Detecting Future Biological Threats

Neutron Scattering Research and Technologies

June 9, 2020

Fiscal Year 2020 Report to Congress

Homeland Security

Countering Weapons of Mass Destruction Office

Message from the Acting Assistant Secretary

June 9, 2020

I am pleased to present the following report, "Detecting Future Biological Threats," which has been prepared by the Countering Weapons of Mass Destruction Office (CWMD).

This document has been compiled pursuant to language in Senate Report 116-125, which accompanies the Fiscal Year 2020 Department of Homeland Security Appropriations Act (P.L. 116-93). The requirement directed CWMD to report how neutron scattering research and technologies, such as cryo-electron microscopy, can be used to develop the tools to combat future biological threats.

The research and development performed by CWMD focuses on developing and improving the deployed sensor technologies that can provide prompt and effective early detection of a biological attack within the country, and importantly, by field operators. Although neutron scattering and cryo-electron microscopy techniques can provide much information about biothreat materials, these technologies employ large, fixed systems requiring the full infrastructure of an established laboratory. Although CWMD is not pursuing these technologies in current research, it will continue to monitor developments in the field for their potential future research applications.

Pursuant to congressional requirements, this report is being provided to the following Members of Congress:

The Honorable Lucille Roybal-Allard
Chairwoman, House Appropriations Subcommittee on Homeland Security

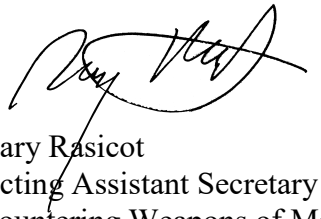
The Honorable Chuck Fleischmann
Ranking Member, House Appropriations Subcommittee on Homeland Security

The Honorable Shelley Moore Capito
Chairman, Senate Appropriations Subcommittee on Homeland Security

The Honorable Jon Tester
Ranking Member, Senate Appropriations Subcommittee on Homeland Security.

I would be pleased to respond to any questions that you may have. Please do not hesitate to contact my office at (202) 254-8866.

Sincerely,



Gary Rasicot
Acting Assistant Secretary
Countering Weapons of Mass Destruction Office

Executive Summary

The use of biological weapons against the U.S. homeland presents a significant challenge to national security. Biological material is omnipresent in the environment, and pathogens can self-propagate. Even a natural outbreak can lead quickly not only to a public health crisis, but also to a biosecurity vulnerability because of the thousands of clinical samples that are generated during an epidemic. The effective detection and attribution of biological threats depend on strong technical detection capabilities and the ability to connect biological information with all other actionable or discriminating information to contribute an additional layer to U.S. weapons of mass destruction (WMD) defense.

CWMD conducts biological research to support operators in the field performing their mission of protecting the United States against a biological WMD attack. This research focuses on developing and improving the deployed sensor technologies required to provide prompt and effective early detection of a biological attack within the country. Efforts will emphasize reducing the time of detection and improving the fidelity of that detection while reducing overall costs. Examples of potential research areas include studies of unique signatures of biological material to improve sensor triggers, data collection, and analysis to enhance the understanding of the biological backgrounds in urban environments; improving the ability to detect through fusion of data from heterogenous sensors networks; and studies comparing theoretical models of sensor system responses against actual data.

Neutron scattering and cryo-electron microscopy techniques can enhance the understanding of biothreat agents. However, the large, stationary laboratory systems required by these technologies are not deployable and will not improve the sensor technologies required to provide prompt and effective early detection of a biological attack within the country. CWMD, accordingly, maintains awareness of these efforts.

Detecting Future Biological Threats

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I. Legislative Language

Senate Report 116-125, which accompanies the Fiscal Year 2020 Department of Homeland Security (DHS) Appropriations Act (P.L. 116-93), includes the following requirement:

> Detecting Future Biological Threats.—The Committee is aware of the potential threats to our Nation posed by the editing of genes to create new biological agents. Accordingly, it is critical for the Department to develop the necessary capabilities to identify, protect, and respond to these potential biological threats. Advances in neutron scattering research and associated data analytics provide an avenue by which the biodefense community can develop the necessary tools to identify threats posed by gene-edited biological agents. The Committee directs the CWMD Office to provide a report not later than 180 days after enactment of this act on how neutron scattering research and technologies, such as Cryo-Electron Microscopy, can be used to develop the tools to combat future biological threats.

II. Background

The use of biological weapons against the U.S. homeland presents a significant challenge to national security. Biological material is omnipresent in the environment, and pathogens can self-propagate. Even a natural outbreak can lead quickly not only to a public health crisis, but also to a biosecurity vulnerability because of the thousands of clinical samples that are generated during an epidemic. The effective detection and attribution of biological threats depend on strong technical detection capabilities and the ability to connect biological information with all other actionable or discriminating information to contribute an additional layer to U.S. weapons of mass destruction (WMD) defense.

The National Security Strategy (2017), National Biodefense Strategy (2018), National Strategy for Countering WMD Terrorism (2018), and National Strategy for Counterterrorism (2018) all list the WMD and biodefense mission as one of the highest priorities of the U.S. Government. These biodefense efforts include research to strengthen the ability to recognize and mitigate situations involving biothreats. As the biological threat continues to evolve, so must our biodefense capabilities. Research to improve biodetection technology is crucial to address these evolving threats, especially efforts to support capabilities deployed in a wide range of operational environments, including cities and urban areas and targets of special interest such as federal buildings or areas where the public gathers such as sports stadiums.

DHS's Countering Weapons of Mass Destruction Office (CWMD) conducts biological research to support the operators in the field performing their mission of protecting the United States against a biological WMD attack. This research focuses on developing and improving the deployed sensor technologies required to provide prompt and effective early detection of a biological attack within the country. Efforts concentrate on reducing the time of detection and on improving the fidelity of that detection while reducing overall costs. Examples of potential research areas include studies of unique signatures of biological material to improve sensor triggers, data collection, and analysis to increase understanding of the biological backgrounds in urban environments; improving the ability to detect through fusion of data from heterogenous sensors networks; and studies comparing theoretical models of sensor system responses against actual data. These efforts will include basic, applied, and developmental research. They will be coordinated with the DHS Science & Technology Directorate, which conducts research in the broader areas of chemical and biological sensors, including high-fidelity laboratory systems.

III. Neutron Scattering Research and Technologies

Neutron scattering is an established technique to provide structural information on small items such as molecules. The method employs neutrons, typically generated by a nuclear reactor or nuclear accelerator, as probes used to interrogate target material. Neutrons have specific advantages in this use because there is no electrostatic interaction between the neutron and the material that it is being used to probe. Instead, neutrons are deflected ("scatter") physically off the nuclei of the targeted material. The technique allows a direct view of the material's structure by measuring the neutron's scattering angle.

Although neutron scattering techniques have the ability to determine structural information about biothreat materials, laboratory-scale instrumentation is required for these measurements. The required components are complex, large, and, expensive. First, a significant source of neutrons is required for scattering measurements, usually generated either by a nuclear reactor or by a large nuclear accelerator. For example, the neutron source employed by the National Institute of Standards and Technology Center for Neutron Research (NCNR) for its neutron scattering measurements is a nuclear accelerator, the NCNR Advanced Cold Neutron Source. The facilities required to operate the nuclear accelerators and the nuclear reactor are very large and expensive. For example, the Oak Ridge National Laboratory Spallation Neutron Source was completed in 2006 at the cost of $1.6 billion. The nuclear accelerator target used to produce neutrons requires 20 tons of mercury.[1]

Second, the detector systems required to provide the necessary spatial resolution for neutron scattering measurements are also quite large and complex. For example, NCNR maintains several small angle neutron scattering detector systems. The Neutron Guide–B 30-meter, Small Angle Neutron Scattering instrument at NCNR requires a 16-meter-long pre-sample flight path and a 15-meter-long detector to provide spatial resolutions on the order of about 1 nanometer (nm) to about 700 nm needed to determine the structure of biothreat materials.[2]

The scale of such systems is outside of the scope of CWMD's research and development (R&D) mission. As noted above, CWMD focuses on tools that can be put in the hands of operators in the field, such as first responders. Such "big science" tools are more squarely within the mission space of other federal agencies.

[1] T. E. Mason, T. A. Gabriel, R. K. Crawford, K. W. Herwig, F. Klose, and J. F. Ankner, "The Spallation Neutron Source: A Powerful Tool for Materials Research," July 2000. Available at http://arxiv.org/abs/physics/0007068.
[2] National Institute of Standards and Technology, Center for Neutron Research. January 2020. Available at https://www.nist.gov/ncnr/ngb-30m-sans-small-angle-neutron-scattering.

IV. Cryo-Electron Microscopy

Transmission electron microscopes (TEM) use a beam of electrons to examine materials. Because the electrons have a much shorter wavelength than visible light used in conventional microscopes, transmission electron microscopes have very high resolution that gives the ability to reveal much finer detail about a material. However, conventional TEMs are not suitable for investigations of biomolecules. They require the biological sample material to be placed in a high vacuum and to be subjected to intense electron beams. These conditions destroy the samples during the measurement process, often before data can be collected.

In 2017, Joachim Frank, Jacques Dubochet, and Richard Henderson received the Nobel Prize in Chemistry for the development of cryo-electron microscopy. This method, which involves the rapid freezing of a biological sample in water, makes it possible to use specialized electron microscopes to investigate biological structures, including the structure of viruses. This is a revolutionary technique that holds significant promise for the study of biological materials.

Cryo-electron microscopes are large, fixed-in-place laboratory instruments that are quite expensive, with microscopes costing about $7 million each.[3] Although the biological research community is working to reduce the overall costs of these systems, they will remain as laboratory instruments for the foreseeable future. As with small angle neutron scattering systems, cryo-electron instruments would be outside the scope of CWMD's R&D focus on tools that can be deployed in support of operators.

[3] Eric Hand. "'We Need a People's Cryo-EM.' Scientists Hope to Bring Revolutionary Microscope to the Masses." *Science*. American Association for the Advancement of Science. January 23, 2020. Available at https://www.sciencemag.org/news/2020/01/we-need-people-s-cryo-em-scientists-hope-bring-revolutionary-microscope-masses.

V. Conclusion

CWMD R&D efforts focus on improving biodetection sensor technologies deployed to cities and other sites of concern. This research emphasizes developing and improving prompt and effective tools for the early detection of a biological attack within the country. Future R&D efforts will focus on reducing the time of detection and improving the fidelity of that detection while reducing overall costs.

The large, stationary laboratory systems used for neutron scattering and cryo-electron microscopy will not improve the sensor technologies needed to be deployed in the field to provide prompt and effective early detection of a biological attack within the country. Although these technologies can enhance the understanding of biothreat agents, they are large, fixed systems requiring the full infrastructure of an established laboratory. CWMD, accordingly, maintains awareness of these efforts.

Appendix: Abbreviations

Abbreviation	Definition
CWMD	Countering Weapons of Mass Destruction Office
DHS	Department of Homeland Security
NCNR	National Institute of Standards and Technology Center for Neutron Research
nm	Nanometer
R&D	Research and Development
TEM	Transmission Electron Microscope
WMD	Weapon of Mass Destruction