System Assessment and Validation for Emergency Responders (SAVER)

Portable Colorimetric Tubes for Chemical Vapor Detection Assessment Report

March 2015
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FOREWORD

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 assessments and validations on commercially available equipment and systems and develops knowledge products that provide relevant equipment information to the emergency responder community. The SAVER Program mission includes:

- Conducting impartial, practitioner-relevant, operationally oriented assessments and validations of emergency response equipment; and
- Providing information, in the form of knowledge products, that enables decision-makers and responders to better select, procure, use, and maintain emergency response equipment.

The SAVER Program is supported by a network of Technical Agents who perform assessment and validation activities. As a SAVER Program Technical Agent, National Security Technologies, LLC (NSTec), has been tasked to provide expertise and analysis on key subject areas, including chemical, biological, radiological, nuclear, and explosives (CBRNE) detection, countermeasures, and test and evaluation, among others. In support of this tasking, NSTec conducted an assessment of commercially available portable colorimetric tubes (PCT) for chemical vapor detection. Colorimetric tubes fall under AEL reference number 07CD-01-KCTC titled Chemical Detection Colorimetric Tape/Tube/Chip Kit.

Visit the SAVER website on First Responder.gov (www.firstresponder.gov/SAVER) for more information on the SAVER Program or to view additional reports on PCTs for chemical vapor detection or other technologies.
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EXECUTIVE SUMMARY

Portable colorimetric tubes (PCTs) for chemical vapor detection are used by emergency responders to identify chemicals in air and determine their concentration. PCTs detect chemicals by drawing air containing the target chemical through a tube. Material in the tube changes color allowing the chemical concentration to be measured. Tubes are specific to targeted chemicals. PCTs can be used for situational awareness, for health and safety, to identify and quantify chemicals from spills or illicit activities, and to detect and identify chemicals that could adversely affect the public, emergency responders, or impact response actions.

PCTs are simple to operate, require minimal training, and can detect and quantify chemicals from the percent to parts-per-billion (ppb) range. Accuracy generally ranges from plus or minus 10 to 25 percent of the concentration reading. Accuracy is dependent on the specific chemical being measured, the concentration range of the chemical, and environmental conditions.

In October 2014, the System Assessment and Validation for Emergency Responders (SAVER) Program conducted an operationally oriented assessment of hand pump PCT systems.

Four hand-pump PCT systems were assessed by emergency responders. Each PCT system consisted of a hand pump, chemical-specific detection tubes, and various available accessories. The criteria and scenarios used in this assessment were derived from the results of a focus group of emergency responders with experience using PCTs. The assessment addressed 13 evaluation criteria in five SAVER categories: Affordability, Capability, Deployability, Maintainability, and Usability. The overall results of the assessment are highlighted in the following table.
1. INTRODUCTION

Portable colorimetric tubes (PCTs) for chemical vapor detection are used by emergency responders to identify chemicals in air and determine their concentration. PCTs detect, identify, and quantify chemicals by drawing air containing the target chemical through a tube. Tubes are chemical-specific. Material in the tube changes color allowing the chemical concentration to be read on the tube. PCTs can be used for situational awareness, for health and safety, to identify and quantify chemicals from spills or illicit activities, and to detect and identify chemicals that could adversely affect the public, emergency responders, or impact response actions.

PCTs are simple to operate, require minimal training, and can detect and quantify chemicals in the percent to parts-per-billion (ppb) range. Accuracy generally ranges from plus or minus 10 to 25 percent of the concentration reading. Accuracy is dependent on the specific chemical being measured, the concentration range of the chemical, and environmental conditions.

In October 2014, the System Assessment and Validation for Emergency Responders (SAVER) Program conducted an operationally oriented assessment of hand-pump PCT systems. The purpose of this assessment was to obtain information on PCTs that will be useful in making operational and procurement decisions. The activities associated with this assessment were based on recommendations from a focus group of emergency responders with experience using PCTs.

1.1 Evaluator Information

Nine emergency responders from various jurisdictions and with at least 11 years of experience using PCTs were selected to be evaluators for the assessment. Evaluator information is listed in Table 1-1. Prior to the assessment, evaluators signed a nondisclosure agreement, conflict of interest statement, and photo release form.
Table 1-1. Evaluator Information

<table>
<thead>
<tr>
<th>Participant</th>
<th>Years of Experience</th>
<th>State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Firefighter—HazMat, CBRNE, CT, ICS, WMD</td>
<td>20+</td>
<td>CA</td>
</tr>
<tr>
<td>Law Enforcement—CBRNE, HazMat, WMD</td>
<td>20+</td>
<td>FL</td>
</tr>
<tr>
<td>Law Enforcement—HSB/ARMOR, CBRNE</td>
<td>20+</td>
<td>NV</td>
</tr>
<tr>
<td>Firefighter—HazMat</td>
<td>16-20</td>
<td>VA</td>
</tr>
<tr>
<td>Firefighter—HazMat</td>
<td>11-15</td>
<td>CA</td>
</tr>
<tr>
<td>Firefighter—HazMat</td>
<td>11-15</td>
<td>CA</td>
</tr>
<tr>
<td>Firefighter—HazMat</td>
<td>11-15</td>
<td>MD</td>
</tr>
<tr>
<td>Law Enforcement—HSB/ARMOR, CBRNE</td>
<td>11-15</td>
<td>NV</td>
</tr>
<tr>
<td>Law Enforcement—HazMat</td>
<td>11-15</td>
<td>VA</td>
</tr>
</tbody>
</table>

Acronyms:

ARMOR—All Hazards, Regional, Multi-Agency, Operations, and Response
CBRNE—Chemical, Biological, Radiological, Nuclear, and Explosives
CT—Counterterrorism
HazMat—Hazardous Materials
HSB—Homeland Security Bureau
ICS—Incident Command System
WMD—Weapons of Mass Destruction

1.2 Assessment Products

Four hand-pump PCT systems were selected for the assessment based on market research and focus group recommendations. Each PCT system consisted of a hand pump, chemical-specific tubes, and various accessories. Final selection was based on how well each product met the focus group specified product selection criteria, which is listed below:

- Hand-powered (manual) pumps;
- The number of target chemical tubes available;
- Availability of application specific kits;
- Availability of multi-tube sampler accessories; and/or
- Availability of multi-layer detection tubes.

The products selected for assessment met at least four of the product-selection criteria. Most systems had either multi-tube samplers or multi-layer detection tubes, but not both. Table 1-2 presents the products that were assessed.
Table 1-2. Assessed Products

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Product</th>
<th>Product Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>Draeger</td>
<td>Accuro Bellows Hand Pump</td>
<td></td>
</tr>
<tr>
<td>Gastec (Nextteq)</td>
<td>GV-110² Piston Hand Pump</td>
<td></td>
</tr>
<tr>
<td>Kitagawa (Sensidyne)</td>
<td>AP-20S Piston Hand Pump</td>
<td></td>
</tr>
<tr>
<td>MSA (Uniphos)</td>
<td>Kwik-Draw Deluxe Bellows Hand Pump</td>
<td></td>
</tr>
</tbody>
</table>

Notes:
1. Associated tubes and accessories from each vendor were also selected for assessment
2. The GV-110-SOHA-TR model was assessed

2. EVALUATION CRITERIA

The SAVER Program assesses products based on criteria in five established categories:

- **Affordability** groups criteria related to the total cost of ownership over the life of the product. This includes purchase price, training costs, warranty costs, recurring costs, and maintenance costs.

- **Capability** groups criteria related to product features or functions needed to perform one or more relevant tasks.

- **Deployability** groups criteria related to preparing to use the product, including transport, setup, training, and operational/deployment restrictions.

- **Maintainability** groups criteria related to the routine maintenance and minor repairs performed by responders, as well as included warranty terms, duration, and coverage.

- **Usability** groups criteria related to ergonomics and the relative ease of use when performing one or more relevant tasks.

The focus group of emergency responders met in February 2014 and identified 13 evaluation criteria within the five established SAVER categories: Affordability, Capability, Deployability,
Maintainability, and Usability. They assigned a weight for each criterion’s level of importance on a scale of 1 to 5, with 1 being somewhat important and 5 being of utmost importance. The SAVER categories were assigned a percentage to represent each category’s importance relative to the other categories.

Products were assessed against 13 evaluation criteria. Table 2-1 presents the evaluation criteria and their associated weights as well as the percentages assigned to the SAVER categories. Refer to Appendix A for evaluation criteria definitions.

Table 2-1. Evaluation Criteria

<table>
<thead>
<tr>
<th>Evaluation Criteria</th>
<th>SAVER Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Overall Weight</td>
</tr>
<tr>
<td>Usability</td>
<td>30%</td>
</tr>
<tr>
<td>Capability</td>
<td>27%</td>
</tr>
<tr>
<td>Deployability</td>
<td>25%</td>
</tr>
<tr>
<td>Maintainability</td>
<td>13%</td>
</tr>
<tr>
<td>Affordability</td>
<td>5%</td>
</tr>
</tbody>
</table>

| Readability of Tubes         | Weight: 5        |
| Tube Availability            | Weight: 5        |
| Pumps: Manual                | Weight: 4        |
| Warranty and Repair          | Weight: 2        |
| Consumable Costs             | Weight: 3        |
| System Ease-of-Use           | Weight: 3        |
| Performance                  | Weight: 5        |
| Available Accessories        | Weight: 3        |
| Tube Safety                  | Weight: 2        |
| Target Chemical List         | Weight: 4        |
| Training                     | Weight: 2        |
| Manual and Instructions      | Weight: 4        |
| Unknown Chemical Characterization | Weight: 3   |
3. ASSESSMENT METHODOLOGY

The products were assessed over three days. On the first day of the assessment, a subject matter expert (SME) and facilitators presented a safety briefing and an overview of the assessment process, procedures, and schedule to the evaluators. Each product was then assessed by each evaluator in two phases: (1) a specification assessment and (2) an operational assessment.

3.1 Phase I/Specification Assessment

During the specification assessment, evaluators assessed each product based on vendor-provided information and specifications (Figure 3-1). Product information was confirmed by vendors prior to the assessment.

3.2 Phase II/Operational Assessment

During the operational assessment, evaluators assessed each product based on hands-on experience with the product after becoming familiar with its proper use, capabilities, and features. The SME and facilitators assisted the evaluators with system training and use during product familiarization and the assessment. During the assessment, evaluators had access to reference material included with each product. The products were assessed in four operational scenarios: (1) characterization of toxic and corrosive atmospheres, (2) identification and characterization of an unknown chemical, (3) confined-space reconnaissance, and (4) building entry. While the scenarios refer to “spills”\(^1\), the volatile chemicals used in the assessment were in open containers, rather than spilled on a surface. Evaluators used each system one at a time and completed the assessment worksheets for one system before assessing the next system.

---

\(^1\) “Spills” in this context are simulated and refer to open chemical containers that were closed and removed after assessment activities were complete. This provided conditions for gas detection, which simulated conditions of an actual spill.
3.2.1 Characterization of Toxic and Corrosive Atmospheres

In the toxic and corrosive atmospheres scenario the evaluators characterized several common toxic or corrosive chemicals (Figure 3-2). The chemicals used were ammonia at 10 parts per million (ppm) and 500 ppm, and low ppm concentrations of chlorine, isopropyl alcohol—a volatile organic compound (VOC), and acetic acid—an organic acid. The responders used vendor-supplied field sheets, selected the correct tubes, identified any correction factors, sampled the air at the designated location, and read the concentration from the tube for each chemical. Evaluators used this task to rate the readability of the tubes, the ease-of-use of the system, tube safety, and system performance.

Figure 3-2. Toxic and Corrosive Atmospheres

3.2.2 Identification and Characterization of an Unknown Chemical

In the identification and characterization of an unknown chemical scenario the evaluators followed vendor-supplied methods and processes for identifying and characterizing an unknown chemical (Figure 3-3). This scenario included the use of both multi-tube samplers and multi-layer tubes, if available. The evaluators used this scenario to rate the system capability for unknown chemical characterization and tube safety.

Figure 3-3. Identification and Characterization of an Unknown Chemical
3.2.3 Confined-Space Reconnaissance

In the confined-space reconnaissance scenario the evaluators, wearing PPE, sampled VOC spills in confined spaces that were difficult to access and that required the use of extension tubes or wands (Figure 3-4). This included three spills, one in a contained space, a second inside a pipe, and a third in a difficult-to-reach position shown in the left panel of Figure 3-4. The evaluators used this scenario to rate the accessories available for each system to support working in confined spaces.

![Figure 3-4. Confined-Space Reconnaissance](image)

3.2.4 Building Entry

In the building entry scenario the evaluators sampled VOC spills in various locations in a low-light environment. They used either a flashlight or a headlight for illumination while wearing PPE to simulate realistic operating conditions. The evaluators noted the difficulty of reading field sheets, operating pumps, and interpreting tube results in a low-light environment. The scenario was used to rate the deployability of the system in a low-light indoor environment.

![Figure 3-5. Building Entry](image)
3.3 Data Gathering and Analysis

Each evaluator was issued an assessment workbook that contained vendor-provided information and specifications, assessment procedures, and worksheets for recording criteria ratings and comments. Evaluators used the following 1 to 5 scale to rate each product:

1. *Meets none* of my expectations for this criterion;
2. *Meets some* of my expectations for this criterion;
3. *Meets most* of my expectations for this criterion;
4. *Meets all* of my expectations for this criterion; and
5. *Exceeds* my expectations for this criterion.

Criteria that were assessed multiple times were assigned a final overall rating by the evaluators. Evaluators noted advantages and disadvantages for the assessed products as well as general comments on the PCT assessment and the general process for technology assessment. Once assessment activities were completed, evaluators had an opportunity to review their criteria ratings and comments for all products and make adjustments as necessary.

At the conclusion of the assessment activities, an overall assessment score, as well as category scores and criteria scores, were calculated for each product using the formulas referenced in Appendix B. In addition, evaluator comments for each product were reviewed and summarized for this assessment report.
4. ASSESSMENT RESULTS

Overall scores for the assessed products ranged from 2.8 to 3.5. Table 4-1 presents the overall assessment score and category scores for each product. Products are listed in order from highest to lowest overall assessment score throughout this section. Calculation of the overall score uses the raw scores for each category, prior to rounding.

**Table 4-1. Assessment Results**

<table>
<thead>
<tr>
<th>Product</th>
<th>Overall Score</th>
<th>Overall</th>
<th>Usability</th>
<th>Capability</th>
<th>Deployability</th>
<th>Maintainability</th>
<th>Affordability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Draeger/Accuro Bellows Hand Pump</td>
<td>3.5</td>
<td>3.9</td>
<td>4.0</td>
<td>2.4</td>
<td>3.8</td>
<td>3.7</td>
<td></td>
</tr>
<tr>
<td>Gastec/GV-110 Piston Hand Pump</td>
<td>3.3</td>
<td>3.6</td>
<td>3.7</td>
<td>2.5</td>
<td>3.1</td>
<td>3.4</td>
<td></td>
</tr>
<tr>
<td>Kitagawa/AP-20S Piston Hand Pump</td>
<td>3.1</td>
<td>2.9</td>
<td>3.4</td>
<td>2.4</td>
<td>4.1</td>
<td>3.8</td>
<td></td>
</tr>
<tr>
<td>MSA/Kwik-Draw Deluxe Bellows Hand Pump</td>
<td>2.8</td>
<td>3.1</td>
<td>3.2</td>
<td>2.0</td>
<td>2.7</td>
<td>3.3</td>
<td></td>
</tr>
</tbody>
</table>

Table 4-2 presents the criteria ratings for each product. The ratings are graphically represented by colored and shaded circles. A green, fully shaded circle represents the highest rating. Refer to Appendix A for evaluation criteria definitions. Table 4-3 presents vendor-provided key specifications for the assessed products.
Table 4-2. Criteria Ratings

<table>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Usability</td>
<td>Readability of Tubes</td>
<td>🔴</td>
<td>🔴</td>
<td>🔴</td>
<td>🔴</td>
</tr>
<tr>
<td></td>
<td>System Ease-of-Use</td>
<td>🔴</td>
<td>🔴</td>
<td>🔴</td>
<td>🔴</td>
</tr>
<tr>
<td></td>
<td>Tube Safety</td>
<td>🔴</td>
<td>🔴</td>
<td>🔴</td>
<td>🔴</td>
</tr>
<tr>
<td></td>
<td>Training</td>
<td>🔴</td>
<td>🔴</td>
<td>🔴</td>
<td>🔴</td>
</tr>
<tr>
<td>Capability</td>
<td>Tube Availability</td>
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<td>🔴</td>
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<td></td>
<td>Performance</td>
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<td>🔴</td>
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<td></td>
<td>Target Chemical List</td>
<td>🔴</td>
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<td>🔴</td>
<td>🔴</td>
</tr>
<tr>
<td></td>
<td>Manual and Instructions</td>
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<td>🔴</td>
<td>🔴</td>
<td>🔴</td>
</tr>
<tr>
<td></td>
<td>Unknown Chemical Characterization</td>
<td>🔴</td>
<td>🔴</td>
<td>🔴</td>
<td>🔴</td>
</tr>
<tr>
<td>Deployability</td>
<td>Pumps: Manual</td>
<td>🔴</td>
<td>🔴</td>
<td>🔴</td>
<td>🔴</td>
</tr>
<tr>
<td></td>
<td>Available Accessories</td>
<td>🔴</td>
<td>🔴</td>
<td>🔴</td>
<td>🔴</td>
</tr>
<tr>
<td>Maintainability</td>
<td>Warranty and Repair</td>
<td>🔴</td>
<td>🔴</td>
<td>🔴</td>
<td>🔴</td>
</tr>
<tr>
<td>Affordability</td>
<td>Consumable Costs</td>
<td>🔴</td>
<td>🔴</td>
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Table 4-3. Key Specifications

<table>
<thead>
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</thead>
<tbody>
<tr>
<td>MSRP</td>
<td>$440</td>
<td>$480¹</td>
<td>$407</td>
<td>$600</td>
</tr>
<tr>
<td>Warranty Duration²</td>
<td>5-year</td>
<td>Limited lifetime</td>
<td>Lifetime</td>
<td>1-year</td>
</tr>
<tr>
<td>Pump Type</td>
<td>Bellows</td>
<td>Piston</td>
<td>Piston</td>
<td>Bellows</td>
</tr>
<tr>
<td>Tube Diameter</td>
<td>7 mm</td>
<td>5 mm</td>
<td>5 mm</td>
<td>7 mm</td>
</tr>
<tr>
<td>Adjustable Stroke Volume</td>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>End of Stroke Indicator</td>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Stroke Counter</td>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>One Hand Operation</td>
<td>✓</td>
<td>Adapter included¹</td>
<td>Adapter available</td>
<td>✓</td>
</tr>
<tr>
<td>Weight (pounds)</td>
<td>0.5</td>
<td>0.5</td>
<td>0.65</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>Number of Tubes</td>
<td>&gt;200</td>
<td>&gt;500</td>
<td>&gt;330</td>
<td>&gt;70</td>
</tr>
<tr>
<td>Number of Chemicals</td>
<td>&gt;500</td>
<td>&gt;600</td>
<td>&gt;220</td>
<td>&gt;170</td>
</tr>
<tr>
<td>Application Kits Available (lists are not comprehensive)³</td>
<td>Civil Defense; HazMat; Clandestine Lab; Custom</td>
<td>Civil Defense; HazMat; Clandestine Lab; Custom</td>
<td>Disaster Relief; HazMat; Custom</td>
<td>HazMat/CWA Indoor Air Quality; Industry</td>
</tr>
<tr>
<td>Multi-tube Sampler</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Multi-layer Tubes</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

Notes:
✓—equipped with corresponding feature
Blank cell—not equipped with corresponding feature
MSRP—manufacturer’s suggested retail price
¹ The GV-110 SOHA-TR model was assessed. This model includes the one-hand adaptor and a temperature ring—both options on the base GV-110 model. The price reflects the additional features in the assessed model.
² Accessories typically have a 1-year warranty and tubes have expiration dates.
³ Those listed were identified as important by the focus group.
4.1 **Draeger Accuro® Bellows Hand Pump**

The Draeger Accuro Bellows Hand Pump (Figure 4-1) received an overall assessment score of 3.5 and costs $440 as assessed. This price does not include tubes as they are consumable supplies. Draeger products are supplied through regional distributors.

The following sections, broken out by SAVER category, summarize the assessment results.

**Usability**

The Draeger Accuro Bellows Hand Pump received a Usability score of 3.9. The following information is based on evaluator comments:

- The pump is simple and requires minimal training.
- Very comfortable and secure feel in gloved hand, though the pump requires some effort and pressure to squeeze. The pump can be difficult for small hands to use because of the amount of pressure required, especially in awkward positions.
- Larger tube diameters result in easier-to-read markings.
- The tubes used in the assessment had definitive and easily readable color changes. While the color changes were easy to read in incandescent and LED light, they were slightly harder to read in fluorescent lab lighting. Tubes with dark color changes were more difficult to read because of black tube markings on dark backgrounds.
- Many tubes used in the assessment required 5 to 10 or more strokes and had a very high resistance requiring a waiting period after each stroke, for the air flow to complete. One hand use resulted in hand fatigue.
- The poly-tube (multi-layer tube) lacked a flow direction arrow on the tube and stroke count requirements on the box.
- The full-stroke indicator is difficult to see when holding the pump away from the body, and is too small.
- The strap-mounted tube breaker works well, but does not collect the broken glass. The tube scorer is provided as a separate unit and could easily become separated from the pump.
- The remote sampler is a flexible tube.

**Capability**

The Draeger Accuro Bellows Hand Pump received a Capability score of 4.0. The following information is based on evaluator comments:

- Excellent user manual that is very comprehensive and well written. The manual provides color photographs of positive changes for tube color change interpretation. Training and support materials are easily available online with iPhone® and
Android™ apps available. The evaluators noted that the apps for field use were extremely useful.

- The field sheets provided clear procedures and results for unknown chemical identification, but it was sometimes difficult to get the sheets out of the tube box if the sheet was stuck between a set of tubes. Some evaluators noted the fonts were small on the field sheets.

- The unknown chemical identification procedures permit classification of many chemical families with a minimal number of tubes; however, a full unknown chemical analysis could be time consuming.

- Specification sheets for tubes answered all questions on cross-sensitivities and operating conditions. Tube boxes were clearly marked with tube shelf-life.

### Deployability

The Draeger Accuro Bellows Hand Pump received a Deployability score of 2.4. The following information is based on evaluator comments:

- The pump feels very rugged though it is small and light.

- A wide variety of functional accessories and scenario specific kits are available and the tubes worked well with the hose adaptor. However, the extension tube was difficult to attach to the pump and it was difficult to remove tubes while wearing gloves.

- The pump requires very little maintenance. It is easy to wipe down the outside of the pump, but if the inside were contaminated, decontamination would be difficult. Several evaluators noted that it would be more efficient to dispose of a contaminated pump.

### Maintainability

The Draeger Accuro Bellows Hand Pump received a Maintainability score of 3.8. The following information is based on evaluator comments:

- The pump has a 5-year warranty with a limited life-time warranty. Accessories have a 1-year warranty.

### Affordability

The Draeger Accuro Bellows Hand Pump received an Affordability score of 3.7. The following information is based on evaluator comments:

- Some evaluators noted that the shelf-life of the tubes is poor, but it is consistent with industry standards.
4.2 Gastec GV-110 Piston Hand Pump

The Gastec GV-110 Piston Hand Pump (Figure 4-2) received an overall assessment score of 3.3 and costs $480 as assessed. This price does not include tubes as they are consumable supplies. Nextteq, LLC, is the exclusive U.S. Master Wholesale Distributor of the Gastec Pump and Tube System. Gastec products are supplied through regional distributors.

The following sections, broken out by SAVER category, summarize the assessment results.

Usability

The Gastec GV-110 Piston Hand Pump received a Usability score of 3.6. The following information is based on evaluator comments:

- The pump was comfortable and feels secure.
- Features include a temperature gauge, a stroke counter, a half-stroke indicator, and the ability to cock the pump for one-handed operation; however, cocking the pump required two-hands. The evaluators liked the stroke counter. Some of these features may require additional training to use properly.
- When setting the handle for one-handed operation, there is the potential for it to snap back causing problems and potential injury.
- The location of the end-of-stroke indicator at the end of the draw handle worked for normal operation, but the indicator was difficult to read when the plunger was extended, at certain angles, and in low light.
- The tube markings were legible and easy to read while in PPE.
- Some evaluators noted that the small diameter of tubes and small markings made reading challenging.
- The color changes on some tubes did not exactly match the illustrations; the change was obvious but different than expected. Color changes were not always apparent. One tube used in the darkened room changed from white to light blue, which was difficult to read in limited light.
- If a tube were completely saturated (i.e., the entire tube changed color) it was difficult to tell if the color had changed, and comparison against an unused tube was required.
- The tube scorer/breaker broke tips inconsistently with one failure resulting in reagent drawn into the extension tube. The breaker clogs easily and a small tool, such as a paper clip, was required to clean the unit; however, the tubes themselves broke cleanly when properly scored.
**Capability**

The Gastec GV-110 Piston Hand Pump received a Capability score of 3.7. The following information is based on evaluator comments:

- Training and manuals were easy to read and understand with multiple reference sources available for different accessories and kits. However, the manual is black and white, precluding color comparisons for tubes.
- The handbook was very useful for determining tube availability. A large number of target gases along with tubes for various concentrations are available. Many chemicals had tubes with very low (ppm) range capabilities.
- Correction factors were provided for various special cases such as half-strokes, but the presentation of these factors could be simplified.
- Good iPhone and Android apps are available along with web-based materials.
- A large number of well-designed kits are available (but were not assessed).
- The multi-gas tubes worked very well.
- For the tubes used in this assessment, the suggested temperature ranges for storage (32° to 50°F) and use (32° to 104°F) would not work well for many jurisdictions where ambient temperatures in vehicles could significantly exceed this range.
- The tube boxes had expiration dates visible and tube sheets noted cross sensitivities and interferences. In some cases, cross sensitive materials created a different color change than a positive detection of the target chemical, which is a useful feature.
- The tubes had good reading times. For many of the tubes used in the assessment only one pump stroke was required.
- The poly-tubes, which detected more than one chemical, worked well and the evaluators noted they would be useful.
- Field sheets for unknown chemical identification were easy to read and understand, but limited as identification requires both the flow chart and tube instructions (a separate sheet) for use. Also, instructions seemed incomplete. For example, it did not show alcohol as a potential unknown chemical family.
- While instructions were good, the unknown chemical identification process was complex, with many steps, and required a large number of tubes.

**Deployability**

The Gastec GV-110 Piston Hand Pump received a Deployability score of 2.5. The following information is based on evaluator comments:

- The pump is well designed, rugged, and it appears that it can be decontaminated. It is easily maintained and can be wiped off.
- There are numerous accessories available including a 2- to 9-foot extension pole. The one-handed adapter is a good, simple, easy-to-use accessory, and the multi-layer (Polytec) tubes worked very well.
Maintainability
The Gastec GV-110 Piston Hand Pump received a Maintainability score of 3.1. The following information is based on evaluator comments:

- Limited lifetime warranty, but the pump must be sent in for evaluation and repairs. The warranty only covers diagnostic costs and not the cost of repairs.

Affordability
The Gastec GV-110 Piston Hand Pump received an Affordability score of 3.4. The following information is based on evaluator comments:

- Costs are comparable to industry standards.
- If storage requirements are followed, many tubes require refrigeration, restricting typical responder agency storage in response vehicles.

4.3 Kitagawa AP-20S Piston Hand Pump
The Kitagawa manufactured piston hand pump and tube system used in this assessment were supplied by Sensidyne. The Sensidyne/Kitagawa AP-20S Piston Hand Pump (Figure 4-3) received an overall assessment score of 3.1 and costs $407 as assessed. This price does not include tubes as they are consumable supplies. Sensidyne is a wholesale distributor of Kitagawa products in the United States. These products are available through regional distributors.

The following sections, broken out by SAVER category, summarize the assessment results.

Usability
The Kitagawa AP-20S Piston Hand Pump received a Usability score of 2.9. The following information is based on evaluator comments:

- The pump has a comfortable, secure feel in a gloved hand and is easy to operate.
- The tip-breaker provided clean breaks with excellent storage of broken tips and was easy to empty. Evaluators noted that this was the best tip-breaker in the assessment.
- There is no stroke counter but most tubes require only a single stroke. There is no half-stroke lock so careful operation is required for half-stroke accuracy.
- The end-of-stroke indicator is at the end of the pump and inside a smoked plastic cover. This made it difficult to see in many sampling positions such as overhead, extended, or behind obstacles, and in low-light conditions.
- The small tube diameter makes it difficult to read markings, especially in PPE or low light conditions. Tube markings on some tubes were light blue rather than black, contributing to legibility issues.
- The multi-layer tubes result in fewer tubes required for testing unknown chemicals, but use of the multi-layer tubes requires above average initial and recurrent training.
**Capability**

The Kitagawa AP-20S Piston Hand Pump received a Capability score of 3.4. The following information is based on evaluator comments:

- Tube box instructions are well written with relevant information on box tops; however, tube shelf-life is only presented in the manual.
- Reading tube color changes during the assessment was identified as a major weakness in this system. All evaluators noted that color change in most of the tubes used in the assessment was faint and difficult to identify, though a few chemical-specific tubes had more obvious changes. Bleeding at the color-change interface made readings imprecise. Color instructions and charts in the manual would be helpful, especially because of faint color changes in tubes.
- The manual is comprehensive, well organized, and written with outstanding illustrations. Several evaluators commented on the small font size. There are no mobile apps.
- The field sheets for unknown chemical identification are great and provide additional information such as exposure limits and correction factors and include very helpful color charts. But the field sheets could be improved, for example clarification of how pre-test color is interpreted for multi-layer tube results.
- The unknown chemical characterization procedure is complex and not intuitive. However, once mastered, it uses a minimal number of tubes to identify a large number of chemicals. The process requires above average initial and recurrent training. Some calculations are required to follow the procedures.
- For distinguishing unknowns you need to reverse some tubes during the process (i.e., use a specific type of tube, first in one direction then the same type in another direction). This requires marking or labeling tubes of the same type prior to sampling, which may be difficult in the field.

**Deployability**

The Kitagawa AP-20S Piston Hand Pump received a Deployability score of 2.4. The following information is based on evaluator comments:

- The pump has a simple, rugged design with all-plastic exterior components, which can be easily wiped down. It is easy to disassemble and it appears that it can be decontaminated.
- The tube breaker and tip retainer were excellent and integrated into the pump.
- The leak test procedure was simple and effective.
- Standard accessories, such as extension tubes, are available. The multi-layer tubes are complex but effective.
- The hose used for the multi-layer tube in the assessment was long and required two people to operate. Pump operation required two hands and another person must hold the sample tube.
• The sample hose was a favorite during use; however, when attaching the hose to the pump, some evaluators noted it did not seem rugged and it does not lock the tube in place.

**Maintainability**

The Kitagawa AP-20S Piston Hand Pump received a Maintainability score of 4.1. The following information is based on evaluator comments:

• There is a lifetime warranty on the pump and a 1-year warranty on the accessories.

**Affordability**

The Kitagawa AP-20S Piston Hand Pump received an Affordability score of 3.8. The following information is based on evaluator comments:

• Tube costs and shelf life are consistent with industry standards.

**4.4 MSA Kwik-Draw® Deluxe Bellows Hand Pump**

The MSA Kwik-Draw Deluxe bellows hand pump and tube system used in this assessment was supplied by Ion Science USA. The MSA Kwik-Draw Deluxe Bellows Hand Pump (Figure 4-4) received an overall assessment score of 2.8 and costs $600 as assessed. This price does not include tubes as they are consumable supplies. Ion Science USA is the Master Distributor in the U.S. for Uniphos. Uniphos produces detector tubes with MSA’s specification and technology. MSA products are available through regional distributors.

The following sections, broken out by SAVER category, summarize the assessment results.

**Usability**

The MSA Kwik-Draw Deluxe Bellows Hand Pump received a Usability score of 3.1. The following information is based on evaluator comments:

• The pump was easy to operate, but one-handed operation was difficult in some positions or for a large number of strokes. There is no half-stroke capability.

• The end-of-stroke indicator was very visible but could be obscured by a gloved hand.

• The stroke counter was adjustable, but requires that the handle hit the indicator button, which could result in missed strokes. The stroke counter was easy to reset, but could be accidentally reset during operation. Opinions were mixed, with some evaluators liking the stroke counter while others did not.

• Tube markings were easy to read even in PPE and in low light. The tubes had good color change and contrast. For some chemicals, the tubes had high- and low-concentration scales, which evaluators liked. These tubes had the most distinct color changes of all those used in the assessment.
Some tubes required calculations based on stroke counts and tube readings to determine the concentration. Evaluators noted this could be a source of error in the field.

Removal of the tube from the rubber sleeve on the pump required significant force. Special caution was required as injury could occur if the tube were released suddenly.

The tip-breaker failed consistently, jamming after only one or two tubes. Tubes often had jagged edges as the glass seemed thinner than that from other manufacturers.

The available literature and training materials were limited, though very little training is needed for pump maintenance and use.

**Capability**

The MSA Kwik-Draw Deluxe Bellows Hand Pump received a Capability score of 3.2. The following information is based on evaluator comments:

- The full manual was good and had examples, but is only available online and must be printed. Color comparison will be dependent on the printer color quality.
- The field sheet was easy to read, but no mobile apps are available. The website was unorganized.
- The tubes were easy to read with expiration dates printed on the box. Cross sensitivities and interferences were clearly listed.
- The tube reading times were quick.
- The process to identify an unknown chemical had an easy-to-follow flow chart. However, the process required a large number of steps and was non-specific, with a long list of organic compounds provided as the final result. Also, the cross sensitivities for the unknown chemical process are not listed on the process sheet, and require reference to multiple instruction sets.
- Information regarding the number of strokes required for unknown chemical identification was inconsistent with the information provided with the tubes.

**Deployability**

The MSA Kwik-Draw Deluxe Bellows Hand Pump received a Deployability score of 2.0. The following information is based on evaluator comments:

- Maintenance and cleaning are easy. A leak test is the only validation required.
- The stroke counter seemed fragile and would probably not hold up well to repeated use.
- The bellows-type pump would be hard to decontaminate.
- Parts can be replaced easily.
- The available accessories were limited and costly.
- Some evaluators noted issues with the pump strap.
Maintainability
The MSA Kwik-Draw Deluxe Bellows Hand Pump received a Maintainability score of 2.7. The following information is based on evaluator comments:

- The pump has a 1-year warranty.

Affordability
The MSA Kwik-Draw Deluxe Bellows Hand Pump received an Affordability score of 3.3. The following information is based on evaluator comments:

- Tube costs and storage requirements meet industry standards.

5. SUMMARY

PCTs for chemical vapor detection are valuable tools used by emergency responders to identify chemicals in air and determine their concentration. PCTs are relatively inexpensive, simple to operate, require minimal training, and can detect and quantify chemicals in the percent to parts-per-billion (ppb) range with accuracy dependent on the chemical measured and measurement conditions.

PCTs can be used for situational awareness, for health and safety, to identify and quantify chemicals from spills or illicit activities, and to detect the presence of chemicals that could adversely affect the public, emergency responders, or impact response actions.

PCTs are typically used in difficult environments with the first responder often wearing PPE. As such, one-handed operation, handling with gloves, and ease of reading the results are important. Evaluators preferred systems with easily seen and read stroke-counters, tubes with legible markings and distinct color changes, and clear, concise instructions. Since all readings require the operator to score and break tube tips, evaluators strongly preferred systems with tip breakers that worked well and that stored the broken glass.

The advantages and disadvantages for the assessed products are highlighted in Table 5-1. Emergency responder agencies that consider purchasing PCTs should carefully research each product’s overall capabilities and limitations in relation to their agency’s operational needs.
### Table 5-1. Product Advantages and Disadvantages

<table>
<thead>
<tr>
<th>Vendor/Product</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Draeger Accuro Bellows Hand Pump</td>
<td>• Very easy one-handed use for medium and large hands</td>
<td>• Tubes tested required a large number of strokes</td>
</tr>
<tr>
<td></td>
<td>• Audible click for stroke indicator</td>
<td>• Pump was stiff and tended to cause hand fatigue on high-stroke counts</td>
</tr>
<tr>
<td></td>
<td>• Easy to insert and remove tubes</td>
<td>• One-handed operation of the pump was difficult for small hands</td>
</tr>
<tr>
<td></td>
<td>• Good color change with high contrast and sharp interface on tubes tested</td>
<td>• Incorrect grip could result in an incomplete stroke</td>
</tr>
<tr>
<td></td>
<td>• Counter reset button cannot be accidentally reset but requires a tool for reset (an unbroken tube can be used)</td>
<td>• End-of-stroke indicator was small and sometimes difficult to see due to its size and location</td>
</tr>
<tr>
<td></td>
<td>• The logic tree/flow chart for unknown chemical characterization is easy to follow</td>
<td>• Tube instructions have very small font</td>
</tr>
<tr>
<td></td>
<td>• Color manual pictures make it easy to verify tube color change</td>
<td>• Extension hose tubes are easy to attach but difficult to remove</td>
</tr>
<tr>
<td></td>
<td>• Android and iPhone apps available for display of user manual</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Extensive accessories available</td>
<td></td>
</tr>
<tr>
<td>MSRP: $440 Overall Score: 3.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vendor/Product</td>
<td>Advantages</td>
<td>Disadvantages</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
</tbody>
</table>
| Gastec GV-110 Piston Hand Pump | • Ergonomic and easy to hold and use  
  • Stroke counter was easy to use, read, and reset; however, could be inadvertently reset during operation  
  • End-of-stroke indicator was easy to read in limited light  
  • One-handed adaptor (included accessory) worked well, though two hands were required to arm the pump  
  • On-board tip breaker collects glass but became jammed occasionally  
  • For tubes tested, when exposed to a cross-sensitive chemical, the color change was different from that of the target chemical  
  • The multi-layer tube accessory was easy to use and worked well  
  • Thermometer on pump supports easy temperature correction of readings  
  • Extensive accessories available  
  • User can perform repairs and maintenance and many parts are user replaceable | • Plunger lock could release if not aligned properly and if lock-alignment was missed, then the plunger snapped forward (potentially resulting in injury)  
  • The stroke counter is advanced on plunger lock reset  
  • The location of the end-of-stroke indicator made it difficult to see in some circumstances, and it was difficult to read in bright sunlight  
  • Color change was difficult to read in the tubes tested  
  • Markings on small diameter tubes were difficult to read in PPE  
  • Decision tree for unknown chemicals was difficult to follow and complex. Limited charts are provided for unknown chemical identification unless extended kits are purchased |
<table>
<thead>
<tr>
<th>Vendor/Product</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| Kitagawa AP-20S Piston Hand Pump | • Ergonomic and easy to use  
• Tip-breaker worked well and retained tips  
• Tip receptacle can be closed  
• Despite being a complex procedure, good instructions were provided for unknown chemical characterization. Procedure was quick and required only a limited number of tubes and measurements  
• User can perform repairs and maintenance, and many parts are user replaceable | • For tubes tested, color changes were very faint and difficult to detect. This was noted as a major shortcoming  
• End-of-stroke indicator was difficult to see and in an awkward position  
• Tubes had a large draw resistance, and after a stroke required some time for air to pass through the tube; however, a smaller number of strokes was required. Total measurement time was thus similar to that of the other pumps assessed  
• Unknown chemical characterization required more training than for other systems  
• Unknown chemical characterization required the same tube-type to be used in opposite orientations |

MSRP: $480  
Overall Score: 3.1
<table>
<thead>
<tr>
<th>Vendor/Product</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSA Kwik-Draw Deluxe Bellows</td>
<td>• Ergonomics and operations very good for one-handed use</td>
<td>• Long performance validation test—10 minutes</td>
</tr>
<tr>
<td>Hand Piston Pump</td>
<td>• Sharp color changes with crisp boundaries and good color contrast were observed for tubes tested</td>
<td>• Clean breaks of the tubes were difficult to achieve and the tube breaker jammed continually, exposing glass shards and creating a safety hazard</td>
</tr>
<tr>
<td></td>
<td>• Tube markings are very legible</td>
<td>• Tools were required to remove the cover in order to clear tube breaker jams</td>
</tr>
<tr>
<td></td>
<td>• End-of-stroke indicator is large and highly visible</td>
<td>• The tubes used required a large number of strokes with a long recovery time (large flow resistance in tubes)</td>
</tr>
<tr>
<td></td>
<td>• Training instructions were good</td>
<td>• Tube removal from the pump was difficult. Significant force was required, creating a safety hazard and possible damage to tube holder</td>
</tr>
<tr>
<td></td>
<td>• Good one-page overview; however, there is not a comprehensive manual or index; rather there is a series of individual documents. A comprehensive index would have been helpful</td>
<td>• Stroke counter was easily obscured by hand during operation</td>
</tr>
<tr>
<td></td>
<td>• The pump was easily disassembled</td>
<td>• Stroke counter could be accidently advanced, missed, or decreased during a stroke</td>
</tr>
<tr>
<td>MSRP: $600 Overall Score: 2.8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX A. EVALUATION CRITERIA DEFINITIONS

The focus group identified 13 evaluation criteria, which are defined as follows.

**USABILITY**

**Readability of Tubes** refers to tube legibility and markings; the ease of results interpretation - such as definite color changes and sharp, not smeared, transitions; and the ability to read the tubes when wearing personal protective equipment (PPE). The focus group recommended assessing a short list of chemical tubes.

**System Ease-of-Use** refers to ergonomics, availability of a stroke counter, half-stroke capability, the accuracy of stroke operations (i.e., availability of an end-of-stroke indicator), and the complexity of system operation. It also refers to air-flow resistance of the tubes, which the evaluators noted may be chemical-specific. The focus group recommended assessing a short list of chemical tubes.

**Tube Safety** refers to whether or not the tubes are shatter proof, ease-of-use of the tube scorer, whether or not tube ends break cleanly, and whether or not aspects of tube operation meet safety expectations.

**Training** refers to the availability of training materials and support, the amount of training required to operate the system, and the expected amount of recurrent training required.

**CAPABILITY**

**Tube Availability** refers to the number of chemicals and concentration ranges targeted.

**Performance** refers to reading time, storage conditions, interferences, cross-sensitivity, accuracy and specificity, and shelf-life of tubes. The focus group noted that these criteria may be chemical-specific and recommended assessing a short list of common chemicals.

**Target Chemical List** refers to the availability of tubes for chemicals on lists used by emergency responders and if the available concentration ranges for those chemicals met expectations.

**Manual and Instructions** refers to the understandability and readability of the manuals, the technical coverage of the manuals, and the availability of electronic media. It also refers to the availability of field sheets, their simplicity and readability, and if they include correction factors.

**Unknown Chemical Characterization** refers to the ability of the system to characterize unknown chemicals, including the complexity of the process or method, and the clarity of the results.

**DEPLOYABILITY**

**Pumps: Manual** refers to ruggedness, required maintenance, calibration requirements, and the ability to decontaminate the manual pumps.

**Available Accessories** refers to the availability of multi-tube samplers, multi-layer tubes, and to the number and types of kits designed for specific scenarios. It also refers to whether other accessories such as extension tubes or wands, carrying cases and straps, humidity, and other specialized filters are available and meet expectations.
**MAINTAINABILITY**

*Warranty and Repair* refers to warranty length and availability of an extended warranty.

**AFFORDABILITY**

*Consumable Costs* refers to minimal tube order and tube shelf-life recommendations. The evaluators noted that these criteria may be chemical-specific and recommended assessing tubes for a short list of common chemicals.
APPENDIX B. ASSESSMENT SCORING FORMULAS

The overall score for each product was calculated using the product’s averaged criterion ratings and category scores. An average rating for each criterion was calculated by summing the evaluators’ ratings and dividing the sum by the number of responses. Category scores for each product were calculated by multiplying the average criterion rating by the weight assigned to the criterion by the focus group, resulting in a weighted criterion score. The sum of the weighted criterion scores was then be divided by the sum of the weights for each criterion in the category as seen in the formula and example below.

**Category Score Formula**

\[
\frac{\sum (\text{Average Criterion Rating} \times \text{Criterion Weight})}{\sum (\text{Criterion Weights})} = \text{Category Score}
\]

**Category Score Example**

\[
\frac{(4.3 \times 4) + (5 \times 4) + (4 \times 3) + (4.5 \times 3) + (4.5 \times 3)}{4 + 4 + 3 + 3 + 3} = 4.5
\]

To determine the overall assessment score for each product, each category score was multiplied by the percentage assigned to the category by the focus group. The resulting weighted category scores were summed to determine an overall assessment score as seen in the formula and example below.

**Overall Assessment Score Formula**

\[
\sum (\text{Category Score} \times \text{Category Percentage}) = \text{Overall Assessment Score}
\]

**Overall Assessment Score Example**

\[
\begin{align*}
\text{Capability} & \quad \text{Usability} & \quad \text{Affordability} & \quad \text{Maintainability} & \quad \text{Deployability} \\
(4.0 \times 33\%) & + (4.2 \times 27\%) & + (4.2 \times 20\%) & + (3.8 \times 13\%) & + (4.5 \times 7\%) = 4.1
\end{align*}
\]

1Examples are for illustration purposes only. Formulas will vary depending on the number of criteria and categories assessed and the criteria and category weights.