Homeland Security
Science and Technology

Summary

U.S. Department of Homeland Security
SAVER
System Assessment and Validation for Emergency Responders

The U.S. Department of Homeland Security (DHS) established the System Assessment and Validation for Emergency Responders (SAVER) Program to assist emergency responders making procurement decisions.

Located within the Science and Technology Directorate (S&T) of DHS, the SAVER Program conducts objective operational tests on commercial equipment and systems and provides those results along with other relevant equipment information to the emergency response community in an operationally useful form. SAVER provides information on equipment that falls within the categories listed in the DHS Authorized Equipment List (AEL).

The SAVER Program is supported by a network of technical agents who perform assessment and validation activities. Further, SAVER focuses primarily on two main questions for the emergency responder community: "What equipment is available?" and "How does it perform?"

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Guide for the Selection of Chemical Agent and Toxic Industrial Material Detection Equipment for Emergency First Responders, Guide 100-04, Volume I and II

This document focuses specifically on chemical agent (CA) and toxic industrial material (TIM) detection equipment and was developed to assist the emergency responder community in the evaluation and purchase of detection equipment. The information contained in the guide was obtained through literature searches and market surveys. Vendors were contacted multiple times during the preparation of the guide to ensure data accuracy, and information is supplemented with test data from other sources (e.g., Department of Defense) if available. The guide is an update of the Guide for the Selection of Chemical Agent and Toxic Industrial Material Detection Equipment for Emergency First Responders, NIJ Guide 100-04*, published in June 2000.*

Background

The Office of Law Enforcement Standards (OLES) at the National Institute of Standards and Technology (NIST), supported by the Department of Homeland Security (DHS), the Technical Support Working Group (TSWG), the U.S. Army Edgewood Chemical and Biological Center (ECBC), and the Interagency Board for Equipment Standardization and Interoperability (IAB), has developed chemical and biological defense equipment guides. The guides focus on chemical and biological equipment in areas of detection, personal protection, decontamination, and communication.

The primary purpose of the *Guide for the Selection of Chemical Agent and Toxic Industrial Material Detection Equipment for Emergency First Responders* is to provide emergency responders with information to aid them in the selection and utilization of CA and TIM detection equipment. The guide is intended to be more practical than technical and provides information on a variety of factors that should be considered when purchasing and using detection equipment, including sensitivity, detection states, and portability to name a few. Due to the large number of chemical detection equipment items identified in the guide, the guide is separated into two volumes. Volume I represents the actual guide and Volume II serves as a supplement to Volume I since it contains the detection equipment data sheets only.

Chemical Agents

Chemical agents are chemical substances that are intended for use in warfare or terrorist activities to kill, seriously injure, or seriously incapacitate people through their physiological effects. A CA attacks the organs of the human body in such a way that it prevents those organs from functioning normally. The results are usually disabling or even fatal. Chemical agents, when referred to in the guide, refer to nerve and blister agents only. The most common CAs are the nerve agents, GA (Tabun), GB (Sarin), GD (Soman), GF, and VX; the blister agents, HD (sulfur mustard) and HN (nitrogen mustard); and the arsenical vesicants, L (Lewisite).

Nerve Agents

All nerve agents belong to the chemical group of organo-phosphorus compounds; many common herbicides and pesticides also belong to this chemical group. Nerve agents are stable, easily dispersed, highly toxic, and have rapid effects when absorbed both through the skin and the respiratory system. Nerve agents can be manufactured by means of fairly simple chemical techniques. The raw materials are inexpensive but some are subject to the controls of the Chemical Weapons Convention and the Australia Group Agreement.

The nerve agents considered in the guide are described below. The term volatility refers to a substance's ability to become a vapor at relatively low temperatures. A highly volatile (nonpersistent) substance poses a greater respiratory hazard than a less volatile (persistent) substance.

- ***GA***: A low volatility persistent CA that is taken up through skin contact and inhalation of the substance as a gas or aerosol.
- ***GB***: A volatile nonpersistent CA that is mainly taken up through inhalation.
- ***GD***: A moderately volatile CA that can be taken up by inhalation or skin contact.
- ***GF***: A low volatility persistent CA that is taken up through skin contact and inhalation of the substance either as a gas or aerosol.
- ***VX***: A low volatility persistent CA that can remain on material, equipment, and terrain for long periods. Uptake is mainly through the skin but also through inhalation of the substance as a gas or aerosol.

Nerve agents, either as a gas, aerosol, or liquid, enter the body through inhalation or through the skin. Poisoning may also occur through consumption of liquids or foods contaminated with nerve agents. The route of entry also influences the symptoms developed and, to some extent, the sequence of the different symptoms. Generally, the poisoning works fastest when the agent is absorbed through the respiratory system rather than other routes because the lungs contain numerous blood vessels and the inhaled nerve agent can rapidly diffuse into the

the blood circulation and thus reach the target organs. If a person is exposed to a high concentration of nerve agent, death may occur within a couple of minutes.

The poisoning works slower when the agent is absorbed through the skin. Because nerve agents are somewhat fat-soluble, they can easily penetrate the outer layers of the skin, but it takes longer for the poison to reach the deeper blood vessels. Consequently, the first symptoms do not occur until 20 minutes to 30 minutes after the initial exposure but subsequently, the poisoning process may be rapid if the total dose of nerve agent is high.

Blister Agents

There are two major families of blister agents (vesicants): sulfur mustard (HD) and nitrogen mustard (HN), and the arsenical vesicants (L). All blister agents are persistent and may be employed in the form of colorless gases and liquids. They burn and blister the skin or any other part of the body they contact. Blister agents are likely to be used to produce casualties rather than to kill, although exposure to such agents can be fatal.

In its pure state, mustard agent is colorless and almost odorless. It earned its name as a result of an early production method that resulted in an impure product with a mustard-like smell. Mustard agent is also claimed to have a characteristic odor similar to rotten onions. However, the sense of smell is dulled after only a few breaths so after initial exposure the odor can no longer be distinguished. In addition, mustard agent can cause injury to the respiratory system in concentrations that are so low that the human sense of smell cannot distinguish them.

At room temperature, mustard agent is a liquid with low volatility and is very stable during storage. Mustard agent can easily be dissolved in most organic solvents but has negligible solubility in water. In aqueous solutions, mustard agent decomposes into nonpoisonous products by means of hydrolysis but, since only dissolved mustard agent reacts, the decomposition proceeds very slowly. Oxidants such as chloramine, however, react violently with mustard agent, forming nonpoisonous oxidation products. Consequently, these substances are used for the decontamination of mustard agent.

Arsenical vesicants are not as common or as stable as the sulfur or nitrogen mustards. All arsenical vesicants are colorless to brown liquids. They are more volatile than mustard and have fruity to geranium-like odors. These types of vesicants are much more dangerous as liquids than as vapors. Absorption of either vapor or liquid through the skin in adequate dosage may lead to systemic intoxication or death.

Most blister agents are relatively persistent and are readily absorbed by all parts of the body. Poisoning may also occur through consumption of liquids or foods contaminated with blister agents. These agents cause inflammation, blisters, and general destruction of tissues.

In the form of gas or liquid, mustard agent attacks the skin, eyes, lungs, and gastrointestinal tract. Internal organs, mainly blood-generating organs, may also be injured as a result of mustard agent being taken up through the skin or lungs and transported into the body. Since mustard agent gives no immediate symptoms upon contact, a delay of between 2 hours and 24 hours may occur before pain is felt and the victim becomes aware of what has happened. By then, cell damage has already occurred. The delayed effect is a characteristic of mustard agent.

Toxic Industrial Materials

Toxic industrial materials are chemicals other than chemical warfare agents that have harmful effects on humans. Toxic industrial materials, often referred to as toxic industrial chemicals (TICs) are used in a variety of settings such as manufacturing facilities, maintenance areas, and general storage areas. While exposure to some of these chemicals may not be immediately dangerous to life and health, these compounds may have extremely serious effects on an individual's health after multiple low-level exposures.

Although they are not as lethal as the highly toxic nerve agents, TIMs' ability to make a significant impact on the populace is assumed to be more related to the amount of chemical a terrorist can employ on the target(s) and less related to their lethality. None of these compounds are as highly toxic as the nerve agents, but they are produced in very large quantities (multi-ton) and are readily available; therefore, they pose a far greater threat than CAs.

For instance, sulfuric acid is not as lethal as the nerve agents, but it is easier to disseminate large quantities of sulfuric acid because of the large amounts that are manufactured and transported every day. It is assumed that a balance is struck between the lethality of a material and the amount of materials produced worldwide. Other toxic chemicals such as hydrogen cyanide (characterized as a chemical blood agent by the military) or phosgene (characterized as a choking agent) are included as TIMs.

TIMs are ranked into one of three categories—high, medium, low—that indicate their relative importance and assist in hazard assessment. High Hazard indicates a widely produced, stored, or transported TIM that has high toxicity and is easily vaporized. Medium Hazard indicates a TIM that may rank high in some categories but lower in others such as number of producers, physical state, or toxicity. Low Hazard indicates that this TIM is not likely to be a hazard unless specific operational factors indicate otherwise. Table 1 lists TIMs by hazard index (see Page 5).

Overview of Chemical Agent and TIM Detection Technologies

The applicability of CA and TIM detection equipment to potential user groups will be dependent upon the characteristics of the detection equipment, as well as the type of CA or TIM detected and the objective of the emergency responder unit. Numerous technologies are available for the detection of CA and TIM vapors; some technologies are available for detection and identification of liquid droplets of CAs on surfaces; and many laboratory-based technologies exist for detection of TIMs in water. The quality of analytical results from the various analyzers is dependent upon the ability to effectively sample the environment and get the sample to the analyzer.

Equipment designed for vapor detection will not be readily applicable for detection of low volatility liquid contamination on surfaces or contamination in water. In addition, vapor detection equipment could have difficulty in identifying a small amount of CA or TIM in a high background of nonhazardous environmental chemicals. For example, a chemical vapor detector may readily detect trace levels of CAs or TIMs in a rural setting such as a forest or an open field, but the same detector may not be capable of detecting the same level of CA or TIM in an urban setting such as a crowded subway station or busy city street. More urban (continued on page 6)

High	Medium	Low
Ammonia	Acetone cyanohydrin	Ally isothiocyanate
Arsine	Acrolein	Arsenic trichloride
Borontrichloride	Acrylonitrile	Bromine
Boron trifluoride	Allyl alcohol	Bromine chloride
Carbon disulfide	Allylamine	Bromine pentafluoride
Chlorine	Allyl chlorocarbonate	Bromine trifluoride
Diborane	Boron tribromide	Carbonyl fluoride
Ethylene oxide	Carbon monoxide	Chlorine pentafluoride
Fluorine	Carbonyl sulfide	Chlorine trifluoride
Formaldehyde	Chloroacetone	Chloroacetaldehyde
Hydrogen bromide	Chloroacetonitrile	Chloroacetyl chloride
Hydrogen chloride	Chlorosulfonic acid	Crotonaldehyde
Hydrogen cyanide	Diketene	Cyanogen chloride
Hydrogen fluoride	1,2-Dimethylhydrazine	Dimethyl sulfate
Hydrogen sulfide	Ethylene dibromide	Diphenylmethane-4,4'-diisocyanate
Nitric acid, fuming	Hydrogen selenide	Ethyl chloroformate
Phosgene	Methanesulfonyl chloride	Ethyl chlorothioformate
Phosphorus trichloride	Methyl bromide	Ethyl phosphonothioic dichloride
Sulfur dioxide	Methyl chloroformate	Ethyl phosphonic dichloride
Sulfer acid	Methyl chlorosilane	Ethyleneimine
Tungsten hexafluoride	Methyl hydrazine	Hexachlorocyclopentadiene
	Methyl isocyanate	Hydrogen iodide
	Methyl mercaptan	Iron pentacarbonyl
	Nitrogen dioxide	Isobutyl chloroformate
	Phosphine	Isopropyl chloroformate
	Phosphorus oxychloride	Isopropyl isocyanate
	Phosphorus pentafluoride	n-Butyl chloroformate
	Selenium hexafluoride	n-Butyl isocyanate
	Silicon tetrafluoride	Nitric oxide
	Stibine	n-Propyl chloroformate
	Sulfur trioxide	Parathion
	Sulfuryl chloride	Perchloromethyl mercaptan
	Sulfuryl fluoride	sec-Butyl chloroformate
	Tellurium hexafluoride	tert-Butyl isocyanate
	n-Octyl mercaptan	Tetraethyl lead
	Titanium tetrachloride	Tetraethyl pyroposphate
	Trichloroacetyl chloride	Tetramethyl lead
	Trifluoroacetyl chloride	Toluene 2,4-diisocyanate
		Toluene 2,6-diisocyanate

Table 1. Toxic industrial materials listed by hazard index

environments typically contain many chemicals produced by everyday human activities (driving an automobile, deodorant/ perfumes use, insecticide/herbicide application, etc.) that look like a CA or TIM to the detection equipment and may affect the reliability (number of false readings) of the instrument as well as its sensitivity. However, by testing the equipment prior to an emergency use, the operator can become familiar with the idiosyncrasies of the detection equipment when exposed to various environmental chemicals expected in operational areas. As technological advances continue to be made, more effective and accurate methods of detection that are less affected by environmental chemicals in operational areas will become commercially available at lower costs.

Chemical agents can be detected by several means that incorporate various technologies. The technologies discussed in this guide are grouped into three major categories: point detection, standoff detection, and analytical instruments. The technology needed for CA and TIM detection will be dependent on the CA agent or TIM used and the objective of the emergency responder unit.

Point Detection Technologies

Point detection technology is applicable in determining the presence of CA or TIM and can be used to map out contaminated areas if enough time is available. Point detectors can be used as warning devices to alert personnel to the presence of a toxic vapor cloud. In this scenario, the detector is placed up-wind of the first responder location. When the toxic chemical is carried towards this location, it first encounters the detector, thus sounding an alarm and allowing the emergency responders to don the necessary protective clothing. It should be noted that if the concentration of CA or TIM is high enough to be immediately life threatening, point detectors may not provide sufficient time to take protective measures.

Another use of a point detector would be to monitor the vapor contamination originating from a decontamination site. Point detectors can also be used during post-release triage to determine the contamination level of each person (i.e., highly contaminated personnel, lightly contaminated personnel, and uncontaminated personnel) with the idea that all contaminated people need rapid decontamination while noncontaminated people do not need to be decontaminated. This allows for conservation of decontamination resources and prevents wasted effort on noncontaminated personnel. The following point detection techniques were identified in the guide:

- Ionization/Ion Mobility Spectrometry (18 items identified)
- Flame Photometry (7 items identified)
- Infrared Spectroscopy (5 items identified)
- Electrochemistry (63 items identified)
- Colorimetric (24 items identified)
- Surface Acoustic Wave (4 items identified)
- Photoionization Detection (8 items identified)
- Thermal and Electrical Conductivity (2 items identified)
- Flame Ionization (1 item identified)
- Polymer Composite Detection Materials (1 item identified)

Standoff Detectors

Standoff detectors are used to give advance warning of a CA cloud. Standoff detectors typically use optimal spectroscopy and can detect CAs at distances as great as 5 km. Agent-free spectra are used as a baseline to compare with freshly measured spectra that may contain CA. Standoff detectors are generally difficult to operate and usually require the operator to have some knowledge of spectroscopy in order to interpret results. Passive standoff detectors collect infrared radiation emitted and/or measure infrared radiation absorbed from the background to detect CA and TIM vapor clouds. The following standoff techniques were identified in the guide:

- Fourier Transform Infrared and Forward Looking Infrared (6 items identified)
- Ultraviolet Spectroscopy (1 item identified)

Analytical Instruments

Analytical instruments can be used to analyze samples as small as a few microliters or milligrams. They are designed to differentiate between and accurately measure the unique chemical properties of different molecules. Accuracy and reliability requires that only very pure reagents be used, very rigid protocol and operating procedures be followed, and careful handling be employed to prevent contamination and malfunction. Since the instruments do not display the measured data in a straightforward manner, interpretation of the measured data generally requires a technical background and extensive formal training. This typically precludes their use outside of a laboratory environment, which is staffed by technically trained people. However, some analytical instruments have been developed for field applications. The following analytical techniques were identified in the guide:

- Mass Spectrometry (15 items identified)
- Gas Chromatography (14 items identified)
- High Performance Liquid Chromatography (4 items identified)
- Ion Chromatography (1 item identified)
- Capillary Zone Electrophoresis (1 item identified)

Detection Equipment Selection Factors

The guide recommends the emergency responder community consider 16 selection factors when selecting and purchasing CA and TIM detection equipment. The selection factors were compiled by a panel of scientists and engineers with multiple years of experience and relevant expertise in the areas of CA and TIM detection, identification and analysis, domestic preparedness, and identification of emergency responder needs. The factors have also been shared with the emergency responder community in order to obtain their thoughts and comments. The following analytical techniques were identified in the guide:

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- Chemical agents detected
- Toxic industrial materials detected
- Sensitivity
- Resistance to interferents
- Response time
- Start-up time
- Detection states
- Alarm capability
- Portability
- Battery needs
- Power capabilities
- Operational environment
- Durability
- Unit cost
- Operator skill level
- Training requirements.

Equipment Evaluation

The market survey conducted for CA and TIM detection equipment identified 186 different pieces of detection equipment. The details of the market survey to include data on each piece of equipment are provided in *Volume II* of the guide. Each equipment item was evaluated against the 16 selection factors and the results are presented in *Volume I.*

In order to display the evaluation results in a meaningful format, the detection equipment was grouped into seven categories based on the prospective manner of usage by the emergency responder community. These usage categories included the following:

- Handheld-portable detection equipment (92 equipment items identified)
- Handheld-stationary detection equipment (31 equipment items identified)
- Vehicle-mounted detection equipment (5 equipment items identified)
- Fixed-site detection systems equipment (16 items identified)
- Fixed-site analytical laboratory systems (13 equipment items identified)
- Standoff detection systems items (4 equipment identified)
- Detection systems with limited data (25 equipment items identified).

Along with the evaluation results of the 186 pieces of detection equipment, a series of questions are offered that should assist officials in selecting products from the large number in the present day marketplace.

For more information, or for reports on other technologies, visit the SAVER Web site (https://www.rkb.us/saver).