Field Portable Gas Chromatograph Mass Spectrometers

Assessment Report

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The *Field Portable Gas Chromatograph Mass Spectrometer (GC/MS) Assessment Report* was prepared by the National Urban Security Technology Laboratory for the U.S. Department of Homeland Security, Science and Technology Directorate.

Photos included herein were provided by the National Urban Security Technology Laboratory, unless otherwise noted.

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.
- Providing information, in the form of knowledge products, that enables decision-makers and responders to better select, procure, use and maintain emergency response equipment.

SAVER Program knowledge products provide information on equipment that falls under the categories listed in the DHS Authorized Equipment List (AEL), focusing primarily on two main questions for the responder community: "What equipment is available?" and "How does it perform?" These knowledge products are shared nationally with the responder community, providing a life-and cost-saving asset to DHS, as well as to federal, state and local responders.

The SAVER Program is managed by the National Urban Security Technology Laboratory (NUSTL). NUSTL is responsible for all SAVER activities, including selecting and prioritizing program topics, developing SAVER knowledge products, coordinating with other organizations and ensuring flexibility and responsiveness to first responder requirements.

NUSTL provides expertise and analysis on a wide range of key subject areas, including chemical, biological, radiological, nuclear and explosive weapons detection; emergency response and recovery; and related equipment, instrumentation and technologies. NUSTL developed this report to provide emergency responders with information obtained from an operationally oriented assessment of field portable gas chromatograph mass spectrometers (GC/MS), which fall under AEL reference number 07CD-01-DPGC, titled *Mass Spectrometer, Chemical, Portable.*

For more information on NUSTL's SAVER Program or to view additional reports on field portable GC/MS or other technologies, visit www.dhs.gov/science-and-technology/SAVER.

U.S. Department of Homeland Security

SAVER

System Assessment and Validation for Emergency Responders

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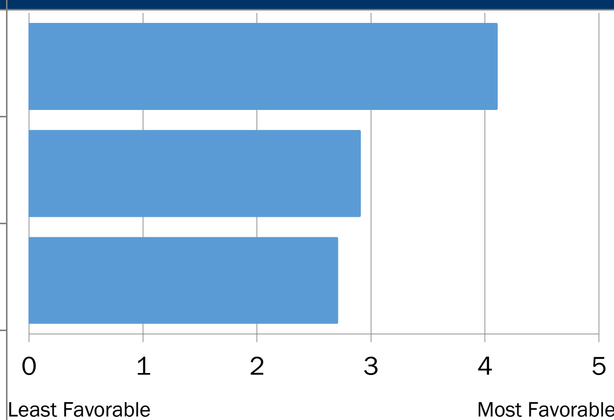
EXECUTIVE SUMMARY

In July 2019, the System Assessment and Validation for Emergency Responders (SAVER) Program conducted an operationally oriented assessment of field portable gas chromatograph mass spectrometer (GC/MS) instruments at the City of Seattle Joint Training Facility, in Seattle, Washington.

Three GC/MS instruments were assessed by personnel from seven federal, state and local emergency responder organizations. The assessment was planned based on recommendations provided by a focus group of emergency responders experienced in the use of GC/MS or other chemical detection and identification instruments. The instruments were evaluated on 30 evaluation criteria in four SAVER assessment categories: capability, deployability, maintainability and usability. The overall and category numerical scores are summarized in the table below.

Product	Overall Score	Overall	Usability	Deployability	Maintainability	Usability
FLIR Detection, Inc./Griffin G-510		**4.1**	4.2	3.8	4.2	4.3
PerkinElmer/Torion T-9		**2.9**	3.1	2.8	2.6	3.2
Inficon AG/Hapsite ER		**2.7**	2.6	2.6	2.7	2.9



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1.0 INTRODUCTION

Field portable gas chromatograph mass spectrometers (GC/MS) are used by first responders during field operations to chemically analyze substances suspected to be narcotics, explosives, toxic industrial chemicals/materials, chemical warfare agents or other hazardous substances. They are capable of measuring a variety of gases, volatile and semi-volatile liquids and vapors produced by some solids. Trace amounts of chemical compounds can typically be detected at the parts-per-billion to parts-per-trillion level. These instruments weigh between 30 and 40 pounds and cost approximately $150,000.

In July 2019, the System Assessment and Validation for Emergency Responders (SAVER) Program conducted an operationally oriented assessment on commercial, off-the-shelf (COTS) field portable GC/MS instruments. Three field portable GC/MS instruments were assessed by a group of first responders based on recommendations provided by a focus group on GC/MS held in February 2019[i]. The purpose of this assessment was to obtain information useful to first responder organizations making decisions about procuring and using field portable GC/MS instruments.

1.1 Evaluator Information

Seven emergency responders participated as evaluators for this assessment, including six individuals who participated in the GC/MS focus group. Assessment evaluators had 8 or more years of experience with field portable GC/MS or other chemical detection instruments and were drawn from five different states and from the District of Columbia. See Table 1-1 for evaluator demographics.

Table 1-1 Evaluator Demographics

Evaluator	Years of Experience	State
Firefighter/HAZMAT	20+	IN
Public Health	18	NY
Law Enforcement/HAZMAT	16	DC
Law Enforcement	12	AZ
Firefighter/HAZMAT	11	NY
National Guard Weapons of Mass Destruction/Civil Support Team	10	WA
Firefighter/HAZMAT	8	FL

[i] SAVER GC/MS Focus Group Report is available at: www.dhs.gov/sites/gcms-focus-group-report.

1.2 Assessment Products

Three instruments were evaluated in this assessment: the Griffin G-510, produced by FLIR Detection; the Torion T-9, produced by PerkinElmer; and the Hapsite ER, produced by Inficon AG. The only other field portable GC/MS instrument currently available on the commercial market, the Smiths Detection GUARDION, is a variant of the Torion T-9 that is sold under a licensing agreement with PerkinElmer. The GUARDION was not evaluated due to its close similarity to the Torion T-9.

The product descriptions and summary table below provide a general overview of the features and capabilities of each instrument. The information was obtained from instrument operating manuals, product data sheets, and communications with product representatives.

1.2.1 FLIR Griffin G-510

Figure 1-1 FLIR Griffin G-510

Courtesy of FLIR Detection, Inc.

The Griffin G-510 GC/MS is a linear quadrupole-based mass spectrometer that provides a measurement range of 18 to 510 atomic mass units (AMU), and its gas chromatograph is programmable over a 40°C to 300°C temperature range. It is designed to allow users to introduce gases, liquids and vapors from solid samples into the instrument for analysis. It has a vapor sampling probe for performing rapid mass spectrometric only analyses (herein referred to as 'survey analysis') or full GC/MS analysis of chemical vapors. There is also a sample introduction port for introduction of organic liquids, samples collected on solid-phase microextraction (SPME) fibers and other sample collection media. An optional accessory for direct introduction of solid sample vapors can be purchased from FLIR, but operation with this accessory was not evaluated during the assessment.

The Griffin G-510 is equipped with a built-in nine-inch color touchscreen Windows tablet computer that is used to control general instrument operation. The operating software provides for three user levels with differing abilities to modify instrument settings, delete data, etc. Data files can be exported via universal serial bus (USB) drive or wirelessly.

The gas chromatograph operates on helium carrier gas supplied by a removable internal gas cylinder. The G-510 does not have a gas level indicator when using an internal cylinder, but it does use a resettable injection counter to indicate when it is time to change the cylinder. The system also alerts the operator automatically when it is low on carrier gas. Operating power can be supplied by external 120-to-240-volt alternating current (AC) electrical sources or by two internal rechargeable lithium ion (Li-ion) batteries. Starting with one fully charged battery, the operating time is approximately 2 hours in survey mode and 1 hour in full GC/MS mode; operating times double when starting with two fully charged batteries. Battery recharge time is 5 hours when the battery is in the G-510 or 2 hours using the supplied external charger.

The Griffin G-510 weighs 36 pounds with two batteries and carrier gas cylinder installed. Its dimensions are 13.25 x 13.25 x 15.75 inches. Its environmental operating temperature range is from 32°F to 104°F and its storage temperature range is from -13°F to 131°F. It has an Ingress Protection (IP) rating of 65 when operated in 'sealed mode', i.e., with cooling vents closed; however, operation in sealed mode is limited to about 30 minutes due to the limited ability to disperse generated heat. FLIR recommends that only survey mode analyses be performed when operating in sealed mode. The G-510 conforms to military standard (MIL-STD) 810G for shock and vibration resistance.

1.2.2 Inficon AG Hapsite ER

The Hapsite ER GC/MS is a quadrupole mass spectrometer that provides a 41 to 300 AMU measurement range and its gas chromatograph is programmable over a temperature range from 45°C to 200°C. It has a vapor sampling probe for performing rapid survey analysis or full GC/MS analysis of chemical vapors. Accessories can be connected or attached to allow users to introduce samples collected using SPME fibers, from headspace analysis or using other devices for survey or full GC/MS analysis. Two optional sampling accessories, the Hapsite HeadSpace Sampling System for headspace sampling of volatile organic compounds in water, soil and solids, and the Hapsite SituProbe™ for water analysis, are available for purchase but were not evaluated during this assessment.

Figure 1-2 Inficon AG Hapsite ER

Courtesy of Inficon AG

The Hapsite ER is operated via a 6.5-inch color touchscreen and a multi-button keypad, except for the vapor sampling probe, which is controlled using a keypad built into the sampler head. Its operating software provides for two user levels with differing abilities to modify instrument settings or limit operations (e.g., tune), etc. Analysis data can be exported by USB cable or wirelessly.

The gas chromatograph uses nitrogen (N2) carrier gas supplied by two removable internal gas cylinders. Operating power can be supplied by external 120-to-240-volt AC sources or an internal rechargeable nickel metal hydride (NiMH) battery. A fully charged battery provides 2 to 3 hours of operation time. Battery recharge time is approximately 15 hours.

The Hapsite ERs weigh 42 pounds including the internal gas cylinders and battery. Its dimensions are 18 x 7 x 7 inches. It operates over an ambient environmental temperature range from 32°F to 113°F and has a storage temperature range of -40°F to 158°F. Product literature provided by the manufacturer does not provide an IP rating or state that the Hapsite ER conforms to any shock or vibration resistance standard.

1.2.3 PerkinElmer Torion T-9

The Torion T-9 GC/MS is a toroidal ion trap-based mass spectrometer that provides a measurement range from 43 to 500 atomic AMU, and a gas chromatograph that is programmable over a 50°C to 300°C temperature range. Sample introduction options include vendor-specific SPME fibers, needle traps and other sample collection media; and organic liquid samples can also be directly injected for analysis. The Torion T-9 is not equipped with a vapor sampling probe and cannot perform survey analyses.

Figure 1-3 PerkinElmer Torion T-9

Courtesy of PerkinElmer

The Torion T-9's user interface consists of a 5.7-inch color touchscreen and a three-button keypad. Its operating software provides for two user levels with differing abilities to modify instrument settings, delete data, etc. Data files can be exported by secure digital (SD) card, USB cable, or wirelessly.

The gas chromatograph uses helium carrier gas supplied by an internal gas cylinder. An external supply of carrier gas can be connected for extended operations. Operating power can be supplied by external 120-to-240-volt AC sources or by an internal rechargeable Li-ion battery. The Torion T-9's operating time, starting with a fully charged battery, is approximately 2.5 hours.

The Torion T-9 weighs 32 pounds, including the internal Li-ion battery and carrier gas cylinder. Its dimensions are 15 x 15.5 x 9 inches. It has an operating temperature range of 41°F to 113°F and a storage temperature range of -4°F to 140°F. Torion T-9 product literature does not provide an IP rating for this instrument or state that it conforms to any shock or vibration resistance standard.

Table 1-2 provides key specifications for each instrument.

Table 1-2 Key Instrument Specifications

Specification	Griffin G-510	Torion T-9	Hapsite ER
Mass Spectrometer Range	18 to 510 AMU	43 to 500 AMU	41 to 300 AMU
GC Column Temp. Range	40°C to 300°C	50°C to 300°C	45°C to 200°C
GC Carrier Gas	Helium	Helium	Nitrogen
Carrier Gas Supply	One internal cylinder or external via port	One internal cylinder or external via port	Two internal cylinders
Sample Introduction	Vapor probe or sample port	Sample port	Vapor probe or sample port
Sample Analysis Modes	Survey and Full GC/MS	Full GC/MS	Survey and Full GC/MS

Specification	Griffin G-510	Torion T-9	Hapsite ER
Dimensions	13.25 x 13.25 x 15.75 inches	15 x 15.5 x 9 inches	18 x 7x 7 inches
Weight	36 pounds	32 pounds	42 pounds
Operating Temp. Range	32°F to 104°F	41°F to 113°F	32°F to 113°F
Storage Temp. Range	-13°F to 131°F	-4°F to 140°F	-40°F to 158°F
Batteries	Two Li-ion	One Li-ion	One NiMH
Run Time on Batteries	2 hours (survey mode) 1 hour (GC/MS mode)	2.5 hours	2 to 3 hours
Data Export Modes	USB, wireless	USB, SD card, wireless	USB, wireless

2.0 EVALUATION CRITERIA

The SAVER focus group on field portable GC/MS held in February 2019 recommended that the products be assessed on 35 evaluation criteria and assigned each evaluation criterion to one of the five established SAVER assessment categories defined below:

- **Affordability** criteria relate 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** criteria relate to product features or functions needed to perform one or more responder relevant tasks.
- **Deployability** criteria relate to preparing to use the product, including transport, setup, training and operational/deployment restrictions.
- **Maintainability** criteria relate to the routine maintenance and minor repairs performed by responders, as well as included warranty terms, duration and coverage.
- **Usability** criteria relate to ergonomics and the relative ease of use when performing one or more responder relevant tasks.

The focus group assigned weights indicating the level of importance of each evaluation criterion and of the five SAVER assessment categories. Evaluation criteria were weighted on a 1 to 5 numerical scale, with a ‘1’ indicating an evaluation criterion of minor importance and a ‘5’ indicating an evaluation criterion of utmost importance. SAVER assessment category weights were assigned using a percent scale summing to 100 percent. Evaluation criterion and assessment category weights factored into the calculation of overall product scores and assessment category scores that came out of this assessment. See Appendix B for the equations used to calculate these scores.

These focus group recommendations were largely followed in executing the assessment; however, several evaluation criteria identified by the focus group were eliminated, moved or merged, and due to these changes, one SAVER assessment category was eliminated:

- *Cost of Instrument* and *Maintenance Costs,* which the focus group had assigned to the Affordability category, were eliminated because instrument manufacturers were reluctant to provide pricing information. The remaining evaluation criterion in the Affordability category, *Cost of Consumables* was moved to the Maintainability category, and the Affordability category was eliminated.
- *AC Power* was eliminated. All three instruments can be operated on standard 120-volt power sources.
- *Field Serviceability* was eliminated. A review of instrument operating manuals and discussions between National Urban Security Technology Laboratory (NUSTL) and Pacific Northwest National Laboratory (PNNL) staff and product representatives indicated that there was little that basic users would be able to maintain using only simple tools.
- *Decontaminability* and *Storage Conditions* were moved from the Deployability to the Maintainability category. It was the judgement of the NUSTL Test Director that these evaluation criteria more closely aligned with the general concept of instrument maintainability than instrument deployability.
- *User Manual Quality* and *Training Materials*, which were assigned to the Usability category by the focus group, were combined into one evaluation criterion that was renamed *Product Reference Materials*.

The weights assigned to the four remaining assessment categories were modified from those recommended by the focus group in keeping with its recommendation that the weights of the assessment categories be proportionate to the number of evaluation criteria in them so that all evaluation criteria had roughly equal influence on overall product scores. The weight of the Capability category was changed from 10% to 15%, Deployability from 40% to 30%, and Maintainability from 10% to 20%. Table 2-1 lists the 30 evaluation criteria used to assess the instruments, the SAVER assessment categories the evaluation criteria were assigned to, and the weights assigned to each evaluation criterion and assessment category.

Table 2-1 Evaluation Criteria

SAVER CATEGORIES			
Usability	**Deployability**	**Maintainability**	**Capability**
Overall Weight 35%	Overall Weight 30%	Overall Weight 20%	Overall Weight 15%
EVALUATION CRITERIA			
Data File Formats	Hot Swappable Batteries	Technical Support	Data Analysis
Weight: 4	Weight: 5	Weight: 5	Weight: 4
Operation with PPE	Hot Swappable Carrier Gas	Software/Library Updates	Data Export Modes
Weight: 4	Weight: 5	Weight: 4	Weight: 4
Sample Introduction Options	Battery Characteristics	Tuning Requirements	Column Temperature Range
Weight: 4	Weight: 5	Weight: 4	Weight: 3
Simplicity of Operation	Start-Up Time	Storage Conditions	AMU Range
Weight: 4	Weight: 5	Weight: 4	Weight: 2
Product Reference Material	Operating Temperature Range	Decontaminability	Detection Threshold
Weight: 4	Weight: 4	Weight: 3	Weight: 2
Library Modification	Time between Runs	Cost of Consumables	
Weight: 3	Weight: 4	Weight: 3	
Configurable User Interface	Portability		
Weight: 3	Weight: 3		
Display Screen Characteristics	Sample Preparation Time		
Weight: 3	Weight: 3		
Report Content	Water and Dust Resistance		
Weight: 3	Weight: 3		
Status Indicators			
Weight: 3			

3.0 ASSESSMENT ACTIVITIES

The assessment took place from July 23 to 25, 2019, at the City of Seattle Joint Training Facility (JTF), in Seattle, Washington. The assessment began with an opening session in which the NUSTL Test Director provided assessment participants with an overview of planned assessment activities, roles and responsibilities of assessment participants and the schedule of activities. Evaluators were then grouped into three teams, each of which assessed one instrument per day. Each day's assessment activities consisted of a series of hands-on operational use sessions focusing on different aspects of instrument operation, and a debrief session at the end of the day in which evaluators provided their assessments of the instruments. NUSTL and PNNL staff were embedded within each assessment team during the operational assessment sessions to ensure that assessment activities were carried out safely and according to the assessment plan. A score adjustment session was held at the end of the day on July 25 to give the evaluators an opportunity to re-evaluate and modify the evaluation criterion scores they provided for each product. Sections 3.1 to 3.7 below provide more detailed descriptions of each assessment session.

3.1 Sessions 1 and 2: Product Overview/Start Up and Calibration

The Field Portable GC/MS Assessment Plan envisioned that these two sessions would take place sequentially. In Session 1, Product Overview, the product representatives provided an initial overview of the instrument, while in Session 2, Start Up and Calibration, the instruments would be turned on and calibrated. At the start of the first day of the assessment, product representatives for all three instruments indicated that they would be able to provide a more effective overview once the instruments had been turned on, and so the two sessions were combined.

Figure 3-1 Hapsite ER Product Overview Session

The overviews provided by the product representatives covered technical specifications of the instrument's GC/MS, the instrument's user interface, sample introduction options, carrier gas and battery replacement and instrument maintenance. At the start of these two combined sessions, each instrument had been turned off for at least the 12 previous hours, as required for assessing the 'Cold Start Up' evaluation criterion. Once the instruments were turned on, the evaluators performed necessary instrument calibration/tuning procedures, ran system blanks and adjusted instrument settings as necessary to run the samples to be analyzed in the following assessment sessions. Evaluators carried the instrument to assess portability, e.g., weight, size and positioning of handles and carrying straps.

3.2 Session 3: Initial Sample Analysis

In this session, evaluators performed what is often the first step in the GC/MS analysis of an unknown sample, which is to analyze the vapor produced by volatile or semi-volatile compounds. The test samples provided to the evaluators to analyze—isopropyl alcohol, acetone-based nail polish remover and ethyl acetate-based nail polish remover—are consumer products with relatively simple chemical compositions and whose primary ingredient is an organic compound with an appreciable vapor pressure.

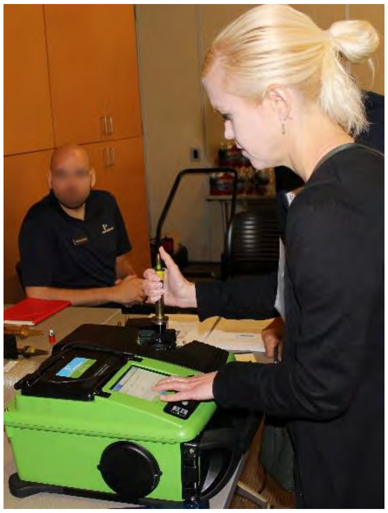

Figure 3-2 Torion T-9 Initial Sample Analysis Session

Evaluators analyzed the test samples following procedures demonstrated to them by a product representative. Product representatives supplied any items needed to prepare the test samples and introduced them into their instruments. Each evaluator analyzed at least one test sample and as a team the evaluators reviewed analysis results. Product representatives provided technical assistance and responded to evaluators' questions about instrument features and capabilities, but otherwise allowed the evaluators to complete all steps needed to perform the analyses. Blanks were run as recommended by the product representatives.

Sample introduction and analysis procedures varied due to differences in instrument design. The Griffin G-510 and Hapsite ER evaluators used their vapor sampling probes to analyze the test samples. The samples were first analyzed using the instruments' survey mode, and then using the instruments' full GC/MS analysis mode. The Torion T-9 evaluators used the vendors SPME fiber device to collect a vapor sample; this SPME fiber was then inserted into the Torion T-9's sample introduction port to initiate a full GC/MS analysis.

Evaluators reviewed analysis results against chemical compositions reported by the test sample manufacturers. Evaluators observed no significant failure of any instrument to identify compounds present in the test samples.

Analysis data files were saved for possible use in Session 6, Data Analysis, Report Generation and File Export. Evaluators also reviewed operator manuals and other available sources to assess how helpful they were in understanding instrument operation.

3.3 Session 4: Continued Sample Analysis

Each evaluator team analyzed at least one solid and liquid test sample chosen from those listed below.

- Liquid test samples: oral analgesic, caffeinated beverage, liniment, fabric spot cleaner, menthol electronic cigarette fluid, spray lubricant
- Solid test sample: aspirin/caffeine pill, ibuprofen, wintergreen candy, wood filler.

These test samples had a greater number of chemical components than those analyzed in Session 3, with some samples requiring a longer analysis time due to the presence of chemical compounds with higher molecular weights that required a longer separation time to effectively elute all the components.

The evaluators first analyzed volatile chemical compounds produced by the test samples using the same procedures as in Session 3. The Griffin G-510 and Torion T-9 evaluators also tried other sample analysis procedures demonstrated to them by each instrument's product representative. Griffin G-510 evaluators dissolved and diluted test samples in an organic liquid solvent and then used a commercial microliter syringe to inject a known volume into the instrument via its sample introduction port. Torion T-9 evaluators dissolved and diluted the test sample in an organic liquid solvent, then sampled the resulting solutions with a coiled microextraction (CME) sampling device provided by PerkinElmer. The CME sampling device was then inserted into the Torion T-9's sample introduction port.

Figure 3-3 Sample Introduction via Syringe - Griffin G-510

Product representatives provided the items needed to prepare and introduce test samples into their instruments. They provided technical assistance to evaluators as needed, but otherwise stood by while the evaluators performed these analyses. Blanks were run between sample analyses as recommended by each instrument's product representative. The evaluators performed at least one test sample analysis while wearing Level A gloves taken from an encapsulated protective suit to assess instrument operation while wearing personal protective equipment (PPE).

Figure 3-4 Vapor Sample Analysis Mode - Hapsite ER

The evaluator teams also analyzed samples of opportunity that were not specified in the assessment plan:

- The Griffin G-510 and Hapsite ER assessment teams used vapor sampling probes to perform survey and full GC/MS analyses of fuel vapors emitted by vehicles in the JTF parking lot. Torion T-9 assessment teams sampled vehicle fuel vapors with an SPME fiber that was then brought to the Torion T-9 and inserted into its sample introduction port to perform a full GC/MS analysis.
- Volatile chemical compounds emitted by pine trees growing adjacent to an outdoor patio area at the JTF were also sampled and analyzed. Griffin G-510 and Hapsite ER evaluators either used vapor sampling probes to perform a survey or full GC/MS analysis. The probe was held either near the branch of a pine tree or at the mouth of a vial containing pine needles.
- Torion T-9 evaluators used SPME fiber to sample the headspace of a vial containing pine needles, and then inserted the SPME fiber into the Torion T-9's sample introduction port to initiate a full GC/MS analysis.

Figure 3-5 Analysis of Pine Needle Vapors - Griffin G-510

Additionally, a Torion T-9 product representative used a small battery powered air sampler to collect a vapor sample close to the branch of a live pine tree. The air sample contained a detachable needle trap device (NTD) packed with a sorbent material that was detached from the sampler and inserted into the Torion T-9's sample introduction port to initiate a full GC/MS analysis.

Evaluators reviewed their analysis results and compared compounds identified to chemical composition information provided by test sample manufacturers. Evaluators observed no significant failure of any instrument to identify compounds present in the test samples. The exact chemical makeup of the samples of opportunity was unknown, but each instrument identified chemical compounds that members of the test team and product representatives knew to be present in such samples.

Analysis data files were saved for possible use in Session 6, Data Analysis, Report Generation and File Export. Evaluators reviewed operator manuals and other available information to assess how helpful they were in understanding how to operate the instrument as required in this session.

3.4 Session 5: Consumables and maintenance

In this session, evaluators assessed factors relating to battery and carrier gas usage and replacement, instrument decontamination and processes for updating instrument analyte mass spectral libraries. Product representatives discussed and demonstrated how to replace internal batteries and carrier gas cylinders, discussed battery operation and recharge times and demonstrated how to update instrument libraries.

Figure 3-6 Hapsite ER Consumables and Maintenance Session

Battery replacement – Each instrument was operated on battery power from the beginning of the day until the batteries were nearly depleted; this typically occurred during Session 3 or 4. The instrument was then operated on external AC power until this session took place. All three instruments started to recharge depleted batteries once they began to operate on external AC power. Evaluators found that the degree to which batteries could be 'hot swapped', i.e., removed and replaced without affecting instrument operations, differed:

- The Griffin G-510 contains two internal Li-ion batteries. One battery can be removed while the instrument continues to operate using the other battery. The Griffin can also be operated on external AC power during battery replacement.
- The Torion T-9 must be turned off to replace its internal Li-ion battery.
- The Hapsite ER's internal NiMH battery can be replaced while in operation by connecting it to an external battery pack or to an external AC power source.

Carrier gas replacement – All three instruments were able to operate on their original internal carrier gas cylinders through all three days of the assessment. Product representatives nevertheless demonstrated the process for replacing carrier gas cylinders for each instrument, since this was one of the evaluation criteria on which the instruments were to be evaluated.

Evaluators found the gas cylinder replacement process simple to perform for all three instruments; however, they noted significant differences in the degree to which gas cylinders could be hot swapped:

- The Griffin G-510 can remain turned on while its internal carrier gas cylinder is replaced, but no GC/MS analyses can be performed while the depleted cylinder is being replaced.
- The Torion T-9 must be turned off to replace a depleted helium carrier gas cylinder.

The Hapsite ER holds two internal nitrogen carrier gas cylinders. It can continue to operate on one gas cylinder while the other cylinder is replaced.

Decontaminability – Evaluators examined the instruments from the standpoint of how easily and effectively they can be decontaminated and cleaned. They were asked to consider whether external surfaces could be decontaminated by the methods they would employ, whether port covers can be easily lost and to consider any available information about water resistance that might be relevant to the decontamination measures. They were also encouraged to identify any other factors affecting instrument decontamination.

Mass Spectral Library Modification – Evaluators assessed procedures for modifying or adding compounds to each instrument's analyte library, which were demonstrated to them by each instrument's product representative.

3.5 Session 6: Data Analysis, Report Generation and File Export

Evaluators performed the activities in this session under the guidance of the product representative. Data analysis assessment activities included:

- Locating previously saved analysis data files.
- Viewing test sample chromatograms and the mass spectra associated with different peaks in the chromatograms.
- Comparing test sample mass spectra against reference library mass spectra.
- Using spectrum analysis software to explore test sample mass spectra, e.g., subtracting reference library mass spectra from measured mass spectra to identify residual spectrum peaks.
- Evaluators produced summary reports of analysis results obtained in earlier sessions. They explored options for tailoring report content to recipients (e.g., incident commanders). Paper copies of several summary reports were printed for evaluators to review.
- Evaluators exported analysis data and summary report files from the instrument to a vendor-provided laptop computer. Depending on the instrument, this was by cable connection to a laptop computer, export to a USB memory device, or wireless export.

3.6 Evaluator Debrief

At the end of each day, NUSTL and PNNL data collectors administered product questionnaires to the evaluators to obtain numerical ratings on each evaluation criterion. Evaluators provided their ratings based on their experience using the instruments in the operational assessment sessions and by reviewing manufacturer-verified product specifications, instrument operating manuals and product literature.

Figure 3-7 Evaluator Debrief Session

The evaluators were encouraged to supplement their numerical ratings with comments pertinent to the evaluation criteria, and any such comments were recorded by the data collectors.

Evaluation criterion were rated on a 1-to-5 scale that was defined as follows:

1. The product meets none of my expectations for this criterion
2. The product meets some of my expectations for this criterion
3. The product meets most of my expectations for this criterion
4. The product meets all my expectations for this criterion
5. The product exceeds my expectations for this criterion

Evaluators were given an opportunity to reconsider these ratings during the score adjustment session as discussed in Section 3.7 below.

3.7 Score Adjustment Session

The final activity of the assessment was a score adjustment session held at the end of the day on July 25. The purpose of this session was to provide the evaluators with an opportunity to revise their numerical scores based upon the perspective gained from using all three instruments and from considering the opinions offered by their fellow evaluators.

Under the direction of the NUSTL Test Director, the evaluators reviewed and discussed the evaluation criteria ratings given to all three instruments. Emphasis was given to evaluation criteria for which the range of numerical scores for an evaluation criterion was greater than 2 (e.g., the lowest score given was a ‘2’, and the highest, a ‘5’). The evaluators discussed the rationale by which they arrived at their scores and were then asked whether they wished to change their scores after considering the opinions offered by other evaluators. It was clearly stated to evaluators that they were free to hold to their original scores and that any changes were entirely voluntary. NUSTL and PNNL staff took notes on evaluator comments made during this session for incorporation into the feedback reported in Section 4. At the end of this session, all evaluation scores were taken to be final and it is these scores that were used to calculate the overall and SAVER category scores presented in this report.

4.0 ASSESSMENT RESULTS

Based on the evaluation criterion ratings provided by the evaluators, an overall assessment score and category scores and criteria scores were calculated for each product using the formulas referenced in Appendix B.

Table 4-1 summarizes these results. Overall numeric scores for the three instruments ranged from 4.1 to 2.7, and SAVER assessment category scores ranged from 2.6 to 4.3.

Table 4-1 Overall Ratings

Product	Overall Score	Overall	Usability	Deployability	Maintainability	Usability
FLIR Detection, Inc./Griffin G-510		**4.1**	4.2	3.8	4.2	4.3
PerkinElmer/Torion T-9		**2.9**	3.1	2.8	2.6	3.2
Inficon AG/Hapsite ER		**2.7**	2.6	2.6	2.7	2.9

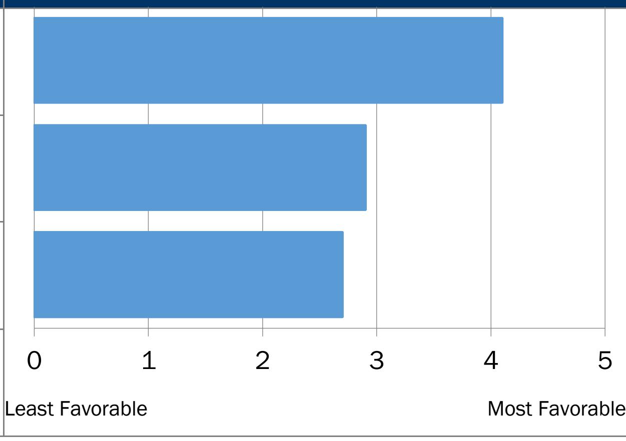

Table 4-2 presents the average evaluation criterion scores the instruments received from the evaluators for each evaluation criteria. A green, fully shaded circle represents the highest rating, while a red, unshaded circle represents the lowest rating.

Table 4-2 Evaluation Criteria Ratings

Key: Lowest Rating → Highest Rating: ○ ◔ ◑ ◕ ●

Category	Evaluation Criteria	Griffin G-510	Torion T-9	Hapsite ER
Usability	Data File Formats	●	◕	◑
	Operation with PPE	◕	◕	◑
	Sample Introduction Options	●	◔	◔
	Simplicity of Operation	◕	◕	◑
	Product Reference Material	●	◔	◔
	Library Modification	●	◕	◔
	Configurable User Interface	●	◔	◑
	Display Screen Characteristics	◕	◔	◔
	Report Content	◕	◕	◔
	Status Indicators	◑	◕	◕
Deployability	Hot Swappable Batteries	◕	◔	○
	Hot Swappable Carrier Gas	◑	○	◕
	Battery Characteristics	◕	◕	○
	Start-Up Time	◕	◑	◑
	Operating Temperature Range	◕	◕	◕
	Time between Runs	◕	◕	◔
	Portability	◕	◑	◑
	Sample Preparation Time	●	◔	◑
	Water and Dust Resistance	◕	◑	◑
Maintainability	Technical Support	●	○	◔
	Software/Library Updates	●	◔	◔
	Tuning Requirements	●	◑	◑
	Storage Conditions	◕	◕	◕
	Decontaminability	◑	◕	◑
	Cost of Consumables	●	◔	◔
Capability	Data Analysis	◕	◑	◑
	Data Export Modes	●	◔	◑
	Column Temperature Range	◕	◕	◔
	AMU Range	●	◕	◔
	Detection Threshold	●	◕	◑

Evaluator comments recorded by data collectors during the evaluator debrief sessions are summarized in Sections 4.1 to 4.3 below.

4.1 FLIR Detection, Griffin G-510

The Griffin G-510 received an overall assessment score of 4.1, while scores for individual assessment categories ranged from 3.8 to 4.3. Evaluator comments provided during the debrief sessions are reported below, grouped by assessment category.

Figure 4-1 Griffin G-510 Operation in Vapor Sampling Mode

4.1.1 Usability

The Griffin G-510 received a Usability score of 4.2. Evaluator feedback on evaluation criteria related to this assessment category included:

- Evaluators unfamiliar with the Griffin G-510 stated that they were quickly able to learn how to operate it. The user interface provided prompts that were helpful in correctly performing sample analysis steps.
- The Griffin's G-510's vapor sampling probe and sample introduction port provided flexibility in sample introduction. Samples in different physical states (vapors, liquids) or collected with different types of sampling devices (microliter syringes, SPME fibers) were readily introduced for analysis. Evaluators indicated that using the vapor sampling probe for survey analyses was a useful way to quickly obtain initial sample identification information. Several evaluators particularly liked that microliter syringes are a standard liquid sample introduction device because they are easy to use and can be purchased from many suppliers. The evaluators were able to quickly and easily switch between the sample introduction and analysis modes when analyzing different kinds of test samples.
- The operating software provides for basic and advanced user levels. Evaluators liked the flexibility provided in selecting which instrument functions to make available to basic users.
- Evaluators had no difficulty reading the display screen when operating the Griffin G-510 outdoors in bright sunlight. Some evaluators commented that the advanced user mode display screens were too cluttered and used font sizes that were too small to easily read.
- Evaluators had no difficulty activating touchscreen buttons while wearing Level A protective gloves, but some of them found it difficult to use the touchscreen stylus when doing so.
- The ability to remotely operate the Griffin G-510 was considered a potentially useful feature for operation in potentially hazardous environments.
- Evaluators found the user manual to be a useful resource. FLIR-produced instruction videos that can be viewed on the Griffin G-510's display screen was considered to be a helpful feature, as was the ability to upload and view reference material produced by the instrument user's organization.

- The Griffin G-510 has a resettable injection counter that indicates when it is time to change the gas cylinder, but it does not provide an indication of the current carrier gas level. The evaluators considered this to be a drawback because instrument users would be better able to plan their field sampling work having a real-time indicator of the carrier gas supply.
- Summary reports of analysis results obtained during the assessment sessions were clear and informative; however, the evaluators considered it to be a drawback that the summary reports could not be modified to tailor them to specific recipients.

4.1.2 DEPLOYABILITY

The Griffin G-510 received a Deployability score of 3.8. Evaluator feedback on evaluation criteria related to this assessment category included:

Figure 4-2 Assessing Griffin G-510 Portability

- The Griffin G-510's Li-ion batteries are truly hot-swappable, i.e., evaluators were able to operate the instrument on one battery while the other battery was replaced. Recharge times for depleted batteries were comparable to the operating time they provided. The evaluators considered these to be useful features for extended operation in the field.
- The batteries are non-proprietary items that can be purchased from multiple suppliers. Evaluators considered this be an advantage because it provides more options for quickly acquiring new batteries.
- Carrier gas hot swappability is somewhat limited. To avoid shutting down when the carrier gas cylinder is replaced, a second gas cylinder can be externally connected via a gas port. This was not considered to be an optimal replacement method when operating in the field.
- Several evaluators indicated that the operating temperature range was insufficient for winter temperatures encounter in their regions.
- Some evaluators commented that their ability to operate the Griffin G-510 when carrying it was hindered by its uneven weight distribution.
- The display screen orientation could be changed, which made it easier to read when the Griffin G-510 was operated while being carried.

4.1.3 MAINTAINABILITY

The Griffin G-510 received a Maintainability score of 4.2. Evaluator feedback on evaluation criteria in this assessment category included:

- Evaluators considered the ability of FLIR tech support personnel to remotely access the Griffin G-510 to diagnose problems to be a valuable feature.

- Instrument port covers are not attached to the instrument body and so are susceptible to loss. Loss of the port covers could make it more difficult to decontaminate external surfaces near the ports.

4.1.4 Capability

The Griffin G-510 received a Capability score of 4.3. Evaluator feedback on evaluation criteria related to this assessment category included:

- The mass spectrometer AMU range and GC column temperature range were well suited for the kinds of analyses required by evaluators' organizations.
- Evaluators had mixed opinions about the data analysis tools available in the advanced user mode. Some evaluators found these analysis tools easy to use, while others did not.
- The ability to wirelessly e-mail data files was considered a useful data export option.

4.2 PerkinElmer, Torion T-9

The Torion T-9 received an overall assessment score of 2.9, while numeric scores for individual assessment categories ranged from 2.6 to 3.2. Evaluator comments provided during the debrief sessions are reported below, grouped by assessment category.

Figure 4-3 Torion T-9 Start-Up and Familiarization

4.2.1 Usability

The Torion T-9 received a Usability score of 3.1. Evaluator feedback on evaluation criteria related to this assessment category included:

- Evaluators found the Torion T-9's user interface easy to navigate. It provided helpful prompts to guide them through the sample introduction process.
- Evaluators considered a vapor sampling probe to be a convenient tool for field sampling work, thus the absence of such a probe was considered a disadvantage.
- Some evaluators had difficulty reading the display screen when operating outdoors in bright sunlight.
- The operating manual was comprehensive and clearly written. Evaluators suggested that it should be supplemented by instructional videos that can be accessed on the internet or viewed on the instrument's display screen.
- Evaluators experienced no difficulty operating the Torion T-9 while wearing Level A protective gloves.
- Evaluators liked the flexibility provided for tailoring summary reports of sample analysis results to specific recipients.
- Evaluators indicated that the Torion T-9's operating software should provide greater options for limiting access to instrument functions based on user experience level.

4.2.2 Deployability

The Torion T-9 received a Deployability score of 2.8. Evaluator feedback on evaluation criteria related to this assessment category included:

- Battery hot swappability was somewhat limited. An external battery could be connected to serve as a temporary power supply during battery replacement, but this was considered a less than optimal method when operating in the field. The battery recharge time was comparable to the run time it provided, which was considered to be useful for extended operations in the field.
- Torion T-9's Li-ion battery is a non-proprietary item that can be purchased from multiple suppliers. The evaluators considered this to be a positive feature because it provided more options for quick battery replacement.
- It is necessary to shut down the Torion T-9 to replace its internal carrier gas cylinder, which was considered a less than optimal method when operating in the field.
- Analysis of vapor samples took longer than for the other two instruments due to the absence of a vapor sampling probe.
- The evaluators were able to carry the Torion T-9 from one location to another without turning it off; however, it lacked a vapor sampling probe, which somewhat limited the benefit provided by its portability.
- Several evaluators indicated that the operating temperature range was insufficient for winter temperatures that they encounter in their regions.
- Port covers were not attached to the instrument and so could easily be lost. Evaluators indicated that the loss of port covers could make it difficult to decontaminate or clean surfaces around the ports.

4.2.3 Capability

The Torion T-9 received a Capability score of 3.2. Evaluator feedback on evaluation criteria related to this assessment category included:

- The mass spectrometer AMU range and GC column temperature range were well suited for the kinds of analyses required by evaluators' organizations.
- Mass spectrometric analysis results are not displayed until the full GC/MS analysis of a sample is complete. Evaluators indicated that it would be better if GC/MS analysis results were reported as soon as they became available, i.e., as individual compounds eluted from the GC column.

Figure 4-4 Torion T-9 Touchscreen Interface

- Evaluators noted limitations in two data export options. First, only summary reports can be wirelessly exported; other file types must be exported by another data export method. Second, while the SD card can be used to export data files, the operating manual cautions against removing it when there is a likelihood of data being written to it, e.g., while samples are being analyzed.

4.2.4 Maintainability

The Torion T-9 received a Maintainability score of 2.6.

4.3 Inficon AG, Hapsite ER

The Hapsite ER received an overall assessment score of 2.7, while numeric scores for individual assessment categories ranged from 2.6 to 2.9. Evaluator comments provided during the debrief sessions are reported below, grouped by assessment category.

4.3.1 Usability

The Hapsite ER received an overall Usability score of 2.6. Evaluator feedback on evaluation criteria related to this assessment category included:

Figure 4-5 Operation of the Hapsite ER with PPE

- The Hapsite ER was easy to operate in vapor sampling mode. Operation of the vapor sampling probe in survey mode was considered a useful way to quickly obtain initial sample identification information.
- The sample introduction attachments needed to analyze non-vapor samples were awkward to connect and use, particularly while wearing Level A protective gloves.
- Some evaluators considered it a drawback that the Hapsite ER could only be operated at the basic user level when not connected to a laptop computer.
- The operating manual was a useful reference with many helpful photos. Evaluators suggested that the operating manual be supplemented with internet-based or onboard instructional videos.
- The process for generating summary reports of analysis results was cumbersome.
- Information was clearly presented on the Hapsite ER's display screen and a color-coding scheme was helpful in quickly understanding analysis results. Some evaluators had difficulty reading the display screen outdoors in bright sunlight, however.

4.3.2 Deployability

The Hapsite ER received a Deployability score of 2.6. Evaluator feedback on evaluation criteria related to this assessment category included:

- The Hapsite ER's NiMH battery can be replaced without shutting down the instrument by connecting an external battery. While this provides a degree of hot swappability, evaluators considered this to be a less than optimal procedure when operating in the field.

The battery recharge time, approximately 15 hours according to manufacturer specifications, was not considered to be well suited for field operations because multiple spare batteries would be required for extended operations on battery power.

- The battery is a proprietary item available only from the Hapsite ER's manufacturer, Inficon AG. Evaluators expressed a preference for batteries and other parts that are obtainable from multiple suppliers to provide more options for quick replacement if necessary.
- Carrier gas cylinders were truly hot swappable, i.e., the Hapsite ER could operate on one carrier gas cylinder while the other was replaced. Evaluators considered this to be a useful feature for extended field operations.

Figure 4-6 Hapsite ER Pine Needle Vapor Analysis

- Several evaluators indicated that the operating temperature range was insufficient for winter temperatures that they encounter in their regions.
- The evaluators indicated that time between sample analyses was good if all samples were to be analyzed using the gas sampling probe, but if non-vapor samples were also to be analyzed, connecting the needed sample introduction attachment would result in an inconvenient delay.
- The evaluators indicated that the Hapsite ER's portability was reduced when connected to external sample introduction attachments.

4.3.3 Maintainability

The Hapsite ER received a Maintainability score of 2.7. Evaluator feedback on evaluation criteria related to this assessment category included:

- Evaluators considered the ability of the manufacturer's technical support personnel to remotely access the Hapsite ER to be a useful feature; however, they indicated that it would be better if remote access could be accomplished without needing to use the Hapsite ER's laptop computer as an intermediary device.
- While the Hapsite ER has not been tested to drop test or shock test standards, the evaluators judged that its sturdy case and the position of the control interface would allow it to hold up well in field use.
- Evaluators judged that exterior surfaces could be effectively decontaminated; however, a regular Hapsite ER user expressed concern that the gasket that seals the battery/carrier gas compartment could come loose and would then be difficult to reseat.

4.3.4 CAPABILITY

The Hapsite ER received a Capability score of 2.9. Evaluator feedback on evaluation criteria related to this assessment category included:

- The mass spectrometer AMU range and GC column temperature range were not sufficient for some kinds of analyses that evaluators' organizations needed to perform, for instance, analysis of samples for fentanyl.
- The Hapsite ER's onboard analyte library was limited in size compared to the analyte library available on its accompanying laptop computer. Some evaluators indicated that this was a drawback because connecting the instrument to a laptop computer was not always feasible during field work.
- Evaluators were able to easily export analysis data using a USB thumb drive or a USB cable connection to the Hapsite ER's accompanying laptop computer. They considered the ability to export data files wirelessly to be a particularly useful option when operating in the field.

5.0 SUMMARY

The evaluators identified several differences among the three field-portable GC/MS instruments that are relevant to the needs of first responders. They indicated that a direct vapor sampling capability with a handheld probe was a desirable feature in this type of instrument and that methods for introducing non-vapor samples into the instruments should be simple to perform. Instruments whose mass spectrometer systems are capable of measuring to a high AMU range and whose GC columns can be operated to a high temperature would serve the needs of a wider range of first responder organizations. Evaluators expressed a preference for instruments whose batteries and carrier gas are truly hot swappable, i.e., they can be replaced without shutting off the instrument or relying on a temporary external attachment. They also expressed a preference for non-proprietary batteries and other consumable items that might need to be frequently replaced. The environmental operating temperature range of all three instruments was not sufficient for winter conditions that some evaluators encounter. See Table 5-1 below for a summary of the advantages and disadvantages of each instrument with respect to these points. Evaluators noted no significant failures of any of the three assessed instruments to perform its core chemical identification function; however, it should be noted that this assessment was not designed to be a rigorous test of the analytical performance of these instruments.

This report provides the assessments offered by evaluators drawn from several different first responder disciplines and several different regions of the United Sates. While it is hoped that the feedback provided in this report is of general relevance to first responder organizations throughout the nation, individual first responder organizations that intend to purchase field portable GC/MS instruments should carefully research the capabilities and features of available instruments to identify the product best suited to their operational requirements.

Table 5-1 Product Advantages and Disadvantages

Product	Advantages	Disadvantages
 FLIR Detection Griffin G-510	• AMU and GC column temperature ranges permit a wide range of chemical compounds to be identified • Probe for sampling vapors • Sample port readily accepts a range of sample types • Fully hot swappable, non-proprietary Li-ion batteries	• Does not indicate carrier gas level • Operating temperature range not sufficient for winter conditions in some regions
 PerkinElmer Torion T-9	• AMU and GC column temperature ranges permit a wide range of chemical compounds to be identified • Non-proprietary Li-ion battery	• No vapor sampling probe • Operating temperature range not sufficient for winter conditions in some regions
 Inficon AG Hapsite ER	• Probe for sampling vapors • Fully hot swappable carrier gas cylinders	• AMU and GC column temperature range limit the range of compounds that can be identified • Introduction of non-vapor samples was cumbersome • Proprietary NiMH battery; long recharge time • Operating temperature range not sufficient for winter conditions in some regions

APPENDIX A. EVALUATION CRITERION DEFINITIONS

CAPABILITY

Data Analysis – Whether data analyses are informative. The focus group indicated that, for example, when a specific compound cannot be confidently identified, it would be useful for specific functional groups that can be identified with confidence to be indicated. Conversely, noting that a peak(s) is "unknown" was not considered helpful or useful.

Data Export Modes – From the hardware standpoint (e.g., Wi-Fi, Bluetooth, SD card, memory stick, etc.), how and can the measurement data can be exported to send to commercial vendor support or use in other commercial post-analysis software packages.

Column Temperature Range – The temperature range (lower and upper) that the portable GC/MS system can generate for the separation column; evaluators stated that a higher upper range is a positive factor because it is helpful in purging (clearing out) columns.

AMU Range – AMU is the measurable ion mass range of the mass spectrometer. A high upper value and wider range is a positive factor as it potentially allows identification of a wider range of analytes of interest.

Detection Threshold – The software threshold that affects and/or decides whether a chromatographic peak is detected and used in compound identification by instrument software. The focus group members indicated that whether and how easily users can change this threshold setting were factors to consider in rating this evaluation criterion.

DEPLOYABILITY

Hot Swappable Batteries – Whether batteries can be replaced without shutting down the instrument, and how easily this can be done in the field.

Hot Swappable Carrier Gas – Whether the carrier gas supply can be replaced without completely shutting down the instrument, and how easily this can be done in the field.

Battery Characteristics – Battery features relevant to field operations, such as battery run time, charge time, the number of batteries needed for continuous operation; also battery type, e.g. nickel-cadmium or lithium ion.

Start Up Time – Time to first field sample analysis from a cold start-up; a cold start-up is defined as more than 12 hours since the instrument was last powered up and operational.

Operating Temperature Range – The practical user environmental temperature range over which the instrument can be operated routinely in the field without intervention.

Time between Runs – The total time period (duty cycle) required for the instrument to be ready for the next sample analysis. Note: this does not include any sample preparation needs.

Portability – Factors relating to carrying or transporting the instrument, e.g., instrument size and weight, suitability of handles or carrying straps.

Sample Preparation Time – How much time is required to prepare a sample prior to introduction into the instrument. Evaluators acknowledge this will be instrument dependent due to sample introduction restrictions/options and requirements. Sample processing steps may be required for some instruments to introduce a sample in the proper form and/or to achieve the proper signal-to-noise (e.g., sample dilution to mitigate detector saturation). Whether the instrument allows for operation in a "real-time" continuous monitoring survey mode and if so, the suitability of operation in this mode, is a factor in rating products on this evaluation criterion.

Water and Dust Resistance – Suitability of the instrument for field deployment with regard to field exposure to water and dust, as indicated by Ingress Protection (IP), Mil-Spec, or other relevant protective ratings.

MAINTAINABILITY

Technical Support – Ability of the instrument manufacturer to quickly respond to technical support requests from responders in the field. Evaluators stated that the schedule of availability of the manufacturer's technical support personnel and the ability of technical support personnel to remotely operate the instrument to diagnose problems, were positive features.

Software/Library Updates – Availability of library updates from manufacturer, manufacturer notification of library updates, and whether users can delay implementation of updates.

Tuning Requirements – The ease and required frequency of tuning the instrument.

Storage Conditions – Temperature and humidity ranges for proper instrumental storage, this may include standby electrical power recommendations.

Decontaminability – How easily, quickly and effectively an instrument can be decontaminated, based on factors such as the instrument's IP rating, the design of its external surfaces and ports, or other considerations.

Cost of Consumables – The cost of consumables needed to operate the instrument, figured as an estimated cost per sample analysis.

USABILITY

Data File Formats – Suitability of file formats in which acquired data can be saved for further analysis external to the instrument. Focus group participants expressed a preference for non-proprietary data file formats.

Operation with PPE – How effectively the instrument can be operated when wearing personal protective equipment, e.g., ease of activating buttons, touchscreen, etc.

Sample Introduction Options – The availability, suitability and ease of use of sample introduction methods or attachments for the variety of sample types that responders commonly encounter and analyze.

Simplicity of Operation – Ease of use of instrument operating software. Responders indicated a preference for the smallest possible number of software steps to perform instrument functions.

Product Reference Material – The clarity and completeness of the information provided in the instrument's user manual, and the availability and quality of training materials. Responders considered the availability of informative online training videos to be a positive factor.

Library Modification – Whether it is possible for users to modify and/or add to libraries and how easily this can be done. Responders suggested as a positive factor the ability/willingness of the manufacturer to update libraries for analytes of interest to a particular organization.

Configurable User Interface – Whether appropriate control settings can be set for users of different abilities, e.g., basic and advanced user interfaces.

Display Screen Characteristics – Factors related to ability to read displayed data, e.g., screen visibility in bright/dark conditions, font size, contrast, whether displayed information is clearly presented.

Report Content – Usefulness of instrument-generated reports for responder needs.

Status Indicators – Existence and suitability of status indicators, e.g., battery life, carrier gas level, calibration gas level or number of analyses possible before replacement is needed.

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 divided by the sum of the weights for each criterion in the category as seen in the formula and example below.

Category Score Formula

$$\frac{\sum(\textit{Average Criterion Rating} \times \textit{Criterion Weight})}{\sum(\textit{Criterion Weights})} = \textit{Category Score}$$

Category Score Example[ii]

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

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

$$\sum(\textit{Category Score} \times \textit{Category Percentage}) = \textit{Overall Assessment Score}$$

Overall Assessment Score Example

$$\underbrace{(4.0 \times 33\%)}_{\textit{Capability}} + \underbrace{(4.2 \times 27\%)}_{\textit{Usability}} + \underbrace{(4.2 \times 20\%)}_{\textit{Affordability}} + \underbrace{(3.8 \times 13\%)}_{\textit{Maintainability}} + \underbrace{(4.5 \times 7\%)}_{\textit{Deployability}} = 4.1$$

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