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Research to Advance Decontamination, Sampling, and Analytical Approaches Following Biological Terror Incidents

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In the fall of 2001, several envelopes containing spores of *Bacillus anthracis* (the causative agent of anthrax) were sent through the U.S. mail to locations in New York, New Jersey, Florida, and Washington D.C. As a result, numerous government and private buildings were contaminated to varying degrees [1]. Full remediation of these facilities cost over $650 million, and took more than three years to complete [1,2]. This relatively small incident underscores the need for bioterror preparedness, as a biological attack on a much larger spatial scale which would require significantly more time and resources for recovery [3-5].

Under the National Response Framework, the U.S. Environmental Protection Agency (EPA) is tasked as the lead agency for the federal response to a hazardous substance release [6]. In addition, Homeland Security Presidential Directive 10 tasks EPA to take the federal lead for developing specific standards, protocols, and capabilities to address the risks of contamination following a biological weapons attack; and to develop strategies, guidelines, and plans for decontamination of persons, equipment, and facilities following such an attack [7]. To address these emerging needs, the EPA increased its investment in homeland security preparedness, response capability, expertise, and research. One such investment, the National Homeland Security Research Center (NHSRC) within EPA's Office of Research and Development (ORD), was created in 2002 and currently leads EPA's Homeland Security Research Program (HSRP). A critical mission of the HSRP is to develop products and knowledge, through applied research, that enhance our nation's ability to respond to and recover from biological attacks affecting indoor and outdoor environments. HSRP research is designed to aid incident responders at 1) effectively detecting, identifying, and characterizing contamination; 2) rapidly containing contamination and mitigating the effects of contamination spread; and 3) efficiently remediating and recovering (decontaminate, treat, and dispose of contaminated material) after contamination incidents [8].

EPA's HSRP has made numerous advancements to the areas of sampling, detection, and decontamination [9-19]. However, several significant gaps and challenges remain. Specifically, numerous challenges related to determining the extent and magnitude of biological contamination following an incident need to be adequately addressed. One of the major issues relates to the strategies used for selecting how and where to collect samples following a contamination incident [20-22]. Potential sampling strategies may incorporate targeted (or judgmental) sampling, statistical sampling, or a combination of sampling strategies to ensure representativeness of the area and certainty of the sampling results [23]. Additionally, new methodologies are needed to rapidly detect *B. anthracis* spores in contaminated sites during and after remediation.

Improvements in surface sampling and recovery efficiencies, as well as enhanced methods for concentration of agents during dislodgement and extraction procedures, would lower limits of detection and increase confidence in sampling results. The HSRP has recently developed rapid viability polymerase chain reaction (RV-PCR) which provides a faster, more cost-effective, and more sensitive method to detect viable *B. anthracis* spores within environmental samples [19,24,25]. With estimated daily samples processing loads in the hundreds to thousands following a large-scale biological release, innovative technologies are needed to increase laboratory throughput and improve turnaround times. Traditional technologies are labor- and time-intensive, causing laboratory throughput issues and sample backlogs, making rapid sample turnaround, and therefore, responsiveness, challenging [4]. Specifically, using such technologies with the current nation-wide laboratory capacity will require many months to years to analyze the large number of samples that will be generated during response and recovery to a wide area incident. Development of sampling techniques that reduce laboratory burden, yet provide robust data on the spatial extent and magnitude of contamination would expedite recovery operations. Other sampling and detection challenges include a lack of method specificity for *B. anthracis* (especially amongst a high background of other microorganisms), difficulty detecting and/or recovering *B. anthracis* from complex material surfaces, lack of validation for all available sampling methodologies (surface and air), and uncertainties in correlating surface contamination levels with risk of exposure. Closing these sampling gaps, through systematic research and subsequent knowledge transition to responders, will increase our ability to detect and characterize the magnitude and extent of contamination before and after remediation. This capability also improves the ability to select and implement optimum remediation methods appropriate for the level of contamination and types of materials contaminated.

Currently, there is a paucity of empirical data characterizing agent resuspension from surfaces in the time following an incident. In the wide-area scenario, understanding the degree to which spores resuspend from outdoor surfaces would allow development of informed response and recovery operations. Without such data, it is impossible to estimate the risk of chronic and/or acute exposure within the affected areas. Accordingly, further research into agent resuspension is warranted, in order to inform decisions to reduce risk.

Other challenges are logistical in nature, including how to best decontaminate structures and the most effective response to a wide-

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area release. Past experience from the 2001 incident highlighted the extensive time and costs associated with building decontamination efforts [1,2]. Remediation was also complicated by the many different types of materials requiring decontamination, and the lack of products and technologies that were proven to be effective against *B. anthracis* spores [1] on such complex materials [22]. Wide-area biological releases present unique and significant challenges with respect to scale, availability of resources, and the time required to remediate a large outdoor area [4,21]. While volumetric (fumigation) decontamination using chlorine dioxide, hydrogen peroxide vapor, and formaldehyde have shown to be very effective for specific applications in facilities [1,2,26], in a wide-area incident, the number of available fumigant generators may be insufficient to rapidly decontaminate all affected buildings [4,27]. In addition, outdoor areas and items (streets, vehicles, etc.) would likely require surface treatment, as volumetric methods may not be feasible for most open areas [4]. Accordingly, lower tech methods such as liquid-based decontamination approaches may be deployed in order to ease application over wide areas, and therefore increase decontamination capacity [4,27]. While liquid-based sporicides are promising for some material types, other more complex materials are difficult to decontaminate using these methods [15,18,28]. Thus, more research is needed to identify and evaluate novel liquid- and foam-based sporicides, application methods, and scalability; as increasing our options for decontamination will greatly enhance our ability to rapidly recover from a large-scale incident.

Disposal of contaminated waste during a remediation is a topic often overlooked. Waste disposal can greatly influence cost-effectiveness of a particular decontamination option, as the amount of waste generated varies greatly between decontamination approaches. As such, options and methods for waste disposal should be considered from the beginning of any response [5,29]. Current on-going research is aimed at improving the understanding of the effectiveness of currently-available waste treatment technologies, lowering the cost of waste disposal operations, reducing the amount of waste requiring stringent treatment before disposal, and informing incident responders of ways to optimize waste handling/segregation procedures while minimizing waste generation. Additional research in this area could yield information or technologies that significantly enhance waste management.

A crucial final issue is the confirmation, following decontamination, of the effectiveness of methods employed and how best to determine when to proclaim a building or outdoor area clear for re-occupancy or reuse [30]. The current precedent for clearance standards following decontamination state that there be "no detection of viable spores" from any environmental sample where decontamination methods have been used [23]. Notably, differences in material surface types sampled, sampling and analysis methods utilized, the number of samples collected, and other factors can affect the confidence in sampling results. An additional issue is whether the previously-used clearance standard is achievable, and therefore appropriate, for outdoor areas or over wide-areas. Innovative sampling strategies and methodologies are needed to address these challenges.

Ongoing research within EPA's HSRP seeks to address current sampling (strategies and methods), decontamination, and waste management gaps in order to enhance our preparedness to respond to and recover from a biological contamination incident, from a small-scale structure to a wide-area biological terror incident. Filling these significant research gaps requires the continuation of innovative lab- and field-scale research efforts, further improving effective communication between researchers and incident responders (end users) to get the information to the field (technology transfer), and advancing coordination between the various federal agencies within the homeland security mission space.

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