technical BRIEF

www.epa.gov/nhsrc

Technology Performance Summary for Chemical Detection Instruments

Sixteen Instruments Tested to Determine Their Capability to Screen Samples Submitted to All Hazards Receipt Facilities

All Hazards Receipt Facilities (AHRFs) were developed to prescreen for chemical, radiochemical, and explosive hazards in samples collected during suspected terrorist attacks. The technologies (i.e., instruments) used in AHRFs are intended to screen samples prior to a full analysis, helping protect responders, laboratory workers, and others from potential injury.

Evaluations of these technologies are summarized in two technology evaluation reports:

1) *Testing of Screening Technologies for Detection of Chemical Warfare Agents in All Hazards Receipt Facilities* (CWAs)

2) *Testing of Screening Technologies for Detection of Toxic Industrial Chemicals in All Hazards Receipt Facilities* (TICs)

The chemicals included in the reports were chosen because they might be used during, or develop as a by-product from, a terrorist attack.

The screening technologies are intended:

- To be rapid and qualitative
- To be simple to use and of relatively low cost
- To indicate if samples contain hazardous chemicals of concern.

Not all of the technologies evaluated were deemed suitable for the AHRF, although they might be useful for on scene responders.

As part of USEPA's Office of Research and Development, the National Homeland Security Research Center (NHSRC) provides products and expertise to improve our nation's ability to respond to environmental contamination caused by terrorist attacks on our nation's water infrastructure, buildings and outdoor areas.

NHSRC conducts research related to

- Detecting and containing contamination from chemical, biological and radiological agents
- Assessing and mitigating exposure to contamination
- Understanding the health effects of contamination
- Developing risk-based exposure advisories
- Decontaminating and disposing of contaminated materials.

Technology Descriptions

The screening technologies tested were chosen based on a review of commercially available detection devices. From the variety of detection instruments reviewed, 16 screening technologies were selected for testing based on their suitability for use in AHRFs.

The 16 technologies ranged from simple test papers, kits, and color-indicating tubes to hand-held electronic detectors based on ion mobility spectrometry (IMS), photoionization detection (PID), and flame spectrophotometry (FSP). Each technology was tested with three replicate samples for each matrix (vapor, liquid, or on a surface) containing either a CWA or TIC. CWAs and TICs were tested at concentrations known to be hazardous to humans within a few minutes of exposure (e.g., AEGL = Acute Exposure Guide Level (www.epa.gov/opptintr/aegl) and RDT&E = Research, Development,

This document does not constitute nor should be construed as an EPA endorsement of any particular product, service, or technology.

Test, and Evaluation Standards (Chemical Surety, Chapter 6: Army Regulation 50-6, 26 June 2001)).

The following performance parameters were evaluated for each technology:

- Identifying the number of false positives/false negatives and the repeatability of test results
- Time in which the instrument detected the presence of a chemical (i.e., response time)
- Operational information including ease of use and response indication (e.g., color change indicating chemical detection)
- Cost including initial, sample, and continuing operating costs.

Technologies were tested to determine their detection capability for the following hazardous chemicals in different matrices:

Vapor	Liquid	Surface
Hydrogen cyanide	Cyanide	Nerve agent (VX)
Cyanogen chloride	Hydrogen peroxide	
Phosgene	Fluoride	
Chlorine	Sarin	
Hydrogen sulfide	Sulfur mustard	
Arsine	Nerve agent (VX)	
Sarin		
Sulfur mustard		

Testing Methodologies

Each technology was tested with one chemical target agent at a time.

Vapor Testing – Each screening technology was first sampled (or was exposed to) the clean air flow, and any response or indication from the screening technology was noted. After this background measurement, the 4-way valve was switched to the challenge plenum to deliver the target gas. The sequence of exposure to clean air, followed by exposure to the target gas, was carried out three times for each screening technology.

The test apparatus used to evaluate the technologies allowed both the temperature and relative humidity (RH) to be adjusted. For each technology, the test sequence of three clean air blanks interspersed with three target gases was conducted under four different conditions (i.e., base temperature and RH; elevated temperature and RH; low temperature and RH; and base temperature and RH with an interferent, a mixture of hydrocarbons representative of polluted urban air). Testing at the base temperature and RH was conducted first, and if a technology failed under this condition, then no tests were conducted using the other three conditions.

Liquid Testing – For CWAs, testing was conducted for technologies and target agents in liquid samples that were diluted in isopropyl alcohol (IPA) or deionized (DI) water. The detection device was tested with three blank samples of the solvent used (IPA or DI water) and three samples of the test solution containing the target agent. If a technology detected the chemical in at least one of the three samples in the pure solvent, then the challenge was repeated with a hydrocarbon mixture interferent (1% of the total volume) added to both the blank and challenge samples.

This document does not constitute nor should be construed as an EPA endorsement of any particular product, service, or technology.

For TICs, samples were prepared in DI water, in municipal tap water, and in DI water containing 3.0% sodium chloride by weight to simulate potential interfering sample matrices that might be encountered. Each screening technology was tested with three blank samples and with three samples containing the TICs. If the instrument failed to detect a TIC in all three challenge samples with the DI water matrix, then no tests were conducted with that TIC in tap or salt water.

Surface Testing – Testing was conducted for each technology using three blank glass coupons and three glass coupons spiked with the nerve agent VX. All tests were conducted at room temperature and approximately 50% relative humidity. For those technologies that correctly indicated the presence of VX in at least one of these three tests, interference tests were then conducted by spiking approximately 1 mg of interferent per coupon onto both the blank and VX-spiked coupons. Additionally, for these same technologies, the blank and spiked coupon tests (without interferent) were repeated at the same low and high temperature and relative humidity conditions used in the vapor testing.

Test Results

Table 1 provides a summary of the detection capability of the screening technologies tested. The following summarizes the testing information for each matrix form:

Vapor

- Draeger Civil Defense Kit (CDK) detected 6 of 7 chemicals 100% of the time
- Sensidyne Gas Detector Tubes detected 5 of 5 chemicals 100% of the time
- Draeger Chip Measurement System (CMS) Analyzer, MSA Single CWA Sampler Kit, and Nextteq Civil Defense Kit (CDK) detected 4 chemicals 100% of the time (out of 4, 5, and 5 chemicals tested, respectively)
- Anachemia CM256A1, Safety Solutions HazMat Smart-Strip® (SS), and Truetech M183A detected 2 of 4 chemicals 100% of the time and Proengin AP4C detected 2 of 6 chemicals 100% of the time
- Anachemia C2 and RAE Systems MultiRAE Plus detected 1 chemical 100% of the time (out of 5 and 8 chemicals tested, respectively)
- Smiths Detection APD2000® did not detect either of the 2 chemicals tested 100% of the time.

Liquid

Due to the lack of acceptable results, samples that were diluted with isopropyl alcohol for CWA testing were not factored into the Table 1 summary results. One explanation for the lack of acceptable results may be that the technologies were not designed for application using non-aqueous solvents.

- Truetech M272 Water Kit detected 3 of 3 chemicals 100% of the time
- Severn Trent Services Eclox™ Strip detected 2 of 2 chemicals 100% of the time
- Proengin AP4C and Safety Solutions HazMat Smart-Strip® detected 1 chemical 100% of the time (out of 4 and 5 chemicals, respectively)
- Anachemia C2, Anachemia CM256A1, and Nextteq CDK did not detect any chemical 100% of the time (3 chemicals tested).

Surface

- All of the tested instruments detected the presence of VX 100% of the time, regardless of temperature, relative humidity, or presence of interferent.

False Negatives and Positives

This document does not constitute nor should be construed as an EPA endorsement of any particular product, service, or technology.

False negative results indicate that the screening technology was not able to detect the presence of a chemical known to be present. This information is factored into the test results provided in Table 1 and in the summary information above.

Testing for false positive responses was done using "clean" blank samples (i.e., clean air in the vapor testing, pure solvents in the liquid testing, and a clean coupon in the surface testing) or interferent blank samples (i.e., samples with the hydrocarbon mixture interferent, but without any test chemical present). Few false positives occurred. The following summarizes these occurrences:

Vapor

- False positive sarin responses occurred in all three interferent blank samples using Draeger CDK and the MSA Single CWA Kit
- One false positive sulfur mustard response occurred in the three interferent blank samples using Smiths Detection APD2000®.

Liquid

- As indicated, false positives were observed only in the IPA blank samples, which was likely due to incompatibility of the screening technologies with that solvent. Proengin AP4C, in particular, responded positively to every IPA blank sample.

Surface

- Two false positive responses occurred using the Proengin AP4C at the high temperature and relative humidity condition.

<u>Repeatability</u>

Repeatability for the presence of TICs was tested for those instruments yielding quantitative results (i.e., Draeger CMS Analyzer, RAE Systems MultiRAE Plus, and Sensidyne Gas Detector Tubes). Quantitative results were recorded for each of the triplicate tests, and repeatability was calculated in terms of percent relative standard deviation (% RSD). The following summarizes the test information:

- 32 of the 40 results had less than 15% RSD
- Over half of the results (22 of 40) had less than 10% RSD
- Several % RSD values exceeded 20% (e.g., Draeger CMS Analyzer for hydrogen cyanide and chlorine).

Note: The PID principle of the MultiRAE Plus was not necessarily expected to respond to TICs or CWAs tested as part of this evaluation (see Table 1); however, it was tested based on the instrument's promotion as a general toxic compound detector.

Conclusions from this testing indicate that these instruments can provide reproducible results; however, this cannot be assumed to be the case under different environmental conditions (i.e., varying temperature and relative humidity) or with different concentrations.

Operational Information

Table 2 provides operational information on the 16 screening technologies tested. Information included in the table includes:

- Response time information (seconds or minutes to obtain an instrument response)
- Ease of use
- Response indication (e.g., detection is indicated by color change)
- Initial cost.

<u>Response and Ease of Use Information</u>

This document does not constitute nor should be construed as an EPA endorsement of any particular product, service, or technology.

The speed and simplicity of the vapor screening process varied widely among the tested technologies. Ease of use was not necessarily correlated with instruments' detection capabilities. The following provides some general highlights on response time and ease of use for each sample matrix:

Vapor

- Color-indicating tube technologies were simple to use in principle, but differed in the time and difficulty of obtaining samples.
  - The number of manual pump strokes required to draw in the air sample ranged widely, as did the manual effort needed for those technologies requiring multiple pump strokes.
  - Nextteq CDK used an electric air sampling pump that greatly reduced the physical effort needed; however, it still required a few minutes to draw the required sample volume.
- The three real-time technologies tested (RAE Systems MultiRAE Plus, Proengin AP4C, and Smiths Detection APD2000®) provided easy and rapid sample analysis for chemicals in vapor; however, there was a wide range in instruments' detection capability.
- Safety Solutions HazMat Smart-Strip® was the simplest technology, requiring only removal of a protective film to expose the indicating patches on the card. The detection response occurred within seconds.
- Color-indicating tubes that require the minimum sample volume are preferable for use in AHRFs. Additionally, the use of an electrical sampling pump is helpful if a large numbers of samples are to be screened.

Liquid and Surface

- For surface samples, M8, M9, and 3-way indicating papers were especially easy to use and responses typically occurred within seconds.
- For liquid samples, Severn Trent Services Eclox™ Strip and Truetech M272 Water Kit were relatively easy to use and responses occurred within minutes.
- Analysis of liquid and surface samples with Proengin AP4C was relatively rapid because the detector's attachments were simple to use.

During homeland security events, it would be important for the technologies to screen for multiple chemicals simultaneously. Technologies using multiple color-indicating tubes at once provide this capability. Proengin AP4C provided multi-chemical detection and could be used to detect chemicals in vapor, liquid, and surface samples.

<u>Cost</u>

The initial cost of the technologies varied substantially, ranging from a few hundred to a few thousand dollars. The two exceptions were Proengin AP4C at a discounted cost of nearly $16,000 and Smiths Detection APD2000® at a cost of $10,000. Comparing purchase prices of different technologies can be misleading. Many of the technologies can screen relatively few samples with the originally supplied materials. For example, several technologies that rely on color-indicating tubes initially come with only enough tubes to screen 10 to 40 samples. Testing larger numbers of samples requires additional tubes. All technologies tested require consumable items such tubes and batteries. Simple test papers are the least expensive, with costs estimated at less than $0.50 per sample. Most technologies tested had similar costs per sample, typically ranging from $4 to $20 per sample.

For more information about the technologies evaluated for use in AHRFs, or by first responders, visit the NHSRC Web site at www.epa.gov/nhsrc, or view the full reports, *Testing of Screening Technologies for Detection of Chemical Warfare Agents in All Hazards Receipt Facilities* at:

http://cfpub.epa.gov/si/si_public_record_report.cfm?address=nhsrc/&dirEntryId=182964

February 2011
EPA/600/S-09/015

This document does not constitute nor should be construed as an EPA endorsement of any particular product, service, or technology.

and *Testing of Screening Technologies for Detection of Toxic Industrial Chemicals in All Hazards Receipt Facilities* at:

http://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=189630

Principal Investigator: Eric Koglin
Feedback/Questions: Kathy Nickel (513) 569-7955

February 2011
EPA/600/S-09/015

This document does not constitute nor should be construed as an EPA endorsement of any particular product, service, or technology.

Table 1. Instrument Detection/Screening Capabilities for Various Hazardous Chemicals in Vapor, Liquid, and/or Solid Form[a]

Technology Vender (Instrument Name)	TIC Vapor Testing Accurately Detected Results (%)						CWA Vapor Testing Accurately Detected Results (%)		TIC Liquid Testing Accurately Detected Results (%)			CWA Liquid Testing Accurately Detected Results[b] (%)			CWA Surface Testing Accurately Detected Results (%)
	Hydrogen cyanide	Cyanogen chloride	Phosgene	Chlorine	Hydrogen sulfide	Arsine	Sarin	Sulfur mustard	Cyanide	Hydrogen peroxide	Fluoride	Sarin	Sulfur mustard	VX Nerve agent	VX Nerve agent
Agentase (CAD Kit)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	100
Anachemia (C2)	0	0	0	NA	NA	NA	100	25	NA	NA	NA	0	0	0	100
Anachemia (CM256A1)	100	100	NA	NA	NA	NA	0	0	NA	NA	NA	0	0	0	100
Draeger (CMS Analyzer)	100	NA	100	100	100	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Draeger (CDK)	100	92	100	100	NA	100	100	100	NA	NA	NA	NA	NA	NA	NA
MSA (Single CWA Detector Kit)	100	100	100	NA	NA	NA	100	0	NA	NA	NA	NA	NA	NA	NA
Nextteq (CDK)	100	100	100	NA	NA	NA	0	100	NA	NA	NA	0/0/0[c]	83/0/0[c]	33/0/0[c]	100
Proengin (AP4C)	75	0	NA	NA	82	100	100	0	0	NA	NA	100	83	0	100
RAE Systems (MultiRAE Plus)[d]	0	0	0	0	100	0	0	0	NA	NA	NA	NA	NA	NA	NA
Safety Solutions (HazMat Smart-Strip®)	0	NA	NA	100	100	NA	0	NA	0	100	0	0	NA	0	NA
Safety Solutions (HazMat Smart-M8®)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0	0	0	100
Sensidyne (Gas Detector Tube)	100	NA	100	100	100	100	NA	NA	NA	NA	NA	NA	NA	NA	NA
Severn Trent Services (Eclox™ Strip)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	100	NA	100	NA
Smiths Detection (APD2000®)	NA	NA	NA	NA	NA	NA	0	75	NA	NA	NA	NA	NA	NA	NA
Truetech (M272 Water Kit)	NA	NA	NA	NA	NA	NA	NA	NA	100	NA	NA	100	NA	100	NA
Truetech (M18A3)	100	0	75	NA	NA	NA	100	NA	NA	NA	NA	0	0	0	100

Note: Information was derived from the *Testing of Screening Technologies for Detection of Toxic Industrial Chemicals in All Hazards Receipt Facilities* and the *Testing of Screening Technologies for Detection of Chemical Warfare Agents in All Hazards Receipt Facilities*. Technologies were tested to determine their ability to accurately detect hazardous chemical in various matrices, at various environmental conditions, or with the addition of an interferent (Refer to the text in this brief or to the reports for specific details). The % of accurately detected results is based on the number of samples each technology accurately detected each target chemical (within an acceptable concentration range). Ranges were based on chemical concentrations that would cause irreversible or long-lasting adverse health effects (e.g., AEGL = Acute Exposure Guideline Level).

[a]NA = Not applicable, Green = Technology accurately detected chemical 100% of the time, Yellow = Technology accurately detected chemical >0% and <100% of the time, Red = Technology did not accurately detect chemical at all (0% of the time), TIC = Toxic industrial chemicals, and CWA = Chemical warfare agents.

[b]Due to the lack of acceptable results, samples that were diluted with isopropyl alcohol were not factored into the % of accurately detected results. One explanation for the lack of acceptable results may be that the technologies were not designed for application using non-aqueous solvents.

[c]Results for to M8 paper, M9 paper, and 3-way paper, respectively.

[d]The PID principle of the MultiRAE Plus was not necessarily expected to respond to TICs or CWAs tested as part of this evaluation; however, it was tested based on the instrument's promotion as a general toxic compound detector.

February 2011
EPA/600/S-09/015

This document does not constitute nor should be construed as an EPA endorsement of any particular product, service, or technology.

Table 2. Performance Factors Including Response Time, Operational Information, and Cost Associated with Hazardous Chemical Detection Technologies

Technology Vender (Name)	Technology Type	Matrix (Chemical Type)[a]	Response Time Information[b]	Operational Information	Instrument Cost[c]
Agentase (CAD Kit)	Color-indicating pen	Surface (CWA)	Seconds – Response (color change) within 1 second at room conditions and up to 26 seconds at low temperature/relative humidity or with interferent present	Simple procedure	$286
Anachemia (C2)	Color tubes	Vapor (TIC and CWA)	Minutes – A few minutes needed for pump strokes (40 strokes for CWAs and 10 for TICs)	Relatively complex procedure Arm/hand strength needed for pump	$684
	Color ticket	Vapor (CWA)	Minutes – Response (color change) within 2 minutes	Simple procedure	
	3-way paper	Surface (CWA)	Seconds – Response (color change) within 5 seconds	Simple procedure	
Anachemia (CM256A1)	Multifunction card	Vapor (TIC and CWA)	Minutes – Response (color change) occurs within several seconds after exposure and manipulation of card takes up to one minute	Simple procedure Breakage of two green ampules at the same time creates fumes and green liquid spray	$189
	3-way paper	Surface (CWA)	Seconds – Response (color change) within 5 seconds	Simple procedure	
Draeger (CMS Analyzer)[d]	Multicolor tubes on a chip	Vapor (TIC)	Minutes – Automated color tube sampler and reader take several minutes for a reading	Simple procedure Misaligned gears can cause chips to become unusable	$1,922
Draeger (CDK)	Color tubes	Vapor (TIC and CWA)	Seconds – Initial response within a few pump strokes; a few minutes required for requisite 50 pump strokes Five compounds can be tested at one time	Simple procedure Easily distinguishable color changes Arm/hand strength needed for pump	$3,114
MSA (Single CWA Detector Kit)	Color tubes	Vapor (TIC and CWA)	Minutes – 2 minutes (30 pump strokes) needed for noticeable color change. Note: The time for noticeable color change depends on concentration of analyte	Simple procedure Arm/hand strength needed for pump Some color changes difficult to distinguish	$1,295
Nextteq (CDK)	Color tubes	Vapor (TIC and CWA)	Minutes – Sample drawn for 3.5 minutes; time for noticeable color change depends on concentration of analyte; required sample volume takes several minutes with electric pump Five compounds can be tested at one time	Simple procedure Some color changes difficult to distinguish	$1,875
	M8 paper	Liquid and Surface (CWA)	Seconds – Response (color change) within about 10 seconds with liquid and surface samples	Simple procedure	
	M9 paper	Surface (CWA)	Seconds – Response (color change) within 25 seconds	Simple procedure	
	3-way paper	Surface (CWA)	Seconds – Response (color change) within 5 seconds	Simple procedure	
Proengin (AP4C)[d]	Flame spectrometer	Vapor (TIC and CWA)	Seconds – Response typically occurs within a few seconds	Simple procedure of starting device and observing readings from vapors or taking samples and observing readings from liquids and surface samples With regular use, batteries and low-pressure hydrogen supplies need replacement periodically	$15,708[e] (discount for testing)
		Liquid (TIC and CWA)	Seconds – Response within 10 seconds. Note: It takes less than 1 minute to install instrument parts necessary to collect liquid samples.		
		Surface (CWA)	Seconds – Response within 25 seconds		

This document does not constitute nor should be construed as an EPA endorsement of any particular product, service, or technology.

Technology Vender (Name)	Technology Type	Matrix (Chemical Type)[a]	Response Time Information[b]	Operational Information	Instrument Cost[c]
RAE Systems (MultiRAE Plus)[d]	PID	Vapor (TIC)	Seconds – Response within approximately 15 seconds	Simple procedure	$3,290
Safety Solutions (HazMat Smart-Strip®)	Multifunction card	Vapor (TIC)	Seconds – Response (color change) within several seconds	Simple procedure of peeling of protective cover for immediate use Some color changes difficult to distinguish	$20
		Liquid (TIC)	Seconds – Response (color change) within a few seconds		
Safety Solutions (HazMat Smart-M8®)	M8 paper	Surface (CWA)	Seconds – Response (color change) typically within 5 seconds	Simple procedure of peeling of protective cover for immediate use	$6
Sensidyne (Gas Detector Tube)[d]	Color tubes	Vapor (TIC)	Seconds – Response (color change) within a few seconds (1 minute needed per pump stroke). Note: Analytes tested required only one pump stroke. Only one TIC can be tested at a time	Simple procedure Number of pump strokes needed depends on suspected concentration	$532
Severn Trent Services (Eclox™ Strip)	Color ticket	Liquid (CWA)	Minutes – Response within 3 minutes due to reaction time needed for color change.	Simple procedure	$510
Smiths Detection (APD2000®)	Ion mobility	Vapor (CWA)	Seconds – Most responses within 30 seconds	Simple procedure The provided chemical surrogate vapor source allows for rapid indication of proper operation Contains a small radioactive source	$9,620
Truetech (M272 Water Kit)	Color tubes	Liquid (TIC)	Minutes – Response requires several minutes due to complexity of required procedure	Relatively complex procedure Requires 60 mL of sample and multiple steps for detection Minimal effort but time consuming	$386
	Color ticket	Liquid (CWA)	Minutes – Response within 3 minutes due to reaction time needed for color change	Simple procedure of wetting pad with sample and pressing together with a second reagent pad	
Truetech (M18A3)	Color tubes	Vapor (TIC)	Minutes – Recommended 60 pump strokes take several minutes to complete; color change begins in a fraction of that time	Relatively complex procedure Arm/hand strength needed for pump Some color changes difficult to distinguish	$1,189
	Color ticket	Vapor (CWA)	Minutes – Response within 3 minutes due to reaction time needed for color change	Simple procedure	
	M8 paper	Surface (CWA)	Seconds – Response (color change) within 10 seconds	Simple procedure	

[a]TIC = Toxic industrial chemicals and CWA = Chemical warfare agents

[b]Green = Response time occurs in seconds and Yellow = Response time occurs in minutes

[c]These costs represent purchase prices. For long-term use, the cost of samples and consumable items need to be evaluated (refer to subject matter reports for more information on these cost).

[d]Draeger (CMS), RAE Systems (MultiRAE Plus), and Sensidyne (Gas Detector Tube) provide quantitative readings. The PID principle of the MultiRAE Plus was not necessarily expected to respond to TICs or CWAs tested as part of this evaluation (see Table 1); however, it was tested based on the instrument's promotion as a general toxic compound detector. Proengin (AP4C) provides semi-quantitative readings.

[e]A model newer than the model tested is now available. The cost of the newer model is $11,700.

This document does not constitute nor should be construed as an EPA endorsement of any particular product, service, or technology.