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CONFERENCE PROCEEDINGS

# Designing an Effective Microbial Forensics Program for Law Enforcement and National Security Purposes

**Randall S. Murch**

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**Abstract** Forensic capabilities that provide lead information, and investigative, intelligence, prosecution and policy decision support can be invaluable for responding to and resolving bioterrorism events. Attributing biological attacks through scientific and other resources and processes is an important goal, for which science can be instrumental. Some even believe that having effective microbial forensics capabilities along with others can even deter adversaries from using biological weapons. For those nations that do not have such or wish to integrate or upgrade capabilities, thoughtful analysis and consideration of certain design principles will increase the likelihood that success will be attained.

**Keywords** Microbial forensics and attribution · Program design principles

## Introduction

A new forensic investigative capability was launched in the United States in 1996 to support bioterrorism and biocrime investigations. That new program was created in the U.S. Federal Bureau of Investigation Laboratory in concert with the agency's emerging operational and investigative responsibilities with bioterrorism, and growing interest and concern in the U.S. at many levels with regards to this worrisome and complex threat. From the outset, this program drew on existing scientific, biomedical and civil support capabilities in the military, emergency response, national laboratory, public health and agricultural protection agencies. What resulted leveraged these into one system which truly had forensic investigation as a priority as well as sought to incorporate legal, operational and policy requirements. From this national effort, the science, practice and communication of what became the field of *microbial forensics* was born. Since that time, a number of other nations have created their own versions of capabilities from what originated in the U.S. The science of microbial forensics and those disciplines upon which it was built and those upon which it is being advanced transcends national boundaries, governmental systems, priorities and applications.

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R. S. Murch (✉)
Virginia Polytechnic Institute and State University, Arlington, VA, USA
e-mail: rmurch@vt.edu

## Definitions

In order to provide common terms and perspectives for this paper, these definitions are offered for context:

- *Forensic Science*: The collection, preservation, transport, analysis, interpretation and reporting on physical evidence to determine its relevance to events, people, places, tools, methods, processes, intentions, plans involved in events pertaining to criminal, civil or international law. Of principal focus is the identification and characterization of evidence and determine its value and utility to answering key investigative and legal questions which lead to legal action (i.e. indictment, prosecution, conviction) or exoneration. Of utmost importance among these are the so-called "attribution questions": "Who did it?" "Who is responsible or involved?" Ideally, forensic science is performed by trained, qualified personnel, using validated methods and appropriate technology in well-supported laboratories under a regime of robust quality management.

- *Attribution* has two main components:
  - Scientific Attribution: Assignment of a *sample of questioned origin* to *a source of known origin* to the *highest degree of scientific certainty possible,* at the same time excluding origination from other sources. Attribution requires the comparison of samples from one or more questioned sources ("Q") with samples from one or more known sources ("K"), using samples that can be analyzed with highly discriminating methods. Attribution can be quantitatively and qualitatively expressed. Increasingly and more intensely, the science underlying "attribution" is being scrutinized and expectations are increasing for accuracy, reliability, validity because of the importance and impact of legal decisions made that forensic science can contribute to.
  - Legal (or Policy) Attribution: A determination with respect to who committed acts of interest or who is otherwise involved, according to criteria accepted and applied within a legal system, e.g., "beyond a reasonable doubt" (the legal standard for conviction of a crime in legal systems such as in the U.S.). While science can inform an attribution decisions, they are rarely made based upon science alone.
- *Microbial forensics* is the development and application of forensic science and relevant sciences to investigative and legal problems involving infectious disease and toxin agents and what was done with and imparted to them for weaponization and dissemination. Microbial forensics also encompasses the exploitation of associated physical evidence contaminated with infectious disease and toxin agents.

Today, microbial forensics is still a relatively young scientific field, and is well addressed in a number of publications including three textbooks (Breeze et al. 2005; Budowle et al. 2011; Cliff et al. 2011). Some nations, such as the United States, have invested considerable resources in and developed increasingly mature microbial forensics response, investigative, scientific and decision support capabilities that reach from the site of suspect or actual events all the way to the pinnacle of decision making in respective governments. By design, these microbial forensic capabilities inform tactical, operational and strategic decision making in the law enforcement, public health and safety, criminal jurisprudence, national security and policy communities and are tailored by country.

The purpose of this paper is to state and develop those design principles which should be considered to develop and implement an effective microbial forensics capability to support national needs for law enforcement and national security purposes. These principles are:

- Forensic capabilities should help to answer key investigative, legal, operational and policy questions;
- Microbial forensics capabilities should coincide with accepted understanding, uses and expectations of forensic science;
- Microbial forensic capabilities should incorporate best practices, quality measures, and pertinent science and technology from related fields;
- Forensic capabilities should be dynamic and agile, and adaptive to new science and technology when it adds value.

## Design Principle 1: Forensic Capabilities Should Help to Answer Key Investigative, Legal, Operational and Policy Questions

Basic or fundamental science seeks to answer questions relating to understanding the existence, phenomena or outcomes in the natural or physical worlds in the quest for deepening knowledge and possible technological advances. In contrast, while leveraging advances in knowledge and technology, all disciplines of forensic science exists to address and inform key questions posed by a complex of non-scientific stakeholders, particularly those who work in law enforcement, legal, judicial, operational, national security and policy communities to support the panoply of decisions that are made in the processes they work with and the outcomes sought. Simply put, if science performed does not help to answer questions of these "customers" according to their needs, it is not forensic science.

Further, the science and associated functions performed, and information provided, should:

- Be useful and timely Information to decision makers at all sectors for what is needed as events unfold;
- Provide decision makers with information that can be scrutinized and applied, with the attributes and limitations understood;
- Be one of several sources of information that are in place, leveraged and integrated for decision makers and practitioners to use during the response, investigative, legal, public safety and security, intelligence, operational and decision making phases;
- Be useable for simple as well as complex decisions that are made at the tactical, operational and strategic levels

recognizing that requirements, needs and circumstances can be dynamic and not always anticipated.

To frame this discussion in the microbial forensics context, we might consider how biological attacks, or suspected or threatened attacks, might present. Decision makers at all levels, from responders to heads of state could face a range of possibilities that would rely on robust microbial forensics and related capabilities, including: a high impact attack, small to large scale, with no warning; a high impact attack, small to large scale, with warning; a focused and limited attack against facilities or populations; a suspicious or very unusual disease outbreak; an uncertain situation for which intelligence or an investigation might suggest that an attack has occurred or will occur but is as yet uncorroborated; and, a possible attack or claim of an attack, which turns out to be a hoax.

What kinds of questions would senior leaders want answers to should any biological event of interest manifest? Such questions are likely to include: What is or was it? How bad are the effects, and how much worse will it get? Who did it? Did it come from a program or labs we know about? Will there be more attacks? What are we and the other nations involved doing about it? What can we know, by when, and with what confidence? For all but the second question, microbial and other forensic sciences can make important contributions to answering them. The third and fourth are the "attribution" questions (Who did it? Who is responsible?) that rely heavily on forensic investigation and information for decision making.

Investigators, lawyers, operational and intelligence personnel seek more specific answers to related and included questions, some of which senior leaders and their advisors will also consider: Did a crime or event of interest actually occur? What happened? How did it occur? When did it occur? Where did it occur? Why did it occur? Who was involved or is responsible? What evidence exists, what does it tell us and how strong is it? How reliable and credible is the evidence? What alternative explanations are there for each piece and the sum total of the evidence? Can we defend our conclusions and actions based on the evidence? The answers to all of these questions can be informed, and are often reliant upon, forensic evidence, and in cases in which infectious disease or toxin agents are at issue, microbial forensic evidence. Forensic and specifically microbial forensics can even be used to address more specific aspects of bioterrorism perpetrators and adversaries and their preparation and operational processes, e.g., their concepts and intentions; biological weapons designs, development and dissemination; planning; acquisition, logistics and movement; experimentation; biological agent production and testing; training and preparation; operations and attack; evasion and escape; and, even denial and deception.

As one moves ever closer to answering the attribution questions, built on and supported by answers to the other questions and leveraging the resources available, the designers and implementers of the desired microbial forensics capability should be very mindful of these overarching questions:

- What is required for an attribution decision?
  - In order to prevent a planned or impending event?
  - In order to successfully prosecute those responsible following an attack?
  - For situations that permit interdiction, disruption, mitigation of an attack?
- What type, quality and amount of evidence, information and intelligence are needed to make an "attribution" decision?
- How accurate, reliable, timely, credible and defensible is the evidence, information and intelligence used to base a decision?

Clearly, these are issues that must be addressed by countries themselves, based on their respective governmental systems, requirements, priorities, needs, resources and current and envisioned capabilities.

If forensic capabilities, including those devoted to microbial forensics, do not effectively inform questions of importance to leaders and decision makers with sufficient fidelity and timeliness, value will be questioned and reliance on it will be discounted.

## Design Principle 2: Microbial Forensics Capabilities Should Coincide with Accepted Understanding, Uses and Expectations for Forensic Science by Practitioners as Well as Stakeholders

Traditional forensic science has been in existence for well over 100 years. What started out with long-discarded practices as well as some that endure with better understanding and technology, forensic science encompasses such disciplines as crime scene investigation, analysis and reconstruction, pattern recognition and association (e.g., fingerprint, document, shoeprint, tire tread, firearms and toolmarks), human DNA analysis, chemistry, drug analysis and toxicology, forensic medicine and pathology, anthropology, materials science, trace evidence (e.g., hairs, fibers, debris and botany), geology and mineralogy (e.g., soils, glass), explosives and improvised devices, engineering (materials and structures properties and failures), and information and communications technology (e.g., computers, personal data assistants, smart phones). Many of these forensic disciplines have acquired and do seek knowledge and technology that was or is developed for other disciplines and applications and have been tailored and validated for forensic uses. Innumerable publications and resources are available in the open literature which detail and review past and present methods, capabilities and experiences in these and other forensic areas.

One important issue to keep in mind is that forensic validation differs from validation performed in a research or clinical laboratory as legal requirements are incorporated. No matter where the science and technology originated from, the forensic adaptations of existing, new and emerging knowledge and technology must incorporate both what the science and technology allows for but also respective limitations, as well.

Regardless of where forensic science is researched, developed, tested, published, used, or offered as evidence or attacked in court, it primarily exists for use in the investigation and litigation of matters of criminal or civil law. This is a major departure from how science and engineering are thought about, conducted and communicated in academic disciplines. Thus, while forensic science is expected to meet the requirements of sound science and practice, it is also expected to meet the legal requirements of national and sometimes international jurisprudence systems, as well. Essentially, when they are important, these requirements usually focus on acceptance by the appropriate scientific community, accuracy, reliability and defensibility. In those legal systems that scrutinize forensic science being considered for acceptance or offered in courts of law, at least in the U.S. the legal and judicial communities have developed procedures that attempt to assess the validity and acceptability of forensic evidence and underlying science and practice (Daubert v. Merrill Dow Pharmaceuticals 1993; Federal Rules of Evidence 2011, updated; Frye v. United States 1923) which other countries have based their legal process and decisions on. While these approaches do have value, there are limitations for a number of reasons including how new science is treated or revisited.

In many countries, including the United States, there are increasing demands and expectations for forensic science and its practitioners to ensure that justice is served and liberties ensured by respective constitutions and rule of law are protected. These demands have come and are coming from realizations of failures and shortfalls in forensic science and practice which have significantly contributed to wrongful prosecutions and convictions, incarcerations and worse. Because of these concerns and realities, recent national-level studies have been conducted (National Research Council 2009) and actions taken (42 U.S. Code 14136c and Public Law 113-65 2013; The White House 2014) to improve forensic science in all aspects from conduct to use across the national enterprise.

Yet, even as forensic science and evidence has been expanded to address matters such as terrorism, legal requirements are at the forefront with regard to what science, engineering and technology is used or developed, how and why it is used, what the expectations are for practitioners and their practice and how it is treated by those who generate and communicate forensic information and those who use it. Given that terrorism investigations often include a variety of international dimensions, the requirements of policy makers and those who serve them (e.g., advisors, diplomats, intelligence experts and military commanders) can be added to the requirements and expectations for forensic science that informs their decisions as well.

These aspects and considerations should be incorporated into the design and implementation of a national forensics capability, including one for the investigation and prosecution of the illicit acquisition, transfer, enablement, development, possession and use of biological agents or weapons.

There are increasing expectations from a diverse community of stakeholders that any discipline of forensic science, and those who conduct such, what results and how it is used, must be held to the highest standards of science and practice possible; this includes microbial forensics.

## Design Principle 3: Microbial Forensic Capabilities Should Incorporate Best Practices, Quality Measures, Pertinent Science and Technology from Related Fields

In 1996 in the United States, the Federal Bureau of Investigation created the first-ever national forensic program focused on the illicit use of chemical, biological, radiological and nuclear weapons, also known as weapons of mass destruction, that would be acquired, developed and used in acts of terrorism. The forensic programs focused on chemical, radiological and nuclear weaponry and terrorism are outside of the scope of this paper, were created from and have been reliant on knowledge and technology developed for other purposes, including non-proliferation and treaty verification, though increasingly forensic knowledge and requirements have been levied on those legacy enterprises to bring U.S. capabilities to their current states.

A few investigations of the alleged use of biological weapons have occurred intermittently in the 20th century, including a very important and revealing one investigated by team led a renowned scientist in response to an accidental release from an illicit, clandestine biological weapons laboratory in the former Soviet Union (Meselson et al. 1994). However, some were not necessarily conducted with forensic and legal requirements in mind. With these historical events and instant and emerging requirements and opportunities of the day in mind, early papers on a national microbial forensics capability described what the creators envisioned (Budowle et al. 2003; Murch 2001, 2003).

Since then, some nations including the United States have established, resourced and regularly exercise capabilities in one or more departments and levels of government from across the entire system, from collection, transport and analysis of evidence to reporting and decision making on forensic evidence associated with biological terrorism (infectious disease agents and toxins, associated equipment, crime scene evidence and items contaminated with hazards which can be exploited for traditional forensic evidence). Also, microbial forensics, sometimes called "forensic microbiology" or "bioforensics", has also since been established as recognized forensic and microbiology disciplines.

Space does not permit an extensive review of the literature of this still new and emerging field. However, the textbooks cited earlier (Breeze et al. 2005; Budowle et al. 2011; Cliff et al. 2011), reviews of the science developed and used in major cases (National Research Council 2011), strategic assessments of the status and needs of the discipline (Budowle et al. 2005a, b, c; Fletcher et al. 2006) and a host of legacy and newer method—and application-specific papers provide for good grounding in the past, present and near-term future of the field.

The scientific disciplines that microbial forensics draws from in addition to forensic science are different than what one would find in traditional forensic disciplines and includes: epidemiology; genomics and metagenomics; bioinformatics; microbial, host, reservoir and vector ecology; biostatistics and population genetics; bacteriology, virology and mycology; plant pathology; biomedical and public health sciences; veterinary medicine and pathology; food science and microbiology; analytical chemistry and biochemistry; microscopy; materials science; process engineering; physical sciences and aerobiology. Many of the analytic methods and technologies used in microbial forensics are common to these other fields but are used to address different questions and purposes.

Microbial forensics is still a young discipline; many challenges exist in spite of the advancements that have been made since its origination. Unlike traditional forensic science, wherein the "known universe" is well understood, the field of microbial forensics is confounded by considerable fundamental and applied uncertainties, from genomics to the ecology of microbes of interest and many aspects between these. Usually, identifying and performing at least some characterization of a pathogen or toxin is not difficult, using methods that are derived from clinical microbiology and related fields. The more difficult and challenging forensic issues relate to the attribution or "where did it come from and how confident are we" questions. Only a few of the most likely infectious disease agents and biological toxins to be used as weapons are sufficiently well understood and with validated methods available to allow for forensic analysis with defined confidence according forensic and legal requirements, within the limits of what the science will allow and acceptable to the community of stakeholders.

Even with intense discussion about or science performed to support forensic investigation involving those agents on "threat agent" lists (Centers for Disease Control and Prevention 2014), much remains to be done to bring microbial forensics to maturity such that all phases of an investigation and its resolution can leverage knowledge and methods that are available on demand, not just with agents on threat lists, but any one of thousands of pathogens or biological toxins that could be used as weapons, depending on the intentions, goals, objectives, resources and capabilities of an adversary.

As the reader considers the complexity of this part of the problem space, add on that a sufficiently well-designed and resourced infrastructure should be in place or available as needed (trained, certified personnel, deployable components, accredited laboratories with appropriate equipment and instrumentation, and research, development, test and evaluation support). Further, the protocols and methods across the system should meet the goals of: robust collection and preservation of evidence with integrity maintained; relevant exploitation of the sample; high discrimination of differences between samples of the same type; enables comparison of samples from known and questioned sources across known and encountered sample types; accuracy; reliability; defined and acceptable error rate; speed and responsiveness; repeatability; transferability, validity can be independently established; and, results are probative (informative), interpretable, explainable and defensible regardless of who needs the information and what decision is to be made with it.

Because of the gaps in knowledge with microbial forensics and those fields that are directly leveraged, it certainly can add value in an investigation or operation but both the attributes and limits of what can be derived or provided must be clearly understood, incorporated and communicated so that expectations are managed and decisions are properly constructed. Essential to this is, like other forensic disciplines, microbial forensics has requirements for validation to maximize confidence for performers as stakeholders (Budowle et al. 2008; Schutzer et al. 2009).

A competent microbial forensics capability can add significant benefits and value with, and even be essential to, the investigation and resolution of events involving biological weapons and terrorism; however, because of properties of and gaps in knowledge about the agents themselves and related science, relative newness of the field, the attributes and limitations should be taken into account and used in concert with other sources of information and investigative methods for decision making.

## Design Principle 4: Forensic Capabilities Should Be Dynamic and Agile, and Adaptive to New Science and Technology When It Would Add Value

Bioterrorism and other high priority events for which microbial forensics would or could be employed can be expected to require timely and high stakes decisions and actions. When lives, public safely, societal integrity and national security are at issue and perpetrators are at-large, the response to and stabilization of such circumstances demands in-place, timely, effective and agile capabilities that can address most if not all situations that manifest.

While all threats and respective presentation cannot be predicted, the most important ones usually can and investments in preparedness can be made. Among those resources for bioterrorism response and investigation should be a forensic infrastructure that can reasonably deal with the dynamic range of adversaries, threats, events and scenarios that would likely be encountered. With bioterrorism, the proliferation of biological threats, the misuse of science for nefarious purposes, and natural evolution and discovery of pathogens that could be exploited for illicit purposes, the number and range of possibilities are considerable and "surprise" looms large. Further, terrorism or criminal events involving biological weapons will most likely garner high level political attention as well as media coverage. In spite of the array of challenges and uncertainties, reasonable, strategic judgments and investments can be made to manage risks and "surprise", reduce the impact of threats and adversaries, and provide timely decision support as crises unfold. Even if perpetrators are apprehended and then a long, slow criminal jurisprudence process engages and forensic science can respond more slowly, the crisis phase of events demand just-in-time answer with sufficient fidelity to address the needs of decision makers on a highly compressed timeline. As America learned with the anthrax letter mailing cases in 2001, scientific support for investigations and prosecutions of this sort should not routinely take years to develop and validate, because of this and unreasonably delay and negatively impact investigations.

When considering the design and implementation of a robust microbial forensics capability one should contemplate investments, ways and means to:

– Increase speed and reduce time of "discovery to decision";
– Aid in reducing uncertainty and risk and increasing success in responding and managing what can most likely to be expected from adversaries;
– Provide the accuracy, fidelity, type and quality of science and reporting that delivers on the requirements and anticipated needs of decision makers whether in fast moving or slow moving phases;
– Have resources available to organize and move quickly to deal with "surprise", such as more sophisticated adversaries, new modus operandi and new threat agents;
– Incorporate new science and technology in thoughtful, balanced, near- to long-term program to increase the power of exploitation of evidence, increase confidence, reduce time-to-answer, and provide deeper, more probative information to the limits of what science can permit.

Steps can be taken and thoughtful considerations can be incorporated to design and implement a first-generation (or subsequent) microbial forensics capability but also to lay out a multidimensional strategy and plan that aids in properly manages resources, time, opportunity, risk and uncertainty while supporting and advancing national interests. Systems analyses and scenario-based table top and field exercises can be helpful in these regards.

## Conclusion

An effective microbial forensics capability will not likely be put into place simply by identifying credentialed scientists and technologists, amassing and appropriating large amounts of resources including funding and acquiring equipment and facilities. Rather, a host of other considerations should be incorporated that maximize the effectiveness and timeliness of what such a capability would permit. A "systems approach" is recommended which incorporates best science, practice, outputs aligned to needs and requirements on many levels and ultimately responsiveness to decision makers who are to be supported in a spectrum of circumstances.

## References

42 U.S. Code 14136c and Public Law 113-65 (2013) National Forensic Science Commission

Breeze RG, Budowle B, Schutzer SE (eds) (2005) Microbial forensics. Elsevier Academic Press, San Diego

Budowle B, Schutzer SE, Einseln A et al (2003) Building a microbial forensics response to bioterrorism. Science 301:1852–1853

Budowle B, Johnson MD, Fraser CM et al (2005a) Genetic analysis and attribution of microbial forensics evidence. Crit Rev Microbiol 31:233–254

Budowle B, Murch RS, Chakraborty R (2005b) Microbial forensics: the next great forensics challenge. Int J Legal Med 119:317–330

Budowle B, Schutzer SE, Ascher MS et al (2005c) Toward a system of microbial forensics: from sample collection to interpretation of evidence. Appl Environ Microbiol 71:2209–2213

Budowle B, Schutzer SE, Morse SA et al (2008) Criteria for validation of methods in microbial forensics. Appl Environ Microbiol 74:5599–5607

Budowle B, Schutzer SE, Breeze RG et al (eds) (2011) Microbial forensics, 2nd edn. Elsevier Academic Press, Amsterdam

Centers for Disease Control and Prevention (2014) Bioterrorism Agents/Diseases. Available at: http://www.bt.cdc.gov/agent/agentlist-category.asp

Cliff JB, Kreuzer HW, Ehrhardt CJ, Wunschel DS (eds) (2011) Chemical and physical signatures for microbial forensics. Humana Press, Heidelberg

Daubert v. Merrill Dow Pharmaceuticals (1993) 509 U.S. 579, 593

Federal Rules of Evidence (2011, updated), U.S. Public Law 93-595 (1975, updated)

Fletcher J, Bender C, Budowle B et al (2006) Plant pathogen forensics: capabilities, needs and recommendations. Microbiol Mol Biol Rev 70:450–471

Frye v. United States (1923) 293F 1013 (DC Circuit Court)

Meselson M, Guillemin J, Hugh-Jones M et al (1994) The Sverdlovsk anthrax outbreak of 1979. Science 266:1202–1208

Murch RS (2001) Forensic perspective on bioterrorism and bioproliferation. In: Firepower in the Laboratory: Proceedings of the Symposium on Research Needs for Laboratory Automation and Bioterrorism, July 2001, National Academy Press, Washington, DC

Murch RS (2003) Microbial forensics: building a national capacity to investigate bioterrorism. Biosecur Bioterror 1:117–122

National Research Council (2009) Strengthening forensic science in the United States: a path forward. National Academy Press, Washington, DC

National Research Council (2011) Review of the scientific approaches during the FBI's investigation of the 2001 anthrax letters. National Academy Press, Washington, DC

Schutzer SE, Keim P, Czerwinski K et al (2009) Use of forensic methods under exigent circumstances without full validation. Sci Transl Med 1:8cm7

The White House (2014) National Forensic Science Commission. Available at: http://www.whitehouse.gov