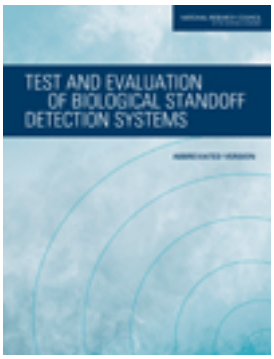

Test and Evaluation of Biological Standoff Detection Systems: Abbreviated Version

Committee on Test and Evaluation of Biological Standoff Detection Systems, National Research Council

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Test and Evaluation of Biological Standoff Detection Systems

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Preface

The office of the Product Director for Test Equipment, Strategy, and Support (PD TESS) of the Joint Program Executive Office for Chemical and Biological Defense in the Department of Defense (DOD) is responsible for ensuring that sufficient infrastructure exists for the effective and timely testing and evaluation of chemical and biological defense equipment. That responsibility requires technical knowledge, capital, and physical resources.

To support its mission, PD TESS asked the National Academy of Sciences (NAS) to assess current and future needs for testing and evaluating biological standoff detection systems, to assess current test and evaluation (T&E) capabilities (in scientific and technical knowledge and existing or near-term facilities), and to provide guidance on how to meet the future needs of this T&E mission.[1] NAS convened a committee of experts in a wide array of fields related to chemical and biological defense, remote detection, and T&E to evaluate the requirements for and feasibility of whole-system testing of biological standoff detection systems.[2] In particular, the committee was asked to:

- Review the scope, adequacy, and limitations of current and potential near-future biological standoff detection system testing protocols and methods.
- Identify test protocols and methods that should be adopted to ensure that current and future biological standoff detection systems will meet operational requirements and state why the identified test protocols and methods were chosen.
- Consider the testing of live or active biological warfare agents (BWAs), killed or inactivated BWAs, and simulants and agent-like organisms (ALOs).[3]
- Discuss the knowledge and confidence that can be gained with each level of testing and the shortfalls and risks associated with each level.
- For each of the three options—active BWA testing, inactivated BWA testing, and ALO testing—comment on the relative scientific and technological risks and discuss the relative cost-benefit and risk-benefit considerations, including regulatory issues that would affect each level of testing.

[1] The full Statement of Task can be found in Appendix A.
[2] Committee biographies can be found in Appendix B.
[3] Live and active BWAs are sometimes used interchangeably. *Live* refers to the viable form of the organism, meaning it can reproduce; active refers only to toxins, which are not organisms. Therefore, active BWA refers only to toxins and live BWA refers to all other classes of BWAs.

In addition to the Statement of Task, PD TESS asked the committee the following questions (Myers 2007):

- Is testing with live or active BWAs necessary for adequate testing and evaluation of the performance of biological standoff detection systems?
- If testing of live or active BWAs is necessary, is it feasible? If so, what technologies and concepts should be pursued?
- If testing of live or active BWAs is unnecessary or infeasible, what level of testing is required?

Those questions and the Statement of Task helped the committee focus its deliberations.

Efforts were made to estimate costs associated with the test materials. Despite the committee's best efforts, these estimates had substantial uncertainties and were not considered reliable. Furthermore, the current state of knowledge constrained the committee's ability to quantify the risks associated with the test materials. Specifically, fundamental questions about certain effects on the target signal need to be answered before there can be a quantitative discussion of how well simulants correlate with ALOs and BWAs. Therefore, the committee has provided only its qualitative judgment of the risks and costs associated with the test materials.

At the present time, lidar-based standoff detection technology is being explored for the Joint Biological Standoff Detection System. Although the major development emphasis is on lidar technology, considerable discussion of alternative methods occurred during the committee's review. The committee believes that a T&E strategy needs to be developed that will permit a wide array of technologies that may be eligible for T&E in the future to be appropriately compared with each other and tested at different levels.

The committee also approached the utility of and opportunities for modeling and simulation (M&S). Although current efforts in T&E are predominantly empirical, a number of M&S approaches were discussed. The committee considered research efforts that involved both a greater reliance on understanding and predictions of the characteristics of a BWA plume and hardware-in-the-loop simulation.

Finally, the committee discussed issues of operational versus developmental testing and the effect that T&E would have on the future of biological standoff detection. In addition to requirements for key technical performance data, it is important to understand the impact of effective detection on military operations. It is critical to ensure that detection systems will both meet technical performance specifications and support troops in the field by increasing their probabilities of survival and making missions easier. The difference between operational and developmental testing and the military concept of operations were both highlighted.

The sensitive nature of much of the information concerning biological standoff detection presented a challenge in the writing of the committee's report. The committee's report has been determined to contain information exempt from mandatory disclosure under 5 U.S.C. 552(b).

Section 15 of the Federal Advisory Committee Act provides that the National Academies shall make its final report available to the public unless the National Academies determines that the report would disclose matters described in one or more of the exemption provisions under the Freedom of Information Act (FOIA). In such case, the National Academies "shall make public an abbreviated version of the report that does not disclose those matters." This unrestricted, abbreviated version of the committee's report was written to fulfill the National Academies' statutory obligation. This abbreviated version represents in so far as possible the committee's

findings, recommendations, and other substantive material without disclosing materials described in title 5 U.S.C. section 552(b).

Acknowledgment of Reviewers

This report has been reviewed in draft form by persons chosen for their diverse perspectives and technical expertise in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making the published report as sound as possible and to ensure that it meets institutional standards of objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following people for their review of this report:

Ed Eloranta, University of Wisconsin, Madison
Ted Hadfield, Midwest Research Institute
Bernadette Johnson, Massachusetts Institute of Technology Lincoln Laboratory
Sallie Keller-McNulty, Rice University
D. Warner North, Northworks, Inc.
Donald Prosnitz, RAND Corporation
Lynn Russell, University of California, San Diego
Albert Sciarretta, CNS Technologies, Inc.
Shiv Sharma, University of Hawaii

Although the reviewers listed above provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Dr. Royce Murray, University of North Carolina, Chapel Hill. Appointed by the National Research Council, he was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

CONTENTS

Summary

A biological warfare agent (BWA) is a microorganism (or a toxin derived from a living organism) that causes disease in humans, plants, or animals or that causes the deterioration of material (NATO 1996). The effectiveness of a BWA is greatly reduced if the attack is detected in time for the target population to take appropriate defensive measures. Therefore, the ability to detect a BWA, in particular to detect it before the target population is exposed, will be a valuable asset to defense against biological attacks. The ideal detection system will have quick response (detection on the order of seconds) and be able to detect a threat plume at a distance (on the order of kilometers) from the target population.[4] The development of reliable biological standoff detection systems—*standoff detection* refers to detection at a distance from the aerosol or plume or detector[5]—therefore is a key goal.

Detection of biological agents is complex. This report focuses on one aspect of the biological defense problem: How can we test whether a biological standoff detection system fulfills its mission reliably if we cannot conduct open-air field tests with live BWAs?

Test and evaluation (T&E) of biological standoff detection systems to certify that they fulfill their mission is difficult because open-air field tests with BWAs are not permitted under international conventions and because the wide variety of environments in which detectors might be used may affect their performance. Further, a T&E protocol should provide the opportunity to demonstrate that a biological standoff detection technology can reliably differentiate between a plume that is benign and one that contains BWAs.

Current and near-term standoff detection technologies are based on lidar (light detection and ranging). Lidar uses pulsed lasers to optically detect and characterize aerosols[6] at a distance. The basic components of lidar are a transmitter (laser), a receiver, and a detector. Lidar uses the laser radiation that is scattered by aerosol particles to determine some property of the aerosol. The major types of lidar currently relevant to biological standoff detection are elastic-backscatter lidar, ultraviolet-laser-induced fluorescence lidar, high-spectral-resolution lidar, Doppler lidar, differential-scatter lidar, and depolarization lidar. Different lidar technologies attempt to exploit different signatures to infer characteristics of an aerosol. That is difficult because aerosol particles interact with laser radiation in different ways. Aerosol particles consist of many molecules and are therefore much larger than molecules. Their varied microphysical properties (that is, particle size distribution, shape, and composition) affect the extinction and backscatter intensity of the signal used to probe a BWA.

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[4] The committee recognizes that all BW threats are not aerosols, but for purposes of this report the committee considered all BW threats as aerosols, hence the emphasis on plumes.

[5] The actual standoff detection distance may vary based on the operational requirements for a specific technology. For example, the Joint Biological Standoff Detection System (JBSDS) is required to detect aerosol plumes at a distance of up to 5 km and discriminate BWA from naturally occurring organisms from 1to 3 km. For the purposes of this report, standoff distance refers to that which is required by the JBSDS operational requirements document.

[6] An aerosol is a system of particles suspended in a medium (in this case the atmosphere). For the purposes of this report, BWAs are assumed to be disseminated as aerosol particles.

Once a plume has been detected, the varied characteristics of BWAs make discrimination between threat and non-threat plumes even more difficult. The conventional wisdom several years ago was that fluorescence cross sections of BWAs depended on the specific agents; for example, dipicolinic acid is a fluorophore that is present in *Bacillus anthracis* spores but not *Francisella tularensis*. However, recent laboratory work has shown that interspecies differences can be obscured by other effects (Hargis et al. 2007). This critical finding suggests that a standoff capability to detect the signatures associated with those effects may be more valuable than one that can detect only specific agents. Such information is important to both developers and evaluators in assessing test conditions.

Department of Defense Approach

The Department of Defense (DOD) is developing biological standoff detection technology in phases. The first objective is to be able to detect an approaching plume of biological material, whether human-made or natural, and determine its size and extent. The goal is to provide longer warning times than are provided by biological point detectors, which can detect biological agents based on direct samples of agent collected at the "point" at which the detector is placed. Point and standoff detectors have different abilities to determine whether a plume contains a BWA. Standoff detectors that can detect a plume but not determine its nature might be deployed in conjunction with point detectors placed upwind from a site that is to be protected. That would provide two independent kinds of warning: one that a plume is approaching and one that a plume contains a BWA.

Standoff detection systems can be highly sensitive to various features in the atmosphere, such as clouds, dust, and the like. A military unit might react to information that a plume was approaching without knowing whether it was a natural aerosol plume, a dust storm, some other phenomenon, or an actual threat; soldiers might be ordered repeatedly to don personal protective equipment, although no biological threat is present, and this would reduce their operational effectiveness.

In order to be effective, biological standoff detection requires a capability to at least identify the approach of concentrations of biological substances. If the false-alarm rate is not too high, and in conjunction with other intelligence or warnings, it might be acceptable to act on information that some sort of biological material is approaching even if it turns out to be only natural spores from nearby fields or trees. Under such a scenario, it might still be valuable to detect an approaching plume of biological material and order troops to find protection, even if the standoff detector could not determine whether the approaching biological material is dangerous. However, it would be important to know that the standoff detection system is capable of spotting enemy-made biological agents and not only natural airborne materials. Therefore, T&E of such a system would necessarily include a demonstration that the system is not blind to enemy-made biological agents either alone or in the presence of other materials, such as contaminants or interferents.

Ultimately, DOD hopes to be able with standoff detectors to identify species in a plume, that is, to identify specific BWAs. To test and evaluate a detector with such capability, it would be necessary to demonstrate that the standoff detection system could dependably detect perhaps a dozen or more enemy-made biological agents in the presence of other atmospheric phenomena,

contaminants, and interferents.[7] T&E would thus require surrogates that could be released to imitate the behavior of live, enemy-made agents in the field; in the absence of such surrogates, tests with actual live BWAs would be necessary. Tests would need to be conducted in a facility with reliable safety features to contain the BWAs in question. It also would require test facilities to duplicate realistic field conditions. In some cases, the test facilities might have to be large so that the limitations of the test facilities do not interfere with the measurements being made.

Test and Evaluation of Biological Standoff Detection Systems

T&E needs to be tailored to the level of operational capability being tested. The T&E required for a biological standoff detection system that identifies a threat plume by species is substantially different from and more complex than for a detection system that only discriminates between biological and nonbiological aerosols, which requires more complex T&E than a system that only detects a plume. Therefore, T&E needs to occur in a graduated manner from detecting a plume, to discriminating between biological and nonbiological aerosol, and finally to identifying a specific BWA.

Similarly, laboratory tests of a system should be used to inform the design and conduct of tunnel tests, whose results should be used to inform the design and conduct of open-air tests. Laboratory testing allows the determination of the impact of other effects on available signatures. From laboratory testing the T&E strategy should expand to examine the influences of the environment and different delivery systems on the system's detection capability. Testing at this level may indicate new limitations (for example, if the presence of some urban contaminants masks BWA signatures or increases false-alarm rates) or indicate opportunities to enhance detection capabilities (for example, if it is found that cueing by other detectors to focus on a particular event might allow better interrogation of a plume by the standoff detector system, which may require a change in system requirements). This testing offers another chance to assess where programmatic and test strategy decisions should be reviewed.

Standoff detectors with no ability to identify specific biological agents require less elaborate test facilities than would highly capable futuristic systems. Although less elaborate test facilities are required for the T&E of a standoff detector that is intended to only measure the extent of an approaching plume and determine its dimensions and velocity, the T&E capabilities required are still challenging.

DOD does not have an adequate set of tools to test biological standoff detection systems fully under both laboratory and field conditions and at component, subsystem, and full-system levels and then to correlate the results. It has invested in developing test facilities for standoff systems that can detect plumes, but the facilities are not suitable for standoff experiments requiring containment, although some may have limited containment capabilities. The technical and engineering difficulties of developing a set of facilities, complemented by modeling and simulation tools, that can accommodate active standoff detection system development while providing necessary containment are substantial and will make it expensive to develop such facilities.

[7] The committee recognizes that this assumes the threat agent to be detected is actually known and cataloged. In reality the committee understands that by definition "enemy-made" could be an engineered biological agent not previously known.

The committee believes that the technology to provide standoff identification of specific BWAs is not likely to be practicable for many years. Current research indicates that the signals detectable by current technologies associated with other effects can overwhelm the signals from specific biological species. This critical finding means that substantial work will be required to characterize those effects before a standoff capability to identify specific BWAs is possible. Not only is the technology for standoff species identification challenging, but the T&E of such systems would be difficult and complex.

Finally, being able to identify specific threat species assumes that there is both a known set of threat agents and that certain procedures associated with those agents are known. Characterization of novel unanticipated threats is not easily imagined.

Findings and Recommendations

The findings and recommendations presented below are intended to provide DOD and the office of the Product Director for Test Equipment, Strategy, and Support with a clear path to developing a robust process for testing and evaluation of biological standoff detection systems.

FINDING: The Department of Defense requires an integrated approach to development, testing, and evaluation of biological standoff detection systems.

DOD needs a comprehensive T&E process that uses design of experiments and integrated statistical analyses to dynamically and iteratively combine modeling, simulation, theory, and laboratory efforts with the results of field testing. The process should quantify, through models and data, the performance of every hardware and software component and the interaction of the interrogation methods with the atmosphere and with aerosol particles. The performance quantification needs to include uncertainty quantification. The process needs to integrate diverse types of information into a single framework, including data from laboratory, tunnel, and open-air testing and data from modeling and simulation.

All aspects of T&E should be integrated and coordinated with the development of biological standoff detection systems. T&E should inform the development of biological standoff detection systems, and interactions between the development and T&E communities should be a routine part of the research and development process. Tracking opportunities for development will allow the T&E community to insert new test technology into the T&E process and develop new T&E capabilities to address evolving needs.

FINDING: Current understanding of the relationship between detection signals and the properties of biological aerosols is insufficient to allow reliable correlation between surrogates and agents.

A process for building a body of knowledge about the interaction of laser radiation and other active interrogation techniques with aerosol (especially biological) particles and plumes needs to be developed. ALOs and simulants have been used as surrogates for live BWAs in testing, but the corresponding T&E results are valid only if a detection signal from a live BWA can be predicted from the detection signal of a surrogate. Developing a robust model for prediction requires an understanding of how a detection signal correlates with biological aerosol properties. Achieving a high level of confidence requires comparison of predicted and measured signals in a laboratory test bed that can accommodate live BWAs. There appears to have been

insufficient emphasis on integrating laboratory-scale T&E to support such studies, which can include conventional and scaled-down test beds.

FINDING: Referee systems need to be more accurate and precise than the system under test.

Calibrated lidar is necessary to compare past, present, and future lidar data. Calibrated lidar provides backscatter intensity and extinction data in physical units (for example, per meter per steradian) that allow the data to be used in models of the integrated system. In recognition of the importance of lidar as a key instrument in T&E of biological standoff detection systems, the understanding, calibration, and reproducibility of lidar data should be emphasized. The most accurate technique to calibrate aerosol lidar is high-spectral-resolution lidar (HSRL; Eloranta 2005), and there are eye-safe HSRL systems. Tunnel and range facilities require several well-calibrated nephelometers[8] and visibility sensors to document scattering and extinction of both plume and background.

A combination of point-based referee systems[9] is necessary in tunnel and scaled-down testing to measure the size distribution of the aerosol plume and background as accurately as possible. The current Aerodynamic Particle Sizer can measure the size distribution only down to a diameter of 0.5 μm. Smaller particles in the plume require alternative detection technologies, such as the Scanning Mobility Particle Sizer. Such measurement capability is critical for understanding how aerosol particles contribute to the overall signal detected by a standoff system.

RECOMMENDATION: The Department of Defense should develop an integrated framework for test and evaluation of biological standoff detection systems that includes modeling and simulation; uncertainty quantification; and laboratory, tunnel, and open-air testing.

Viewing the T&E process as an integrated array of capabilities—as a "T&E system"—can improve overall T&E capabilities substantially. Design of experiments should be used to guide the integrated T&E framework, and uncertainty quantification should be an inherent goal.

Uncertainty quantification is a vital component of the integrated framework. Its purpose is to measure system performance and to measure errors present in each combination of test conditions and test modality (laboratory, tunnel, open-air, and modeling and simulation testing). The evaluation process is limited without an appropriate quantification of both system performance and the associated uncertainties. Once the evaluation process is associated with quantified uncertainties, the T&E community needs to make decisions in light of the uncertainties. Each decision should be based on an evaluation of the additional reward or benefit that it offers with respect to uncertainty quantification.

Modeling and simulation (M&S) play an important role in an integrated array of T&E capabilities. Test and experimentation capabilities should be considered with respect to the data they provide and how the data can be integrated into a strategy that includes M&S. Data from experimentation can help develop and improve M&S with the goal of creating a "virtual test bed" or "virtual T&E infrastructure." This will reduce overall cost while expanding test capability, especially for T&E of systems, such as biological standoff detection systems, that can

[8] A nephelometer is an instrument used to measure the light-scattering coefficient of aerosols.
[9] A referee system, sometimes referred to as a ground truth system, is used to characterize an aerosol plume at a higher fidelity than the system under test.

never be physically tested under realistic field conditions. The M&S capabilities developed to test nuclear weapons after nuclear tests were banned are an example of such work.

RECOMMENDATION: The Department of Defense should assess the development and construction of new facilities that are suitable for whole-system testing of standoff detectors, for example, a large Biosafety Level 3 facility, in the context of an integrated approach to test and evaluation.

It is possible that a large-scale Biosafety Level 3 (BSL-3) chamber will be required to demonstrate that a full-scale biological standoff detection system works reliably. However, given the current state of knowledge, building such a facility is premature. One critical issue that must be resolved before a BSL-3 facility is built is the impact of other effects on the detection signal.[10]

An integrated T&E protocol must be an essential part of decision making regarding a large-scale BSL-3 chamber for testing standoff detectors. The design and characteristics of a BSL-3 facility would depend on the understanding gained from other aspects of the integrated T&E approach and on the identified knowledge gaps that could not be filled by existing facilities. It is critical to understand how data from a BSL-3 facility will be integrated into a framework that can predict the response of a detection system to an open-air release of a biological threat under realistic field conditions. With the current level of understanding, it is not clear how data from a BSL-3 facility could be reliably interpreted. Laboratory and tunnel testing and M&S efforts should be pursued to enhance the state of knowledge needed to decide whether to build a large BSL-3 chamber.

It is likely that additional facilities that enhance current T&E capabilities will be required. For example, scaled-down test beds with containment capabilities are likely to produce valuable data. Development of these capabilities should be pursued before other more risky and expensive options are considered. Building a large-scale BSL-3 facility is a high-risk endeavor given the technical difficulties and likely cost. Specifically, it is unclear whether the technical solutions proposed in the preliminary designs for the facility (see Chapter 4) would be sufficient to result in a facility that is capable of producing the requisite data.

RECOMMENDATION: The test and evaluation community should place more emphasis on testing the capability of standoff detection systems to discriminate between human-made biological aerosols and natural biological aerosols.

The rational behind this recommendation is discussed in the committee's full report.

RECOMMENDATION: Design of experiments should be used to efficiently explore the array of test conditions required to characterize a detection system's performance fully in different environments and threat scenarios.

In a given test modality, many factors affect a detection signal. Experimentation that tests one factor at a time is highly inefficient. Design of experiments affords an opportunity to choose combinations of factors that will yield results with the same information content as one-factor-at-a-time experimentation but at a much lower cost. A sound experimental design approach will also allow the T&E process to determine potential interactions between factors. And a sound experimental design approach can inform and guide research and development

[10] These effects are discussed in the committee's full report.

efforts if the research and development and T&E processes are appropriately managed and coordinated.

In many highly complex and expensive systems, adaptive design of experiments is a valuable tool. Adaptive design can be broadly classified as follows: "Given the uncertainty (as evidenced by test data, models, analysis of results, and so on) in a system at time *t*, what modality of testing, which factors, and what levels of those factors can maximize the reduction in uncertainty at time $t + 1$?" The term *adaptive* refers to the notion that the question is asked after each test is run. Adaptive designs are valuable, but they are also sequential; it takes substantial time to complete a fully adaptive approach to testing and evaluation. Thus, a hybrid approach that contains small-scale classical design of experiments and interim assessments of uncertainty would provide an opportunity to evaluate uncertainty periodically and to revise the test plan.

Design of experiments should extend beyond laboratory, tunnel, and open-air concepts to include M&S experiments that are recommended in the integrated approach to T&E. The design-of-experiments protocol for the M&S process should be developed in light of the design-of-experiments approach for laboratory, tunnel, and open-air experiments. The M&S approach should be conducted according to principles of design of experiments and with the objective of linking laboratory, tunnel, and open-air results.

RECOMMENDATION: The test and evaluation community should use the operational requirements for biological standoff detection systems to drive the development of testing and evaluation.

The need for T&E capabilities is determined in part by the performance requirements of the standoff detection system under scrutiny. The likelihood that additional T&E capabilities are needed depends on whether the goal of the standoff detection system is to detect an aerosol plume, to detect a plume and determine whether it contains aerosol of biological origin or not, to detect a plume and determine whether its signature is biological and human-made, or to detect a plume and identify its signature as a BWA.

Regardless of the biological standoff detector's performance requirements, laboratory testing will be required to establish correlations between BWAs and surrogates. Data for the correlation can be collected in confined chambers.

Once the correlation is established, if the goal of the standoff detection system is simply to detect an aerosol plume without regard to its composition, whole-system testing with simulants can be conducted to establish the detector's performance under operationally relevant conditions. The correlation between BWAs and surrogates (in this case simulants) is required to ensure that the standoff detection system is not blind to aerosols that contain BWAs.

If the goal of the standoff detection system is to detect plumes and distinguish between those that contain biological aerosols and those that do not, chemical characterization is needed in addition to physical and optical characterization. Chemical characterization by identification of the signatures associated with material of biological origin (such as amino acids) requires laboratory testing with surrogates, such as simulants, ALOs, or killed or inactivated BWAs. In addition to open-air testing with simulants, tunnel testing with killed ALOs may be used to reduce the uncertainties in the detector's potential performance with BWAs. It may be possible to do some testing with risk group 2 (RG-2) organisms, such as live ALOs in the active standoff chamber or a facility similar to it if sufficient containment is demonstrated to further reduce the uncertainties.

If the goal of the standoff detection system is to detect plumes and distinguish between plumes that contain human-made biological aerosol and plumes that contain naturally occurring biological aerosol, unique chemical characterization is required in addition to physical and optical characterization. Unique chemical characterization is required to detect evidence of a human "fingerprint" on the aerosol. Laboratory testing with such surrogates as simulants, ALOs, or killed or inactivated BWAs will be required. In addition to open-air testing with simulants, tunnel testing with killed ALOs may be necessary to predict the detection system's performance on BWAs. As before, it may be possible that some testing with RG-2 organisms can be conducted in a facility to reduce the uncertainties in correlating surrogates with BWAs. These tests should also vary certain procedures to determine the effects of those procedures on the target signal.

If the goal of the standoff detection system is to identify a specific BWA, controlled releases of live ALOs, killed or inactivated BWA, or even live BWA in a high-containment facility may be required. However, such testing is not necessary at the present time.

RECOMMENDATION: The test and evaluation community must base its test and evaluation of biological standoff detection systems on a system's measures of performance, measures of effectiveness, and concepts of operations.

Materiel developers, combat developers, and T&E professionals must have a clear understanding of what information a candidate standoff system can provide and of the operational value of this information. In determining what information requirements a system can satisfy, developers and evaluators must consider the entire family of detector systems that commanders will have available to them and how detection functions may best be allocated to different systems. Identifying reasonable expectations for a technology allows applied development programs to focus on delivery of equipment designed to satisfy operational needs and allows T&E professionals to determine operationally relevant testing protocols.

RECOMMENDATION: The Department of Defense should foster the development of a multidisciplinary biological testing community with increased interactions with the broader research community.

The T&E community would benefit if staff and contractors were supported in getting results published in refereed literature. There is tension between protecting national security and maintaining open scientific exchange, but many aspects of the basic research carried out by members of the standoff detection group would benefit from peer review. Outside unbiased evaluation of experimental protocols and results would help guide T&E strategies. The annual Joint Conference on Standoff Detection for Chemical and Biological Defense held in Williamsburg, Virginia, publishes its proceedings, and the standoff detection community should present results at other conferences and publish in peer-reviewed literature.

Because the field of biological standoff detection continues to evolve, the T&E community would benefit from a scientific advisory board composed of independent engineers and scientists to provide continuing direction and integration of the science and technology, development, and operational communities. The board could help develop measures of operational effectiveness and system performance and allow for review of emerging test results between phases of system definition and development. This advisory board might interact with the DOD Test Resource Management Center (TRMC). A T&E science and technology program

exists in the DOD TRMC to develop new test technologies for enhancing T&E capabilities. It would be beneficial if the TRMC included biological T&E as a focus area.

Finally, greater interaction between the biological point detection and standoff detection communities is urged. Analysis of the concept of operations for either kind of detection program suggests that exchange is crucial during T&E, inasmuch as information from the deployed systems must be exchanged to achieve detection for warning and protection.

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Appendix A

Statement of Task

At the request of the U.S. Army, the National Academies will evaluate the requirements for and feasibility of whole-system testing of biological standoff detection systems using active biological warfare agents (BWAs) and issue a report. The committee will:

- Review the scope, adequacy, and limitations of current and potential near-future biological standoff detection system testing protocols and methodologies and
- Identify what test protocols and methodologies should be adopted to ensure that current and future biological standoff detection systems will meet operational requirements and why.

In particular, the review will consider the use of (1) active BWA testing, (2) inactivated BWA testing, and (3) simulants/agent-like organisms (ALOs) testing and

- Discuss the knowledge and confidence gained for each level of testing as well as the shortfalls and risks associated with each, and
- For each of the three options (active BWA testing, inactivated BWA testing, ALO testing), comment on the relative scientific and technological risks and discuss the relative cost-benefit and risk-benefit. This should include consideration of regulatory issues that would affect each level of testing.

Appendix B

Biographical Sketches of Committee Members

Michael J. Goldblatt (Co-chair), Functional Genetics
Dr. Goldblatt is the chief executive officer of Functional Genetics, a biotechnology company engaged in the development of novel therapeutics for infectious disease, Alzheimer's disease, cancer, and other human diseases. Previously, Dr. Goldblatt was director of defense sciences at the Defense Advanced Research Projects Agency, where his responsibilities included creating foundational efforts to make biology a strength for the Department of Defense. Dr. Goldblatt has spearheaded product development and corporate venture capital efforts and worked with a variety of regulatory and legal issues as science and technology officer for McDonald's and other employers.

Anantha Krishnan (Co-chair), Lawrence Livermore National Laboratory
Dr. Krishnan is director of research and development and section leader for meso-, micro-, and nanoscale technology at the Lawrence Livermore National Laboratory. Before his appointment there, Dr. Krishnan was a program manager with the Microsystems Technology Office of the Defense Advanced Research Projects Agency, where he was responsible for managing programs that focused on developing advanced multidisciplinary design tools for mixed-technology integration in microsystems. Dr. Krishnan had held various positions, including vice-president for advanced technology, at Computational Fluid Dynamics Research Corporation, where he managed several projects in semiconductor processing technology, MEMS/bio-MEMS, mesoscale systems, conformal integrated electronics, supercritical fluid technology, crystal growth, and aerospace and rocket propulsion. His technical expertise includes fluid and plasma transport and heat and mass transfer and chemistry in chemical and biological systems. His efforts focused on the development of multidisciplinary analytic tools to simulate coupled interactions among fluidic, thermal, chemical, structural, and electromagnetic phenomena in complex engineering systems. Dr. Krishnan obtained his doctorate in mechanical engineering from the Massachusetts Institute of Technology in 1989. He has more than 50 publications in international journals and conferences.

Nancy Connell, University of Medicine and Dentistry of New Jersey
Dr. Connell is an associate professor of microbiology and molecular genetics at the University of Medicine and Dentistry of New Jersey (UMDNJ)-New Jersey Medical School. She is also director of the UMDNJ Center for BioDefense, which was established in 1999 and is the recipient of $11.5 million in congressional recommendations (2000-2004) for research into the detection and diagnosis of biological warfare agents and biodefense preparedness. Dr. Connell also is director of the Biosafety Level 3 Facility of UMDNJ's Center for the Study of Emerging

and Re-emerging Pathogens and chairs the Recombinant DNA Subcommittee of the university's Institutional Biosafety Committee. She chairs the National Institutes of Health's Center for Scientific Review Study Section BM-1, which reviews bacterial-pathogenesis submissions to the National Institute of Allergy and Infectious Diseases. Dr. Connell's involvement in biological weapons control began in 1984, when she was chair of the Committee on the Military Use of Biological Research, a subcommittee of the Council for Responsible Genetics, based in Cambridge, Massachusetts. Dr. Connell received her Ph.D. in microbiology from Harvard University. Her major research focus is the interaction between *Mycobacterium tuberculosis* and the macrophage.

Philip E. Coyle III, Science Strategies
Mr. Coyle served as assistant secretary of defense and director of operational test and evaluation at the Department of Defense (DOD). In this capacity he was principal adviser to the secretary of defense and the under secretary of defense for acquisition, technology, and logistics of testing and evaluation. Mr. Coyle has 30 years of experience in testing and test-related matters. From 1959 to 1979 and 1981 to 1993, he worked at the Lawrence Livermore National Laboratory in Livermore, California, where he served as an associate director. During the Carter administration, he served as principal deputy assistant secretary for defense programs in the Department of Energy, in which capacity he had oversight responsibility for the nuclear-weapons testing programs of the department. The International Test and Evaluation Association awarded Mr. Coyle the Allan R. Matthews Award, its highest award, for his contributions to the management and technology of testing and evaluation. Mr. Coyle was awarded the Defense Distinguished Service Medal by DOD Secretary Perry and the Bronze Palm of the Defense Distinguished Service Medal by DOD Secretary Cohen. Mr. Coyle received a B.A. and an M.S. in mechanical engineering from Dartmouth University.

Eric Eisenstadt, J. Craig Venter Institute
Dr. Eisenstadt is deputy vice-president for research at the J. Craig Venter Institute. Dr. Eisenstadt, whose background is in microbial physiology and genetics, has cultivated interdisciplinary programs in biotechnology for the past 17 years at the Defense Advanced Research Projects Agency, Defense Sciences Office and the Office of Naval Research Biological Science and Technology Division. As a program manager at DARPA and ONR, Dr. Eisenstadt developed and managed diverse research in which interdisciplinary teams analyzed single-cell gene regulatory networks, sequenced biological warfare microbes, created computational tools for the de novo design of novel proteins, and explored biofabrication's potential in high-efficiency solar cells. He was the Navy's technical representative to the joint services program for basic and applied research programs in chemical and biologicalwarfare defense. Dr. Eisenstadt received his Ph.D. in biology from Washington University.

Eric E. Gard, Lawrence Livermore National Laboratory
Dr. Gard, a chemist, leads the Lawrence Livermore National Laboratory's Defense Biology Division, where he has worked for the past six years to develop a system that can detect airborne pathogens and sound a warning in less than a minute. He and his team have answered that challenge by developing the Bioaerosol Mass Spectrometry system, which won a 2005 research and development 100 award as one of the year's most promising technologies and is now available for licensing. Dr. Gard received his Ph.D. from the University of California, Davis.

Michael J. Hopmeier, Unconventional Concepts, Inc.
Mr. Hopmeier is the chief of innovative and unconventional concepts at Unconventional Concepts, Inc., an engineering and scientific consulting firm that provides research, organization, and technology-integration services. He is a technical adviser and an operational consultant to numerous government agencies, including the Defense Advanced Research Projects Agency Defense Sciences Office, the U.S. Army Medical Research and Materiel Command, the Centers for Disease Control and Prevention National Center for Infectious Diseases, and the office of the U.S. Air Force surgeon general. His project fields include chemical and biological incident response, combat casualty care and medical support, crisis response and management, unconventional pathogen countermeasure programs, federal agency protective measures, counterterrorism, and integrated federal-civilian disaster response. Mr. Hopmeier holds bachelor's and master's degrees in mechanical engineering from the University of Florida.

Murray V. Johnston, University of Delaware
Dr. Johnston is a professor in the Department of Chemistry and Biochemistry at the University of Delaware. He began his academic career as an assistant professor of chemistry and a fellow of the Cooperative Institute for Research in Environmental Sciences at the University of Colorado, Boulder. He received a Center for Advanced Study fellowship in 1999, the Outstanding Scholar Award in the College of Arts and Sciences in 2001, and the Delaware Section Award of the American Chemical Society in 2003. Dr. Johnston's research includes applications of mass spectrometry to a wide array of materials, from airborne particles to biological and polymeric macromolecules. Over the past 15 years he has used real-time single-particle mass spectrometry to study microchemical reactions within particles, heterogeneous reactions between gas-phase and particulate-phase species, and ambient particles at various urban sites. His current work emphasizes the use of photoionization aerosol mass spectrometry to characterize organic components of combustion and ambient aerosols, nanoparticle mass spectrometry to characterize individual particles and macromolecules 10 nm and smaller, and conventional mass spectrometry to characterize oligomers in secondary organic aerosols. His work has led to some 130 publications.

Frances Ligler, Naval Research Laboratory (NAE)
Dr. Ligler is the U.S. Navy's senior scientist for biosensors and biomaterials and a member of the Center for Bio/Molecular Science and Engineering at the Naval Research Laboratory (NRL). She earned a D.Phil. and a D.Sc. from Oxford University; has published two books and over 220 articles in scientific journals, which have been cited over 3,000 times; and has 19 issued patents. Before joining NRL in 1985, she performed basic and clinical research in immunology in academe and industry. She is a winner of the Christopher Columbus Homeland Security Award, the Navy Merit Award and Superior Civilian Service Medal, the National Drug Control Policy Technology Transfer Award, the American Chemical Society Hillebrand Award, the NRL technology transfer award, three NRL Edison awards for patent of the year, the Furman University Bell Tower Award, and the national Women in Science and Engineering Outstanding Achievement in Science Award. She chaired the 1994 Gordon Research Conference on Bio/Analytical Sensors and was elected a fellow of SPIE—The International Society for Optical Engineering. She is regional editor for North and South America for *Biosensors & Bioelectronics* and serves on the editorial boards of the *Journal of Biomedical Optics*, *Applied*

Biochemistry & Biotechnology, and Sensors Letters. In 2002 she was the American representative on the organizing committee for the International Biosensors Congress in Kyoto, Japan, and was elected to the permanent organizing committee of the European Conference on Optical Sensors (UK 2002, Spain 2004, Germany 2006). In 2003 she was awarded the presidential rank of Distinguished Career Professional.

Shane D. Mayor, National Center for Atmospheric Research
Dr. Mayor is a scientist at the Earth Observing Laboratory of the National Center for Atmospheric Research (NCAR). Dr. Mayor received his Ph.D. from the University of Wisconsin, Madison. The Wisconsin lidar program has two major thrusts: volume-image lidar (VIL) and high-spectral-resolution lidar (HSRL). Dr. Mayor's dissertation work focused on using VIL data to improve fine-scale numerical simulations of atmospheric boundary layer turbulence. After completing his Ph.D., Dr. Mayor worked at NCAR through the Advanced Studies Program and the Atmospheric Technology Division to develop Raman-shifted eye-safe aerosol lidar (REAL), an eye-safe version of the Wisconsin VIL. Through collaboration with ITT Industries, a hardened version of REAL now operate to protect buildings from bioaerosol attack. Dr. Mayor is now working on methods to marry the REAL and HSRL concepts so that future REALs can provide calibrated aerosol backscatter, depolarization ratio, and other quantities, such as vector winds from the scan data. Before going to Wisconsin, he worked at the National Aeronautics and Space Administration on differential absorption lidar and at NCAR on heterodyne Doppler lidar.

Timothy F. Moshier, Syracuse Research Corporation
Mr. Moshier is senior principal scientist at the Syracuse Research Corporation. He has over 25 years of experience in chemical and biological defense. He received a B.A. in biology from the State University of New York at Oswego in 1981, an M.S. in biology from Syracuse University in 1990, and a master's degree in military art and science from the U.S. Army Command and General Staff College in 1994. In his 21 years of Army service, Mr. Moshier held a variety of positions with tactical and research, development, and acquisition (RD&A) organizations. Among his tactical assignments, Mr. Moshier served with the 5th Infantry Division (Mechanized), the 10th Mountain Division, and the 196th Field Artillery Brigade (during Operation Desert Storm). Mr. Moshier also served for six months with the United Nations Special Commission in 1995 investigating Iraq's biological-weapons program. Among his RD&A assignments, Mr. Moshier served at the U.S. Army Dugway Proving Ground (as installation biological safety officer and operations officer) and in the Joint Program Office for Biological Defense (as detection project officer and manager for the Critical Reagents Program). Mr. Moshier is a certified Acquisition Level III Professional. After retiring from the Army in 2002, he worked for SPARTA, Inc., as chief of the homeland security division, where he was responsible for the daily operation of an organization consisting of threat and international relations specialists; chemical, biological, and nuclear defense experts; and a group of explosive ordnance disposal experts. Mr. Moshier is a staff member of the Environmental Science Center at Syracuse Research Corporation.

C. Shane Reese, Brigham Young University
Dr. Reese is associate professor of statistics at Brigham Young University. He received his Ph.D. in statistics from Texas A&M University. He is associate editor of the *Journal of the*

American Statistical Association. He also serves as vice chair of the association Committee on Federally Funded Research and as a member of the ASA Committee on Science and Public Affairs. He has also served as president of the Albuquerque Chapter of the association (2000-2001). At Brigham Young he is a member of the university awards committee and chairs the Search Committee and the Computer Committee. Dr. Reese's research interests include Bayesian hierarchical models, Bayesian optimal experimental design, and sports statistics.

Upendra N. Singh, National Aeronautics and Space Administration
Dr. Singh is chief technologist at the Systems Engineering Directorate at the National Aeronautics and Space Administration Langley Research Center. Before joining NASA Langley, he was chief scientist for Hughes STX Corporation. Dr. Singh is principal investigator and coinvestigator of NASA's lidar risk reduction program and laser-lidar technologies for explorations project. He designed and developed two state-of-the-art lidar systems: NASA's first mobile stratospheric Rayleigh-Raman ozone lidar system for monitoring ozone depletion and a mobile aerosol and temperature lidar system with three primary wavelengths (1064, 532, and 351 nm) and one secondary wavelength (382 nm) for stratospheric aerosol measurements. Dr. Singh coordinated the Integrated NASA Lidar System Strategy Team. He also selected representatives from NASA Langley and the Goddard Space Flight Center for the team and formed alliances with other government agencies, industry, and academe. Through workshops and meetings, they assessed the status of laser technology, identified key technologies that needed development, and established a basis of future collaboration and partnership. He received the Exceptional Service Medal from NASA in June 2006. He has a B.S. in physics, an M.S. in applied physics, an M.Phil. in physics, a *Diplôme d'Etude Approfondis*, and a Ph.D. in physics from the University of Pierre and Marie Curie in Paris, France.

Appendix C

Glossary

Agent-like organisms: Organisms having physiological, physical, and chemical properties similar to those of a corresponding biological warfare agent while presenting a reduced risk of infection. Agent-like organisms are most often derived from a vaccine or attenuated strain of a biological warfare agent or a nonviable or an inactive form of a biological warfare agent.

Backscatter: the laser radiation returned, or scattered back, to a lidar system after an interaction with an aerosol particle or a molecule at a distance.

Biological warfare agent: a microorganism (or a toxin derived from it) that causes disease in humans, plants, or animals or that causes the deterioration of material (NATO 1996). There are six classes: bacteria, fungi, rickettsiae, chlamydia, viruses, and toxins.

Elastic scattering: interaction of laser radiation with molecular or particulate matter in which the incident radiation is redirected by the molecular or particulate matter. Elastic scattering changes only the direction of the radiation; its energy and therefore wavelength are conserved.

Extinction: the sum of scattering and absorption.

Inelastic scattering: interaction of laser radiation with molecular or particulate matter in which the incident radiation is absorbed and reradiated by the molecular or particulate matter. Inelastic scattering shifts the wavelength of the radiation.

Operational test and evaluation: The field test, under realistic conditions, of an item (or a key component) of weapons, equipment, or munitions for the purpose of determining the effectiveness and suitability of the weapons, equipment, or munitions for use in combat by typical military users, and the evaluation of the results of such tests.

Plume: a cohesive collection of particles released to the atmosphere.

Referee system: system used to characterize an aerosol plume at a higher fidelity than the system under test. Referee system is sometimes referred to as a ground truth system.

Scattering: multiple reflection of electromagnetic radiation by gases or particles in the atmosphere (Sabins 1978). Scattering can be categorized as *elastic* or *inelastic.*

Simulants: Nonpathogenic or nontoxic warfare agent surrogates that provide useful evaluative information on the performance of a biological detection system and can sometimes be directly correlated with the biological warfare agent being simulated.

Standoff detection: Detection at a distance away from the aerosol/plume or detector system (Joint Program Executive Office for Chemical and Biological Defense 2004).

Surrogate: an organism or material that serves as a substitute for biological warfare agent.

Appendix D

Summary of Committee Meetings

The Committee on Test and Evaluation of Biological Standoff Detection Systems first convened in January 2007 and held additional meetings over a period of 5 months. During these meetings, the committee received briefings from government officials, academics, and outside experts on current and potential biological standoff detection systems, how such systems can be evaluated, and test agents. The committee also toured the Dugway Proving Ground in Dugway, Utah.

January 16-17, 2007, in Washington, D.C. Briefings received from the following. Product Director – Test Equipment, Strategy and Support (PD TESS): briefings on the purpose of the study and charge to committee members and PD TESS' perspective of future directions and key limitations; West Desert Test Center, Dugway Proving Ground: current biological standoff detection capabilities and requirements; Joint Biological Standoff Detection System (JBSDS) Team: current biological standoff detection testing systems.

March 1-2, 2007, in Washington, D.C. Briefings received from the following. Johns Hopkins University Applied Physics Laboratory: briefing on technical evaluation of biological standoff detection systems; Army Test and Evaluation Command: the Army and Air Force perspective on operational evaluation of biological standoff detection systems; Institute for Defense Analyses: briefing on the Office of the Secretary of Defense perspective on test and evaluation of biological standoff detection systems; Joint Program Manager – Biological Detection Systems: overview of JBSDS Increment 1; Defense Advanced Research Projects Agency: briefing on femtosecond adaptive spectroscopy techniques for remote agent detection; National Center for Atmospheric Research: provided the description of Raman-shifted Eye-safe Aerosol Lidar (REAL) plume algorithms; Massachusetts Institute of Technology Lincoln Laboratory: briefing on the standoff aerosol active signature testbed.

March 20-21, 2007, at the Dugway Proving Ground, Dugway, Utah. Committee members were given a tour of the Joint Ambient Breeze Tunnel, the Active Standoff Chamber, the Containment Agent Chamber, and an overview of laboratory and range operations. The committee also received a briefing on regulatory and treaty issues.

April 24-25, 2007, in Washington, D.C. Briefings received from the following. Center for Disease Control: briefing on biosafety levels and Biosafety and Microbiological and Biomedical Laboratories guidance; Pentagon Force Protection Agency: alternative test and evaluation approach; Sandia National Laboratories: briefing on agent-simulant cross section measurements; Dugway Proving Ground: information on agent and simulant preparation.

May 22-23, 2007, in Washington, D.C. Committee deliberations and report drafting.

Appendix E

Role of Test and Evaluation in Department of Defense Acquisition

The Department of Defense (DOD) major system acquisition process is described briefly here to explain the role of test and evaluation (T&E). Further information is widely available. A recent Congressional Research Service report provides a good overview of defense acquisition (Chadwick 2007).

The acquisition of a new capability starts with the generation of a mission needs statement, which identifies and supports the need for a new or an improved capability. The acquisition process is initiated on approval of the mission needs statement by the secretary of defense (referred to as Milestone A). On approval of the secretary of defense, a DOD component runs the program. The Joint Program Executive Office Chemical and Biological Defense (JPEO CBD), which coordinates biological defense efforts of the four services, is the DOD component responsible for the T&E of biological standoff detection systems.

The next phase in the acquisition process is a competitive exploration of alternative system concepts. Demonstration and validation follow approval of the alternative system concepts. Pending the outcome of the demonstration and validation, a preferred system is recommended. On approval of the secretary of defense (Milestone 1), full-scale engineering development of the preferred system starts. Procurement of long-lead production items and limited production for operational test and evaluation (OT&E) are approved at this time (Milestone B).

On successful completion of the full-scale engineering development and on the basis of the outcome of the OT&E, JPEO CBD may recommend production of a detection system. If approved by the secretary of defense (Milestone C), production of the system begins, and the services are authorized to deploy the system.

Two types of measurements are required to verify and validate the performance of lidar systems. First, metrics must be provided to establish the quality of the modeling and simulation products used to relate the performance of the lidar during both T&E and later operation. The metrics will identify the underlying assumptions that produce a positive detection event from a certain type of data and the confidence level and variability in that decision-making process. Second, metrics must be provided to yield functional data that go into a model to produce a positive call. These measurements should identify the variation in each element of the data and explain how uncertainties are compounded. Often, they are measurements of performance and effectiveness and of the merit of the system under test (for more information, see *http://vva.dmso.mil/Special_topics/Measures/default.htm*).

Measures of merit (MOMs) relate the effects of a concept or system to the mission that the concept or system supports. MOMs measure concept or system capabilities in terms of the effects of the capabilities on the overall mission of which the concept or system is a part. They cover mission attributes that define the overall objectives of the simulation. For example, an

attribute of a standoff detector is usability. Measures of detector usability might include weight, power use, mean time between failures, and difficulty in reading data.

Measures of effectiveness (MOEs) assess a system's effectiveness in the accomplishment of a task. MOEs measure capabilities in terms of task accomplishment or system attributes. Tested capabilities should be related directly to operational capabilities in terms of engagement or battle outcome. MOE evaluation criteria (acceptability criteria) should be quantitative if possible. For example, measures of standoff detection include accuracy, false-alarm rates, response time, reliability, range of detection, and discrimination between target and threat.

Measures of performance (MOPs) gauge system or component capabilities or characteristics. MOPs are quantitative or qualitative measures of simulation capabilities and characteristics. They are based on capabilities and characteristics that are defined by the requirements of the intended application or that meet user-defined system performance requirements. Quantitative MOPs are used when it is difficult to assess an MOE directly or when quantitative criteria need to be established. Qualitative MOPs are categorical measures of performance that refer to the presence or absence of specified characteristics. Quantitative MOPs can frequently be related to a numerical scale. A MOP for a standoff detector would be how many simultaneous plumes can be detected, tracked, and analyzed. A qualitative MOP would be how much more rapidly a standoff detector allows a battlefield commander to decide to change a protective posture. Subjective measurement techniques are generally used to address qualitative MOPs.

Associated with each measure is a criterion that shows how well the measure needs to be addressed by the simulation if it is to be acceptable for the intended use. Those criteria are typically called acceptability criteria because they define a minimal level of performance, degree of effectiveness, level of success, or the like that the simulation needs to achieve to be acceptable to the user.