a>
Dimethylphosphite	868-85-9	<a href="http://www.cdc.gov/niosh/ipcsneng/neng1599.html">http://www.cdc.gov/niosh/ipcsneng/neng1599.html</a>
Distilled Mustard (HD)/Mustard Gas (H)	505-60-2	<a href="http://www.gulfweb.org/bigdoc/report/apphd.html">http://www.gulfweb.org/bigdoc/report/apphd.html</a>
1,4-Dithiane	505-29-3	<a href="http://physchem.ox.ac.uk/MSDS/DI/1,4-dithiane.html">http://physchem.ox.ac.uk/MSDS/DI/1,4-dithiane.html</a>
Mustard (HT)	172672-28-5	<a href="http://chppm-www.apgea.army.mil/dts/docs/detht.pdf">http://chppm-www.apgea.army.mil/dts/docs/detht.pdf</a>
Ethylchloroarsine (ED)	598-14-1	<a href="http://environmentalchemistry.com/yogi/chemicals/cn/Ethyl%20Dichloroarsine.html">http://environmentalchemistry.com/yogi/chemicals/cn/Ethyl%20Dichloroarsine.html</a>
Fenamiphos	22224-92-6	<a href="http://www.cdc.gov/niosh/ipcsneng/neng0483.html">http://www.cdc.gov/niosh/ipcsneng/neng0483.html</a>
Lewisite (1)	541-25-3	<a href="http://www.uscg.mil/mlclant/KDiv/Envrm%20Hlth/IH-MSDS/MSDS/LewisiteMSDS.doc">http://www.uscg.mil/mlclant/KDiv/Envrm%20Hlth/IH-MSDS/MSDS/LewisiteMSDS.doc</a>
Lewisite (2)	40334-69-8	MSDS not available; information presented from: <a href="http://www.epa.gov/opptintr/aegl/pubs/rest133.htm">http://www.epa.gov/opptintr/aegl/pubs/rest133.htm</a>
Lewisite (3)	40334-70-1	MSDS not available; information presented from: <a href="http://www.epa.gov/opptintr/aegl/pubs/rest133.htm">http://www.epa.gov/opptintr/aegl/pubs/rest133.htm</a>
Methyl parathion	298-00-0	<a href="http://www.cdc.gov/niosh/ipcsneng/neng0626.html">http://www.cdc.gov/niosh/ipcsneng/neng0626.html</a>
Mevinphos	7786-34-7	<a href="http://pmep.cce.cornell.edu/profiles/extoxnet/metiram-propoxur/mevinphos-ext.html">http://pmep.cce.cornell.edu/profiles/extoxnet/metiram-propoxur/mevinphos-ext.html</a>
Nicotine	54-11-5	<a href="http://physchem.ox.ac.uk/MSDS/NI/nicotine.html">http://physchem.ox.ac.uk/MSDS/NI/nicotine.html</a>
Phencyclidine	77-10-1	<a href="http://www.cerilliant.com/search.htm">http://www.cerilliant.com/search.htm</a> (search cat no P-001)
Phorate	298-02-2	<a href="http://www.piindustries.com/tech_main.htm">http://www.piindustries.com/tech_main.htm</a>
Sarin (GB)	107-44-8	<a href="http://www.gulfweb.org/bigdoc/report/appgb.html">http://www.gulfweb.org/bigdoc/report/appgb.html</a>
Soman (GD)	96-64-0	<a href="http://www.gulfweb.org/bigdoc/report/appgd.html">http://www.gulfweb.org/bigdoc/report/appgd.html</a>
Cyclohexyl sarin (GF)	329-99-7	MSDS not available; information presented from: Abercrombie, PL (September 2003)
Strychnine	57-24-9	<a href="http://www.cdc.gov/niosh/ipcsneng/neng0197.html">http://www.cdc.gov/niosh/ipcsneng/neng0197.html</a>
Tabun (GA)	77-81-6	<a href="http://www.gulfweb.org/bigdoc/report/appga.html">http://www.gulfweb.org/bigdoc/report/appga.html</a>
Tetraethyl pyrophosphate (TEPP)	107-49-3	<a href="http://www.segulab.com/en/t_msdms.htm">http://www.segulab.com/en/t_msdms.htm</a>
Thiodiglycol	111-48-8	<a href="http://www.cdc.gov/niosh/ipcsneng/neng1601.html">http://www.cdc.gov/niosh/ipcsneng/neng1601.html</a>
1,4-Thioxane	15980-15-1	<a href="http://www.fluorochem.net/msds.asp?txtCatNo=001450&amp;x=25&amp;y=6">http://www.fluorochem.net/msds.asp?txtCatNo=001450&amp;x=25&amp;y=6</a> (search for cat no 001450)
Trimethyl phosphite	121-45-9	<a href="http://www.osha.gov/SLTC/healthguidelines/trimethylphosphite/recognition.html">http://www.osha.gov/SLTC/healthguidelines/trimethylphosphite/recognition.html</a>
VX	50782-69-9	<a href="http://www.gulfweb.org/bigdoc/report/appvx.html">http://www.gulfweb.org/bigdoc/report/appvx.html</a>
Crimidine	535-89-7	<a href="http://yosemite.epa.gov/oswer/ceppoehs.nsf/profiles/535-89-7?opendocument">http://yosemite.epa.gov/oswer/ceppoehs.nsf/profiles/535-89-7?opendocument</a>
Methyl fluoroacetate	453-18-9	<a href="http://www.fluorochem.net/msds.asp?txtCatNo=006800&amp;x=29&amp;y=10">http://www.fluorochem.net/msds.asp?txtCatNo=006800&amp;x=29&amp;y=10</a> (search for cat no 006800)



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## **Chapter 3**

### **General Wipe Sampling Information**

#### **3.1 Background**

Wipe sampling is one of the primary techniques for assessing surface contamination. When using the appropriate wipe sampling media coupled with an appropriate solvent (or used dry, as warranted), the type and amount of chemical on a particular surface can be identified by wiping a sufficient area of the surface and analyzing the wipe. This technique is a quick and easy means of determining what chemicals reside on a surface. Though wipe sampling is often employed, the methods and materials associated with wipe sampling vary greatly. Most wipe sampling procedures are a manual process, and the pressure applied for each wiping procedure could vary significantly among field operators. Different government agencies use different wipe methods for various compounds. Even within a particular field (such as occupational exposure assessments), variations in wipe sampling methodologies have been reported.

In this section, the general uses of wipe sampling techniques by different government agencies, various researchers, and studies are described in three primary areas: environmental, occupational, and homeland security-related applications. This information is summarized in Table 2. Performance information on wipe sampling methods is provided in Section 3.6. This chapter is meant to provide only a brief overview of wipe sampling applications and performance data. It is not meant to provide exhaustive coverage of all available studies but rather a synopsis of relevant information that describes what wipe sampling methods have been performed by various organizations to help establish the credibility of wipe sampling as a useful technique.

#### **3.2 Environmental Applications**

Wipe sampling is an integral part of the sampling protocol for many environmental assessments including evaluating remedial progress, environmental compliance, and for human exposure monitoring. A review of the literature for wipe sampling techniques in these areas is described in this section.

EPA has devised wipe sampling methods for polychlorinated biphenyl (PCB) analysis (3, 4). This technique is used to verify PCB cleanup on hard, smooth, non-porous surfaces. In this application, filter papers (such as Whatman 40 ashless or Whatman 50 smear tabs) or a gauze pad are used for the wipe material. The wipes are wetted with a solvent, such as isooctane or hexane, held with forceps or rubber gloves, and rubbed over a 100 square centimeter (cm<sup>2</sup>) area.

**Table 2. General Uses of Wipe Sampling Techniques**

Compound	Agency or Agency Affiliation	Wipe Material	Wetting Solvent	Wipe Surface	Reference
<b>Pesticides</b>					
polar pesticides	ASTM	cotton gauze pads	IPA	smooth, non-porous; 100 cm <sup>2</sup>	10
malathion	ASTM	cotton gauze pads	isooctane, DCM	smooth, non-porous; 100 cm <sup>2</sup>	10
2,4-D	EPA	gauze pads	70:30 phosphate buffer:acetonitrile; IPA	uncarpeted floors, table tops, window sills, carpet; 850cm <sup>2</sup> - 2m <sup>2</sup>	12, 15, 16
chlorpyrifos	ASTM	cotton gauze pads	isooctane	smooth, non-porous; 100 cm <sup>2</sup>	10
	EPA, New Jersey Department of Environmental Protection	gauze pads	DI water	carpet; 100 - 800 cm <sup>2</sup>	30
	New Jersey Department of Environmental Protection and Energy	gauze pads	DI water	turf; 100 cm <sup>2</sup>	14
chlorpyrifos, diazinon	EPA	gauze pads	IPA	hard floors, hard surfaces	12
	EPA	gauze pads	DI water	window sill	13
<b>Other Organics</b>					
PCBs	EPA	filter paper, gauze pad	isooctane, hexane	hard, smooth, non-porous; 100 cm <sup>2</sup>	3, 4
	NIOSH	glass wool filter	hexane	hard, non-porous; 1 ft <sup>2</sup>	5
	general <sup>1</sup>	filter paper	dry, water	floors, walls; 200 cm <sup>2</sup>	5
	general <sup>1</sup>	Kleenex®	dry, water	floors, walls; 200 cm <sup>2</sup>	5

**Table 2. (continued)**

Compound	Agency or Agency Affiliation	Wipe Material	Wetting Solvent	Wipe Surface	Reference
PCBs	general <sup>1</sup>	Cloth wipes	octane	NA	5
	general <sup>1</sup>	Whatman filter paper	hexane	ventilation system; 1 ft <sup>2</sup>	5
	general <sup>1</sup>	Whatman smear tabs	methanol	work and tool surfaces; 100 cm <sup>2</sup>	5
	ASTM	cotton gauze pads	hexane, isooctane	smooth, non-porous; 100 cm <sup>2</sup>	10
organic residues	USDA	gauze pads	IPA	100 cm <sup>2</sup>	12
tetrachlorophenol	general <sup>1</sup>	gauze pads	NA	wood; 231 cm <sup>2</sup>	5
chlorophenols	general <sup>1</sup>	Whatman filter paper	NA	wood	5
2,4-ditertbutylphenol	general <sup>1</sup>	cotton swabs	ethanol	rubber	5
2,3,7,8-tetrachlorodibenzo- <i>p</i> -dioxin	general <sup>1</sup>	Whatman glass microfiber paper	none	laboratory surfaces; 625cm <sup>2</sup>	5
<b>Metals</b>					
As, Cu, Cr	EPA	TexWipe TX1009 clean room wipe (100% polyester)	DI water, 0.9% saline	wood; 314 cm <sup>2</sup>	6
Pb, Be, As, Cd, Cr, Ni	Brookhaven National Lab/NIOSH	cotton gauze pads, ashless filter paper, GhostWipes™	DI water, IPA, ethanol, methanol, hexane	metal, plastic, glass, wood, concrete; 100 cm <sup>2</sup>	8
Pb	ASTM	Disposable towellete	pre-moistened	1 ft <sup>2</sup>	7
	general <sup>1</sup>	Wash'nDry® paper towels	pre-moistened	household surfaces; 1 ft <sup>2</sup>	5
	EPA	Swiffer® dry and wet cloths	pre-moistened	floors, window sills	9

**Table 2. (continued)**

Compound	Agency or Agency Affiliation	Wipe Material	Wetting Solvent	Wipe Surface	Reference
<b>Others</b>					
methamphetamine	MN State Department of Health	gauze sponge	methanol	dry, hard, non-porous; 100cm <sup>2</sup>	21
	WA State Department of Health	filter paper	methanol	dry, hard, non-porous; 100cm <sup>2</sup>	22
anthrax	general <sup>1</sup>	Swipe, Heavy Wipe, swab	PBT	vinyl, tile, wood laminate, metal; 929 cm <sup>2</sup>	19
	general <sup>1</sup>	rayon gauze pad, swab	water, PBS	hard surface	20

<sup>1</sup> No particular agency was found to be affiliated with the referenced study.

NA = Not Available.

DCM = dichloromethane

IPA = isopropyl alcohol

PBT = phosphate buffer with 0.05 percent Tween

PBS = phosphate buffer saline

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Other PCB wipe methods are used to determine the extent of PCB contamination. PCB contamination on walls and transformers has been determined by the National Institute for Occupational Safety and Health (NIOSH) using glass wool filter wipes wetted with hexane over a 1 square foot (ft<sup>2</sup>) area (5). Other studies by various researchers have used filter paper and Kleenex®, cloth wipes, Whatman filter paper, and Whatman smear tabs as a sampling medium. These wipes have been used dry, and saturated with octane, hexane, and methanol, respectively. The areas wiped range from 100 cm<sup>2</sup> to 900 cm<sup>2</sup> (5).

Wipe sampling for metals such as lead or arsenic is also routinely done. In a wipe comparison study to determine the dislodgeable arsenic, copper, and chromium residues on chromated copper arsenate treated lumber, EPA used the following wipe media: a TexWipe TX1009 clean room wipe (100 percent polyester) that was saturated with deionized (DI) water, the same polyester wipe moistened with 0.9 percent saline solutions at two times the dry weight of the wipe, and an acid-washed polyester wipe saturated with DI water, though this particular wipe was found to contain traces of the acid wash still in the wipe (6). Wiping was done using a 1.1 kilogram disc that was approximately 8.5 centimeter (cm) in diameter, as a wiping block.

The American Society for Testing Materials (ASTM) has a lead-specific wipe sampling standard method for collecting settled dust on surfaces in and around buildings (7). A packaged, disposable towellette that is pre-moistened with a wetting solvent is used for the sample collection. Overlapping “S” and “Z” patterns are used when collecting the sample from an area of 100 cm<sup>2</sup>.

The Industrial Hygiene Group at Brookhaven National Laboratory uses NIOSH Method 9100 (posted at [www.cdc.gov/niosh/nmam](http://www.cdc.gov/niosh/nmam)) to determine lead and other metals in surface residue (8). A range of wipe materials can be used. Either 2" x 2" or 4" x 4" cotton gauze pads; ashless filter paper (1.5 to 4 inches in diameter); or pre-moistened wipes such as GhostWipes™ are appropriate for lead, beryllium, arsenic, cadmium, chromium, or nickel sampling. Approximately 1-2 milliliters (mL) of solvent such as DI water, isopropanol (IPA), ethanol, methanol, or n-hexane is used with the wipe. A 100 cm<sup>2</sup> area is supposed to be sampled by this method. The solvent used does not appear to be critical for the metal collection, but can impact the sampling surface and should be chosen accordingly.

Other commercially available wipes have also been used for lead sample collection. Wash'nDry® disposable paper towels, moistened with 20 percent denatured alcohol and 1:750 benzalkonium chloride have been used to collect lead dust from general household surfaces (5). Other researchers have used methods similar to the NIOSH Method 9100 described previously. EPA is currently exploring the potential use of dry electrostatic cloths (Swiffer®), as well as wet Swiffer® cleaning pads, for collecting residual dust samples after lead-based paint abatement cleaning (9).

Sampling for organic compounds is an important component of many exposure assessments. ASTM offers a method for taking wipe samples from smooth, non-porous surfaces for organic compounds (10). ASTM recommends the use of sterile, surgical cotton gauze pads (7.6 cm<sup>2</sup>) with pre-cleaning only when necessary. Wipe wetting solvents are recommended on a compound basis. For example, for PCBs and most pesticides, isooctane is recommended (54 to

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80 percent recovery). Hexane can also be used in wipes for PCBs. For carbamates or polar pesticides, IPA is an appropriate solvent for use with the wipe (84 to 96 percent recovery). Acetone is not desirable because it can remove interfering compounds from the sampling surface. A 100 cm<sup>2</sup> wiping area is recommended as is 2 mL of any solvent that is used to wet the wipe. The area should be wiped vertically and then horizontally using firm strokes with minimal overlap.

The USDA also has a published wipe sampling method for detecting organic residues or dusts from surfaces (11). As with the ASTM method, their technique uses a 3" x 3" sterile gauze pad moistened with IPA. A 100 cm<sup>2</sup> area is also sampled.

EPA has conducted multiple exposure studies where wipe sampling for organic compounds on household surfaces played a key role in the assessment. As part of the Children's Total Exposure to Persistent Pesticides and Other Persistent Organic Pollutants (CTEPP) study assessing children's exposures to particular persistent organic pollutants, such as chlorpyrifos and polycyclic aromatic hydrocarbons, wipe samples were taken for residues on hard floors using pre-cleaned, 4" x 4" Johnson and Johnson (J&J) SOF-WICK gauze pads moistened with 2 mL of 75 percent IPA in DI water (12). The J&J SOF-WICK gauze pads were also used in the National Human Exposure Assessment Survey (NHEXAS) exposure study in collecting wipe samples for chlorpyrifos and diazinon from window sills. In this case, the wipes were moistened with 2 mL of DI water and were also pre-cleaned with methylene chloride prior to their use (13). Window sills were wiped in this study by wiping the length of the sill using moderately firm pressure. After wiping the sill in one direction, the wipe was folded in on itself and the sill was wiped in reverse.

EPA's Children's Environmental Exposure Research Study (CHEERS) pilot study also used gauze pads for wipe sampling to determine children's exposure to various pesticides, phthalates, polybrominated diphenyl ethers (PBDEs), and fluorinated compounds. At the time of this study, however, the J&J SOF-WICK gauze pads had been discontinued, so an alternative, Kendall Excilon wipes were used instead. The wipes were the same size as the J&J brand wipes and were also pre-cleaned prior to use with dichloromethane (DCM). They were saturated with 10 mL of IPA before a sample was taken. This amount of IPA has the potential to extract more of the compounds from the surface and sub-surface of the sample area than are otherwise available for human contact and thus dermal absorption.

Black et al. (14) also used wipe samples for measuring dislodgeable chlorpyrifos residues on Kentucky bluegrass turf. The wipes were pre-extracted 7.6 cm x 7.6 cm gauze pads sprayed with DI water. A 100 cm<sup>2</sup> area was sampled based on Occupational Safety and Health Agency (OSHA) methods. Specifically, the area was wiped with one pad in a single direction for 10 strokes. Wipe samples recovered 1 percent to 6 percent of the initial chlorpyrifos deposit from the turf (1 to 3 hours after application). Wipe sampling variability ranged from 37 to 74 percent between different studies performed during the research. Within a particular study, wipe sampling variability averaged 21.5 percent.

Nishioka et al. wiped uncarpeted floors, table tops, and window sills using J&J SOF-WICK cotton gauze dressing sponge moistened with 2 mL of sweat stimulant (70:30 phosphate

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buffer:acetonitrile) (15,16). An area from 850 cm<sup>2</sup> to 2 m<sup>2</sup> was sampled by first wiping in one direction, then folding the wipe in on itself, and then wiping the same area in an orthogonal direction.

Multiple other methods of wipe samples for various compounds have been used over the years, as noted by McArthur (5). Wooden surfaces (231 cm<sup>2</sup>) were sampled for tetrachlorophenol with 12-ply surgical pads using 10 strokes for each of four samples. Chlorophenols were also collected from wooden surfaces using Whatman 1 filter paper (4.25 cm) with a 300 gram weight placed on top. Surface contamination of rubber with 2,4-diterbutylphenol was determined using ethanol-soaked cotton swabs. 2,3,7,8-tetrachlorodibenzo-*p*-dioxin contamination of laboratory surfaces was found by wiping a 625 cm<sup>2</sup> area with dry Whatman glass microfiber paper.

### 3.3 Occupational Applications

Wipe sampling is an important component of occupational exposure analysis. OSHA has multiple wipe sampling methods and recommendations depending on the chemical of interest. OSHA has developed guidelines to provide chemists with a uniform method of evaluating surface sampling wipes (17). As part of these guidelines, information on how to properly conduct wipe sampling is presented. Among the steps is selecting a sampling medium. OSHA recommends the following list of media for wipe sampling: DURX 670 (polyester and cellulose), Pro-Wipe 880 (polypropylene), Ghost Wipes (cross linked polyvinyl alcohol), AlphaWipes (polyester), and even charcoal impregnated discs. Various wetting agents are also recommended: DI water for metals, DI water or IPA for non-volatile organics, or other solvents if the compound being sampled will react with water or IPA. The guidelines also indicate that the ideal sampling surface is a smooth and non-porous, and that the sampling area should be 100 cm<sup>2</sup>.

OSHA has also prepared a chapter in their Technical Manual with more detailed information about wipe sampling (18). Similar to the previous document, each step of the wipe sampling procedure is discussed. Particular attention is paid to the media choice for sampling a surface. A filter is described as the classic wipe sampling technique. Paper filters, mixed cellulose ester filters, and smear tabs are best for metals. For things that are unstable on paper filters, polyvinyl chloride filters are recommended. Squares of a gauze material that are used either wetted (with solvent or water) or dry are purported to be best for organic compounds while volatile solvents are best sampled with charcoal impregnated pads. To sample a surface for isocyanates or aromatic amines, a filter treated with derivitizing reagent is recommended. Glass fiber filters, either wetted or dry, are recommended for many of the chemicals that will be analyzed by gas chromatography (GC) or high-performance liquid chromatography (HPLC).

### 3.4 Homeland-Security Related Applications

Over the last five years, the increased focus on homeland-security related techniques has generated new applications for wipe sampling. For example, airport luggage is screened by wipe sampling followed by ion mobility spectrometry analysis for explosives detection. In recent years, the detection of anthrax has become a critical analytical need. More specifically, the determination of whether or not any anthrax remains in a building after building decontamination

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has become an important use for wipe sampling. Buttner et al. (19) tested the efficiencies of decontamination strategies for *b. anthracis* by taking wipe samples of vinyl tile, wood laminate, and metal surfaces after a simulated dispersion and subsequent decontamination. Three different kinds of wipe samples were used: (1) a Swipe (Speci-sponge) moistened with 30 mL of 0.01M phosphate buffer with 0.05 percent Tween (PBT); (2) a Heavy Wipe (Handy Wipes) moistened with 40 mL of PBT; and (3) a swab sample processing (SSP) kit moistened with 20 drops of buffer. In all cases, a 929 cm<sup>2</sup> area was sampled. For the Swipe and Heavy Wipe samplers, the surface was sampled by wiping the area in a horizontal direction. The wipe was then turned over and the unused surface was used to sample the same area while wiping in a vertical direction. For the SSP kit, the foam swab was used to sample the first half of the pre-moistened surface, then the swab was turned over and the remaining half of the surface was sampled. Removal efficiencies were not presented for any of the methods used in this study, but all three wipe materials collected similar levels of the *b. anthracis* surrogate used during testing, and similar levels of the bacteria were obtained from all three surfaces tested.

In another study by Sanderson et al. (20), two different *b. anthracis* sampling methods were tested. Wipe samples were taken using actual wipes as well as a swab. The wipe was 7.62 cm x 7.62 cm sterile rayon gauze pad that was wetted with 5 mL of sterile water. The sampling area was first wiped using vertical strokes, the wipe was then folded in on itself and the area was wiped using horizontal strokes. The swab was a sterile, rayon swab that was moistened with phosphate buffered saline (PBS) at pH 7.2. Several strokes of the area were first taken with the swab. The swab was then rotated during sampling to ensure that all of the swab was used. Dry swab samples were also taken. Samples were collected from air ducts, machinery, window boxes, and mail sorting bins from a postal facility (all non-porous surfaces). Wet swabs performed better than dry, detecting *b. anthracis* in 54 percent vs. 14 percent of the instances. Wipe sampling detected *b. anthracis* in 87 percent of the instances.

### **3.5 Other Applications**

Illegal methamphetamine labs have become a serious problem for many cities and states. Wipe sampling methods for methamphetamines were found for two state departments, the Minnesota Department of Health (along with the Minnesota Pollution Control Agency) and the Washington State Department of Health (21, 22). Though both methods used 2 mL of methanol as the wetting solvent for their wipes, the wipe material itself was quite different for the two states. Minnesota used a 3" x 3" general use gauze sponge while Washington used filter paper. In both cases, a dry surface was to be sampled. The Washington State procedure specified a hard, non-porous surface be sampled; this was implied in the Minnesota protocol. An overlapping "Z" and "N" pattern are used for sampling.

### **3.6 Wipe Sampling Performance Information**

The wipe sampling studies presented in this chapter mainly discuss applications of wipe sampling. While various applications are important in verifying the validity of the technique, it is also important to discuss and understand the validation and performance of the sampling methods. Some studies have focused on determining performance criteria for various wipe sampling methods.

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Chavalitnitkul et al. (23) conducted an evaluation of wipe sampling variability using lead oxide dust as the test contaminant. This study aimed to evaluate wipe testing methods in general as well as the OSHA wipe testing method, more specifically, for quantitative recovery and repeatability. The study used moistened Whatman filter paper, commercial paper towels, adhesive paper labels, and adhesive tape as wipe media. Formica (a non-porous, smooth surface) and plywood (a rough, porous surface) were tested. Personal variations in performing wipe sampling were first tested using 12 different individuals to collect samples. A wide variation in removal efficiencies was found across participants, indicating potential issues in duplicating sample results between field staff. Much of the variation was caused by the pressure applied during sampling as well as the lack of a consistent sampling area. Removal efficiencies ranged from 31 percent to 212 percent across the 12 samplers in this portion of the study. The degree of sample variation decreased when the area to be sampled was measured prior to sampling, thus allowing for a consistent sampling area across all samples.

In evaluating the different wipe media and wipe surfaces, as described earlier, Chavalitnitkul et al. (23) found that most Whatman filter paper and moist paper towels gave similar, and good, removal efficiencies (80 to 90 percent). The surface sampled, however, was found to have a significant impact on the removal efficiency of the wipe sample. The smooth, non-porous surface (Formica) showed better removal efficiencies than the rough, porous surface (plywood). Removal efficiencies ranged from 57 percent to 91 percent across all sampling media and various applied pressures on formica, while efficiencies ranged from 30 percent to 77 percent on plywood. For plywood, the adhesive tapes gave better removal efficiencies than the paper towels or Whatman filters used. Applying the maximum pressure while sampling increased the removal efficiency of the adhesive media on both surfaces, but provided little impact for the paper towel and Whatman filter.

As part of another lead dust study, Vostal et al. (24) evaluated the efficacy of the wipe sampling procedure using moist, disposable paper towels on household floors. They found low variability between wipe samples and across four different investigators, indicating that the amount of lead obtained by these wipe samples could be reliably reproduced.

As McArthur describes (5), others have also explored the effect of wipe media, surface, and wipe techniques on the wipe sampling collection efficiency. They have determined, as Chavalitnitkul et al. (23) did, that wipe sampling removal efficiency decreased for rough surfaces. Variation was also found between samples taken by different individuals when the sampling area was estimated instead of measured.

Fenske et al. (25) evaluated the applicability of wipe sampling to determine exposure to pesticides in indoor environments. They sampled chlorpyrifos using a surgical gauze pad wetted with either distilled water or IPA. Wipe samples were taken on carpet and aluminum foil surfaces. Wipe samples were taken using a modification of the OSHA method where a 100 cm<sup>2</sup> area was wiped with three strokes in one direction, then a second gauze pad was used to wipe the same area in an orthogonal direction. Removal efficiency was 86 percent to 96 percent from the spiked aluminum foil samples with low variability between the different technicians taking the samples. For wipe samples taken on carpeted surface, the variability was much higher, 40

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percent to 60 percent. Fenske et al. (25) concluded that much of this variability was related to the deposition of the pesticide onto the carpet, not the wipe sampling itself. They further concluded that wipe sampling provides a simple way of estimating the pesticide residues on a surface, but precision for the method could be improved by defining the wipe area and standardizing materials and methods.

### **3.7 Miscellaneous Notes on Other Surface Sampling Methods**

As noted from the studies discussed in this section, wipe sampling can involve various materials and be used on a variety of surfaces. There are a couple of related sampling techniques that warrant mentioning here, but that do not address the surface wipe sampling that is the focus of this report. Dislodgeable residues from carpets can be determined using wipe sampling, as discussed previously; however, the preferred method of collecting dust samples from carpets is using vacuum sampling. For exposure studies a High Volume Small Surface Sampler (HVS3) is generally used for such a purpose. This is essentially a modified vacuum that uses cyclonic action to collect dust particles from the carpet into an attached sampling container. A sample is taken by vacuuming a given area with overlapping path lengths. An ASTM standard method is available for this technique (26).

EPA studies have also used a polyurethane foam (PUF) roller sampler to determine dislodgeable or transferable residues from floors (15-16, 27-29). The PUF roller generally consists of an aluminum frame with aluminum wheels. A PUF sleeve is placed on the frame and the sample is taken by rolling the sampler back and forth over the selected 100 cm traverse path. This technique was used in CTEPP where a 7.6 cm thick pre-cleaned PUF was used on the roller.

One EPA study compared the PUF roller to the Dow drag sled and the California cloth roller methods to determine which was best at estimating the transfer of chlorpyrifos to carpets and vinyl flooring to skin (27, 28). The PUF roller used in this study is similar to the one discussed previously. The PUF sleeve used in the EPA comparison study measured 90 millimeter (mm) outer diameter x 30 mm inner diameter x 76 mm length. A 100 cm sample length was used, with sampling consisting of one forward and one backward pass of the length. The roller was operated at a rate of 10 centimeters per second (cm/s). The drag sled device consisted of a 3" x 3" piece of 3/4" plywood as the base with an 8 pound weight mounted on top. A pre-cleaned 4" x 4" undyed denim cloth was used on the underside as the sampling media. The sled was pulled by a wire along a 48 inch path at a rate of 10 cm/s. The California roller device resembled a large rolling pin made of polyvinyl chloride pipe. The pipe was 63 cm long, 13 cm in diameter covered with 1 cm thick foam, and filled with steel ball bearings. A 17" x 17" pre-cleaned percale sheet cloth (50 percent cotton, 50 percent polyester) was used to collect the sample by placing the cloth on the sampling area, covering it with the plastic, and pushing the roller over it. The study found the drag sled and PUF roller to be better methods than the cloth roller technique. All three methods had reasonable precision (24 to 46 percent). Transfer efficiencies ranged from 2 percent to 7 percent, with the drag sled method averaging 2.1 percent.

Other exposure studies have also relied on the PUF roller for sampling. Nishioka et al. (15-16, 29) used the sampler to determine the available dislodgeable residue or surface dust of 2,4-D on indoor carpets. The PUF sleeves used were 8 cm long x 8 cm outer diameter. The PUF was pre-

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cleaned before use with water and then 70:30 volume/volume acetonitrile:phosphate buffer. In one of these studies, the PUF was moistened with a 70:30 phosphate buffer:acetonitrile mixture that simulates human sweat, allowing the PUF roller to simulate a child's hand contact with the sampling surface. A 0.48 m<sup>2</sup> area was sampled at a rate of approximately 17 cm/s. The PUF roller provided transfer efficiencies of 0.1 percent to 0.2 percent.

In a study by Lu and Fenske (30), the PUF roller method was compared to wipe sampling to determine which was better at simulating hand pick-up of chlorpyrifos residues from carpet. The PUF sleeve used was 8 cm in length and sampling was conducted over a 100 cm length (total of 800 cm<sup>2</sup> area) using techniques similar to those described previously. The PUF sleeve was misted with DI water before use. The wipes used in this study were 12-ply 7.6 cm x 7.6 cm surgical gauze pads. They were also moistened with DI water before sampling was conducted. In this case, a 100 cm<sup>2</sup> area was wiped. The area was first wiped with three strokes, and then the sampling was repeated with a second pad in the orthogonal direction. Results showed that chlorpyrifos residue transfer as measured by these methods was 23 to 36 times greater than that found from normal carpet to skin transfers.

The Minnesota Children's Pesticide Exposure Study compared two different surface sampling methods to determine which better represents realistic estimates of exposure (31). Malathion, atrazine, diazinon, and chlorpyrifos were measured using the Edwards and Lioy (EL) sampler and the Lioy, Wainman, and Weisel (LWW) surface wipe sampler. The EL sampler is a press sampler designed to collect surface dust from carpets or other surfaces. C18 filters were used and a 150 cm<sup>2</sup> area was sampled. Samples were collected from both carpet and another non-carpeted surface. The LWW sampler consisted of a C18 impregnated Teflon filter wetted with IPA and placed on a pressure plate. A sample was taken by sliding the sampler the length of a 100 cm<sup>2</sup> template three times. Wipe samples from smooth surfaces were collected in this manner. The LWW sampler was determined to not be representative of pesticide residues found on a child's hand from dermal contact with contaminated surfaces. The EL sampler, because it uses only a single hand press, represents what dislodgeable residues are available via one hand contact on the surface, not the total amount that might end up on a child's hand.

Other techniques for assessing surface contamination include directly applying a sensing instrument at or near the surface. Some examples of direct sensing techniques include: X-ray fluorescence devices for metals detection, radiation meters for determining radioactivity, and portable photoionization monitors for detecting volatile organic compounds. The application of these direct-sensing techniques is usually limited to: qualitative (e.g., presence/absence) results, higher detection limits, analyte selectivity, and availability of detection capability for the target analyte. For these reasons, wipe sampling techniques are typically used in conjunction with or instead of direct sensing techniques. For example, as noted previously, the TSA often collects wipe samples of passengers' luggage and then tests the wipes for explosives residue using ion mobility spectrometry, a direct-sensing technique. Because we regard this as more of a direct-sensing method rather than a wipe sampling method, this technique was not researched as part of this report.

For many studies, it is important to understand what amount of contaminants a person has transferred from the surface to his hands. Hand wipe samples or dermal wipes have therefore

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played a major role in many exposure studies. Dermal wipes generally consist of some sort of gauze sponge or cloth being used as the wipe, the wipe being wetted, and then the hand being thoroughly wiped. For the CTEPP study, pre-extracted gauze pads, the same as those used for surface wipes, were wetted with 2 mL of 75 percent IPA in DI water and used for hand wipe samples (12). NHEXAS dermal wipes were similar but used 4 mL of IPA (13). OSHA recommends the use of glass fiber filters, mixed cellulose ester filters or smear tabs, gauze sponges, or charcoal impregnated pads moistened with either DI water or a 50 percent solution of IPA in water (18). McArthur (5) notes the use of ethyl alcohol for dermal wipe samples. Though dermal wipes do not measure the contaminated surface, they can provide a more accurate assessment of a person's exposure to a chemical.

### **3.8 Summary**

Numerous wipe sampling methods were found for different government agencies, such as EPA, OSHA, and NIOSH, and for various sampling studies that have been conducted by different researchers. Wipe media ranged from gauze sponges to Whatman filters to pre-wetted, commercially-available wipes. Wipe sampling methods were found for various compounds, such as metals, PCBs, drugs, and pesticides.

Wipe sampling provides a simple way of testing for contamination on a particular surface and can provide information on the mass of a contaminant on the surface. However, variability in reproducibility and removal efficiencies can result from the lack of standardization within a particular wipe sampling method as well as across various other methods. Simply clearly measuring the area to be sampled can significantly lower this variability. Different surface characteristics can also affect wipe sampling efficiency. It is therefore important that a wipe sampling method be fully validated before it is used so that such performance parameters, as discussed here, can be determined and improved.

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## Chapter 4 Physical and Chemical Properties

### 4.1 Chemical Agents and TICs of Interest

Wipe sampling methods exist for a variety of situations and a diverse number of chemicals. The focus of this report, however, is on a select set of compounds. Table 1 lists the compounds of interest to EPA that are the subject of this literature review. The ultimate goal of this review is to determine what wipe sampling methods are available and have been used for these compounds. Before that can be done, however, it is important to better understand the compounds listed in Table 1. To this end, the physical and chemical properties of each of the compounds of interest listed in Table 1 have been obtained, as available, for this report. The chemical structure of each compound has also been collected. The structures are provided in Appendix A.

Tables 3 through 7 provide a summary of some of the physical properties listed in the MSDS information that was obtained. Characteristics that are provided where available include the chemical family that the compound belongs to; the physical state of the compound; its molecular weight and formula; boiling, freezing, and melting points; vapor pressure and density; and solubility. The information listed in Tables 3 through 7 was gathered from the MSDSs listed in Table 1, two other primary references that were used to fill in gaps in the information (1, 2), and those references discussed in Chapter 2.

There are essentially two major classes of compounds in the following tables: organophosphate (OP) pesticides and CWAs and related compounds (e.g., CWA precursors and degradation products). A couple other compound classes round out the list, such as rodenticides and controlled substances, but the OP pesticides and CWAs and related compounds comprise 83 percent of the compounds of interest to this literature review. Within the group of CWAs, there are two different types: blister agents (see Table 3) and nerve agents (see Table 4). HD, H, HT, Lewisite, and ED are all blister agents. Blister or vesicant agents produce burns and blisters on the skin of those who come in contact with them. The mustard agents (HD, H, and HT) are chemically stable. They are not very soluble in water, but that which does dissolve in water can hydrolyze very quickly. HT is actually a mixture of 60 percent H and 40 percent T (a closely related mustard). Lewisite and ED are organic arsenicals. They have similar properties to the mustard agents but they contain arsenic instead of the sulfur found in mustard agents. Lewisite is often found as a mixture of isomers (Lewisite 1, 2, and 3) and is only slightly soluble in water.

**Table 3. Physical/Chemical Properties of CWAs – Blister Agents**

Compounds	CAS #	Chemical Class	Physical State	Molecular Weight	Molecular Formula	Boiling Point	Freezing Point	Melting Point	Vapor Pressure	Vapor Density (air =1)	Specific Gravity (water =1)	Water Solubility	Solvent Solubility
Mustard Gas (H)/ Distilled Mustard (HD)	505-60-2	organic sulfur compounds	liquid	159.08	C <sub>4</sub> H <sub>8</sub> Cl <sub>2</sub> S	423 °F (217 °C)	57 °F (14 °C)	NA	0.09 mmHg @ 30 °C	5.5	1.2741	very slightly soluble; hydrolysis t <sub>1/2</sub> = 5min @ 25 °C only for what dissolves	fats, oils, organic solvents
Mustard (HT)	172672-28-5	organic sulfur compounds	liquid	263.3 (T)	C <sub>8</sub> H <sub>16</sub> Cl <sub>2</sub> S <sub>2</sub> O (T)	> 228 °C	NA	0.0 - 1.3 °C	0.077 mmHg @ 25 °C	6.5	NA	negligible	most organic solvents
Ethylchloroarsine (ED)	598-14-1	halogenated, aliphatic	liquid	174.89	C <sub>2</sub> H <sub>5</sub> AsCl <sub>2</sub>	NA	< -65 °C	NA	2.29 mmHg @ 21.5 °C	6	1.742 @ 14 °C	decomposes/hydrolyzes immediately	ethyl chloride, alcohol, ether, benzene, acetone, kersone, cyclohexane
Lewisite (1)	541-25-3	halogenated, aliphatic	liquid	207.31	C <sub>2</sub> H <sub>2</sub> AsCl <sub>3</sub>	159.8 °C	32.2 °F (0.1 °C)	NA	0.395 mmHg @ 20 °C	7.1	1.88 @ 20 °C	decomposes/hydrolyzes rapidly	ether, alcohol, organic solvents
Lewisite (2)	40334-69-8	halogenated, aliphatic	liquid	233.36	C <sub>4</sub> H <sub>4</sub> AsCl <sub>3</sub>	230 °C	NA	NA	0.108 mmHg @ 20 °C	NA	1.702 @ 20 °C	NA	NA
Lewisite (3)	40334-70-1	halogenated, aliphatic	liquid	259.39	C <sub>6</sub> H <sub>6</sub> AsCl <sub>3</sub>	215.4 °C	NA	NA	0.217 mmHg @ 25 °C	NA	1.572 @ 20 °C	NA	NA

NA = Not Available

**Table 4. Physical/Chemical Properties of CWAs – Nerve Agents**

Compounds	CAS #	Chemical Class	Physical State	Molecular Weight	Molecular Formula	Boiling Point	Freezing Point	Melting Point	Vapor Pressure	Vapor Density (air =1)	Specific Gravity (water =1)	Water Solubility	Solvent Solubility
Sarin (GB)	107-44-8	esters, halogens, phosphine	liquid	140.11	C <sub>4</sub> H <sub>10</sub> FO <sub>2</sub> P	297 °F (147 °C)	-71 °F (-57 °C)	NA	2.9 mmHg @ 25 °C	4.86	1.10 @ 20 °C	miscible; hydrolysis under acidic conditions; t <sub>1/2</sub> = 80hr @ 20 °C, pH7	organic solvents
Soman (GD)	96-64-0	esters, halogens, phosphine, organophosphorus	liquid	182.19	C <sub>7</sub> H <sub>16</sub> FO <sub>2</sub> P	333 °F (167 °C)	-94 °F (-70 °C)	NA	0.401 mmHg @ 25 °C	6.3	1.026	2.1g GD/100g @ 20 °C; hydrolysis, t <sub>1/2</sub> = 45hr @ pH 6.65	organic solvents
Cyclohexyl sarin (GF)	329-99-7	esters, halogens, phosphine	liquid	180.16	C <sub>7</sub> H <sub>14</sub> FO <sub>2</sub> P	228 °C	-30 to -50 °C	NA	0.0927 mmHg @ 25 °C	6.2	1.128 @ 25 °C	3.7g GF/100g @ 20 °C; hydrolysis, t <sub>1/2</sub> = 42hr @ 20 °C in DI water	organic solvents
Tabun (GA)	77-81-6	organophosphorus, phosphoryls, amides	liquid	162.13	C <sub>5</sub> H <sub>11</sub> N <sub>2</sub> O <sub>2</sub> P	248 °C	-51 °F (-46 °C)	NA	0.07 mmHg @ 25 °C	5.63	1.073 @ 25 °C	7.1g GA/100g @ 20 °C; hydrolyzes, t <sub>1/2</sub> = 8.5 hr @ 20 °C, pH 7	organic solvents
VX	50782-69-9	phosphono, sulfur compounds	liquid	267.36	C <sub>11</sub> H <sub>26</sub> NO <sub>2</sub> PS	568 °F (298 °C)	< -60 °F (< -51 °C)	NA	0.0007 mmHg @ 25 °C	9.2	1.0083 @ 25 °C	30 g/L @ 25 °C; miscible @ 9.4 °C; hydrolysis, varies t <sub>1/2</sub> = 17 - 42 days @ 25 °C, pH 7	lipids; organic solvents

NA = Not Available

**Table 5. Physical/Chemical Properties of CWA Precursors and Degradation Products**

Compounds	CAS #	Chemical Class	Physical State	Molecular Weight	Molecular Formula	Boiling Point	Freezing Point	Melting Point	Vapor Pressure	Vapor Density (air =1)	Specific Gravity (water =1)	Water Solubility	Solvent Solubility
Dimethyl phosphite	868-85-9	phosphoryls, esters, alkyl phosphite	liquid	110.05	C <sub>2</sub> H <sub>6</sub> O <sub>3</sub> P <sup>+</sup>	336-342 °F (169-172 °C)	NA	NA	<1.0 mmHg @ 20 °C	NA	1.2	hydrolyzes	organic solvents
1,4-Dithiane	505-29-3	heterocyclic, sulfur, hydrocarbons	solid	120.24	C <sub>4</sub> H <sub>8</sub> S <sub>2</sub>	390-392 °F (199-200 °C)	NA	226-235 °F (108-113 °C)	NA	NA	NA	slightly soluble	alcohol, carbon tetrachloride, ethanol, ether
Thiodiglycol	111-48-8	hydroxyls, aliphatic, mercaptans	liquid	122.18	C <sub>4</sub> H <sub>10</sub> O <sub>2</sub> S	541 °F (283 °C)	3 °F (-16 °C)	NA	1.3 mmHg @ 42 °C	4.2	1.1852	soluble	ethanol, acetone, methanol, chloroform; <b>Slightly Soluble:</b> ether, benzene, carbon tetrachloride
1,4-Thioxane	15980-15-1	ethers, alicyclic, sulfur compounds, ethers	liquid	104.17	C <sub>4</sub> H <sub>8</sub> OS	297 °F (147 °C)	1 °F (-17 °C)	NA	NA	3.59	1.1174	NA	N/A
Trimethyl phosphite	121-45-9	organic, alkyl phosphites	liquid	124.09	C <sub>3</sub> H <sub>9</sub> O <sub>3</sub> P	232-234 °F (111-112 °C)	-108 °F (-78 °C)	NA	17.0 mmHg @ 20 °C	4.3	1.052	reacts	hexane, benzene, acetone, alcohol, ether, carbon tetrachloride, kerosene, organic solvents

NA = Not Available

**Table 6. Physical/Chemical Properties of OP Pesticides and Other Pesticides**

Compounds	CAS #	Chemical Class	Physical State	Molecular Weight	Molecular Formula	Boiling Point	Freezing Point	Melting Point	Vapor Pressure	Vapor Density (air =1)	Specific Gravity (water =1)	Water Solubility	Solvent Solubility
Chloropicrin	76-06-2	nitro, halogenated, aliphatic	liquid	164.38	CCl <sub>3</sub> NO <sub>2</sub>	234 F (112 °C)	-83 °F (-64 °C)	NA	20 mmHg @ 20 °C	5.7	1.7	0.2% @ 20 °C	alcohol, ether, acetone, benzene, acetic acid
Dichlorvos	62-73-7	heterocyclic, organophosphorous	liquid	220.98	C <sub>4</sub> H <sub>7</sub> Cl <sub>2</sub> O <sub>4</sub> P	183 F (84 °C) @ 1 mmHg	NA	NA	0.012 mmHg @ 30 °C	15.3	1.415 @ 25 °C	1%; hydrolysis, t <sub>1/2</sub> = 20 to 80hrs @ pH 9 to pH 4	organic solvents
Dicrotophos	141-66-2	organophosphorus	liquid	237.21	C <sub>8</sub> H <sub>16</sub> NO <sub>5</sub> P	266 °F (130 °C) @ 0.1 mmHg	NA	NA	NA	NA	1.216	miscible; hydrolysis, t <sub>1/2</sub> = 50 days @ 38 °C pH 9.1	acetone, alcohol, isobutanol, hexylene glycol, xylene
Fenamiphos	22224-92-6	organophosphorus	solid	303.39	C <sub>13</sub> H <sub>22</sub> NO <sub>3</sub> PS	NA	NA	120 °F (49 °C)	negligible	NA	1.14	770 ppm @ 20 °C; hydrolysis, t <sub>1/2</sub> = 4hrs @ pH 7	dichloromethane, isopropanol, organic solvents; <b>Insoluble:</b> aliphatic solvents
Methyl parathion	298-00-0	organophosphorus	solid	263.22	C <sub>8</sub> H <sub>10</sub> NO <sub>5</sub> PS	228 °F (109 °C) @ 0.05 mmHg	NA	97 °F (36 °C)	0.000097 mmHg @ 20 °C	NA	1.358	55-60 ppm @ 25 °C; hydrolysis, 100% degradation in seawater, lakes and rivers in 1 week to 1 month	dichloromethane, isopropanol, organic solvents; <b>Slightly Soluble:</b> aliphatic solvents, light petroleum, mineral oils

Table 6. (continued)

Compounds	CAS #	Chemical Class	Physical State	Molecular Weight	Molecular Formula	Boiling Point	Freezing Point	Melting Point	Vapor Pressure	Vapor Density (air =1)	Specific Gravity (water =1)	Water Solubility	Solvent Solubility
Mevinphos	7786-34-7	organophosphorus	liquid	224.16	C <sub>7</sub> H <sub>13</sub> O <sub>6</sub> P	617 °F (325 °C)	-69 °F (-56 °C)	NA	0.003 mmHg @ 20 °C	7.5	1.25	miscible; hydrolysis, t <sub>1/2</sub> = 35 days @ pH 7	acetone, carbon tetrachloride, chloroform, alcohol, benzene, toluene, xylene; <b>Slightly Soluble:</b> petroleum ether, kerosene, carbon disulfide; <b>Insoluble:</b> hexane
Phorate	298-02-2	organophosphorus	liquid	260.39	C <sub>7</sub> H <sub>17</sub> O <sub>2</sub> PS <sub>3</sub>	244-248 °F (118-120 °C) @ 0.8 mmHg	<5 °F (< -15 °C)	NA	0.00084 mmHg @ 20 °C	NA	1.156	50ppm; hydrolysis, t <sub>1/2</sub> = few days to few weeks in acidic water	carbon tetrachloride, dioxane, xylene, alcohols, esters, ethers, vegetable oils, methyl cellosolve, dibutyl phthalate
Tetraethyl pyrophosphate	107-49-3	organophosphorus	liquid	290.22	C <sub>8</sub> H <sub>20</sub> O <sub>7</sub> P <sub>2</sub>	255 °F	NA	NA	0.00047 mmHg @ 30 °C	NA	1.185	soluble; hydrolysis, t <sub>1/2</sub> = 6.8 hrs @ pH 6	alcohol, benzene, acetone, glycerol, ethylene glycol, propylene toluene, xylene, organic solvents; <b>Insoluble:</b> petroleum oils

NA = Not Available













































