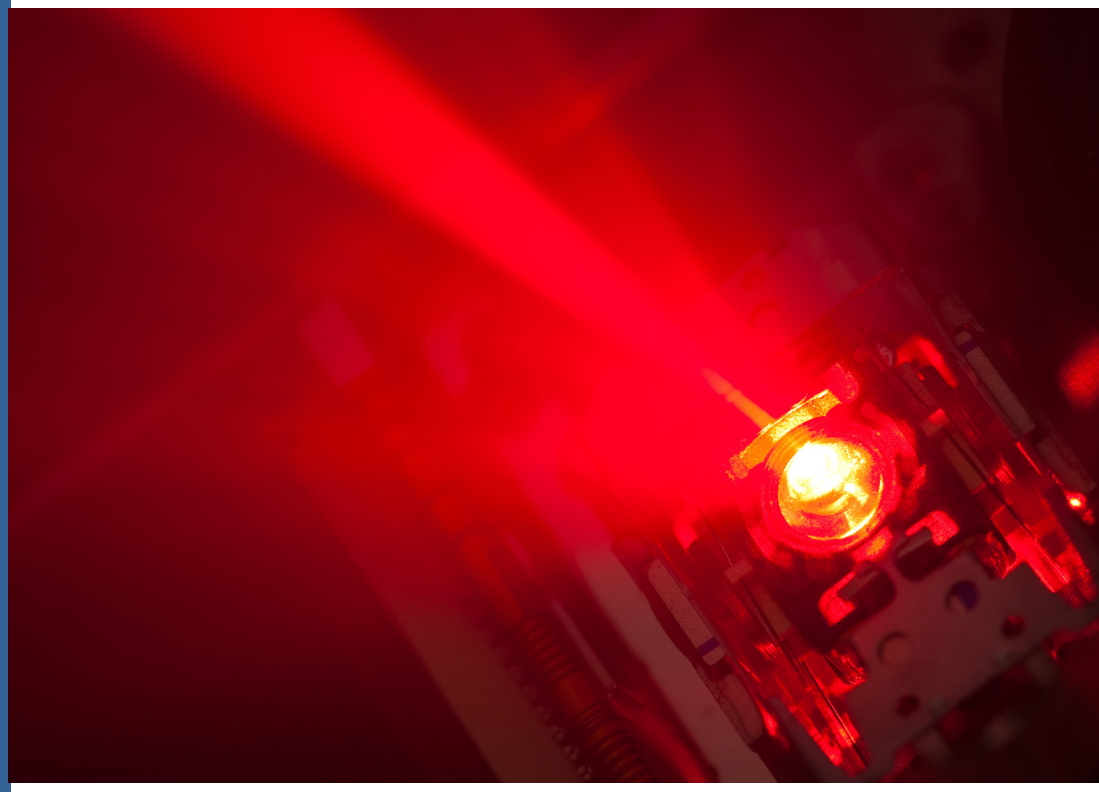
FTCOE
Forensic Technology Center Of Excellence

Landscape Study of **Handheld and Portable Raman Spectrometers**



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NIJ National Institute of Justice

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TABLE OF CONTENTS

Please Note: This report is a good-faith effort by the FTCoE to accurately represent information available via primary and secondary sources at the time of the analysis. Where appropriate, RTI has referenced the primary research with individual sources, and similarly, key secondary sources are identified. All other information is a composite view developed from literature, trade press, and stakeholder input.

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The National Institute of Justice's (NIJ's) Forensic Technology Center of Excellence (FTCoE) at RTI International directed this effort, with input from law enforcement, forensic laboratory, and justice system communities.

Landscape Study of Portable Raman Spectrometers

This report provides a "landscape" view of the issues and products associated with field portable Raman spectrometers for the identification of powders, liquids, gels, or tablets. The document is intended to furnish law enforcement, first responders, and hazardous materials experts with a survey of commercially available products. Specifically, the report provides decision makers and potential end users with the following:

- Exemplary cases that illustrate successful adoption
- Issues to consider related to implementation of portable Raman spectrometers
- Comparison of the capabilities of commercially available Raman spectrometers.

The report is designed to provide the reader with a basic understanding of field portable Raman spectrometers, public safety applications, and benefits and limitations of the devices. The document provides a summary of considerations that will impact procurement, training, fielding, and evaluation.

Forensic Technology Center of Excellence (FTCoE)

FTCoE is a collaborative partnership of RTI International and its FEPAC [Forensic Science Education Programs Accreditation Commission]-accredited academic partners: Duquesne University, Virginia Commonwealth University, and the University of North Texas Health Science Center. In addition to supporting NIJ's research and development (R&D) programs, the FTCoE provides testing, evaluation, and technology assistance to forensic laboratories and practitioners in the criminal justice community. The NIJ funds the FTCoE to transition forensic science and technology to practice (Award Number 2011-DN-BX-K564).

The FTCoE is led by RTI, a global research institute dedicated to improving the human condition by turning knowledge into practice. With a staff of more than 3,700 providing research and technical services to governments and businesses in more than 75 countries, RTI brings an international perspective. The FTCoE builds on RTI's expertise in forensic science, innovation, technology application, economics, data analytics, statistics, program evaluation, public health, and information science.

Thank you to various community members who offered insight, analysis, and review

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Experts offered insight related to the use of handheld and portable Raman spectrometers for law enforcement.

NIJ's Forensic Technology Center of Excellence (FTCoE) at RTI International has researched the adoption criteria, use, impact, and availability of products for handheld and portable Raman spectrometers for law enforcement applications.

Basis For Study

- Development of handheld Raman devices for security and military applications have led to increasing law enforcement awareness of potential benefits of adoption.
- Law enforcement agencies may benefit from an examination of how the technology is acquired and implemented, as well as study of impact on safety, seizure rates, and prosecutorial benefits.
- Growing prevalence of synthetic drugs has challenged the utility of colorimetric tests and has resulted in the need for more information-rich test methods. A need exists to understand available products, features, and capabilities.[1]

Objectives of the Landscape Study

- Investigate how portable and handheld Raman spectrometers have been used for law enforcement applications.
- Provide considerations from current users to inform potential technology adopters and to assist with implementation planning, where appropriate.
- Provide practical and technical considerations in real-world applications of portable Raman spectrometers to public safety professionals.

Research Methodology

- Research secondary sources, including journal and industry literature for information related to need, successful use in the field, influence on legal proceedings, and adoption criteria.
- Discuss the state of the art with subject matter experts and organizations, including practitioners, companies, academic institutes, and other industry experts.
- Document, summarize, and release key findings to the law enforcement community.

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1 Infrared and Raman Spectroscopy in Forensic Science. John M. Chalmers, Howell G. M. Edwards, Michael D. Hargreaves. Wiley. 2012. Page 326.

NIJ Award Number 2011-DN-BX-K564

The study examines the present and future state of Raman spectrometer technology, as well as considerations for and potential benefits of implementation.

Lessons Learned from Previous User Experiences

Several departments are highlighted for their use of portable Raman spectrometer devices, either through trial testing or by full implementation and deployment. While some testers chose to delay device purchase due to lack of funding or inability to use the test results as confirmatory evidence, others have found ways to optimize the device results without necessitating legislative change. Various departments and key stakeholders are featured in the report. Benefits observed through successful deployment include the following:

- Increased investigative efficiency of criminal cases as a tool for interviewing suspects and negotiating plea agreements
- Decreased laboratory backlogs
- Reduced court costs due to faster case closures.

Potential users should consider various key factors before purchasing a portable Raman spectroscopy device. This report explores the following considerations:

- Identifying needs for implementing a new, portable device
- Establishing proper funding sources for device purchase to help ensure a smooth procurement process
- Obtaining the cooperation and acceptance across several key stakeholders within the court system for device use.

Current and Future Product Landscape

As Raman spectrometers and their components (e.g., lasers and detectors) continue to decrease in price and as technology advancements enable innovative packaging and pairing of accessories (e.g., GPS [global positioning system], cameras, and wireless printers), handheld and portable Raman devices may continue to appeal to a growing number of law enforcement agencies.

NIJ Award Number 2011-DN-BX-K564

Commonly used words and phrases

Cutting agents (excipients): a less expensive natural or synthetic material included as a bulking agent in drugs of abuse. (Bhattacharyya et al. "Excipients: Background/Introduction." 2006.)

Evidence Confirmatory: evidence that is presented and accepted in court to provide verification of the composition of an unidentified substance collected in the field. Confirmation can be provided by crime and forensic laboratories.

Evidence Presumptive: evidence that indicates, within a reasonable level of certainty, the composition of a substance obtained in the field. Further analysis by crime and forensic laboratories may be required for acceptance as evidence in court.

Handheld field units: Raman spectrometers that can be operated and held in the palm of the user's hand.

Portable field units: Raman spectrometers that are field portable (rugged), but must be placed on a table or level surface for operation.

Raman Spectroscopy: a method used to measure the change in wavelength of light that is scattered while passing through a transparent medium or reflected by an opaque material to determine its composition. (http://www.dictionary.com)

Scientific Working Group for the Analysis of Seized Drugs (SWGDRUG): A working group formed to recommend minimum standards for the forensic examination of seized drugs and to seek their international acceptance. (http://www.swgdrug.org)

NIJ Award Number 2011-DN-BX-K564

Overview of Raman spectroscopy in law enforcement applications

Introduction

Public safety agencies encounter unknown substances in the field on a daily basis. To respond appropriately with law enforcement, emergency medical, or other actions, these agencies must identify controlled or dangerous substances quickly and accurately. The current methods for identification of unknown substances in the field can lead to the destruction of limited valuable evidence and provide only a presumptive basis for the arrest and charging of suspects.

For example, many law enforcement officers or other personnel rely on presumptive color change field testing kits for narcotics and other substances. These tests require mixing of chemicals and a resulting color change to determine the identity of an unknown substance in the field. The tests can be time consuming and complicated, require destruction of a portion of the seized substance (particularly detrimental when only a small sample or residue is available), can lead to inconclusive results, and produce subjective outcomes that require user interpretation. Chemical test kits (also known as break tests) are non-reusable and lead to recurring costs for testing and identification.

Raman spectroscopy, an approved analytical technique used to provide confirmatory evidence in the laboratory setting, may provide accurate identification for a broader range of unknown substances than is otherwise available to first responders. Raman spectroscopy is a non-contact, non-destructive analytical method—with no recurring testing costs (however, recurring costs may include warranties, routine maintenance cycles, and database upgrades). The units use a laser that can "see" through any clear container medium (plastic or glass, vial or bag) to analyze the contents (liquids, gels, or powders). Use of a non-destructive beam of light eliminates the loss of sample to destructive chemical or thermal tests that can reduce the amount of evidence in the possession of law enforcement officials or crime labs. Testing flexibility (through any clear or translucent packaging) limits officer or agent exposure to potentially harmful samples in the field.

NIJ Award Number 2011-DN-BX-K564

What Is Raman Spectroscopy?[2,3,4,5,6]

The Raman spectroscopic technique identifies a material by directing a laser beam at the material and analyzing the light that is scattered off it. Portable Raman systems use lasers that emit infrared light at either 785 nanometers (nm) or 1064 nm. Some of the incident light is scattered to slightly different wavelengths that depend on the chemical composition of the material. This wavelength shift–called the Raman effect–can be measured and interpreted to determine the identity of an unknown sample.

Typically, less than 0.001% of incident light results in Raman scattering, a very weak signal that requires special measures to distinguish it from other scattered light. The scattered light is collected with a lens and analyzed to obtain a Raman spectrum of a sample. The Raman spectrum is characteristic for a given material. Libraries of reference Raman spectra for a set of given materials (drugs, precursors, hazardous materials, etc.) are stored electronically on portable and handheld analyzers. During sample analysis in the field, the sample Raman spectra are compared with a reference library onboard the device to determine if a match exists.

In some cases, a material will produce other scattered light that will make it difficult to get a good Raman spectrum. In other cases, the laser light will cause the material to produce fluorescent light emissions. Even weak fluorescence can interfere with detection of the low intensity Raman signal, resulting in failure to produce data suitable for analysis or sample identification.[7]

Even very similar materials can be distinguished from each other using Raman spectroscopy, which is why the technique is often used in crime laboratories. Benchtop, laboratory-based Raman spectrometers currently play a role in substance identification and evidence confirmation. However, the miniaturization of lasers, improved optics, and advanced processing technology have enabled packaging of accurate and capable Raman systems into tabletop portable units and handheld units weighing as little as a pound. These portable Raman spectrometers can provide rapid identification of a variety of liquids, powders, solids, and tablets that are encountered by law enforcement officers, first responders, and hazardous material response teams in the field. In the context of field testing, this is presumptive evidence. Rapid identification of unknown substances can be crucial when determining the following:

- Decision to place a suspect in custody
- Threat or danger to the public or first responders
- Appropriate course of treatment for individuals who might have ingested a toxic substance.

[2] Raman Spectroscopy Basics. Princeton Instruments. http://content.piacton.com/Uploads/Princeton/Documents/Library/UpdatedLibrary/Raman_Spectroscopy_Basics.pdf

[3] Portable Raman Spectroscopy Systems for Field Analysis. Eckenrode. FBI Laboratory Services - Forensic Science Communications. October 2001. Volume 4, Number 4. http://www.fbi.gov/about-us/lab/forensic-science-communications/fsc/oct2001/index.htm/eknrode.htm

[4] Handbook of Raman Spectroscopy. From the Research Laboratory to the Process Line. Chapter 18. Raman and Surface Enhanced Resonance Raman Scattering. Applications in Forensic Science. Geoffrey Dent, Peter C. White, W. Ewen Smith, and C. Rodger.

[5] Raw-Material Authentication Using a Handheld Raman Spectrometer. Robert L. Green. Pharmaceutical Technology. Volume 3, Issue 32. http://www.pharmtech.com/pharmtech/article/articleDetail.jsp?id=500408&pageID=1&sk=&date=

[6] Thomas, S. (2014) Infrared and Raman Spectroscopy. http://serc.carleton.edu/61673

[7] Reduction of Fluorescence Interference in Raman Spectroscopy via Analyte Adsorption on Graphitic Carbon. Mark R. Kagan and Richard L. McCreery. Anal. Chem. 1994, vol. 66, 4159-4165. http://www.chem.ualberta.ca/~mccreery/RLM%20publication%20PDFs/mccreery113.pdf

NIJ Award Number 2011-DN-BX-K564

As Raman spectrometers have become more portable and powerful, the potential benefits they might offer to the law enforcement community have become increasingly more apparent. A number of device manufacturers offer Raman spectrometers, spectral libraries, and analytical support specifically tailored to law enforcement agencies. Nonetheless, some barriers to adoption exist for agencies considering portable Raman spectrometers, including cost, implementation issues, and implications for the legal process. This report seeks to provide law enforcement and crime scene investigation professionals, from patrol officers to laboratory directors, with examples of implementation, an investigation of key considerations, and an inclusive review of available Raman spectrometers, their features, and manufacturers. A summary of the technical limitations of Raman spectroscopy is also included. Potential adoptees of handheld Raman devices should be aware of the current technical limitations of Raman analytical techniques, and should make inquiries with manufacturers to fully understand the implications for successful device deployment.

Technical Limitations of Raman Spectroscopy[8]

In general, the user should keep in mind that Raman spectroscopy relies on the sensitive measurement of a relatively small amount of light that scatters from the material under examination. The systems include sophisticated laser systems and optics to make this work, so the portable units should be handled with appropriate care, kept clean, and used within the procedures specified by the device manufacturer.

In particular, before procurement, a department should consider the following technical limitations:

- Fluorescence: Some materials will fluoresce when exposed to laser light. In Raman instruments that rely on 785 nm lasers, this background signal can interfere with measurement of the Raman spectrum and prevent successful sample identification. Cannabinoids—the active ingredients in marijuana—are particularly susceptible to this effect. In some cases, an instrument may be able to "baseline correct" the Raman spectral data to account for the fluorescence. If one wants to examine cannabinoids, it is important to consider a Raman spectrometer based on a 1064 nm laser, seek clarification from the manufacturer about the ability of their system to reliably detect cannabinoids, and conduct field tests personally prior to purchase to ensure that performance meets expectations.

[8] Presumptive Field Testing Using Portable Raman Spectroscopy: Research and Development on Instrumental Analysis for Forensic Science: Award Number 2010-DN-BX-K201. Stephana Fedchak. January 2014. https://www.ncjrs.gov/pdffiles1/nij/grants/244564.pdf

- Sampling errors: Seized drugs are often mixed with other illicit substances or cutting agents. These mixtures are rarely homogenous, and a completely accurate characterization of the full sample may not be possible without multiple tests from different locations within the sample bulk. For example, if only cutting agent particles are illuminated during testing, the spectrometer will fail to detect the presence of any drug.

- Opioid identification: Opioids are notoriously difficult to identify in Raman. This category includes heroin, morphine, and several prescription medications that have become increasingly common drugs of abuse. Laboratory instruments use advanced techniques, including surface enhanced Raman spectroscopy (SERS) to enhance the signal to reliably identify opioid compounds. Manufacturers may claim that their instrument can detect opioids with appropriate protocols, but one should inquire to understand accuracy and the potential for a SERS kit pairing with their device.
  Despite these difficulties, Raman spectrometers are an excellent tool for identification of methamphetamine, ecstasy, cocaine, precursors, and other controlled substances. Raman spectroscopy may present one option to provide a presumptive test for a wide range of controlled substances in the field.

- Mixture analysis: When mixtures contain a large number of constituents, it becomes increasingly more difficult for mixture detection algorithms to sort out and identify each constituent. A drug mixture may also consist of compounds that fluoresce and prevent successful identification. Mixture analysis performance should be explored with the manufacturer prior to procurement to determine if mixture detection accuracy in real-world testing scenarios can adequately meet departmental needs.

- Environmental sensitivity: As noted above, ambient light conditions can interfere with the results. The units may also be sensitive to heat, vibration, and other environmental issues, especially over time and with use. The system may lose sensitivity or calibration. One should carefully and completely follow the manufacturer's recommendations for use, calibration, and maintenance. Further, training should reflect these recommendations and limitations. When possible, field use should be performed in the best environmental conditions available (e.g., ideally indoors at room temperature). Finally, the instruments should be subject to a regular maintenance schedule and quality assurance check to ensure that they are continuing to provide accurate results in the same manner as when they were first put into the field.

NIJ Award Number 2011-DN-BX-K564

Procurement Considerations

Device manufacturers offer a wide variety of Raman spectrometer products and services, with features and capabilities that cater to law enforcement, first responders, and hazardous materials containment teams. A range of devices is available with varying size and weight (handheld vs. portable field units), user interfaces, record keeping and data transfer capabilities, battery choices, and sampling accessories. Select manufacturers also provide and administer identification libraries containing a range of narcotics, hazardous substances, white powders, or common materials for identification of compounds in the field. A product specification table (pages 40–42) is provided to compare exemplary handheld and portable Raman spectrometers.

A police agency should review independent testing and evaluation data prior to making a decision to implement a new technology. For portable Raman spectrometers, in addition to the user reports included in this study, the reader should review the extensive evaluations conducted by the National Forensic Science Technology Center (NFSTC), available online at http://www.nfstc.org/forensic-technology/technology-evaluations/chemistry/. A comparative summary report is also available at the NFSTC website. Manufacturers having NFSTC-evaluated Raman spectroscopy devices have been noted in the product landscape section of this report.

For most agencies, the purchase of drug detection equipment represents a significant investment. It is recommended that an agency determine how portable detection technology fits within their mission, what the requirements for detection technology are for their department, and whether currently available Raman systems fit within those requirements. This analysis should provide a basis for a procurement decision as well as justification for external funding, if needed. The requirements should be used as a basis for evaluation of the portable Raman instruments after fielding to determine if the units are adding to the agency's effectiveness as expected.

The analysis can be used to obtain grant funding, if necessary. Grants can be obtained for device purchase from various sources. Because of limited resources, the grant process can be slow, highly competitive, and cumbersome.

Other strategies for obtaining equipment may include the following:

- Partnering with other agencies or neighboring jurisdictions is a frequent option; for example, the district attorney may benefit from the use of Raman technology because the systems may reduce case backlogs in drug cases.
- A department may consider seizure, abandoned property, asset forfeiture, or local police foundations to raise funds.
- Federal grant funds are available with appropriate justification, such as Coverdell grants and Justice Assistance Grants (http://www.nij.gov/topics/forensics/lab-operations/capacity/nfsia/pages/welcome.aspx). You may contact your State Administering Agency or criminal justice coordinating council to learn more. A good place to start is the National Criminal Justice Association, which provides advice to state and local agencies in obtaining federal grant funds. See http://www.ncja.org/.

NIJ Award Number 2011-DN-BX-K564

As noted, device manufacturers may offer a trial test of their device at a reduced cost or at no charge. Obtaining a trial test may help with funding justifications, particularly if the instrument can prove its value by capturing data on successful detections to measure impact on investigations. Trials would also help with understanding the device benefits and limitations for each jurisdiction.

For further insight on technology procurement processes and best practices, the reader is encouraged to review the U.S. Department of Justice's Community Oriented Policing Services (COPS) Law Enforcement Tech Guide. The Tech Guide provides guidance on how to plan, purchase, and successfully manage new law enforcement technologies: http://www.cops.usdoj.gov/Publications/lawenforcementtechguide.pdf.

Drug Identification Test Results as Evidence

Field-based drug testing evidence is considered to be "presumptive," implying that test results can be used to assist in the arrest and charging process. However, these results must be confirmed by further forensic laboratory testing to be presented as evidence during a trial. Currently, the results of all field-based substance identification techniques are considered presumptive in nature, since the evidence has been collected using tests with low discriminating power (colorimetric tests) or collected in a non-ideal setting by uncertified personnel.

To be upheld in court, sample evidence should be tested in laboratories to confirm composition. Confidence in forensic laboratory test results can be bolstered by conformance to codes of professional practice for drug analysts, education and training requirements, and proper analytical techniques. The Scientific Working Group for the Analysis of Seized Drugs (SWGDRUG) is a body that sets forth recommendations to assist forensic analysts and managers in the development of analytical techniques, protocols, and policies.[10] For example, one prominent SWGDRUG recommendation pertains to the categorization of analytical methods that can be used to establish identity of a specific drug. Three technique categories (A, B, and C) have been established based on discriminating power of the test (where discriminating power is defined as the ability of the chosen analytical scheme to demonstrate the identity of the specific drug present while precluding the potential for false positive identification and minimizing false negatives). The SWGDRUG categories of analytical techniques and their associated analytical methods are referenced in the following table.

[10] Scientific Working Group for the Analysis of Seized Drugs (SWGDRUG) Recommendations. United States Department of Justice Drug Enforcement Administration. Executive Office of the President Office of National Drug Control Policy Counterdrug Technology Assessment Center. Version 6.1, 2013-November-1.

NIJ Award Number 2011-DN-BX-K564

SWGDRUG Categories of Analytical Techniques

Category A	Category B	Category C
Infrared Spectroscopy	Capillary Electrophoresis	Color Tests
Mass Spectrometry	Gas Chromatography	Fluorescence Spectroscopy
Nuclear Magnetic Resonance Spectroscopy	Ion Mobility Spectrometry	Immunoassay
Raman Spectroscopy	Liquid Chromatography	Melting Point
X-ray Diffractometry	Microcrystalline Tests	Ultraviolet Spectroscopy
	Pharmaceutical Identifiers	
	Thin Layer Chromatography	
	Cannabis only: Macroscopic Examination Microscopic Examination	

When a validated Category A technique is used to characterize a sample, at least one other technique from Categories A, B, or C must be used to provide confirmation of the result. When a Category A technique is not used, at least three different validated techniques must be used, with at least two of the three techniques being from Category B.

Currently, laboratory-based Raman spectroscopy (by trained and certified laboratory professionals) is considered by SWGDRUG as a Category A analytical method. However, portable or handheld Raman spectrometers have not demonstrated a sufficiently high discriminating power to be considered as a Category A method. Independent testing conducted by the NFSTC in 2011 established that handheld, portable Raman spectrometers are accurate for roughly half of the analytes collected, with reproducibility of results presenting a significant challenge.[11] The reproducibility issue arises due to a number of factors, including use environment, user expertise, and the technical limitations of the Raman spectroscopy technique itself, as addressed in this report. It should also be noted that the lack of a standard method or guide for drug identification using Raman has also inhibited its adoption in forensic labs as an identification tool, regardless of its Category A designation by SWGDRUG.

The technology can be used to great effect if an agency builds support for it among all stakeholders within an adopting jurisdiction, and a technology adoption plan is implemented that carefully weighs the benefits and limitations. The case studies in this report can provide a foundation for planning for a particular agency (case studies found on pages 19–32). To bolster these efforts, manufacturers of handheld and portable Raman spectrometers offer technical assistance, regular training, expert witness testimony, and laboratory-based confirmation of Raman test results gathered in the field.

[11] A Comparison of Four Commercially Available Portable Raman Spectrometers. National Forensic Science Training Center. http://www.nfstc.org/?dl_id=214

NIJ Award Number 2011-DN-BX-K564

Implementation Considerations

Potential users must first weigh the benefits and challenges of portable Raman spectrometers to determine fit within departments. As illustrated in the following user profiles, implementing these devices can lead to several benefits. A properly chosen device that fits departmental needs is important

Potential Benefits

Timesaving: Test results can be obtained in the field within a matter of minutes, providing instantaneous results on the scene and leading to immediate arrests. Traditional Raman spectroscopy tests conducted at laboratories can take up to 18 months due to delays from transferring the substance to the test site and to laboratory backlogs.

Negotiating plea agreements and obtaining search warrants: Increased number of plea agreements and search warrants can be obtained when local jurisdictions and court systems agree to accept the device test results.

Reducing caseloads and backlogs: Cases are closed more quickly and the number of caseload backlogs is reduced when plea agreements are reached. This also leads to increased court revenue due to obtaining court fees when cases are closed.

Potential Hurdles

Cost of device: Availability of funding to purchase a device may be an issue. Portable devices typically cost $15,000–20,000, which is often a barrier for purchase, particularly if more than one device is needed for successful deployment.

Technical device challenges: Selection of a device based on department needs is important. Contacted users cited the following as important criteria for a useful device: the ability to test mixtures for various constituents beyond testing for the majority substance only, the ability to test both liquid and solid substances, and access to appropriate spectral libraries for substances found within the jurisdiction.

Presumptive evidence: Because test results produced using portable Raman spectrometers are presumptive, successful deployment of the device must rely on participation and acceptance across the stakeholder community of how the test evidence should be used. Stakeholders within the court system need to be convinced prior to implementation.

NIJ Award Number 2011-DN-BX-K564

Once the benefits and limitations have been evaluated and the decision to implement has been made, various factors should be considered for successful procurement and deployment:

1. Obtain Agreement from Key Players.

Although device results are seen only as presumptive evidence, several counties have seen successful results from use of portable Raman spectrometers. This can be done even without changes in legislation. The key to successful deployment and implementation is to obtain agreement across all stakeholders at an early stage by demonstrating the benefits of and opportunities for working with these portable devices. Trial testing at all levels and by all players can be helpful. Law enforcement agencies can benefit from quicker turnaround test results. If the suspect opts for a plea bargain, district attorneys, defense attorneys, and judges can benefit from faster case completions, reducing caseload pressure and backlogs.

All parties must be in alignment and agreement for successful deployment and use of portable Raman spectrometers. If any party opts out of using the portable Raman spectroscopy device as evidence, then the process will revert to relying on traditional laboratory testing.

2. Understand Preferred Device Features.

Users contacted for this landscape study reported the following device features as key factors in selecting a product for use:

Substance testing effectiveness: The ability to test both liquid and solid substances is essential. In the case of a mixture, the ability to test all components, and not just the majority substance, can be important.

Target materials: Understand which materials are likely to be encountered in the field and make sure the instrument will reliably identify the materials of interest.

Readouts: Objective readouts are preferred, but may be an issue when there are multiple substances.

Calibration and assembly requirements: Fewer steps are preferred to help eliminate down time.

Size: Ideal device size is based on preference. Some prefer completely handheld, mobile devices, while others opt to use larger devices that are portable. Most users agree that the size of the testing plate should be adequate.

Database libraries: Access to the correct spectral libraries will help with substance identification. Strong databases are critical in preventing false-positives and false-negatives. Transparency of spectral databases can be important. Some users prefer access to the database with the ability to modify the spectra based on the drugs commonly found in their jurisdictions, which is particularly beneficial with the arrival of new synthetic drugs, while others prefer databases that cannot be changed, to allow for consistency between tests. Database updates, provided by the manufacturer or by the user, can be particularly useful for new synthetic drugs.

Manufacturer relationship: As with any product, customer support services can be critical. Beyond technical assistance, some users value device manufacturers that are willing to work with users to improve the device and/or spectra databases, provide trainings, and offer regular database updates.

Mobile printing connection: Wireless access to a printer allows for easy printing. Reports can be placed directly into case files and handed to the prosecutor.

NIJ Award Number 2011-DN-BX-K564

TABLE OF CONTENTS

Please Note: This report is a good faith effort by the FTCoE to accurately represent information available via primary and secondary sources at the time of the analysis.

NIJ Award Number 2011-DN-BX-K564

Subject matter experts shared insights from their product experiences during trial testing, implementation, and use.

Users of portable Raman spectrometers were contacted to determine how the devices have affected their law enforcement processes and to glean insights from lessons learned related to implementation and deployment. Device manufacturers were also contacted to discuss key features and future trends that are important to end users. The following section lists example questions that were asked.

User Questions

- What positive impact has the technology had on LE departments?
- What have been the largest hurdles for implementation of the technology?
- What standard operating procedures are in place to guide technology use?
- How do LE agencies typically justify investment in portable Raman technology?
- How are device purchases funded?
- What are some best practices to share for smooth procurement processes?
- How many units have been deployed in the field per agency? What logistics are involved in distributing technology among patrols and evidence collection teams?
- What were your key considerations when choosing a product? (vendor, device capabilities, etc.)
- What steps are being taken towards establishing portable Raman evidence as confirmatory in court?

Device Manufacturer Questions

- What product capabilities and design factors are most important for field-based law enforcement screenings?
- What new products or features are anticipated?
- How is spectrometer accuracy determined?
- How often are identification libraries updated?
- Are new products developed in conjunction with LE agencies?
- What support is offered to agencies after purchase? Costs associated with support?
- Does the product meet standards for ruggedization or electronic record keeping? (MilSpec 810G, 21 CFR Part 11, etc.)
- Are there other industry-wide standards that guide the development of new devices?
- What supporting software or hardware is needed in addition to the field unit? (databases, data storage, etc.)
- What steps are being taken towards establishing the status of evidence as confirmatory in court?

NIJ Award Number 2011-DN-BX-K564

Trial testing allows potential users to experiment with devices and better understand product benefits and challenges.

Device manufacturers commonly offer potential users a trial period of their portable Raman spectroscopy devices at a discounted rate or at no cost. This section provides examples of departments that trial tested Raman spectroscopy devices, and provides insights on department experiences and considerations. Desired device features, device analysis, and anticipated next steps are highlighted.

The trial use profiles were selected based on a completed trial test of a portable Raman spectroscopy device. Examples of trial tests include the following:

- An evaluation under an NIJ-funded award by the Las Vegas Metropolitan Police Department
- An evaluation under a device loan from the manufacturer by the Cherokee Multi-Agency Narcotics Squad.

	Las Vegas Metropolitan Police Department, Nevada	Pages 21–22	**Las Vegas Metropolitan Police Department (NV)** plans to purchase handheld Raman spectrometers after evaluating the technology. Contributor: Stephanie Larkin, a Forensic Scientist for the Las Vegas Metropolitan Police Department
	Cherokee Multi-Agency Narcotics Squad, Georgia	Pages 23–24	**Cherokee County (GA)** has conducted field trials using a mobile Raman spectrometer on loan from a manufacturer. Contributor: Philip Price, Commander at the Cherokee County Multi-Agency Narcotics Squad

NIJ Award Number 2011-DN-BX-K564

Las Vegas Metropolitan Police Department

Las Vegas Metropolitan Police Department plans to purchase devices, having recently finished an evaluation under an NIJ-funded award.

Stephanie Larkin is a Forensic Scientist at the Las Vegas Metropolitan Police Department (LVMPD) where she conducted an evaluation of a portable Raman spectroscopy device. The study was funded by an NIJ award, 2010-DN-BX-K201. The evaluation led to recommendations on how to improve the design of the device.

Trial Use Profile

Larkin worked with SciAps to test their ReporteR device from 2008-2013. The study compared laboratory-based results with results collected in the field.

Devices are engineered to err on the side of producing false-negative results rather than false-positives to avoid wrongfully accusing an innocent suspect. The LVMPD team worked closely with the manufacturer and provided suggestions on how to improve accuracy while reducing false negatives. The company permitted LVMPD to create their own spectral library of encountered drugs based on their forensic laboratory testing. The relationship between LVMPD's testing group and the manufacturer enabled device improvements, including higher signal-to-noise ratio and improved matching algorithms. An added portable printer also improved record keeping.

After the suggested enhancements were implemented, methamphetamine testing accuracy increased by 19.4% and cocaine testing accuracy increased by 26.6% in the field.[12]

The department is currently still using color test kits, but plans are in place to move toward portable Raman Spectroscopy devices to reduce the subjectivity in readings.

Device Analysis

- Portable Raman technology is an effective, reliable, and objective tool for presumptively identifying methamphetamine and cocaine in the field.
- A large challenge for full implementation is that test results are not considered confirmatory evidence and are treated as presumptive.
- Another challenge of implementation is funding availability.

Next Steps

- LVMPD is not yet using the devices, but Larkin reported that plans are in place to implement the devices within the next few years. Approximately 20 devices would be needed for full department deployment at LVMPD.
- Online video training will be provided for future end users prior to full implementation.

[12] Presumptive Field Testing Using Portable Raman Spectroscopy: Research and Development on Instrumental Analysis for Forensic Science: Award Number 2010-DN-BX-K201. Stephana Fedchak. January 2014. https://www.ncjrs.gov/pdffiles1/nij/grants/244564.pdf

NIJ Award Number 2011-DN-BX-K564

Cherokee Multi-Agency Narcotics Squad

The Cherokee Multi-Agency Narcotics Squad trialed a device under a loan from a device manufacturer, resulting in a purchase decision.

Philip Price is the Commander at the Cherokee Multi-Agency Narcotics Squad in Georgia. His department tested a portable Raman spectrometer under loan from the manufacturer, and purchased a device after successful testing.

Trial Use Profile

Centice, a device manufacturer, loaned the MFL-3000 device to the Squad for testing and consideration in 2011. The evaluation concluded that the device successfully tested illicit drugs, synthetic marijuana, and prescription pills, including partial pills. Under the evaluation, Price also provided suggestions to Centice regarding desired product features and ways to market to law enforcement agencies based on their needs and pricing requirements. Price believes that an ideal device should accomplish the following:

- Test a mixture for several unknown substances instead of only evaluating the majority constituent, as well as be able to test both liquid and solid substances
- Enable objective readouts
- Have printout capabilities.

Users should also consider calibration with respect to ease, frequency, and time requirements.

The device's impact on the Squad was limited due to the legal system not accepting its test results as confirmatory evidence. After court acceptance is obtained, Price believes that portable Raman spectroscopy devices will potentially be revolutionary to the law enforcement community. He predicts that broad, national impact of handheld Raman devices may occur in the future.

Device Analysis

- The average cost of a portable Raman spectrometer device is $15,000, which Price states is too expensive for a full 15-unit deployment. The ideal price point would be under $5,000.
- The device appears to be an effective way to test unknown substances, but may not be practical if the court system does not accept the results as confirmatory evidence.

Next Steps

- A Raman spectrometer device has been purchased by the Cherokee Multi-Agency Narcotics Squad. Price looks forward to the results being successfully used in the court systems. He believes that changes in national standards and acceptance of the device would be helpful.

NIJ Award Number 2011-DN-BX-K564

Successful deployments in the forensic and law enforcement communities offer insights on implementation.

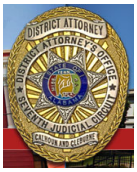
This section provides examples of successful implementation of portable Raman spectroscopy devices to illustrate benefits, potential adoption issues, and examples of ways to overcome adoption barriers. The user profiles offer insights on different ways that the portable technology has been an effective tool for law enforcement agencies, with special focus on the use of the device in the field for identification of unknown substances. Key impacts and lessons learned are highlighted. Examples of successes stemming from deployment of portable Raman spectrometers include the following:

- Obtaining an increased number of plea agreements or search warrants
- Reduction in forensic laboratory testing backlogs.

Mark Hopwood, a Senior Forensic Scientist at the Center for Applied Forensics at Jacksonville State University (JSU), played an instrumental role in getting the devices successfully adopted within many Alabama counties. Hopwood began exploring the use of portable Raman spectrometers for Alabama in 2012 when the forensic laboratories experienced a backlog of over 30,000 cases. He worked with various district attorneys to reduce the turnaround time for receiving laboratory reports, which typically was taking 18–20 months per case. Hopwood experimented with portable Raman spectrometers as a potential solution and, after several successful tests, began supporting and promoting the use of the device across various Alabama counties. According to Hopwood, at least ten Alabama counties now use these devices, reducing laboratory backlogs by up to 30%. Three of the ten Alabama counties (Winston, Calhoun, and Tuscaloosa) that use portable Raman spectrometers are introduced in the following sections.

NIJ Award Number 2011-DN-BX-K564

The highlighted use profiles were selected based on their complete implementation and deployment of portable Raman spectrometers and the acceptance of test results by various players in the criminal justice system:

	Winston County Sheriff's Office	Pages 27–28	**Winston County (AL)** uses portable Raman devices to improve the investigative process, including suspect interviews. Contributor: Wes Brown, a Lieutenant for the Winston County's Sheriff's Office
	Calhoun/Cleburne District Attorney's Office	Page 29–30	**Calhoun County (AL)** uses portable Raman spectrometers as a prosecution tool without need for legislative change Contributor: Brian McVeigh, a Calhoun/Cleburne County District Attorney
	Tuscaloosa County Sheriff's Office	Page 31	**Tuscaloosa County (AL)** used seizure money obtained during initial trial testing to purchase devices. Contributor: Wayne Robertson, Captain in the West Alabama Narcotics Unit in Tuscaloosa County
	Reynolds County Sheriff's Office	Page 32	**Reynolds County (MO)** has used portable Raman devices to save time and lower costs. Contributor: Tom Volner, Sheriff, Reynolds County, Missouri

NIJ Award Number 2011-DN-BX-K564

Winston County Sheriff's Office

Winston County used portable Raman devices to successfully enhance their investigative process.

Wes Brown is a Lieutenant for the Winston County Sheriff's Office. He played a critical role in gathering support from key stakeholders in his county and neighboring municipalities to collectively purchase and adopt a portable Raman device for use in search warrants and plea agreements.

Use Profile

Winston County, a rural jurisdiction, and other neighboring municipalities had been looking for a way to reduce backlogs in court dockets and laboratories. The state of Alabama has only three narcotics testing laboratories, which can lead to long turnaround times. The Huntsville Regional Laboratory, for example, covers approximately 30 counties.

Brown first became aware of the Centice MFL-3000 device at a Regional Organized Crime Information Center (ROCIC) conference. After learning about the potential benefits of the device, he introduced the idea of using the device to various members of the region, including district circuit court judges, district attorneys, defense attorneys, and neighboring agencies. Although the device results are not considered confirmatory evidence, the various key players across the court system agreed that the device report results were sufficient in establishing evidence for plea agreement negotiation and obtaining search warrants. The use of these devices has effectively reduced the number cases that go to trial; Brown noted that the last time he testified for a drug case was over 5 years ago.

The Winston County Sheriff's Office teamed up with neighboring municipalities and local district attorneys to purchase a device, using funds collected at a federal firearms auction ($22,000 from sale of 65 firearms). Approval for selling the abandoned property was obtained from the circuit judges and district attorneys. The entire process for approval and sales took approximately 60 days. The procurement process for purchasing the device was simple and straightforward, once funding was in place. The county worked through Centice's distributor, Advanced Covert Technology (ACT), for purchase. Prior to the official purchase, ACT provided the device 60–90 days in advance for visual demonstration and training.

Device Impact

- Cases are now closed within 6 months rather than two years (due to reduced laboratory testing), and compensation due to case closure occurs more quickly.
- Negotiated plea agreements have increased, reducing the number of cases that go to trial.

Lessons Learned

- Agreement among key players across the justice system is helpful for smooth implementation and acceptance of devices.
- Sales from abandoned property can be used to purchase devices. .

NIJ Award Number 2011-DN-BX-K564

Calhoun/Cleburne District Attorney's Office

Calhoun County uses portable Raman spectrometers as a prosecution tool without need for legislative changes.

Brian McVeigh is the Calhoun and Cleburne County District Attorney (Seventh Judicial Circuit) who supports the use of portable Raman spectroscopy devices for negotiating plea agreements and for reducing laboratory backlogs. He worked with Mark Hopwood (see sidebar on page 25) to implement the devices within his Counties.

Use Profile

The impetus for experimenting with portable Raman spectroscopy devices in both Calhoun and Cleburne counties was the closing of various laboratories within the Alabama Department of Forensic Sciences system. With reduced resources, the circuit sought a fair way to handle physical evidence in both rural and city settings to provide continuity of testing services across all covered areas. Mark Hopwood was asked to coordinate a study to explore the use and effectiveness of these devices with the help of Thermo Fisher, one of the device manufacturers. Several counties and district attorneys were a part of this study.

Thermo Fisher allowed the circuit to field trial and evaluate the devices for 6 months to determine device benefits. During the trial, the device led to two exonerations after the Department of Forensic Sciences confirmed the device test results, which encouraged the circuit to directly purchase the device midway through the trial. The Oxford Police Department provided funding for acquisition of the TruNarc.

Device Impact

- The district's use of the device has increased the number of plea agreements. McVeigh reported that 1–2 plea agreements were typical prior to indictment, but with use of the device, approximately 100 plea agreements are seen per grand jury.
- With fewer cases going to court, laboratory backlogs are reduced and county revenue from court costs has increased due to quicker processing times.

Lessons Learned

- A successful implementation requires a technology champion who not only introduces the device, but also spearheads support from various decision makers. For Calhoun County, Mark Hopwood was the technology champion.
- All parties across the justice system must be in agreement that the portable Raman device employed follows valid scientific processes for use during prosecution. Successful agreement allows the device to be used for plea agreements, even without a change in legislation.
- Trial testing allows parties to determine and understand the device's effectiveness and impact.

NIJ Award Number 2011-DN-BX-K564

Tuscaloosa County Sheriff's Office

Seizure money obtained during initial trial testing was used to purchase devices in Tuscaloosa County.

Wayne Robertson is the Captain in the West Alabama Narcotics Unit in Tuscaloosa County. His team saw immediate impact and obtained enough seizure money during a trial test of a portable Raman spectrometer that they directly purchased their own device before the conclusion of the study.

Use Profile

The West Alabama Narcotics Unit of Tuscaloosa County trial tested Thermo Fisher's TruNarc device with neighboring Shelby County and Jacksonville State University (JSU). The device either was housed at JSU, which required driving the substances to and from JSU for testing, or was housed at Tuscaloosa to allow for in-station testing. Tuscaloosa observed immediate results and impact during the trial test and purchased its own device within a couple of months of testing. In several instances, the trial device helped seize drug money, which was directly used to enable the purchase of a permanent device; in one case, the county seized $470,000.

Although device test results are seen as presumptive only, Tuscaloosa County is able to use the TruNarc device for search warrants and negotiating plea agreements. Various stakeholders in the county, including district attorneys, defense attorneys, and judges, as well as the law enforcement officers, had worked together and agreed that this was an acceptable and effective use of the device in their jurisdiction. Representatives from Thermo Fisher demonstrated to the team that the device reliably and effectively tested unknown substances.

Currently, the device is taken into the field by officers conducting searches and during police raids.

Device Impact

- As of 2013, the TruNarc device has been successfully used in 3,000 cases in Tuscaloosa alone.
- Presumptive device test results are used to obtain search warrants and initiate arrests, saving time previously lost due to laboratory test backlogs.
- Device databases have helped to identify unknown synthetic drugs.

Lessons Learned

- Early agreement across the law enforcement agency and justice system helped drive successful device implementation and use.
- Funding issues were resolved by purchasing the devices using the seizure money that was obtained during trial tests.

NIJ Award Number 2011-DN-BX-K564

Reynolds County Sheriff's Office

Portable Raman devices have led to cost and timesaving in Reynolds County.

Tom Volner is the Sheriff in Reynolds County in rural Missouri, serving approximately 6,700 residents. The county's portable Raman spectrometer is shared with surrounding counties and police departments

Use Profile

Reynolds County, a county of 6,000–7,000 residents, needed a reliable technique to efficiently identify various drugs in the field to allow for immediate arrests. Volner had been searching for a device that allowed for fast and accurate identification of unknown pills and powders, and selected the Centice MFL-3000 device for use, which has a spectral library of over 3,600 narcotics, precursors, synthetic drugs, and prescription pills. The selected Raman device replaced chemical kits and the need to visually identify unknown pills by manually reviewing a prescription pill desk reference.

To verify the spectrometer's accuracy, the sheriff's office sometimes sends substances to the forensic state laboratories for comparisons. Printouts from the device are placed directly into the case file and handed to the prosecutor. To extend the benefits of the device beyond Reynolds, Volner offers access to the device to surrounding counties and police departments. All county deputies have been trained by the device manufacturer on how to use the device, an important requirement for prosecutors to ensure that substances were tested properly.

Device Impact

- The device's speed and accuracy has helped reduce the caseload for prosecutors.
- Unknown substances can be tested without the destruction of evidence.
- Plea agreements, arrests, and prosecutions are obtained more quickly.
- Backlogs in state drug laboratories are reduced.

Lessons Learned

- Training is important. Judges and prosecutors value the training of the individuals using the spectrometers for testifying in court.
- Database updates can help with substance identification. Working with manufacturers to update algorithms allows for better substance detection with increased sensitivity of methamphetamines of various purities.

NIJ Award Number 2011-DN-BX-K564

TABLE OF CONTENTS

Please Note: This report is a good faith effort by the FTCoE to accurately represent information available via primary and secondary sources at the time of the analysis.

NIJ Award Number 2011-DN-BX-K564

Handheld Raman Spectrometers

While all Raman spectrometers employ a laser, optics, detector, and computer to support the primary function of substance identification and verification, hardware and software features and function vary. Device manufacturers offer product configurations that they believe are well suited for field-based law enforcement operations, and provide service and technical support to law enforcement agencies that have purchased Raman spectrometers. Included herein is an explanation of key Raman spectrometer hardware and software features, key manufacturer profiles, and a comparison of commercially available handheld and portable Raman spectrometers. This information is intended to provide law enforcement professionals with the information needed to distinguish between devices and manufacturers when considering whether to deploy Raman technology in their respective agencies or departments.

Disclaimer

Information provided herein is intended to be objective and is based on data collected during primary and secondary research efforts available at the time this report was written. Any perceived value judgments may be based on the merits of device features (hardware, software, and services) as they apply to and benefit the law enforcement and forensic communities. The information is intended to provide a snapshot of current Raman spectrometer manufacturers and a high-level summary of available products, and is not intended as an exhaustive product summary. Features or capabilities of additional devices or manufacturers identified outside of this landscape may be compared with these device features and service offerings to aid in the information-gathering or decision-making process.

NIJ Award Number 2011-DN-BX-K564

Hardware Features

Traditional benchtop Raman spectrometers found in crime and forensics laboratories are instruments with large footprints and multiple separate components. In handheld or portable Raman spectrometers, these components have been shrunk down and packaged in a way to enable convenient use in the field. Important features include the following:

Size and weight – Portable spectrometers require less component miniaturization and may provide more processing power at lower cost, but are large and come in a carrying case. Handheld Raman spectrometers can fit in the palm of the hand, but can be more expensive to manufacture.

Display and controls – Touch screens are often used to display test results and data to the user while enabling intuitive control of the device. Devices also may incorporate buttons, keys, or scroll wheels for control.

Battery – Devices are powered by non-removable lithium ion battery packs and, in some cases, use common alkaline batteries. Battery life depends on the power requirements of the components and frequency of use, and can range from 5 to 10 hours.

Data storage and network connectivity – Devices store information using flash memory, including removable Micro SD cards. Information can be transferred to a central computer or server for record keeping and further analysis via wireless (Wi-Fi or Bluetooth) or wired (Ethernet, mini, or micro USB) connections.

Ruggedization – Device hardware can be "ruggedized" or toughened to meet strict environmental challenges that will be encountered in the field. Typical cited criteria for ruggedization are MilSpec 810G tests for waterproofing, dustproofing, and shock resistance (US military environmental test standard)[13] and IP 67 (dustproof and waterproof in water up to 1m deep for 1 hour, dictated by the International Electrotechnical Commission's IEC 529 standard).[14] Hardware ruggedization requires expensive components and packaging and can lead to higher device cost.

Sampling attachments – Different sampling attachments for handheld and portable Raman spectrometers are available. Fiber optic probes can be used to flexibly orient the laser source into difficult-to-reach positions. Ninety-degree angular attachments can be used to enable hands-free tabletop testing.

Accessories – A variety of external accessories and attachments is available. This includes Bluetooth printers for printing of evidence reports, AC and DC battery chargers, and microscope stage attachments to enable focus on exceptionally small particles of evidence for evaluation.

[13] Department of Defense Test Method Standard. Environmental Engineering Considerations and Laboratory Tests. MIL-STD-810G. October 31, 2008. http://www.atec.army.mil/publications/Mil-Std-810G/Mil-Std-810G.pdf

[14] Explanation of IP Code. DSM&T. Adapted from IEC 60529, "degrees of Protection Provided by Enclosures (IP Codes)," Ed 2.1 (Geneva International Electrotechnical Commission, 2011). http://www.dsmt.com/pdf/resources/iprating.pdf

NIJ Award Number 2011-DN-BX-K564

Software Features

Raman spectrometers are equipped with software interfaces that are simple with self-explanatory features and that prompt users throughout the testing process, with clear indication of test results. Simplicity is paramount to reducing operator error and providing a degree of confidence that is required when policing decisions or emergency medical care may rely on the test results. Software features include the following:

Matching algorithms – All Raman spectrometers used in law enforcement applications are pre-loaded with a matching algorithm that is used to find a match between the sample spectrum and the library of reference spectra. The matching algorithm may return many potential sample identities, with potential identities ranked in order of match likelihood.

Mixture analysis – Street drugs are often mixed with cheap cutting agents to dilute the primary ingredient (cocaine is often cut with baking soda and caffeine). The Raman spectra for a mixture will be a combination of the spectra of the two components. Some device manufacturers have developed algorithms that will identify each mixture component, but these may be limited in accuracy when many different cutting agents are used. Other methods of mixture identification include incorporation of common mixture spectra in identification spectra libraries.

Results display – Test results are displayed on either a large computer screen (portable) or a small screen (handheld). Depending upon the size of the screen, test spectrum graphs may or may not be displayed after testing. In addition to the match score, visual verification of similarity between the sample and reference spectra is often encouraged as a best practice for device users.

Tamper-proofing – Device software permissions can be set by administrators (forensic or crime lab managers, for example) to prevent modification or deletion of test results. Test results can be logged with a date and time stamp to protect the validity of the data.

Scan delay and remote control – In some instances, a Raman laser may generate enough energy to detonate high-explosive materials during analysis. To enhance user safety in case of suspected explosive material testing, devices are enabled with time-delayed scanning and remote controlled test features.

Library choice – Depending upon the testing scenario, users may choose between different reference spectra libraries to improve match specificity. For example, a white powder library or narcotics library may be selected when testing an unknown powder found on a suspect or at a crime scene.

Device calibration – Handheld and portable Raman spectrometers are calibrated using the spectra for polystyrene, the ASTM calibration standard for all analytical Raman spectrometers. Some devices perform calibration automatically each time they are rebooted.

NIJ Award Number 2011-DN-BX-K564

Spectral Libraries for Identification

Chemical compounds have characteristic Raman spectra, which are often unique enough to distinguish compounds. As with all spectral methodologies, not all compounds can be absolutely distinguished from all other compounds by Raman spectra. Comparing the Raman spectra obtained from an unknown material with spectra collected from known reference materials can often result in a reliable identification. For example, if a spectrum for cocaine is contained in a reference library, a lab or field unit would now be able to identify an unknown white powder found at a crime scene as cocaine.

A collection of reference spectra is known as a library. Size, quality, and type of reference spectra contained in spectral libraries play a large role in the usefulness and effectiveness of Raman spectrometers. Libraries can be built or purchased in a variety of ways. Customized libraries can be built by saving results of known substances as a new reference spectrum. Libraries are also often offered by spectrometer manufacturers themselves, or they can be purchased by third-party laboratories that specialize in Raman analysis. Some technology developers offer curated managed library services for their customers, with regular library updates as new cutting agents, illicit materials, synthetic drugs, and drug mixtures are discovered by law enforcement agencies.

Raman Spectrometer Technology Developers for Law Enforcement

The Raman spectroscopy market is well established, with technology providers developing solutions for analytical chemistry applications since the development of the laser in the 1960s. Common Raman spectrometers found in the laboratory are benchtop instruments that are modular in design, with separate laser sources and detectors, and that are often integrated with a microscope to focus the laser onto individual sample particles for analysis. Many of these benchtop Raman spectrometers may already be found in the forensic and criminal investigation laboratories of the readers of this report. However, portable and handheld Raman devices are fairly recent developments enabled by advancements in optics, detection, and increases in computer processing power.[15]

While there are a large number of Raman technology providers, relatively few cater specifically to the law enforcement and emergency response communities. For the purpose of this report, the technology providers that were highlighted place special emphasis on developing handheld and portable Raman spectrometer systems and services for law enforcement or military customers. These manufacturers develop ruggedized, field-ready systems in addition to providing training and offering managed spectral library services, technical support, and even expert witness testimony. A number of factors are responsible, including the recent emergence of the handheld and portable Raman systems, a relatively expensive price tag, the complexity of the legal system, and the level of support and infrastructure needed to successfully support early-adopting government and law enforcement agencies.

[15] Raw-Material Authentication Using a Handheld Raman Spectrometer. Robert L. Green. Pharmaceutical Technology. Volume 3, Issue 32. http://www.pharmtech.com/pharmtech/article/articleDetail.jsp?id=500408&pageID=1&sk=&date=

NIJ Award Number 2011-DN-BX-K564

B&W Tek

Manufacturer of the TacticID® Raman spectrometer, a product launched in early 2014. The TacticID® comes in two models, the TacticID®-N (narcotics) and TacticID®-GP (general purpose). B&W Tek offers and curates both narcotics and general purpose identification reference spectra libraries that can be updated frequently via a secure Wi-Fi or Ethernet network connection to maintain up-to-date identification capabilities. Drug mixtures are also analyzed by a proprietary probability-based algorithm that can identify as many as nine mixture components. Additional features include a high resolution touch screen display for on-the-spot note taking, color coded threat level results, factory and user library customizability and remote operation via tablet computer. http://www.tacticid.com/

Centice

Manufacturer of the Mobile Field Lab 3000 (MFL-3000), a field-portable Raman spectroscopy unit developed and marketed specifically for law enforcement applications, and the Bench-Top Lab, which is a more economical benchtop version for evidence rooms. Centice has developed an embedded, proprietary database that contains over 3,800 prescription drugs, illicit substances, synthetic drugs, cutting agents, and drug synthesis precursors and is updated quarterly, and its software contains an image database of prescription pill markings for quick visual identity verification. Drug analysis systems not only detect substances in mixtures, but also give relative strength of each substance to help with intelligence-led investigations. Centice's patented 'Coded Aperture' delivers accurate results while allowing the laser to be larger and safer, and lowering cost. Centice is an advocate of Raman technology in the legal system and promises to back jurisdictions with expert scientific testimony if required. http://www.centice.com/

NFSTC Centice Mobile Field Lab 3000 (MFL-3000) Evaluation: http://www.nfstc.org/?dl_id=301

Morpho Detection

Manufacturer of the StreetLab® Mobile, a handheld Raman spectrometer developed to identify a broad range of toxic industrial chemicals, materials, explosives, chemical warfare agents, precursors, and narcotics. Identification libraries are drawn from Environmental Protection Agency (EPA) and hazardous materials lists. Morpho Detection offers a 24-hour Customer Assistance Center, as well as access to training experts that provide instruction to operators through year-round on-site and computer-based courses. http://www.morpho.com/IMG/pdf/Morpho_StreetLab_Mobile_DAT.pdf

Real-Time Analyzers

Real-Time Analyzers (RTA) designs, manufactures, and markets high-performance Raman spectrometers for use in chemical, biochemical, and materials identification and characterization. RTA's Raman spectrometers use 1064 nm wavelength lasers for sample excitation while eliminating fluorescence that obscures Raman signals. The RamanID is a portable briefcase system designed for service in field-based environments, which uses a fiber optic probe that can be employed for flexible sampling. RTA has also developed a ruggedized Military Grade 1064 Raman spectrometer for use in the field, capable of withstanding 4 foot drops, loose cargo vibrations, blowing rain, and extreme temperatures. http://www.rta.biz/Content/RamanID_Portable_Raman_Analyzer.asp

NIJ Award Number 2011-DN-BX-K564

Smiths Detection

Smiths Detection designs technologies to detect a wide variety of threats, with major customers including the Department of Defense and the Department of Homeland Security. Smiths is the manufacturer of the ACE-ID, a fully ruggedized handheld Raman spectrometer (MilSpec 810G certification pending), and RespondeR RCI, a field portable Raman analyzer. Smiths offers ReachBackID™ service and support, with experts available 24 hours a day, 7 days a week.
http://www.smithsdetection.com/index.php/en/products-solutions/chemical-identification/57-chemical-identification/ace-id.html#.U4PIVfldV1Y/

NFSTC Smiths Detection RespondeR™ RCI Raman Spectrometer Evaluation: http://www.nfstc.org/?dl_id=203

SciAps (acquired DeltaNu)

To serve the law enforcement community, SciAps has developed the ReporteR, a ruggedized, handheld Raman spectrometer that meets MilSpec 810G standards for waterproofing, dustproofing, and shock resistance. SciAps is Drug Enforcement Administration licensed, and builds its proprietary identification libraries with its own Raman spectrometers to help ensure accuracy. Device test methods and libraries (both user modifiable) can be locked and managed from a central location utilizing SciAps NuSpec software to protect evidence chains of custody. The ReporteR can also be paired with a portable Bluetooth printer to print quick evidence reports that can easily be appended to case files.
http://sciaps.com/reporter/

Thermo Scientific

Thermo Scientific is a developer of high-end analytical instruments, laboratory equipment, software, services, consumables, and reagents for use in a wide variety of research for government, academic, and commercial settings. Thermo's handheld Raman device for drug identification, the TruNarc Handheld Narcotics Analyzer, has been developed to identify drugs of abuse, cutting agents, precursors, and emerging threats such as cathinones (bath salts) and cannabinoids (Spice or K2). Portable, disposable SERS kits are available for use with Thermo Scientific's TruNarc (TruNarc Solution Kit – Type H) to enable greater accuracy in opioid detection at low cost. TruNarc software produces automated tamper-proof records that are time and date stamped to protect evidence. Thermo Scientific offers spectral analysis reach-back support by staff chemists, available 24 hours a day, 7 days a week.[16]
http://www.thermoscientific.com/en/product/trunarc-handheld-narcotics-analyzer.html

NFSTC Thermo Scientific® TruNarc™ Evaluation: http://www.nfstc.org/?dl_id=303

[16] Handheld Raman Analysis in the Field for Improved Efficiency in the Lab. Craig Gardner. Thermo Scientific Portable Analytical Instruments. Thermo Fisher Scientific.

NIJ Award Number 2011-DN-BX-K564

Other Manufacturers

A list of notable and reputable manufacturers that produce significantly advanced portable and handheld Raman spectrometers not actively marketed for law enforcement applications is included below. These devices share similar technology and core capability, and the manufacturers may be contacted for more information regarding future developments of products for law enforcement applications:

Enhanced Spectrometry, Inc – RaPort http://www.enspectr.com

Ocean Optics – IDRaman Mini http://oceanoptics.com/product/idraman-mini/

Snowy Range Instruments – CBEx and CBEx 1064 http://www.wysri.com

Wasatch Photonics – NOVA Handheld Raman http://www.wasatchphotonics.com

InPhotonics – InPhotote Portable Raman System for Rapid Chem ID http://www.inphotonics.com/spectrometers2.htm

NIJ Award Number 2011-DN-BX-K564

Portable Raman Spectrometer Product Comparison

Devices vary based on size, library type, and manufacturer support services.

Handheld Devices

Relative Cost

$: <$12,500
$$: $12,500–$25,000
$$$: $25,000–$37,500
$$$$: $37,500–$50,000
$$$$$: >$50,000

	Thermo Scientific			B&W Tek Inc.	
					
	TruNarc	FirstDefender RM	FirstDefender RMX	TacticID®-GP	TacticID®-N
Relative Cost	$–$$	$$$$	$$$$$	$$$	$$
Point and Shoot	Yes	Yes	Yes	Yes	Yes
Display	Color LED	Color LED	Color LED	Color LED Touch screen	Color LED Touch screen
Spectra Display on Unit	No	Yes	Yes	Yes	Yes
Weight	1.25 lbs	<1.8 lbs	<2.0 lbs	2.0 lbs	2.0 lbs
Size	6.4"x 4.1" x 2.0"	7.6" x 4.2" x 1.75"	7.7" x 4.5" x 2.4"	7.5" x 3.9" x 2.0"	7.5" x 3.9" x 2.0"
Battery Life	>10 hrs	>4 hrs	>4 hrs	>5 hrs	>5 hrs
Ruggedization	Yes, IP64	Yes, MIL-STD-810G and IP67	Yes, MIL-STD-810G and IP67	Yes, IP65	Yes, IP65
Data Storage	Yes	Yes	Yes	Yes	Yes
Network Connection	No	No	No	Wi-Fi, Ethernet	Wi-Fi, Ethernet
Library Type	315 Items: Narcotics, cutting agents, precursors, synthetic cannabinoids, synthetic cathinones	12,100 Items: Explosives, toxic industrial chemicals, chemical warfare agents, narcotics, precursors	12,100 Items: Explosives, toxic industrial chemicals, chemical warfare agents, narcotics, precursors	>5,000 Items: Explosives, toxic industrial chemicals, chemical warfare agents, narcotics, cutting agents, precursors, pharmaceuticals	1,000 Items: Narcotics, cutting agents, precursors, pharmaceuticals
User Library Customizability	No	Yes	Yes	Yes	No
Central Library Updates	Yes, multiple times per year	Yes, annually	Yes, annually	Yes, multiple times per year	Yes, multiple times per year
Mixture Detection	Yes. Automatic mixture analysis & identification of up to 2-component Alarm Item or Clear Items mixtures	Yes. Automatic mixture analysis & identification of up to 4 components	Yes. Automatic mixture analysis & identification of up to 4 components	Yes, as many as 9 components	Yes, as many as 9 components

NIJ Award Number 2011-DN-BX-K564

Portable Raman Spectrometer Product Comparison

Devices vary based on size, library type, and manufacturer support services

Handheld Devices (continued)

Relative Cost

$: <$12,500
$$: $12,500–$25,000
$$$: $25,000–$37,500
$$$$: $37,500–$50,000
$$$$$: >$50,000

	SciAps			Smiths Detection	Morpho
					
	ReporteR	Inspector 300	Inspector 500	ACE-ID	StreetLab Mobile
Relative Cost	$$	$$–$$$	$$$$	$$	$$$
Point and Shoot	Yes	Yes	Yes	Yes	Yes
Display	Color LED	Color LED Touch screen	Color LED Touch screen	Color LED Touch screen	Color LED
Spectra Display on Unit	Yes	Yes	Yes	Yes	Yes
Weight	1.35 lbs	3.8 lbs	3.8 lbs	1 lb	6.5 lbs
Size	6" x 3.4" x 1.7"	7.5" x 6.9" x 1.7"	7.5" x 6.9" x 1.7"	5" x 3.5" x 2.2"	15" x 5.5" x 8"
Battery Life	>4 hrs	Up to 4 hrs	Up to 4 hrs	-	>5 hrs
Ruggedization	Yes, MIL-STD-810G and IP67	Yes, MIL-STD-810G and IP67	Yes, MIL-STD-810G and IP67	Yes, MIL-STD-810G pending	Yes, IP67
Data Storage	Yes	Yes	Yes	Yes	Yes
Network Connection	Bluetooth	Bluetooth	Bluetooth	MicroUSB	2.4 GHz Modem
Library Type	Chemical warfare agents, toxic industrial chemicals, toxic industrial materials, narcotics, explosives, pharmaceuticals, plastics	Chemical warfare agents, toxic industrial chemicals, toxic industrial materials, narcotics, explosives, pharmaceuticals, plastics	Chemical warfare agents, toxic industrial chemicals, toxic industrial materials, narcotics, explosives, pharmaceuticals, plastics	Approximately 500 substances including explosives, precursors, narcotics, and toxic chemicals	>10,000 Items: Extensive and expandable threat libraries drawn from EPA and hazardous materials lists
User Library Customizability	Yes	Yes	Yes	–	Yes
Central Library Updates	No	No	No	–	No
Mixture Detection	Yes	Yes	Yes	Yes, proprietary algorithms enable analysis of binary mixtures	Yes, concentrations as low as 10%

NIJ Award Number 2011-DN-BX-K564

Portable Raman Spectrometer Product Comparison

Devices vary based on size, library type, and manufacturer support services

Portable Devices

Relative Cost

$: <$12,500
$$: $12,500–$25,000
$$$: $25,000–$37,500
$$$$: $37,500–$50,000
$$$$$: >$50,000

	Smiths Detection	Centice	Real-Time Analyzers
			
	ResponderR RCI Portable Raman Spectrometer	Mobile Field Lab 3000	RamanID
Relative Cost	–	$–$$	$$$$
Point and Shoot	Yes	No	No (fixed sample holder for 2 or 20 mL glass vials)
Display	Color LED Touch screen	Color LED Screen	Color LED Screen
Spectra Display on Unit	Yes	Yes	Yes
Weight	6 lbs	11.5 – 20 lbs	30 lbs
Size	8.75" x 7.5" x 4"	6.5" x 11" x 3.5" (Spec) 7" x 10" x 1" (Comp)	20" x 16" x 8"
Battery Life	>5 hrs	10 hrs	5 hrs
Ruggedization	Yes	Yes	Yes
Data Storage	Yes	Yes	Yes
Network Connection	Bluetooth	WiFi, Ethernet	USB
Library Type	9,300+, upgradable to 14,500+ Items: Chemical warfare agents, toxic industrial chemicals, toxic industrial materials, narcotics, explosives, pharmaceuticals, plastics	3600 pharmaceuticals, 200+ illicits: Pharmaceuticals, illicits, precursors, cutting agents, synthetics, and bath salts	ChemID software loaded with 500 spectra in initial library
User Library Customizability	No	Yes	Yes
Central Library Updates	No	Yes	No
Mixture Detection	Yes, residual search capability	Yes, analyzes and identifies up to four components and delivers both mixture makeup and relative strengths of the ingredients identified	No

NIJ Award Number 2011-DN-BX-K564

TABLE OF CONTENTS

Please Note: This report is a good faith effort by RTI to accurately represent information available via primary and secondary sources at the time of the analysis.

NIJ Award Number 2011-DN-BX-K564

To gain the benefits that portable Raman devices can offer, agencies must overcome barriers that hinder implementation.

Investigative Benefits

Time savings: Test results can be obtained in the field within a matter of minutes, providing instantaneous results at the scene or at the agency, providing a tighter interaction of presumptive test information with the investigation. This allows law enforcement and investigators to better understand the nature of the seized material and to improve decisions in the investigation and deployment of personnel. For example, having an immediate Raman spectrometer test result that indicates a material is baking soda and not a controlled substance can allow the decision to not deploy resources for further 'buys' or to change strategies in the investigation.

Comprehensive testing: Raman spectroscopy is more flexible in detecting a wider range of compounds. Commonly used color-based test kits are very effective for the typically encountered cocaine, heroin, methamphetamine, opiates, and benzodiazepines (to name a few common drugs). However, with increasing challenges of new emerging drug compounds that are highly variable and rapidly changing, color kits are not as effective.

Reduced caseloads and backlogs: With information-rich field-based Raman screening techniques, the laboratory can be more efficient in sample processing for confirmatory results. Better-informed results from Raman spectroscopy tests can provide faster and more specific results that can improve negotiated plea agreements and reduce cases proceeding through the court system.

Implementation Hurdles and Potential Solutions

Cost of device: : Availability of funding to purchase a device may be an issue. Portable devices typically cost $15,000–20,000, which is often a barrier for purchase, particularly if more than one device is needed for successful deployment. Partnering with neighboring municipalities to reduce costs, obtaining grants, and trial testing may be options for overcoming funding barriers. Seizure money obtained from previous cases or during trial testing could also be a funding source.

Presumptive evidence: Because portable Raman spectrometers are not yet seen as confirmatory evidence, successful deployment of the device will rely on participation and acceptance of how the evidence resulting from the device should be used. Stakeholders within the court system need to be convinced prior to implementation. Although device evidence is not seen as confirmatory evidence, obtaining agreement from key players across the legal system is sufficient and critical for successful implementation.

Technical device challenges: Selection of a device based on department needs is important. Contacted users cited the following as important criteria for a useful device: the ability to test mixtures for various components beyond testing the majority constituent, the ability to test both liquid and solid substances, access to appropriate spectral databases for substances found within the jurisdiction, and timeliness of incorporating emerging drug information into the databases. Finding a suitable device manufacturer partner with products that fit the department's need is critical.

NIJ Award Number 2011-DN-BX-K564

To learn more about mobile Raman device technology, consider these additional resources

Department of Homeland Security

- Handheld Raman Spectrometers. System Assessment and Validation for Emergency Responders (SAVER). Department of Homeland Security. October 2012. http://www.firstresponder.gov/Saver/Raman_SUM.pdf

Federal Bureau of Investigation

- Portable Raman Spectroscopy Systems for Field Analysis. Eckenrode. FBI Laboratory Services – Forensic Science Communications. October 2001. Volume 4, Number 4. http://www.fbi.gov/about-us/lab/forensic-science-communications/fsc/oct2001/index.htm/eknrode.htm

National Forensic Science Technology Center

- Four Commercially Available Portable Raman Spectrometers. Markert et al. National Forensic Science Technology Center. 2011. http://www.nfstc.org/new-evaluation-report-comparison-of-four-raman-spectrometers/
- Evaluations of Technologies for Chemical Identification and Analysis. Evaluation reports available for select devices. http://www.nfstc.org/forensic-technology/technology-evaluations/chemistry/

National Institute of Justice

- Presumptive Field Testing Using Portable Raman Spectroscopy: Research and Development on Instrumental Analysis for Forensic Science: Award Number 2010-DN-BX-K201. Stephana Fedchak. January 2014. https://www.ncjrs.gov/pdffiles1/nij/grants/244564.pdf

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- Infrared and Raman Spectroscopy in Forensic Science. John M. Chalmers, Howell G. M. Edwards, Michael D. Hargreaves. Wiley. 2012. Page 326.
- Handbook of Raman Spectroscopy. From the Research Laboratory to the Process Line. Chapter 18. Raman and Surface Enhanced Resonance Raman Scattering. Applications in Forensic Science. Geoffrey Dent, Peter C. White, W. Ewen Smith, and C. Rodger.

Ruggedization Information

- Department of Defense Test Method Standard. Environmental Engineering Considerations and Laboratory Tests. MIL-STD-810G. October 31, 2008. http://www.atec.army.mil/publications/Mil-Std-810G/Mil-Std-810G.pdf
- Explanation of IP Code. DSM&T. Adapted from IEC 60529, "degrees of Protection Provided by Enclosures (IP Codes)," Ed 2.1 (Geneva International Electrotechnical Commission, 2011). http://www.dsmt.com/pdf/resources/iprating.pdf

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Whitepapers and Articles

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- Raw-Material Authentication Using a Handheld Raman Spectrometer. Robert L. Green. Pharmaceutical Technology. Volume 3, Issue 32. http://www.pharmtech.com/pharmtech/article/articleDetail.jsp?id=500408&pageID=1&sk=&date=
- Analysis of Synthetic Cannabinoids and Designer Drugs. Thomas G. Brock. Cayman Chemical Whitepaper. https://www.caymanchem.com/app/template/Article.vm/article/2199;jsessionid=23511DEC35A673779AD04B67A07FA677
- Handheld Raman Analysis in the Field for Improved Efficiency in the Lab. Craig Gardner. Thermo Scientific Portable Analytical Instruments. Thermo Scientific. http://www.ascld.org/wp-content/uploads/2013/06/Gardner-TruNarc-Poster.pdf

NIJ Award Number 2011-DN-BX-K564