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U.S. DEPARTMENT OF COMMERCE

Strategic Opportunities to Advance Forensic Science in the United States

A Path Forward Through Research and Standards

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Foreword

This report was developed with input from stakeholders in forensic science, including experts in the field and across the criminal justice community, and through a NIST-hosted workshop and literature review. This document provides a high-level perspective of the nation's forensic science challenges and the strategic research and development (R&D) and standards needed to address those challenges. The report is intended for use by both public- and private-sector stakeholders to inform decisions about R&D and standards that should be pursued to strengthen forensic science procedures and practices that support legal decision-making. This report (NIST Special Publication 1319) is available free of charge from https://doi.org/10.6028/NIST.SP.1319.

Disclaimer

These opinions, recommendations, findings, and conclusions do not necessarily reflect the views or policies of NIST or the United States Government. This report is not intended to imply any criticism of any past, pending, or future legal proceeding involving forensic science or evidence based on forensic science.

Message from the Director

A century ago, NIST was home to one of the first federal forensic scientists and helped establish the FBI laboratory in 1932. Since those early beginnings, NIST's efforts have evolved within its mission to meet demands in advancing measurement science, standards, and technology for forensic science.

In response to the landmark 2009 National Academies report, NIST has significantly expanded its research and standards efforts across a broad spectrum of forensic science disciplines. Today, NIST has a robust Forensic Science Program focused on strengthening the scientific basis of forensic science so that evidence may be appropriately collected, accurately analyzed, and effectively communicated. These NIST efforts seek to bring the best possible forensic science methods and practices to the criminal justice system, thereby eliminating potential bias in measurements, analysis, and interpretation of evidence.

NIST engages the full spectrum of forensic science stakeholders with interests across a range of evidence types through its focused efforts on forensic science research, standards, and scientific foundation studies. NIST works closely with the forensic science community, engaging directly with forensic science practitioners, law enforcement officers, attorneys, researchers, and jurists to identify the most pressing needs and challenges faced by criminal justice stakeholders and to build sustained relationships that ultimately lead to improved public trust in our criminal justice system.

In 2023, NIST initiated a multi-pronged effort to assess the strategic opportunities for forensic science research and standards in the future. In September 2023, NIST convened a roundtable of forensic science thought leaders and, in March 2024, NIST published a comprehensive review of the literature. This report summarizes these inputs to identify the grand challenges facing forensic science today, the strategies for addressing them through advances in research and standards, and the subsequent implementation of the advances into forensic science practice.

NIST looks forward to continuing to strengthen the science that supports forensic science by working together with stakeholders in the forensic science and criminal justice communities to drive significant advancements in the practice of forensic science in the years ahead.

Laurie E. Locascio, Ph.D., NAE
Under Secretary of Commerce for Standards and Technology &
Director, National Institute of Standards and Technology

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Executive Summary

From our nation's beginning, the criminal justice system has been fundamental to civil society. It allows us to maintain law and order, safeguard lives and property, and protect our societal values.

However, the criminal justice system is effective only insomuch as society trusts that the system is fair. "Blind" justice requires that the system maintain an objectivity that can only result from the use of accurate and impartial information. Thus, the system turns to forensic science.

Forensic Science

is the application of scientific or technical practices to the recognition, collection, analysis, and interpretation of evidence for criminal and civil law or regulatory issues.[1]

Forensic science evidence must be gathered and analyzed, and results reported, in ways that promote trust and confidence in the legitimacy of our criminal justice system. While evidence provides an objective means to demonstrate an alleged criminal's connection with a crime, the forensic science methods used to make such determinations must be accurate and must routinely produce consistent results when used over time by different people and in different laboratories.

Demonstrating the validity and reliability of complex methods and techniques for forensic evidence analysis while accounting for factors that can influence the interpretation of the evidence in forensic science casework can be challenging. While courts determine whether forensic evidence is legally admissible, robust research that establishes the accuracy and reliability of those complex analytical methods and techniques will help courts make informed decisions about admissibility.

Accuracy and Reliability of Complex Methods and Techniques for Analysis of Forensic Evidence

Quantify and establish statistically rigorous measures of accuracy and reliability of complex methods and techniques for forensic evidence analysis that clearly demonstrate their validity when applied to evidence of varying quality.

Technical gaps have been identified in many forensic science disciplines, and the forensic science community must keep pace with emerging challenges and increasing demand for examinations of new types of evidence for which existing methods are not available. New methods and techniques, including computational tools such as algorithm-based systems and artificial intelligence, have the potential to produce actionable information in real-time and new analytical insights from complex forensic evidence. However, these types of new methods present both opportunities and challenges (e.g., risks associated with algorithmic biases), and therefore must also be carefully evaluated to ensure fair and appropriate applications.

1. National Commission on Forensic Science (2015) "Views Document on Definitions." (U.S. Department of Justice, Washington, D.C.); available at https://www.justice.gov/ncfs/file/477836/dl?inline.

New Methods and Techniques for Analysis of Forensic Evidence

Develop new methods and techniques for forensic evidence analysis, including those that leverage the benefits of algorithms and next-generation technologies, such as AI, to provide rapid analyses of forensic evidence and produce new analytical insights from complex forensic evidence.

Forensic science practices must be standardized and consistent across forensic service providers. Procedures and practices may vary within and across disciplines and jurisdictions, which can lead to different results from analyses conducted by different providers. If multiple forensic service providers obtain different results for the analysis of the same evidence, then the quality of information on which judicial decisions are based can vary and the criminal justice system would not be well served.

Science-Based Standards and Guidelines for Forensic Science Practices

Develop rigorous science-based standards, conformity assessment schemes, and guidelines across forensic science disciplines to support consistent and comparable results from forensic analyses among laboratories and jurisdictions.

Finally, new advances in forensic science have little utility or impact if they are not adopted and used in forensic science practice. Implementation of new and improved methods and techniques, particularly those that rely on advanced instrumentation and technology, requires significant time and resources, and progress toward implementation of advances in forensic science research and standards has been slow and challenging.

Adoption and Use of Advanced Forensic Analysis Methods, Techniques, Standards, and Guidelines

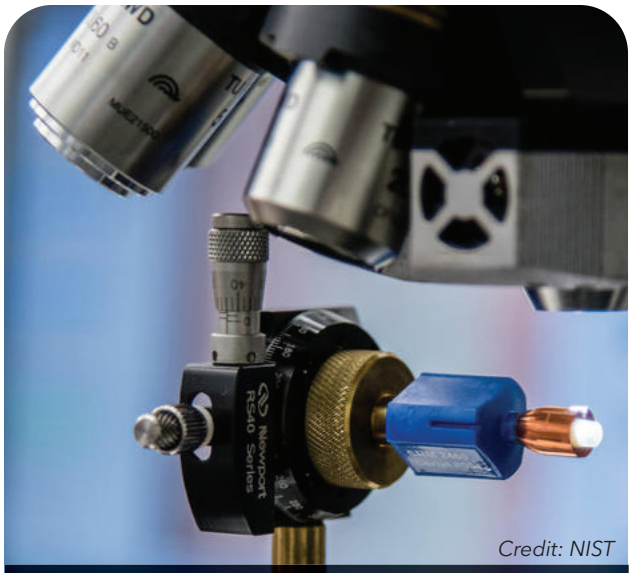
Promote the adoption and use of advances in forensic science standards, guidelines, methods, and techniques aimed at improving the validity, reliability, and consistency of forensic science practices.

To ensure that forensic science fulfills its critical role in jurisprudence, forensic service providers, law enforcement, academia, the legal community, standards development organizations, and other government agencies and private industry must engage collaboratively to strengthen the scientific basis of forensic methods and practices and facilitate continuous improvement across its many interconnected components.

	GRAND CHALLENGE	OUTCOME
Accuracy and Reliability of Complex Methods and Techniques for Analysis of Forensic Evidence	Quantify and establish statistically rigorous measures of accuracy and reliability of complex methods and techniques for forensic evidence analysis that clearly demonstrate their validity when applied to evidence of varying quality.	A robust and defensible forensic science enterprise for which results of complex methods and techniques for forensic evidence analysis include quantified and reported measures of accuracy and reliability that can be trusted by the criminal justice system and the public.
New Methods and Techniques for Analysis of Forensic Evidence	Develop new methods and techniques for forensic evidence analysis, including those that leverage the benefits of algorithms and next-generation technologies, such as AI, to provide rapid analyses of forensic evidence and produce new analytical insights from complex forensic evidence.	A new era of forensic science with the potential to revolutionize current practices and strengthen criminal justice and public safety by more quickly providing more information about the evidence left during the commission of a crime or unlawful act and identification of an alleged perpetrator.
Science-Based Standards and Guidelines for Forensic Science Practices	Develop rigorous science-based standards, conformity assessment schemes, and guidelines across forensic science disciplines to support consistent and comparable results from forensic analyses among laboratories and jurisdictions.	A forensic science community guided by science-based standards and traceable benchmarks that underlie methods and techniques for forensic evidence analysis to help enable fair and just judicial decision-making.
Adoption and Use of Advanced Forensic Analysis Methods, Techniques, Standards, and Guidelines	Promote the adoption and use of advances in forensic science standards, guidelines, methods, and techniques aimed at improving the validity, reliability, and consistency of forensic science practices.	A forensic science ecosystem that remains up to date with advanced methods, techniques, standards, and guidelines to produce accurate and reliable information used in the criminal justice system.

The Role of the National Institute of Standards and Technology

Advancing measurement science, standards, and technology is at the heart of NIST's mission. As the National Metrology Institute of the United States, NIST has a long history of engagement across a broad spectrum of industries and institutions in which accuracy and reliability are fundamental.



Credit: NIST

NIST researchers verifying that a 3D surface scanning microscope is properly calibrated by measuring the striations on the NIST standard bullet (NIST Standard Reference Material 2460)

Soon after its founding in 1901, NIST, then the National Bureau of Standards (NBS), recognized the importance of strengthening the criminal justice system by advancing forensic science. NBS was home to one of the nation's first federal forensic scientists, Dr. Wilmer Souder, and would later establish the Law Enforcement Standards Laboratory, which evolved into the Office of Law Enforcement Standards and ultimately became NIST's Forensic Science Program. The goal of the NIST Forensic Science Program is to strengthen the scientific basis of forensic disciplines so that evidence may be appropriately collected and accurately analyzed, and results effectively communicated. These NIST efforts are intended to bring the best possible forensic science methods and practices to the criminal justice system, thereby eliminating potential bias in measurements, analysis, and interpretation of evidence.

Today, the NIST Forensic Science Program works closely with forensic practitioners across the nation's more than 400 crime laboratories and thousands of other forensic science stakeholders, including law enforcement officers, attorneys, and judges across the United States and internationally. The Program is divided into three sub-units responsible for managing program activities: .

- The **Research Program** employs research, development, testing, and evaluation (RDT&E) to address critical science and technology gaps in analytical methods, standards, and practices.
- The **Standards Program** facilitates the development and adoption of high-quality, technically sound forensic science standards and guidelines via a transparent, consensus-based process that allows all stakeholders to participate.
- The **Foundations Program** conducts independent technical merit evaluations of the scientific information that supports and underpins the methods and practices used in forensic science.

NIST serves as a neutral third party to convene and facilitate open exchange of information across diverse stakeholder groups including other government agencies, industry, and academia. Because NIST is a non-regulatory agency and independent of any entity whose mission involves criminal investigation, law enforcement, or litigation, it is well-positioned to facilitate engagement among all stakeholders on questions of scientific rigor and consistency in forensic science practice throughout the United States.

TABLE OF CONTENTS

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INTRODUCTION

> *Forensic science experts and evidence are routinely used in the service of the criminal justice system. … The law's greatest dilemma in its heavy reliance on forensic evidence, however, concerns the question of whether—and to what extent—there is* science *in any given forensic science discipline.*
>
> — National Research Council (NRC) of the National Academy of Sciences (NAS), Committee on Identifying the Needs of the Forensic Science Community, 2009[2]

Credit: AdobeStock

The Role of Forensic Science in the United States

From our nation's beginning, the criminal justice system has been fundamental to civil society. It allows us to maintain law and order, safeguard lives and property, and protect our societal values.

However, the criminal justice system is effective only insomuch as society trusts that the system is fair. "Blind" justice requires that the system maintain an objectivity that can only result from the use of accurate and impartial information. Thus, the system turns to forensic science.

Forensic science is a complex end-to-end process that starts at a crime scene and ends in a courtroom. The forensic science community comprises a variety of organizations and their staff:

- those who gather evidence in the field, and those who examine it in a lab (forensic providers);
- those who educate and train providers, and those who review and audit their practices to ensure quality results;
- those who research and develop new forensic science technologies and methods, and those who develop guidance so that providers can easily adopt and employ these new approaches; and
- those who deliver results for use in judicial proceedings, and those who make decisions affecting legal outcomes.

Evidence is a cornerstone of the criminal justice system. Evidence must be appropriately collected and accurately analyzed, and results must be effectively communicated. Methods for gathering evidence, analyzing it, and reporting results must be demonstrably valid, reliable, and trustworthy. If they are not, forensic science cannot support an effective and impartial dispensation of justice that preserves public safety and public trust.

Forensic science is the application of scientific or technical practices to the recognition, collection, analysis, and interpretation of evidence for criminal and civil law or regulatory issues.[3]

Credit: NIST

2. National Research Council Committee on Identifying the Needs of the Forensic Sciences Community (2009) *Strengthening Forensic Science in the United States: A Path Forward* (The National Academies Press, Washington, D.C. USA), pages 86-87; available at https://doi.org/10.17226/12589. *Reprinted with permission.*
3. National Commission on Forensic Science (2015) "Views Document on Definitions." (U.S. Department of Justice, Washington, D.C.); available at https://www.justice.gov/ncfs/file/477836/dl?inline.

Forensic service providers span multiple disciplines, including impression and pattern comparison (e.g., fingerprints, firearms, footwear, handwriting), DNA and genetic analysis, digital and multimedia evaluation, trace materials, drugs and toxicology, and pathology. Forensic scientists identify, collect, preserve, and analyze evidence, ranging from microscopic traces at a murder site to digital data in virtual environments, and then interpret and report on the results. During legal proceedings, attorneys, judges, and juries use those findings to better understand the who, what, where, when, and how of the alleged crime.

The Status Quo

Forensic science is one of the most powerful tools for establishing the facts surrounding the commission of a crime or other unlawful act and identifying an alleged perpetrator. Physical and digital evidence recovered at crime scenes or found in the environments of suspects or victims can be used to establish a physical record, reconstruct events, support or refute witness accounts, and establish connections between locations and people. Initial accounts of the use of forensic investigations date back hundreds of years; however, many of these practices were not firmly established until the latter part of the 19th century. The science evolved slowly until the mid-1980s when it took a leap forward with the discovery that DNA could be used to associate biological evidence to a suspect. Today, the forensic science community is working with ever-more advanced tools and technologies, with artificial intelligence (AI) and machine learning (ML) now offering significant potential to advance forensic science even further by more efficiently obtaining accurate results.

As forensic science continues to evolve and technical gaps are identified, the forensic science community must keep pace with emerging challenges and increasing demand for examinations of new types of evidence for which analytical methods and techniques do not currently exist. There is a need for methods that can rapidly analyze forensic evidence in both laboratory and field operations and methods that can produce new analytical insights when applied to complex forensic evidence, such as low-quality pattern impressions, complex biological materials, new types of digital and multi-media evidence, and novel psychoactive substances. Forensic service providers are faced with trying to handle these new demands while managing their casework and finite resources.

> *Forensic science, as performed by [forensic service providers] every day, is a critical element in the administration of justice across the United States. Whether it is assisting to identify and convict the guilty, exonerate the innocent, or give closure to a victim of a crime and their family, the United States citizenry expects and deserves the most current, valid, and reliable forensic science.*
>
> – Matthew Gamette, Laboratory System Director, Idaho State Police Forensic Services, 2020[4]

4. Gamette, M (2020) Improving Forensic Science Integration: A Director's Perspective, *Forensic Science International: Synergy*, 2:183-186; available at https://doi.org/10.1016/j.fsisyn.2020.05.005.

The Role of the National Institute of Standards and Technology

Advancing measurement science, standards, and technology is at the core of NIST's mission. As the National Metrology Institute of the United States, NIST has a long history of engagement across a broad spectrum of industries and institutions in which accuracy and reliability are fundamental. Included among these is the criminal justice system.

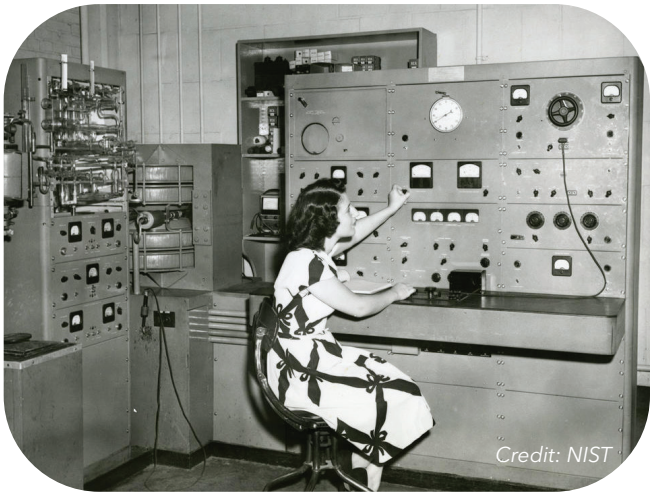
For about a century, NIST has been providing foundational and applied scientific and technical support to the criminal justice system. Soon after its founding in 1901, NIST, then the National Bureau of Standards (NBS), recognized the importance of strengthening the criminal justice system by advancing forensic science. To that end, Dr. Wilmer Souder, an NBS physicist, became one of the nation's first federal forensic scientists. Souder was instrumental in promoting innovation to advance criminal justice capabilities and applying scientific principles to help solve some of the nation's most historically significant crimes, including the Lindbergh kidnapping.

Although NBS no longer involved itself in casework after Souder's retirement in 1954, the Bureau's investment in forensic science continued. In 1971, NBS established the Law Enforcement Standards Laboratory, later renamed the Office of Law Enforcement Standards (OLES). The OLES mission was to "serve as the principal agent for standards development for the criminal justice and public safety communities," with an emphasis on "help[ing] criminal justice, public safety, emergency responder, and homeland security agencies make informed procurement, deployment, applications, operating, and training decisions, primarily by developing performance standards, measurement tools, operating procedures and equipment guidelines."[5]

NIST Mission

To promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life.

Wilmer Souder worked for 39 years with the National Bureau of Standards, focusing on criminalistics.



A NIST staff member operates an early mass spectrometer in 1948.

5. National Institute of Standards and Technology (2003) *Programs, Activities, and Accomplishments*, Office of Law Enforcement Standards, Electronics and Electrical Engineering Laboratory, NISTIR 6952; available at https://nvlpubs.nist.gov/nistpubs/Legacy/IR/nistir6952.pdf.

In 2013, following the publication of the NAS report (see sidebar), NIST restructured OLES as the Forensic Science Program. The goal of the NIST Forensic Science Program is to strengthen the scientific basis of forensic disciplines so that evidence may be appropriately collected and accurately analyzed, and results effectively communicated. These NIST efforts are intended to bring the best possible forensic science methods and practices to the criminal justice system, thereby eliminating potential bias in measurements, analysis, and interpretation of evidence.

Home to experts across the sciences, in metrology and standards development, NIST is able to convene some of the world's most accomplished scientists and practitioners across disciplines. Because NIST is a non-regulatory agency and is independent of any entity whose mission involves criminal investigation, law enforcement, or litigation, it is well-positioned to engage stakeholders on questions of scientific rigor and consistency in forensic science practice throughout the United States. NIST can

In 2009, the National Research Council (NRC) of the National Academy of Sciences (NAS) produced a report, *Strengthening Forensic Science in the United States: A Path Forward*. The report was highly critical of the scientific foundations of many forensic science disciplines and thus galvanized science-based criminal justice reform. Ten years after the report was issued, the Innocence Project celebrated its contribution:

Science and law have existed in two different worlds with contradictory principles and paradigms. Before the NAS report, forensics was held accountable only to the principles established by the law rather than science. The NAS report called on the scientific community to help the criminal justice system establish the resources and processes needed for forensics to move toward the promise of neutral truth teller. The progress that it set in motion cannot be understated—it is not an exaggeration to say that the report has freed innocent people and saved lives.

— Peter Neufeld, co-founder of the Innocence Project, 2019[6]

NIST administration building in Gaithersburg, Maryland
Credit: NIST

6. Innocence Project, "Ten Years Later: The Lasting Impact of the 2009 NAS Report." February 29, 2019; available at https://innocenceproject.org/lasting-impact-of-2009-nas-report/. *Reprinted with permission.*

serve as a neutral third party to facilitate open exchange of information across diverse stakeholder groups including other government agencies, industry, and academia. NIST seeks only to improve the data, clarify the outcomes, and quantify the certainty of those outcomes.

Recognizing NIST's impartiality, Congress has directed NIST to play a role in strengthening the science behind forensic science standards and practices.

> *[P]ublic trust in the justice system relies on the validity and certainty of evidence presented to the courts. … NIST was founded with a specific mission—to define and advance a uniform, scientific, national system of measurement to support industry and other Federal agencies. This system of measurement is underpinned by NIST's measurement science research. This scientific basis for accurate measurements using the most rigorous, soundly defensible, and universally accepted science gives accurate, reproducible, and reliable measurements. In this context, Forensic Science has always been part of NIST, since much of Forensic Science is about forensic measurements.*
>
> – Patrick D. Gallagher, Ph.D., former NIST Director, 2012[7]

The NIST Forensic Science Program in 2024

The Program works closely with forensic practitioners across the nation's more than 400 crime laboratories and thousands of other forensic science stakeholders, including law enforcement officers, attorneys, and judges across the United States and internationally. The Program is divided into three sub-units responsible for managing the following major program areas:

- The **Research Program** employs research, development, testing and evaluation (RDT&E) to address critical science and technology gaps in analytical methods, standards, and practices. The aim is to promote stronger scientific foundations, improve accuracy and reliability, and develop new capabilities to advance forensic science and criminal justice.
- The **Standards Program** facilitates the development and adoption of high-quality, technically sound forensic science standards and guidelines via a transparent, consensus-based process that allows all stakeholders to participate.
- The **Foundations Program** conducts independent technical merit evaluations of the scientific information that support and underpin the methods and practices used in forensic science. These evaluations consist of comprehensive and in-depth reviews of published scientific literature and other relevant sources of data to address questions of reliability, capabilities, and limitations of forensic methods and identify knowledge gaps and areas for future research.

The Program also manages several cross-cutting priority topic areas for forensic applications, including quality assurance, data management, and reference materials (see *Spotlights* on pages 34-37).

7. Gallagher, P, Testimony to U.S. Senate Committee on Commerce, Science, and Transportation, March 28, 2012; available at https://www.govinfo.gov/content/pkg/CHRG-112shrg77701/html/CHRG-112shrg77701.htm.

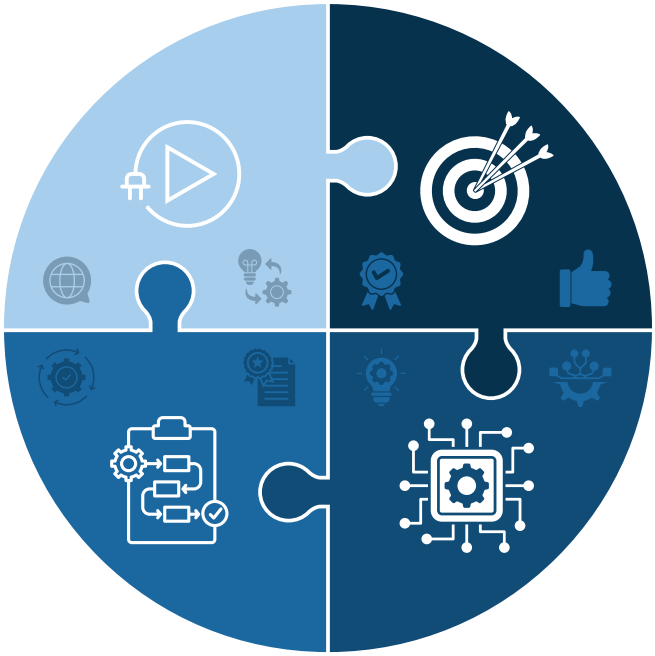
The Imperative

The credibility of forensic evidence used in casework depends on the extent to which there is rigorous quality assurance, including conformance to standards, validation testing, and performance monitoring. The Innocence Project, a non-profit organization dedicated to exonerating wrongfully convicted individuals, claims misapplied forensic science has contributed to nearly a quarter of all wrongful conviction cases since 1989.[8]

> *In approximately half of wrongful convictions analyzed, improved technology, testimony standards, or practice standards may have prevented a wrongful conviction at the time of trial.*
>
> – John Morgan, Ph.D., Research Consultant, National Institute of Justice, 2023[9]

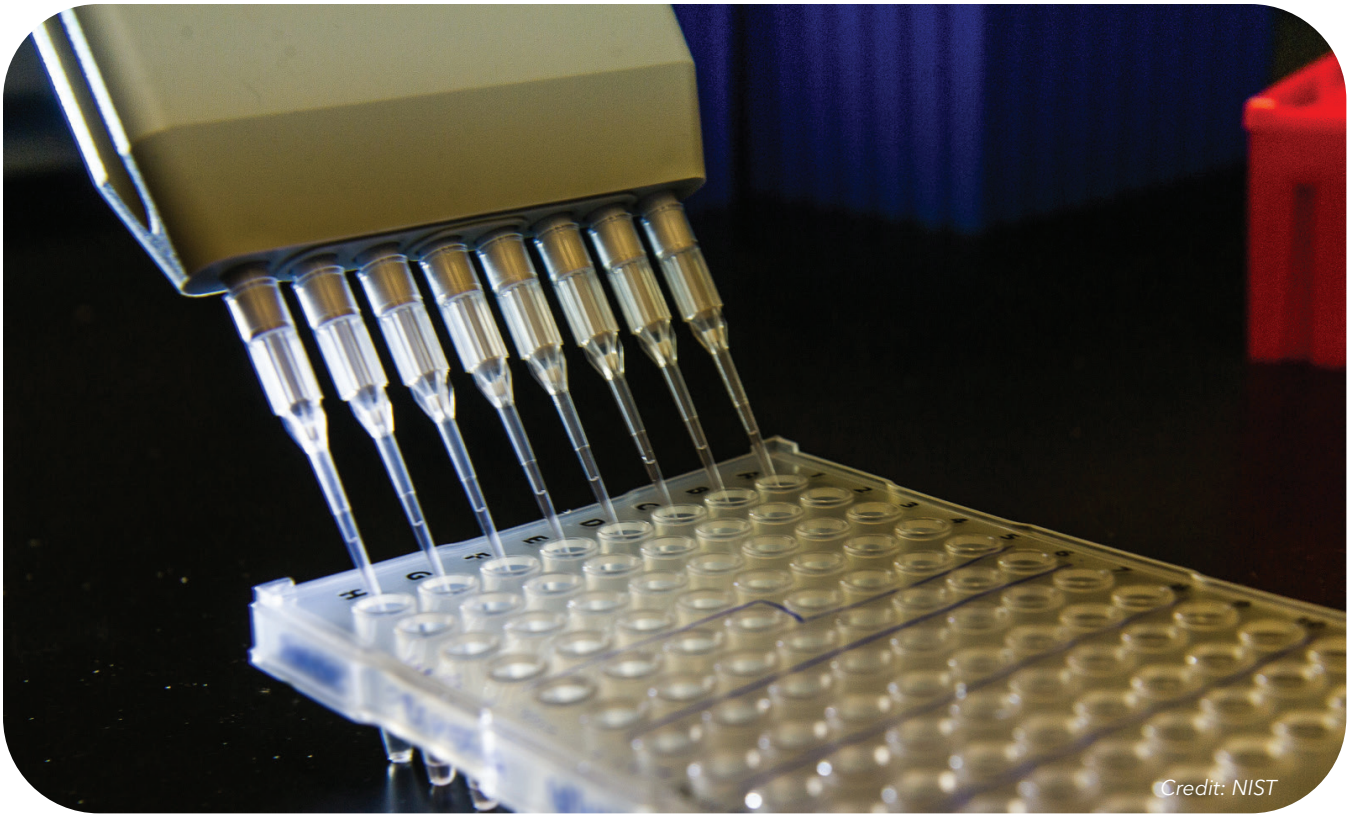
To ensure that forensic science effectively fulfills its role in the criminal justice system, forensic practitioners, service providers, legal experts, standards development organizations, and government agencies must work collaboratively to:

- **Quantify and establish accuracy and reliability** of complex methods and techniques for analysis of forensic evidence
- **Develop new methods and techniques** to provide rapid analyses and new analytical insights from complex forensic evidence
- **Develop science-based standards and guidelines for forensic science practices** across disciplines to support consistent and comparable results among laboratories and jurisdictions
- **Promote the adoption and use** of advances in forensic science standards, guidelines, methods, and techniques



Collectively, these actions will serve to fortify the science that underlies forensic science practices in the United States and provide an interconnected framework for continuous improvement.

8. Innocence Project, "Misapplication of Forensic Science"; available at https://innocenceproject.org/misapplication-of-forensic-science/.
9. Morgan, J. (2023) Wrongful Convictions and Claims of False or Misleading Forensic Evidence, *Jounral of Forensic Sciences*, 68:908-961; available at https://doi.org/10.1111/1556-4029.15233.



Strategic Opportunities to Advance Forensic Science

This report provides a strategy to strengthen our nation's use of forensic science, elevating our justice system in practice and in public perception. The document introduces the factors that are key to rigorous and defensible forensic science: results that are demonstrably valid, reliable, and consistent across providers. The current state of these factors is presented, along with opportunities for improvement. Potential areas of research and standards that can guide effective application of the research findings are identified.

The report is based on an extensive literature review, input from external stakeholders, and feedback from NIST subject matter experts. Throughout 2023, NIST conducted an assessment of the forensic science environment to inform strategic planning efforts by the NIST Forensic Science Program. The resulting *Forensic Science Environmental Scan 2023* report captured salient issues and trends across five different landscapes: governance, economic, societal, scientific and technological, and legal and regulatory.[10] In addition, NIST held a workshop with forensic science thought leaders from across forensic disciplines to discuss the long-term vision and strategic priorities for forensic science in the United States.[11]

10. Swofford, H (2024) *Forensic Science Environmental Scan 2023,* (National Institute of Standards and Technology, Gaithersburg, MD), NIST Interagency Report (IR) NIST IR 8515; available at https://doi.org/10.6028/NIST.IR.8515.
11. Swofford, H (2024) *Long-Term Vision and Strategic Priorities for Forensic Science in the United States: Summary Report of a Roundtable Discussion with Thought Leaders*, (National Institute of Standards and Technology, Gaithersburg, MD), NIST Special Publication (SP) NIST SP 2100-06; available at https://doi.org/10.6028/NIST.SP.2100-06.

ACCURACY AND RELIABILITY OF COMPLEX METHODS AND TECHNIQUES FOR ANALYSIS OF FORENSIC EVIDENCE

> *[C]ourts, both state and federal, remain reluctant to exclude even those kinds of forensic science whose accuracy has been severely questioned over the past few decades. Why is this? ... Whatever the reason, it is evident that the doubts about forensic science so compellingly raised by sources from the Innocence Project to the NAS report have yet to deeply penetrate the judiciary.*
>
> — Jed Rakoff, United States District Court, Southern District of New York, and Goodwin Liu, California Supreme Court, 2023[12]

Credit: AdobeStock

The validity and reliability of complex methods and techniques for forensic evidence analysis, such as those involving advanced computational systems, elaborate analytical schemes, or heavy reliance on subjective judgments of individual analysts, are foundational for their use in the criminal justice system. While decisions concerning whether evidence from forensic science methods and techniques is legally admissible rest with the courts, they may not have a nuanced understanding of the science involved. Consequently, concern has been raised that some forensic evidence may have been introduced in criminal trials without meaningful scientific validation or reliability testing.[13]

There is a need to quantify the accuracy and reliability of complex methods and techniques for forensic evidence analysis, including statistically robust measures of uncertainty and method limitations, to clearly establish and demonstrate the validity of those methods when applied to evidence of varying quality. This would entail empirically testing and evaluating the accuracy, repeatability, and reproducibility of complex methods and techniques for forensic evidence analysis through black-box studies, white-box studies, and interlaboratory studies. To be effective, such studies must be rigorous and representative of the challenges of forensic casework and the data used should be publicly accessible for review, scrutiny, and replication studies.

Blind testing should also be included, as it avoids bias that can be introduced when providers know they are being tested, helps ensure test conditions resemble those seen in everyday casework, and allows service providers to monitor the reliability of the entire process—from evidence submission to reporting results.

The results of such testing can then serve as a foundation for additional research to improve upon those methods and develop standards and reference datasets and materials that allow for consistent application of methods with the goal of producing more reliable and comparable results.

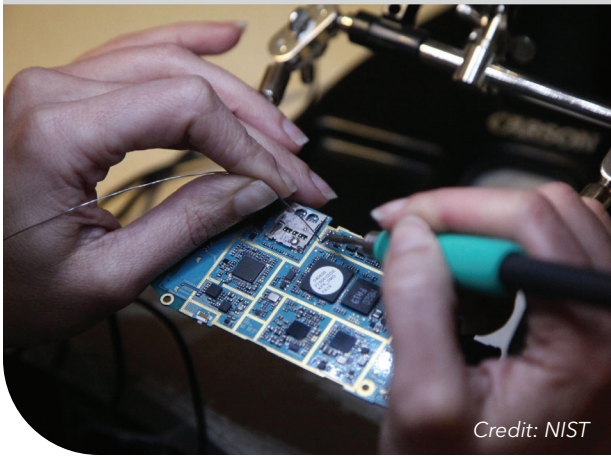
Validity refers to accuracy and whether a method or technique measures what it is intended to measure.

Reliability refers to measures that reflect the extent to which a method provides results that are both repeatable and reproducible over time.

The extent to which a result is trustworthy and can be relied upon depends on whether the measures of validity and reliability of the method or technique are acceptable for its intended application.

Scientific validity and reliability require that a method has been subjected to empirical testing, under conditions appropriate to its intended use, that provides valid estimates of how often the method reaches an incorrect conclusion. … Nothing—not training, personal experience nor professional practices—can substitute for adequate empirical demonstration of accuracy.

– President's Council of Advisors on Science and Technology, 2016[14]



Credit: NIST

12. Rakoff, J, Liu, G (2023) Forensic Science: A Judicial Perspective, *Proceedings of the National Academy of Sciences of the United States of America* 120(41):e2301838120, page 3; available at https://doi.org/10.1073/pnas.2301838120.
13. National Research Council Committee on Identifying the Needs of the Forensic Sciences Community (2009) *Strengthening Forensic Science in the United States: A Path Forward* (The National Academies Press, Washington, D.C. USA), pages 107-108; available at https://doi.org/10.17226/12589.
14. President's Council of Advisors on Science and Technology (2016) *Report to the President, Forensic Science in Criminal Courts: Ensuring Scientific Validity of Featurecomparison Methods* (U.S. Executive Office of the President, Washington, D.C., USA), page 46; available at https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/PCAST/pcast_forensic_science_report_final.pdf.

Black-box studies refer to tests designed to evaluate the output of a method or technique (i.e., analyst's decision) without regard to how those outputs are produced.

White-box studies refer to tests designed to evaluate the basis for the output (i.e., analyst's decision) of a method or technique.

Interlaboratory studies refer to tests designed to evaluate measures of performance when either the same method or technique is applied by two or more laboratories to the same or similar items or when the same sample is analyzed by multiple laboratories using different methods or techniques.

Blind testing involves inserting samples into the regular flow of casework so that practitioners do not know they are being tested.

NIST researchers weigh packages of marijuana prior to preparing samples with very precisely measured amounts of tetrahydrocannabinol (THC), cannabidiol (CBD), and other compounds. Those samples were then sent to labs as part of an interlaboratory study to help labs improve their measurement accuracy.

Credit: NIST

Grand Challenge

Quantify and establish statistically rigorous measures of accuracy and reliability of complex methods and techniques for forensic evidence analysis that clearly demonstrate their validity when applied to evidence of varying quality.

STRATEGY

Research to quantify and establish the validity of complex methods and techniques for forensic evidence analysis using publicly accessible, curated reference datasets

- Create curated reference datasets and research-grade test materials of different types of forensic evidence, such as DNA mixtures, drug mixtures, pattern impressions, and biometric data, of varying quality and with appropriate privacy protections for use during RDT&E activities, including method development, validation testing, and performance monitoring of complex methods and techniques for forensic evidence analysis.
- Conduct studies, including black-box, white-box, and interlaboratory studies and blind testing to define, refine, and measure the accuracy, repeatability, and reproducibility (including robust measures of uncertainty and method limitations) of complex methods for forensic evidence analysis for which there is limited empirical data under various conditions and contexts relevant to forensic science casework, such as analyses of DNA mixtures, examinations of pattern impressions, and detection and identification of drug analogs, metabolites, and trace materials.
- Develop statistical techniques and probabilistic models to quantify evidence quality, variability of features within a population, and certainty of results for complex methods for forensic evidence analysis that rely heavily on subjective judgments of individual analysts (e.g., visual and microscopic analyses), such as in trace materials and pattern impression disciplines.
- Test and evaluate the accuracy, reliability, and fairness of computational systems, including algorithms enabled by AI or ML, to understand data needs and determine conditions for appropriate and trustworthy use, including consideration of sociotechnical impacts.

Research to quantify, interpret, and communicate the statistical reliability of complex methods and techniques for forensic evidence analysis

- Conduct studies to identify and characterize factors that can influence analytical measurements or interpretations and quantify their impact on the reliability of complex methods for forensic evidence analysis when applied to forensic science casework. Examples include but are not limited to evidence quality, sample complexity, computational parameters, and human factors.
- Develop tools to interpret and provide statistically rigorous measures of the reliability of complex methods and techniques for forensic evidence analysis that account for various factors that can influence analytical measurements or interpretations and can be tailored to the specific factors and conditions represented when applied to a particular case.
- Establish research-based means (tools and pathways) of effectively and accurately communicating forensic science information, including quantified measures of reliability of complex methods and techniques for forensic evidence analysis, to the judicial system and the public to enhance their understanding of forensic evidence.

OUTCOME

A robust and defensible forensic science enterprise for which results of complex methods and techniques for forensic evidence analysis include quantified and reported measures of accuracy and reliability that can be trusted by the criminal justice system and the public.

Progress toward addressing this challenge can be measured by the extent to which:

- publicly accessible curated reference datasets and research-grade test materials are used in RDT&E activities and validation studies of complex methods and techniques for forensic evidence analysis;
- results of appropriately designed performance testing and validation studies provide statistically rigorous measures of accuracy, repeatability, and reproducibility of complex methods and techniques for forensic evidence analysis when applied to evidence across the range of conditions encountered in casework; and
- reports describing the results of complex methods and techniques for forensic evidence analysis are accompanied by information about validation testing, method limitations, and factors affecting the interpretation of the results and their uncertainty.

Using advanced technology and equipment available to the NIST Forensic Science Program, NIST researchers have created high-resolution 3D digital replicas of several bullets and bullet fragments from the National Archives that were recovered after the assassination of President John F. Kennedy. In this image, a NIST researcher prepares the "stretcher bullet" for scanning.

Credit: NIST

NEW METHODS AND TECHNIQUES FOR ANALYSIS OF FORENSIC EVIDENCE

> *In 2019…the [National Institute of Justice] published a needs assessment of forensic laboratories… The NIJ needs assessment also recognized new science and technology challenges facing forensic laboratories due to emerging demands for new types of evidence examinations (e.g., opioids and emerging drug threats, digital and multimedia evidence, sexual assault investigations), the need to understand and mitigate the impacts of human factors on evidence interpretation, and the need to increase efficiencies by scaling existing methods (e.g., backlog reduction) and developing tools and methods for field-based applications.*
>
> **– NIST, *Forensic Science Environmental Scan 2023***[15]

Credit: AdobeStock

As forensic science continues to evolve and technical gaps are identified, the forensic science community must keep pace with emerging challenges and increasing demand for examinations of new types of evidence for which analytical methods and techniques do not currently exist. Forensic service providers are faced with trying to handle these new demands while managing their casework and finite resources. There is a need for methods that can rapidly analyze forensic evidence in both laboratory and field operations and methods that can produce new analytical insights when applied to complex forensic evidence, such as low-quality pattern impressions, complex biological materials, new types of digital and multi-media evidence, and novel psychoactive substances.

New methods and techniques that leverage mobile technologies, interconnectivity, and real-time data analyses have the potential to overcome technical and capacity limitations by providing results more efficiently, and potentially with more sensitivity and specificity. Computational tools and algorithm-based systems such as AI and ML underpin many of these capabilities.

While AI systems offer transformative potential, they also present new challenges. Significant amounts of data are needed to train AI systems. The complexity of AI systems makes it difficult to identify and correct failures when they do occur. And AI-enabled technologies may be compromised if biases are incorporated into their algorithms and training datasets.

AI systems must be designed and developed in ways that are characterized by fairness, accountability, transparency, and explainability and they must be studied to help us better understand how they work, when failures occur, and how human factors impact results so that they can be used responsibly and trusted to be valid and reliable.

AI is playing a crucial role in improving the efficiency of evidence analysis and crime scene investigation. ... By embracing AI technologies and leveraging their potential in a responsible, ethical, and well-thought-out manner, police departments have the opportunity to continue to advance their mission of ensuring public safety, combating crime, and protecting the public.

– Wade Carpenter, President, International Association of Chiefs of Police, 2024[16]

AI systems are inherently socio-technical in nature, meaning they are influenced by societal dynamics and human behavior. AI risks—and benefits—can emerge from the interplay of technical aspects combined with societal factors related to how a system is used, its interactions with other AI systems, who operates it, and the social context in which it is deployed.

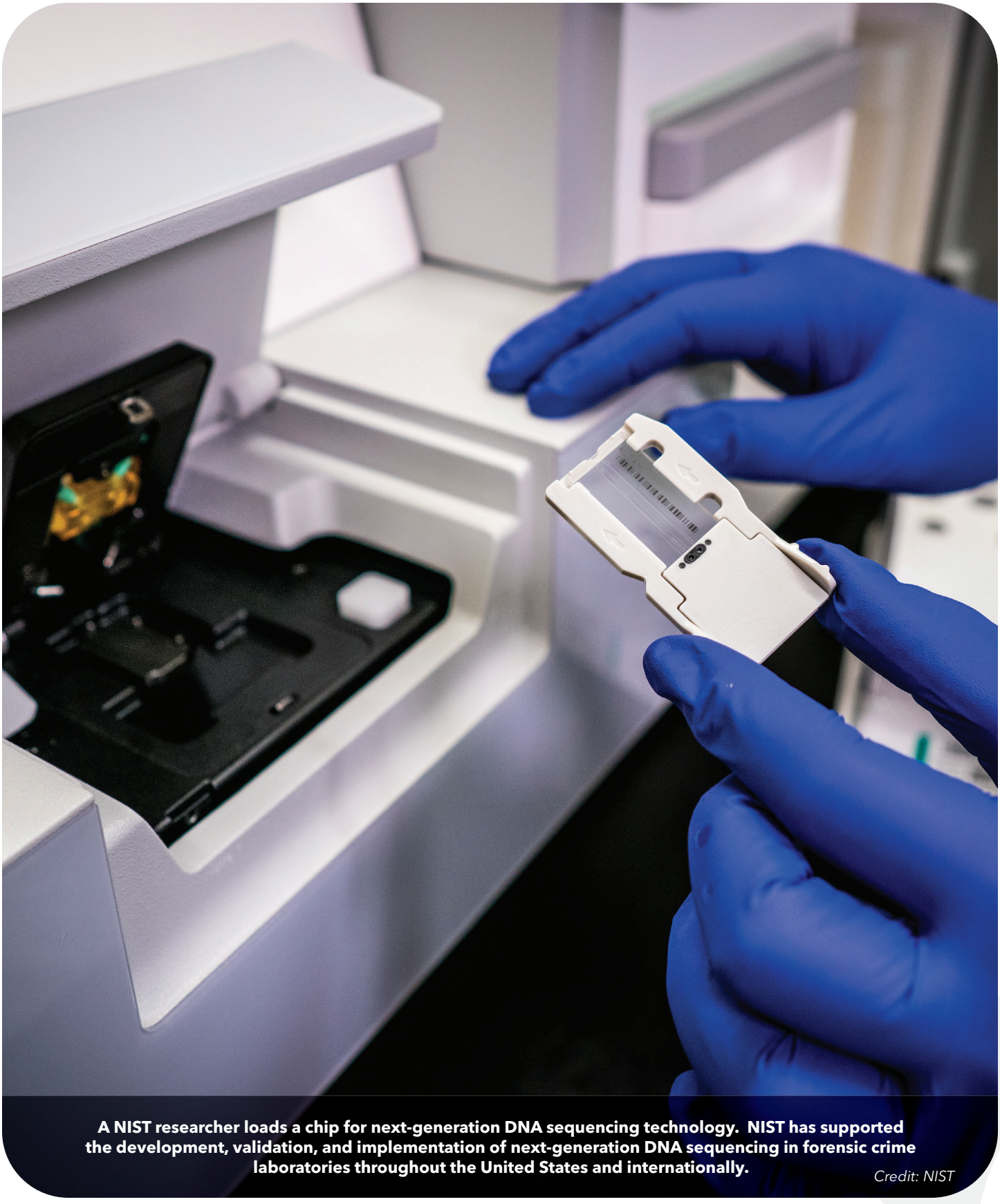
– NIST Artificial Intelligence Risk Management Framework, 2023[17]

Forensic science R&D must keep pace with these rapidly developing (and evolving) technologies and develop new methods and techniques that are tailored to address the unique challenges faced by forensic service providers.

15. Swofford, H (2024) *Forensic Science Environmental Scan 2023* (National Institute of Standards and Technology, Gaithersburg, MD), NIST Interagency Report (IR) NIST IR 8515, page 45; available at https://doi.org/10.6028/NIST.IR.8515.

16. Carpenter, W. (2024) "AI's Transformative Impact," President's Message, Police Chief 91, no. 4: 6–7; available at https://www.policechiefmagazine.org/presidents-message-ais-transformative-impact/.

17. National Institute of Standards and Technology (2023) *Artificial Intelligence Risk Management Framework (AI RMF 1.0)*. (U.S. Department of Commerce, Gaithersburg, MD), page 1; available at https://doi.org/10.6028/NIST.AI.100-1.



A NIST researcher loads a chip for next-generation DNA sequencing technology. NIST has supported the development, validation, and implementation of next-generation DNA sequencing in forensic crime laboratories throughout the United States and internationally.

Credit: NIST

Grand Challenge

Develop new methods and techniques for forensic evidence analysis, including those that leverage the benefits of algorithms and next-generation technologies, such as AI, to provide rapid analyses of forensic evidence and produce new analytical insights from complex forensic evidence.

STRATEGY

Research to develop new methods to rapidly analyze forensic evidence with quantified accuracy and reliability for deployment in forensic laboratories and field operations

- Develop new technologies for scene investigation and analysis, such as contactless tools for rapidly identifying and recording evidence at scenes and virtual and augmented reality for scene investigation, presentation, and training.
- Develop new techniques for rapid extraction, interpretation, and evaluation of information derived from digital devices to produce real-time data analyses and investigative insights.
- Develop new systems for automated and real-time detection, collection, and analyses of pattern impressions (e.g., fingerprints, footwear, handwriting, and bloodstains) and multi-biometric identification systems, including compatibility and interconnectivity between tools such as digital enhancement software, comparison algorithms, and quality assessment programs for real-time identification capabilities.
- Develop new tools for advanced chemical profiling and analysis of trace materials such as glass, soils, paints, tapes, fibers, lubricants, ignitable liquids, and explosives.
- Develop new methods for rapid analyses of drugs, including cannabinoids such as tetrahydrocannabinol, and drug analogs from a variety of plant-based materials, edibles, extracts, and toxicology samples.

Research to develop new methods to analyze complex forensic evidence with quantified accuracy and reliability for deployment in forensic laboratories and field operations

- Develop new methods for collecting and analyzing complex pattern impressions, such as low-quality, partial, distorted, or overlapping fingerprints, footwear, handwriting, or bloodstains recovered from complex surfaces.
- Develop new methods for analyzing and identifying novel psychoactive substances, such as emerging drug analogs and metabolites in complex matrices.
- Develop new methods for analyzing novel biological and chemical substances such as proteins and metabolites, which can provide new information about people, their environment, or recent activities.
- Develop new methods for analyzing complex DNA mixtures (e.g., high numbers of contributors, allele sharing, and degraded samples), including techniques for physical cell separation and optimized DNA sequencing, and new avenues for forensic investigative genetic genealogy.
- Develop new methods for detecting and analyzing digital information from virtual machines and virtual file systems and detecting digitally altered or artificially generated "deepfake" images, audio, video, and other multimedia content.

OUTCOME

A new era of forensic science with the potential to revolutionize current practices and strengthen criminal justice and public safety by more quickly providing more information about the evidence left during the commission of a crime or unlawful act and identification of an alleged perpetrator.

Progress toward addressing this challenge can be measured by the extent to which:

- new or improved methods and advanced techniques are developed, and results of testing and evaluation have shown significant improvements in accuracy and reliability of results, objectivity and consistency, statistical rigor, efficiency, or applicability to diverse materials, environments, or conditions;
- computational tools and algorithm-based systems are developed in ways that enable more transparency and greater explainability and understandability of innerworkings and outputs; and
- AI-enabled technologies are shown to be trustworthy for applications supporting forensic evidence analysis in both forensic laboratories and field environments.

Credit: AdobeStock

SCIENCE-BASED STANDARDS AND GUIDELINES FOR FORENSIC SCIENCE PRACTICES

HFSC's history as a police-run crime lab with a multitude of problems makes us all the more aware of how crucial it is to ensure standards, policies and protocols used by our analysts and examiners are based on strong, sound, objective science.

– Peter Stout, Ph.D., CEO and President, Houston Forensic Science Center, 2019[18]

Credit: AdobeStock

Standards provide technical specifications, performance criteria, or other requirements to guide the development, validation, and application of forensic science methods and techniques. Standards cover a broad spectrum and include written protocols and guidelines (e.g., documentary standards), and certified reference materials and data such as SRMs[19] and SRD[20] that help ensure results are comparable between different instrumentation and equipment, methods, facilities, and individuals.

Standardized and consistent forensic science practices are priorities shared across the forensic science community to help support fair and just judicial decision-making. However, over the last fifteen years since the NAS report was published in 2009, studies have shown that procedures and practices relating to methods and techniques for forensic evidence analysis vary both within and across disciplines. This has contributed to differences in results even when the same types of instruments or software programs are used—leading to concerns about the quality of information produced in casework.

As methods for forensic evidence analysis become more advanced and new methods and techniques are developed, the need for high-quality, science-based standards and guidelines is ever-more critical for providing traceability to established benchmarks (e.g., minimum specifications or known characteristics of quality) and assurance that the forensic science practices conform to established standards and guidelines.

> *Standards provide the foundation against which performance, reliability, and validity can be assessed. Adherence to standards reduces bias, improves consistency, and enhances the validity and reliability of results. Standards reduce variability resulting from the idiosyncratic tendencies of the individual examiner—for example, setting conditions under which one can declare a "match" in forensic identifications. They make it possible to replicate and empirically test procedures and help disentangle method errors from practitioner errors. Importantly, standards not only guide practice but also can serve as guideposts in accreditation and certification programs. Many forensic science disciplines have developed standards, but others have not, which contributes to questions about the validity of conclusions.*
>
> — NRC Committee on Identifying the Needs of the Forensic Science Community, 2009[21]

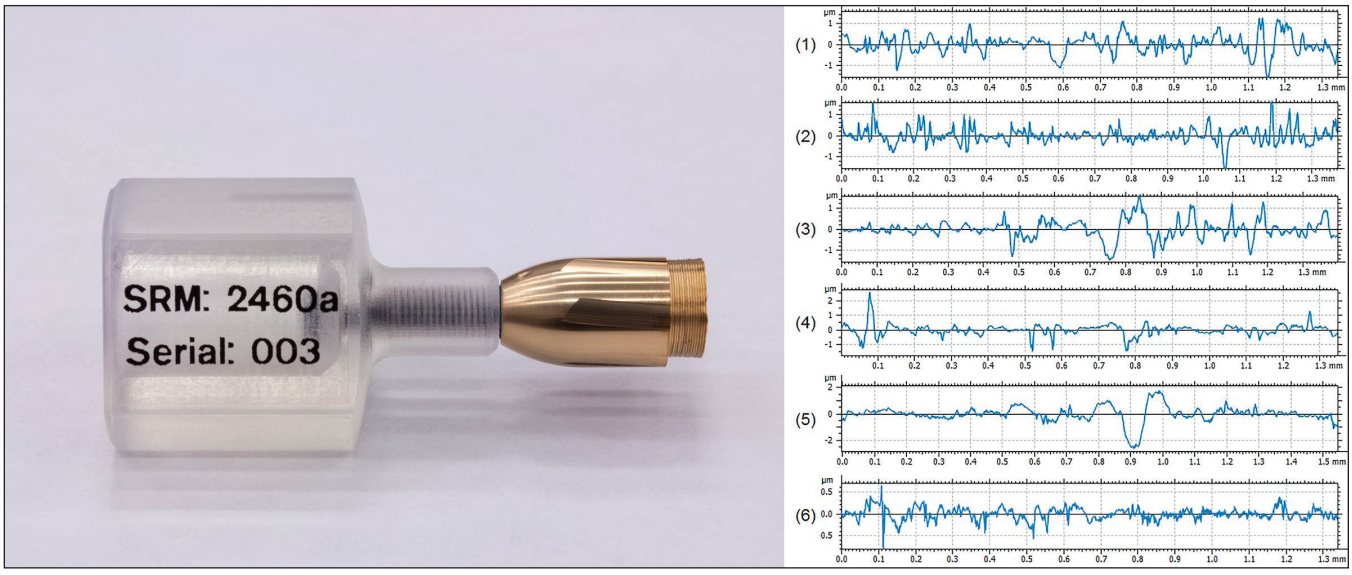
To be effective, guidance must be scientifically grounded, written with sufficient detail, clarity, and specificity to ensure the applications of pertinent methods and techniques are consistent and the results produced are accurate, precise, and reproducible. Further, the guidance must be timely and available to all criminal justice stakeholders, and there should be systematic means for assessing conformance to standards and guidelines. With appropriate standards and guidance to support the development, testing, and evaluation of forensic methods and techniques, including assessments of validity and reliability, forensic service providers can strengthen the quality and credibility of forensic practices and attorneys and judges can litigate forensic science evidence more effectively and make informed decisions related to admissibility.

18. Houston Forensic Science Center (2019, December 14) *HFSC Adopts Standards Approved by National Forensic Organization* [Press release]; available at https://hfsctx.gov/news-release/hfsc-adopts-standards-approved-by-national-forensic-organization/.
19. National Institute of Standards and Technology (n.d.) "Standard Reference Materials"; available at https://www.nist.gov/srm/about-nist-srms.
20. National Institute of Standards and Technology (n.d.) "Standard Reference Data"; available at https://www.nist.gov/srd/srd-definition.
21. National Research Council Committee on Identifying the Needs of the Forensic Sciences Community (2009) *Strengthening Forensic Science in the United States: A Path Forward* (The National Academies Press, Washington, D.C. USA), page 201; available at https://doi.org/10.17226/12589.

Documentary Standards can specify definition of terms; classifications of components; delineation of procedures; specification of dimensions, materials, processes, products and their performance, systems and their performance, services or practices; test methods and sampling procedures; or descriptions of fit and measurements of size or strength.

Standard Reference Materials (SRMs)® are certified reference materials that are well-characterized using state-of-the-art measurement methods and/or technologies for the determination of chemical composition and/or physical properties.

Standard Reference Data (SRD)® include (a) quantitative information related to a measurable physical, chemical, or biological property of a substance or system of substances of known composition and structure, (b) measurable characteristics of a physical artifact or artifacts, (c) engineering properties or performance characteristics of a system, or (d) one or more digital data objects that serve (i) to calibrate or characterize the performance of a detection of measurement system or (ii) to interpolate or extrapolate such data.



The NIST standard bullet (SRM 2460) resembles a 9mm caliber bullet that has been fired from a pistol, with striated markings on the bullet's surface. This bullet comes with data that describe those striations on a microscopic scale. A firearms examiner can test whether their 3D surface scanning microscope is properly calibrated by measuring the striations on the NIST standard bullet and then comparing those measurements with data provided by NIST.

Credit: NIST

Grand Challenge

Develop rigorous science-based standards, conformity assessment schemes, and guidelines across forensic science disciplines to support consistent and comparable results from forensic analyses among laboratories and jurisdictions.

STRATEGY

Science-based standards, conformity assessment schemes, and guidelines for validation and application of complex methods and techniques for forensic evidence analysis

- Develop documentary standards and guidelines for evidence analysis, interpretation, and communicating results in both written reports and testimony to criminal justice decision-makers such as investigators, attorneys, and courts.
- Create certified reference materials such as SRMs and SRD of different types of forensic evidence for use during method development, validation testing, and instrumentation and equipment calibration.
- Provide guidance for appropriate experimental designs and methods for statistical analyses used in validation testing, including blind testing schemes to monitor the on-going performance of methods and techniques in use.
- Create auditing mechanisms and conformity assessment schemes so that conformance to documentary standards and guidelines can be demonstrated and independently assessed.

Science-based standards and guidelines for developing, testing, and evaluating new methods and techniques, including next-generation technologies such as AI, to analyze forensic evidence in both forensic laboratory and field operations

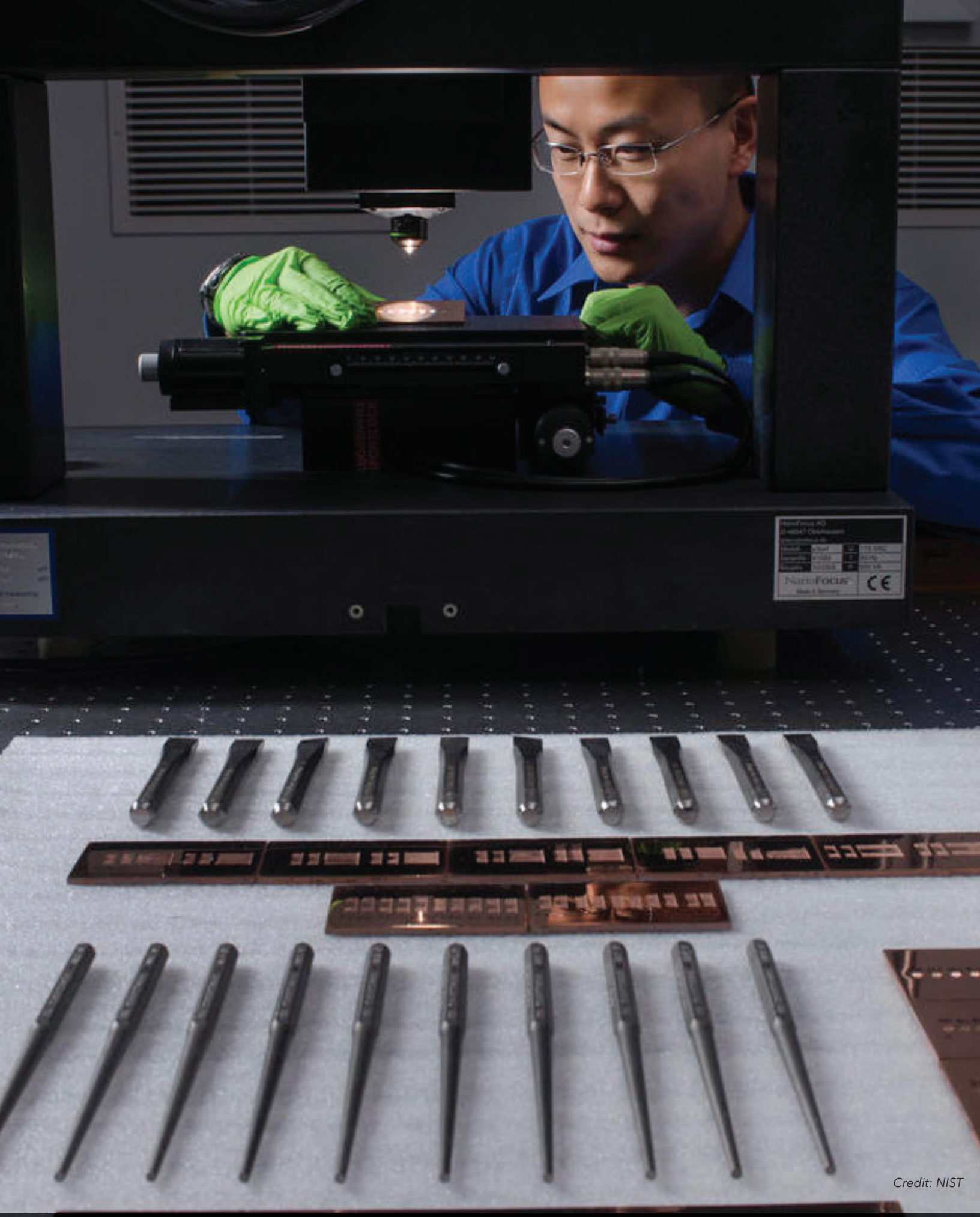
- Develop documentary standards and guidelines for the design and development of new computational tools and technologies that provide specifications for algorithmic transparency and approaches for improving explainability and understandability of the innerworkings and factors influencing the results.
- Develop documentary standards and guidelines for algorithmic data needs and data appropriateness that address common practices of data collection, retention, bias, and representativeness.
- Create frameworks and guidance for independent testing and evaluation of algorithms and next-generation technologies such as those enabled by AI or ML to assess validity, accuracy, reliability, fairness, and risks associated with use in forensic science.
- Establish standardized terms, definitions, taxonomies, and characteristics of AI and ML systems, including specifications for appropriate and trustworthy use in forensic science.

OUTCOME

A forensic science community guided by science-based standards and traceable benchmarks that underlie methods and techniques for forensic evidence analysis to help enable fair and just judicial decision-making.

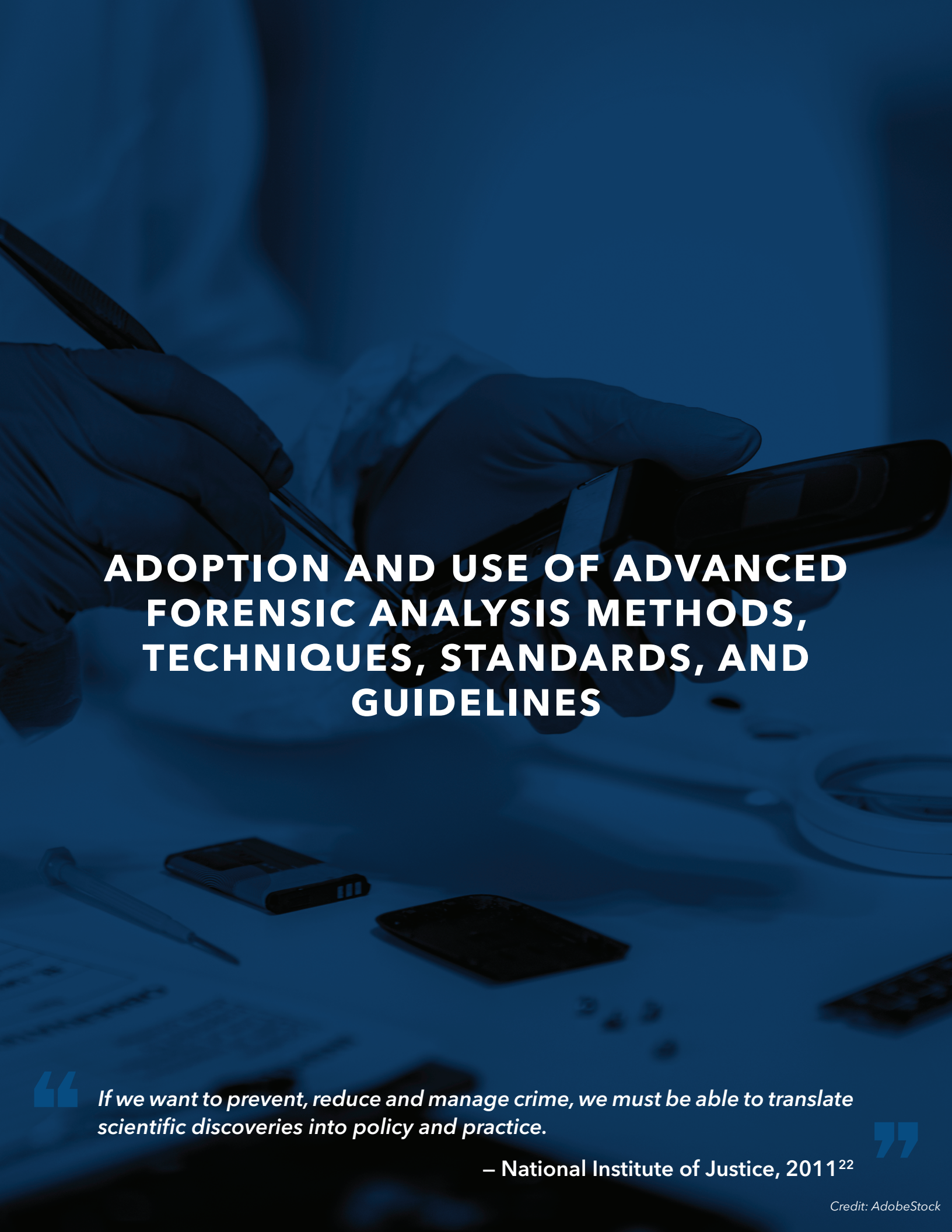
Progress toward addressing this challenge can be measured by the extent to which:

- standards and guidelines account for development, testing, validation, and applications of forensic evidence analysis methods and techniques, including new methods for rapid analyses and applications to complex forensic evidence in laboratory and field operations;
- standards and guidelines are technically sound, clearly written, and scientifically supported to help enable standardized and consistent applications of methods and techniques for analysis of forensic evidence in providers' operations; and
- conformity assessment schemes account for interdisciplinary and discipline-specific standards and guidelines for forensic evidence analysis methods and techniques.



Credit: NIST

A NIST researcher uses a 3D disc scanning confocal microscope to examine toolmarks made by chisels and punches.



ADOPTION AND USE OF ADVANCED FORENSIC ANALYSIS METHODS, TECHNIQUES, STANDARDS, AND GUIDELINES

If we want to prevent, reduce and manage crime, we must be able to translate scientific discoveries into policy and practice.

– National Institute of Justice, 2011[22]

Credit: AdobeStock

If new research or standards are to have any utility or impact, they must be adopted and effectively implemented by forensic service providers and by those within the judicial system (i.e., officers of the court, such as attorneys, judges, and other court officials).

Historically, adoption and use of new methods and techniques has been a relatively slow process. Although the forensic science community has been cautious to move too quickly given the impact to sensitive issues affecting judicial decisions and legal outcomes, progress is often constrained by limitations in resources and training.

Significant resources go into adopting new methods and techniques, particularly those that rely on complex instrumentation and technology. Procurement of new technology, validation studies, development of operating procedures, and staff training can be burdensome for forensic service providers and diverts resources away from casework. Resource limitations also lead to training deficits for both forensic service providers and officers of the court, which can create hesitation to embrace advanced methods, techniques, standards, and guidelines for forensic evidence analysis due to limited awareness or understanding of how to use them effectively in casework and during judicial proceedings.

These issues are further complicated by the often-unequal access to resources across different jurisdictions, resulting in the use of less advanced capabilities in jurisdictions where forensic service providers do not have adequate resources to implement and maintain new technologies or where attorneys and judges have limited knowledge about the science involved and access to training, which affects their ability to litigate complex issues in forensic science. Consequently, the quality of information that judicial decisions are based upon might vary, and people who live in such jurisdictions might be disadvantaged as it relates to their exposure to, and experiences with, the legal system.

One way to reduce the burden and impact of resource limitations on forensic service providers is to establish cross-jurisdictional

Referring to the drug detection testing protocol developed by the NIST Rapid Drug Analysis and Research (RaDAR) program:

For police, there is no other drug detection test available in the field to provide almost instantaneous results with such high accuracy rates. The immediate feedback to the criminal investigators is invaluable.

– Colonel Woodrow W. "Jerry" Jones III, Superintendent of the Maryland State Police, 2021[23]

In addition to being internationally accredited, all six FDLE labs are voluntarily complying with the relevant crime lab standards listed on the OSAC Registry. The OSAC Registry serves as a repository of high-quality, technically sound forensic science standards that have passed rigorous and quality review by OSAC members.

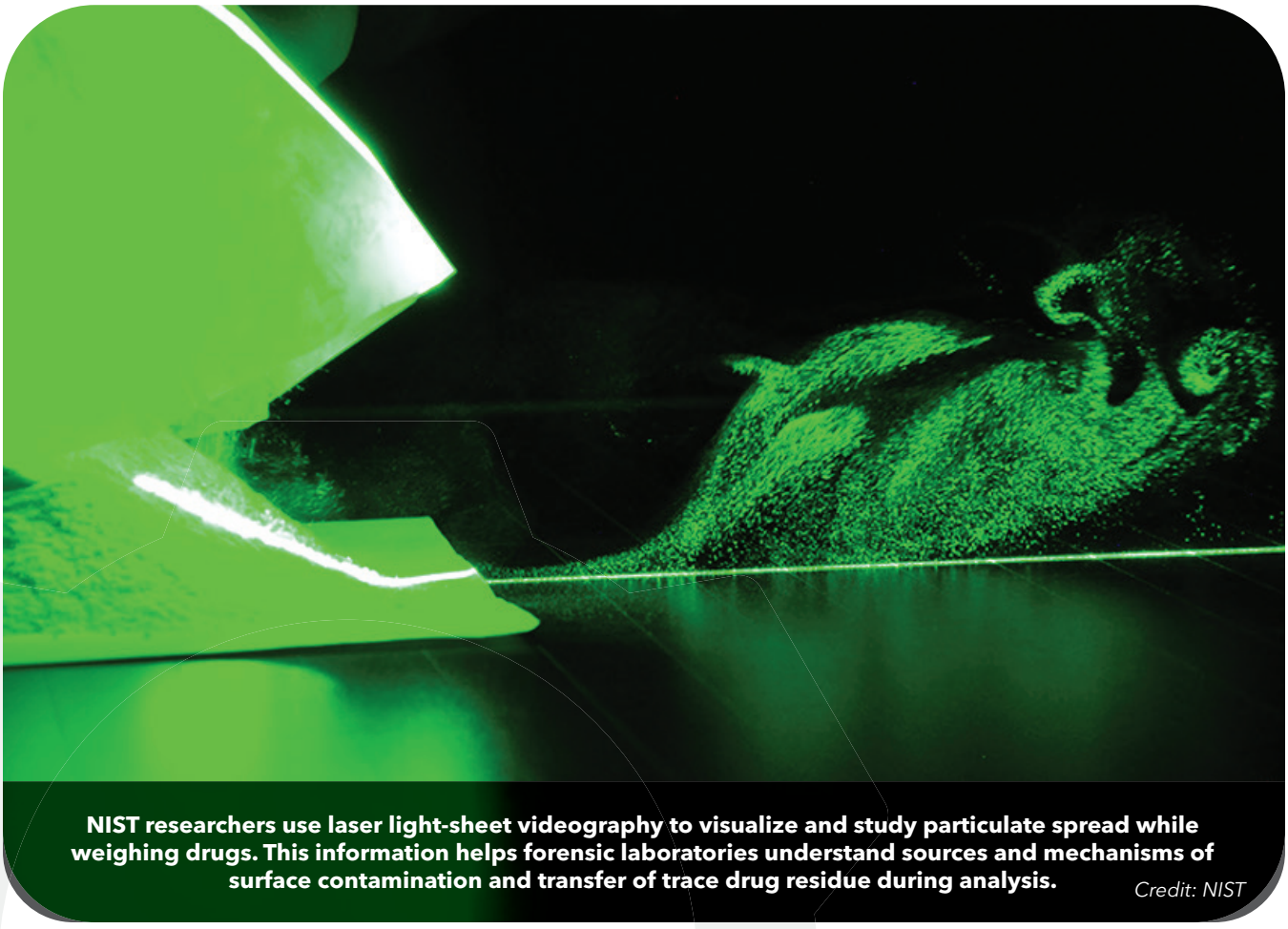
– Jason Bundy, Forensic Services Director, Florida Department of Law Enforcement, 2022[24]

Credit: NIST

22. National Institute of Justice (2011) "What is Translational Criminology?"; available at https://nij.ojp.gov/topics/articles/what-translational-criminology.
23. Addleman, B (2021, September 27) "Maryland Announces Program Aimed at Identifying Illicit Drugs." The Center Square; available at https://www.thecentersquare.com/maryland/maryland-announces-program-aimed-at-identifying-illicit-drugs/article_73a2205e-1fc2-11ec-995d-7b8109256d03.html.
24. Florida Department of Law Enforcement (2022, January 12) *FDLE Recognized for Implementing Gold Standards in Forensic Science* [Press release]; available at https://www.fdle.state.fl.us/news/2022/january/fdle-recognized-for-implementing-gold-standards-in.

and multi-disciplinary collaborations among providers. An important benefit to such collaborations is the sharing of information and materials. Data, validation information, training materials, operating procedures, equipment, and rubrics can be shared by all partners. They can be used to support the implementation of new methods and techniques into operations and accelerate their adoption and use. In addition, collaborations among researchers and practitioners can ensure that research products and standards are responsive to the needs of providers and provide them with practical solutions.

Another way to support adoption and use of advanced methods, techniques, standards, and guidelines for forensic evidence analysis is through improved availability and access to training and continuing education opportunities tailored to forensic service providers and officers of the court. While several entities offer forensics training and continuing education, these efforts can be enhanced by making them easier to apply to the challenges faced in casework and during judicial proceedings (e.g., hands-on experience operating instrumentation and equipment, greater variability in sample quality, and more challenging exercises and case scenarios); expanding curricula to include training on validation as well as effective uses of standards and guidelines; and delivery of training that can be obtained as part of undergraduate and graduate coursework through academic institutions, reducing the need for this instruction after students enter the workforce. Some colleges and universities offer this, but many do not.



NIST researchers use laser light-sheet videography to visualize and study particulate spread while weighing drugs. This information helps forensic laboratories understand sources and mechanisms of surface contamination and transfer of trace drug residue during analysis. *Credit: NIST*

Grand Challenge

Promote the adoption and use of advances in forensic science standards, guidelines, methods, and techniques aimed at improving the validity, reliability, and consistency of forensic science practices.

STRATEGY

Stakeholder engagement to develop and implement partnering mechanisms to support collaborations among forensic service providers and sharing of information, resources, and best practices for accelerating the adoption and use of advanced methods, techniques, standards, and guidelines for forensic evidence analysis

- Convene forensic service providers to share best practices for accelerating the adoption and use of advanced forensic analysis methods, standards, and guidelines.
- Create model partnership agreements such as consortia agreements and memoranda of understandings (MOUs) that forensic service providers can use as templates to enable coordination, collaboration, and sharing of data, technologies, and materials across the forensic science community.
- Establish web-based portals and curated data repositories to support sharing of data and information about advanced forensic analysis methods, standards, and guidelines, such as validation reports, operating procedures, and training materials.

Stakeholder engagement to develop and implement enhanced training and continuing education for forensic service providers and officers of the court to communicate the value of adoption and effective use of advances in forensic evidence analysis methods, techniques, standards, and guidelines within the criminal justice system

- Establish partnerships with professional organizations and academic institutions to identify and define competencies tailored for personnel in different forensic disciplines and stakeholder roles, and establish cross-cutting and discipline-specific content for building those competencies such as through credentialing programs (i.e., academic degrees, certification, or licensing) so that those programs can be more effective and better aligned to the knowledge, skills, and abilities that are needed for those roles.
- Create and curate training and educational curricula tailored to different roles and responsibilities of stakeholder groups within the criminal justice system (e.g., forensic practitioners, attorneys, judges), including but not limited to topics relating to standards, measurement uncertainty, error rates, data interpretation, limitations of methods, weight of evidence, human factors, and communication of scientific results.
- Develop training and educational materials and mechanisms for delivery in various formats, including virtual and in-person learning experiences such as self-study (e.g., short guides, videos, webinars), guided instruction (e.g., presentations, workshops), and practical applications (e.g., "hands-on").

OUTCOME

A forensic science ecosystem that remains up to date with advanced methods, techniques, standards, and guidelines to produce accurate and reliable information used in the criminal justice system.

Progress toward addressing this challenge can be measured by the extent to which:

- data, technologies, and resource materials (e.g., training guides, operating procedures, validation plans) are available and shared across the forensic science community to support implementation by forensic service providers and within the judicial system, and the results of validation studies and curated datasets are publicly available;
- advanced forensic evidence analysis methods and techniques have been adopted and used by forensic service providers, and results of black-box, white-box, and interlaboratory studies, including blind testing, demonstrate accurate, reliable, and consistent applications with results that are comparable across laboratories and jurisdictions; and
- advanced standards and guidelines have been adopted and used by officers of the court to support legal decision-making.

Credit: NIST

PATH FORWARD

Just as medical research is crucial for advancing public health, sustained progress in forensic science—the application of physics, chemistry, biology, computer science, and engineering to matters of law—is critical for advancing public safety and the administration of justice.

– National Institute of Justice, 2021[25]

Credit: AdobeStock

The forensic science community has a significant opportunity to strengthen the validity, reliability, and consistency of existing methods and techniques for the analysis of forensic evidence, develop new methods to analyze complex forensic evidence, advance the development of science-based standards and guidelines, and promote the adoption and use of these advances by forensic service providers and officers of the court.

> *Standards for methods of examination conducted by forensic scientists are essential for the validity and reliability of analyses carried out in crime laboratories and Medical Examiner/ Coroner offices. ... Consistent and steady research is also important as science advances, and the science of forensics must continue to move forward. NIST's programs are extremely important and allow us to achieve those goals.*
>
> – Consortium of Forensic Science Organizations, 2022[26]

In recent years, efforts to strengthen forensic science have been made, and they are having an effect. For instance, through partnerships with NIJ, FBI, and other government agencies, academia, and private-sector industries, NIST has contributed by: serving as a trusted source of scientific information underpinning forensic science procedures and practices through its scientific foundation reviews, human factors analyses, and evidence management guidelines; conducting innovative research to address critical science and technology gaps; developing tools, datasets, and certified reference materials so that crime labs can implement rigorous quality control practices; and convening stakeholders to accelerate the development and adoption of quality forensic science standards and analytical methods (see following *Spotlights*).

Despite the significant progress that has been achieved, a great deal of work remains. This report has described four grand challenges facing the forensic science community and provided a strategy for addressing them through research and development and use of standards. This strategy serves as a roadmap to strengthen the science that underlies forensic science practices in the United States and provides a framework for continuous improvement. By addressing these shared challenges, the forensic science community will strengthen the foundations of our criminal justice system, ensuring fairness and impartiality while also preserving public safety and public trust. Specifically, the outcomes enabled by acting on this strategy include:

- A robust and defensible forensic science enterprise for which results of complex methods and techniques for forensic evidence analysis include quantified and reported measures of accuracy and reliability that can be trusted by the criminal justice system and the public
- A new era of forensic science with the potential to revolutionize current practices and strengthen criminal justice and public safety by more quickly providing more information about the evidence left during the commission of a crime or unlawful act and identification of an alleged perpetrator
- A forensic science community guided by science-based standards and traceable benchmarks that underlie methods and techniques for forensic evidence analysis to help enable fair and just judicial decision-making
- A forensic science ecosystem that remains up to date with advanced methods, techniques, standards, and guidelines to produce accurate and reliable information used in the criminal justice system

25. National Institute of Justice (2021) *The Impact of Forensic Science Research and Development*, NCJ 300422, Washington, DC., page 1; available at https://www.ojp.gov/pdffiles1/nij/300422.pdf.

26. Consortium of Forensic Science Organizations, "Letter to the Honorable Gina M. Raimondo, U.S. Department of Commerce" dated January 28, 2022; available at https://thecfso.org/wp-content/uploads/2022/01/Commerce-Letter-Final-01_2022.pdf. *Reprinted with permission.*

NIST Forensic Science Program *Spotlights*

Biometrics Research

NIST researchers in the Biometrics Research Focus Area have supported the development and validation of reliable biometric forensic science technologies, including interoperability between Automated Biometric Identification Systems (ABIS). The researchers have created and curated biometric research databases that are among the largest and most comprehensive in the world and have been widely adopted for training forensic practitioners, software validations, and novel research. NIST researchers have also conducted detailed testing and evaluation of biometric technologies, characterizing performance and identifying technical limitations, such as algorithmic biases revealed in facial recognition algorithms, that have helped technology developers and vendors improve their design, function, and reliability.

Digital Evidence Research

NIST researchers in the Digital Evidence Research Focus Area have supported the development of reference data and tools for efficient and reliable analyses of digital evidence. NIST researchers developed the National Software Reference Library (NSRL), one of the largest hashset libraries available, which serves as a critical resource for digital evidence investigations, including child sexual exploitation cases. Additionally, NIST researchers have conducted detailed testing and evaluation of digital evidence tools to identify capabilities and technical limitations that should be addressed by vendors and software developers, and to provide independent evaluations of validity and reliability for investigators, attorneys, and courts.

Drugs and Toxicology Research

NIST researchers in the Drugs and Toxicology Research Focus Area have supported the development of implementable solutions to address measurement challenges in handling, analyzing, and interpreting data from drugs of abuse—including traditional drugs (e.g., cocaine and marijuana), fentanyl and synthetic opioids, and emerging threats (e.g., xylazine). Through its Rapid Drug Analysis and Research (RaDAR) program, researchers provide near real-time insights into the illicit drug landscape through quick, comprehensive, and actionable data that is used by forensic science, law enforcement, and public health agencies.

Evidential Statistics Research

NIST researchers in the Evidential Statistics Research Focus Area have supported the development of statistically rigorous approaches for evidence analysis, interpretation, and communication of measurements of error and uncertainty across forensic disciplines. NIST statisticians have helped forensic laboratories implement statistical reporting frameworks for evidence analysis; developed the NIST Footwear Impression Comparison System (FICS), a collection of statistical algorithms for automated footwear comparisons; and created a web-based software tool for statistical inference in multi-unit drug seizures using hypergeometric sampling methods.

NIST Forensic Science Program *Spotlights*

Firearms and Toolmarks Research

NIST researchers in the Firearms and Toolmarks Research Focus Area have supported the development of a sound metrology infrastructure to support forensic laboratories' transition to measurement of three-dimensional (3D) toolmark topography, virtual comparison microscopy, and future algorithmic comparisons. For example, the researchers have invented the Congruent Matching Cell (CMC) method for objective firearm toolmark identification, helped develop the Reference Population Database of Firearm Toolmarks (RPDFT), and developed the NIST Standard Bullet and Cartridge Case (SRMs 2460 and 2461), to provide a benchmark for calibration of 3D surface scanning microscopes.

Forensic Genetics Research

NIST researchers in the Forensic Genetics Research Focus Area have supported the development and maturation of forensic DNA analysis techniques that are viewed as a benchmark for modern forensic science. Researchers have developed reference materials, characterized forensically relevant genetic markers, and assessed emerging technologies for forensic DNA analysis, including rapid DNA technologies and next-generation sequencing. DNA SRMs and population sequencing data provided by NIST serve as a basis for statistics and quality assurance programs for genetic markers used by forensic laboratories around the country.

Quality Assurance Research

NIST researchers in the Quality Assurance Research Focus Area have supported the development of a quality assurance infrastructure across the forensic science community needed for the development, validation, and implementation of forensic evidence analysis methods. NIST researchers design and conduct large-scale, robust interlaboratory studies across forensic disciplines to advance research and to assist standards development bodies in the collection of critical data to assess quality of methods and practices. NIST researchers have conducted interlaboratory studies to determine variability in seized drug screening methods using ambient ionization-mass spectrometry (AI-MS); short tandem repeat (STR) profiling instruments; and facial recognition methods using both algorithms and examiners.

Trace Evidence Research

NIST researchers in the Trace Evidence Research Focus Area have supported the development of measurement characterization tools, methods, and algorithms to improve identification and analysis of small fragments or miniscule quantities of chemical and physical evidence. NIST researchers have developed comprehensive reference collections for rapid matching and identification of tandem mass spectra profiles of genetically variant peptides; developed rapid gas chromatography-mass spectrometry (GC-MS) methods to screen for ignitable liquids in fire debris samples; and worked to characterize the transport and spread of gunshot residue to help forensic laboratories better understand its significance.

NIST Forensic Science Program *Spotlights*

Scientific Foundation Reviews

NIST has begun a series of "scientific foundation reviews" to examine the reliability of forensic science methods and practices. These technical merit evaluations seek to identify the scientific foundations that support and underpin forensic methods, document and evaluate the empirical evidence for the reliability of the methods, explore the capabilities and limitations of the methods, and identify knowledge gaps and areas for future research. To date, NIST has begun and/or completed scientific foundation reviews in five areas: DNA Mixture Interpretation, Digital Investigation Techniques, Bitemark Analysis, Firearm Examination, and Footwear Impressions. Practitioners provide input through workshops, resource groups, interlaboratory studies, or direct involvement with the project team. Practitioners also provide valuable feedback on draft reports during public comment periods and associated public webinars.

Forensic Science Process Maps

NIST researchers have worked closely with federal, state, and local forensic science experts and practitioners to produce process maps that identify key decision points in the forensic evidence examination process. NIST has published eight detailed, discipline-specific process maps for fingerprints, speaker recognition, handwriting, firearms, footwear and tire tread, DNA, seized drugs, and fire investigation. The maps provide a framework for developing standard operating procedures, best practice documents, and quality assurance measures. They help improve efficiencies by reducing errors, highlight gaps in research and standardization, facilitate root cause analyses, assist with training new investigators, and increase transparency. This pioneering effort has gained significant recognition for NIST from forensic science practitioners and the courts.

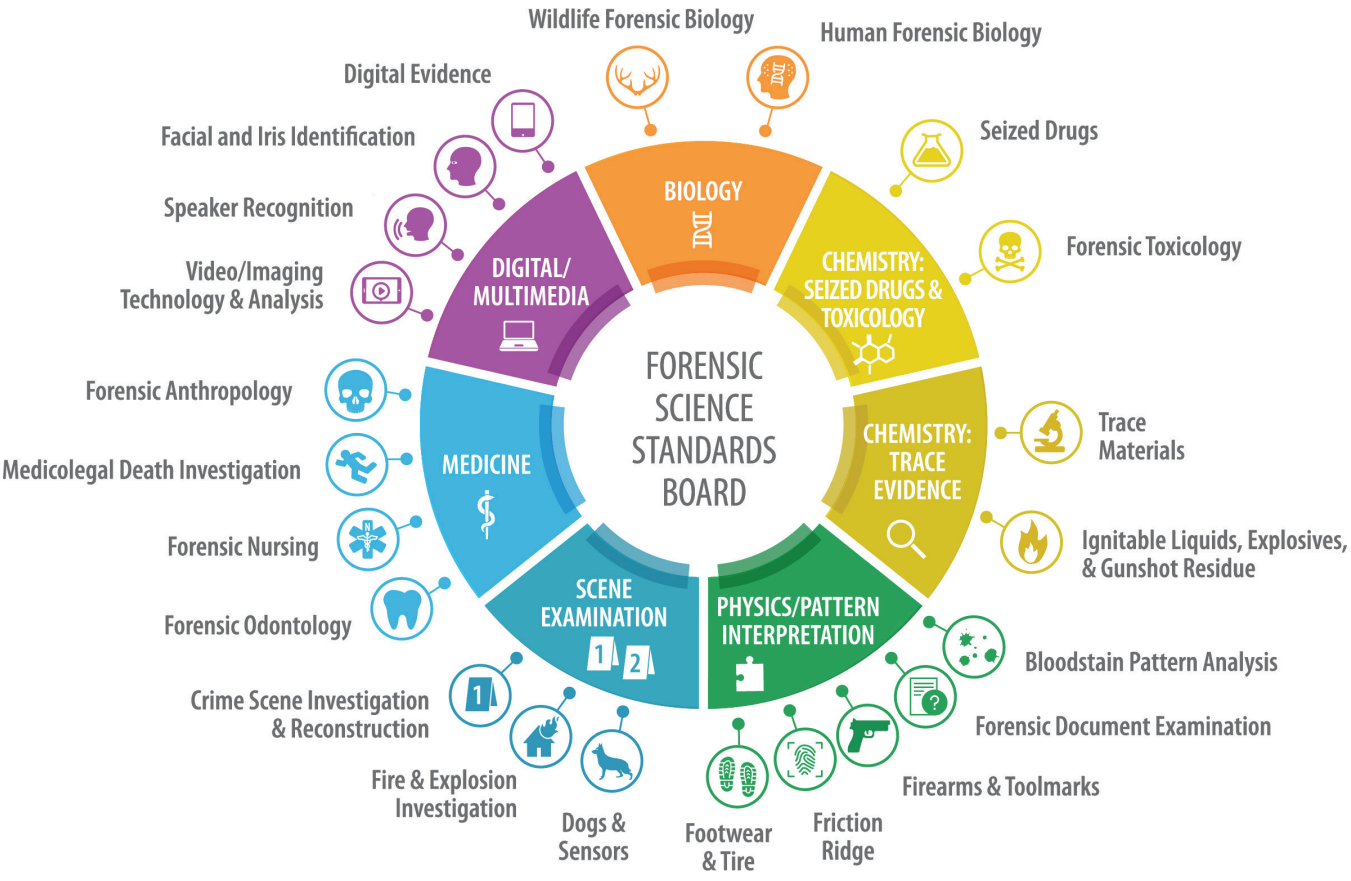
Human Factors in Forensic Science

NIST, in collaboration with the National Institute of Justice, has taken an active role in examining how human factors influence the analysis and interpretation of friction ridge, handwriting, and DNA evidence. These reports have made numerous recommendations for minimizing the influence of bias and human factors, including limiting examiner access to non-relevant case details, increasing transparency during the examination process, providing analysis results along with their limitations, adopting a code of ethics that requires examiners to act in a non-partisan manner, and adopting a culture of openness about errors, all of which result in improved analysis practices. Application of the substantial body of human factors work will improve the overall quality of forensic examinations used throughout the legal system by reducing the likelihood and consequences of human error in the scientific interpretation of evidence.

NIST Forensic Science Program *Spotlights*

Forensic Science Standards

NIST facilitates the development of science-based forensic science standards and promotes their adoption and use through the Organization of Scientific Area Committees (OSAC) for Forensic Science. NIST convenes OSAC's more than 800 volunteer members and affiliates, working in over 500 forensic laboratories and other institutions, with expertise in 22 forensic disciplines. The OSAC Registry now contains 199 forensic science standards (137 published and 62 OSAC proposed standards), a significant growth in just the past four years from about 20 standards on the Registry. Further, 177 forensic service providers have declared that they have implemented relevant standards on the Registry. The graphic below depicts OSAC's 22 disciplinary subcommittees, seven scientific area committees, and its governing board.



Credit: NIST

Acronyms

ABIS	Automated Biometric Identification System
AI	Artificial Intelligence
AI-MS	Ambient Ionization-Mass Spectrometry
CMC	Congruent Matching Cell
DNA	Deoxyribonucleic Acid
FDLE	Florida Department of Law Enforcement
FBI	Federal Bureau of Investigation
FICS	Footwear Impression Comparison System
GC-MS	Gas Chromatography-Mass Spectrometry
ML	Machine Learning
MOU	Memorandum of Understanding
NAS	National Academy of Sciences
NBS	National Bureau of Standards
NIJ	National Institute of Justice
NIST	National Institute of Standards and Technology
NRC	National Research Council
NSRL	National Software Reference Library
OLES	Office of Law Enforcement Standards
OSAC	Organization of Scientific Area Committees for Forensic Science
R&D	Research and Development
RAD	Rapid Analysis of Drugs
RaDAR	Rapid Drug Analysis and Research
RDT&E	Research, Development, Testing, and Evaluation
RPDFT	Reference Population Database of Firearm Toolmarks
SRD	Standard Reference Data
SRM	Standard Reference Material
STR	Short Tandem Repeat

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FOR MORE INFORMATION

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