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technical BRIEF

INNOVATIVE RESEARCH FOR A SUSTAINABLE FUTURE

Decontamination Strategies, Methods, and Related Technical Challenges for Remediation Following a Wide-Area *Bacillus anthracis* Spore Contamination Incident

Purpose

This technical brief provides decision makers with a practical summary of recent US EPA scientific information and data related to remediation strategies and methods following a wide-area *Bacillus anthracis* spore contamination incident.

Summary

This technical brief is a summary of US EPA research publications providing input to solving the technical challenges involved with remediating a large urban area following a contamination incident involving spores of *B. anthracis*, the causative biological agent for anthrax disease. The research topics included in this summary are as follows:

- Attenuation and transport of *B. anthracis* spores in an outdoor environment, with implications for remediation
- Decontamination studies evaluating the following aspects:
    - spore inactivation efficacy
    - spore removal efficiency
    - field demonstrations for remediation of specific infrastructure
    - decontamination issues specific to outdoor materials and conditions
    - increasing decontamination capacity for wide-area events
- Large-scale spray application of decontaminants
- Modelling tools for wide-area decontamination decision making, prioritization, and planning

Introduction

The US EPA's Homeland Security Research Program helps to develop remediation capabilities to recover from wide-area contamination originating from natural disasters, intentional releases, or accidents involving oil or hazardous substances. These hazardous substances can include chemical, radiological, nuclear, and biological materials (such as *B. anthracis* spores). The homeland security research program develops remediation tools with consideration for efficacy, safety, resource demand, logistics, training, and availability of the technology (US EPA, 2020).

Following a large, outdoor release of *B. anthracis* spores, assessments will be needed to determine the extent of the contamination and the expected efficacy of various decontamination techniques. If remediation is not 100% effective, i.e., if low levels of spores are still present in certain locations, multiple lines of evidence may be used to determine if additional decontamination is needed (US EPA, 2021; EPA/600/R-21/124).

After the initial wide-area release and deposition of spores onto surfaces, *B. anthracis* spores may continue to spread through the air due to reaerosolization (US EPA, 2014; EPA/600/R-14/259). Spore transport may also occur over the surface and through the subsurface environment due to precipitation events. Without any remediation, over time the area contamination may enlarge while the quantity of the spores per unit area may diminish. Decisions will need to be made whether decontamination is even necessary for some areas, based on several criteria, such as risk, cost, decontamination efficacy, and sampling/detection limits. Risk may be low if exposure is inconsequential, and/or if medical countermeasures are in place, e.g., the use of vaccines or antibiotics.

In general, remediation measures for a wide-area *B. anthracis* contamination incident may consist of applying chemicals to inactivate the spores; physical removal of the spores or materials containing the spores for off-site treatment and/or disposal; allowing attenuation of the spores from exposure to sunlight and other natural phenomena; and any combination of the above. All these approaches are discussed below.

Persistence and natural attenuation of *B. anthracis* spores and vegetative cells

In a wide-area release of *B. anthracis* spores, natural attenuation or inactivation of the spores may occur if the spores are directly exposed to sunlight. Although *B. anthracis* spores are known to persist in soil for decades, they may become inactivated upon exposure to solar radiation (National Response Team, 2022). In laboratory tests using simulated sunlight, *B. anthracis* spores on glass were inactivated to nearly a 4 $\log_{10}$ reduction (LR) in just a few days, while there was minimal inactivation of spores in soil after 2 months (Wood et al., 2015).

Certain chemical or environmental conditions found naturally in soils (US EPA, 2014; 600/R-14/216), or chemicals (referred to as germinants) added intentionally to soils or other matrices, can initiate conversion of *B. anthracis* spores to vegetative cells. Vegetative cells are less resistant to chemical or environmental inactivation than bacterial spores, and so the vegetative cells could then be inactivated more easily via natural attenuation processes. In a study examining this phenomenon, vegetative *B. anthracis* cells persisted less than 12 hours on wood, concrete, and glass, and no more than 5 days in soil, without any exposure to sunlight (US EPA, 2014; R-14/150).

In a study to assess the recovery of *B. anthracis* surrogate spores over time in the outdoor environment as a function of sampling method and material, several orders of magnitude loss in recovery of spores occurred after 210 days (Mikelonis et al., 2020). The study authors suggested diminished recovery of spores at the same location over time was due to transport/removal of spores from the area of interest and/or inactivation by ultraviolet light from the sun.

Movement of spores through the air

In general, air dispersion models predict that an aerosol release of a particulate contaminant (such as *B. anthracis* spores) would result in higher surface deposition in the immediate area of the release to progressively lower levels as the distance from the release increases (US EPA, 2020; R-20/338).

Once spores have settled on surfaces after the initial release, they can be reaerosolized and spread further, depending on several factors and phenomena (US EPA, 2014; EPA/600/R-14/259). Vehicles, human movement, and other fomites are significant drivers of reaerosolization (US EPA, 2016; R-16/129). Temperature, relative humidity, air movement, and physical disruption also affect the amount of reaerosolization and tracking of spores from contaminated to uncontaminated areas (US EPA, 2012; R-12/064). Thus, in planning remediation approaches following a wide-area release, decontamination procedures should consider the possibility that spores can be reaerosolized from contaminated areas to areas that were previously uncontaminated or previously decontaminated.

Correspondingly, spores have been demonstrated to migrate from the outdoor environment to contaminate the interior of buildings. One study conducted to assess aerosol infiltration into buildings found that Indoor/outdoor particle count ratios ranged from 0.3-0.6 (Rodes et al., 2009). Spores may also migrate in the opposite direction, i.e., they may exfiltrate from the interior of a contaminated building to the outdoor environment during decontamination (Silvestri et al., 2015).

Figure 1. Small wind tunnel used to assess reaerosolization of bacterial spores off materials

Movement of spores via surface water runoff

EPA research has shown that bacterial spores can be further distributed over the outdoor surface environment due to precipitation events (Mikelonis et al., 2020; spore surface interactions). Laboratory tests showed that up to 15% removal of spores from asphalt and concrete materials occurred after an hour of simulated rainfall (Mikelonis et al., 2021; rainfall wash-off).

The modeling of *B. anthracis* spore wash-off and transport processes can help to determine areas where contamination is likely to persist over time or where spores may accumulate in overland flow following a wide-area contamination incident. This may inform decisions about remediation and sampling activities. Surface flow will eventually enter stormwater infrastructure, with spores moving in unanticipated ways due to flow control structures, routing systems, and redirection to storages (Shireman et al., 2021). Measures for containment of stormwater runoff to prevent spore migration to allow for further eventual treatment are being developed (Mikelonis et al., 2021; stormwater containment).

Techniques to Remove Spores from Outdoor Surfaces

Following a wide-area incident, spores can be physically removed from roadways and other outdoor surfaces via water spraying techniques. Such techniques could include the collection of spores using street sweeping/washing equipment. In a pilot-scale study using a walk behind floor scrubber to represent a street sweeper, surrogate *B. atrophaeus* spores were removed from surfaces with an efficiency of 74-99% when dispensing water, depending on the surface material (asphalt or concrete). When the model street sweeper dispensed decontaminants such as dichlor or pH-amended bleach (PAB), over 7 LR was achieved on the surfaces. However, it should be noted that in nearly all the tests, spores were reaerosolized (US EPA, 2018; EPA/600/R-18/271 2018).

In another study using a parking lot as the test surface, it was shown that a pressure washer could remove an average of 12.5% of spores from the surface, compared to approximately only 1.3% with just the use of a garden hose. It was also found that certain wash aids improved the removal efficiency, but only by 1-2% compared to tap water alone (Mikelonis et al., 2021; influence of wash aids).

In tests using a garden hose equipped with a brass nozzle (~ 4 liters per minute at 1 foot distance), and spraying either tap water, surrogate brackish water, or surrogate seawater (no detergent), removal efficiency of *B. atrophaeus* spores from marine grade aluminum was about 90%, with the type of water having no effect. When spores were inoculated onto a rubber material, removal efficiency ranged from around 2-3 LR, depending on the type of water sprayed (US EPA, 2022A).

Wash water may be generated during site remediation activities, such as for spore removal purposes as discussed above, and for equipment or PPE decontamination (US EPA, 2019; Tech Brief S-19/067). This wash water may be collected using procedures similar to stormwater collection, and then subject to treatment. The EPA has developed several treatment methods designed to overcome operational challenges associated with bio-contaminated wash water (US EPA, 2019; Tech Brief S-19/067). Wash water that is not collected would aid in the transport of spores through the environment, similar to spores on exterior surfaces entrained in stormwater during precipitation events.

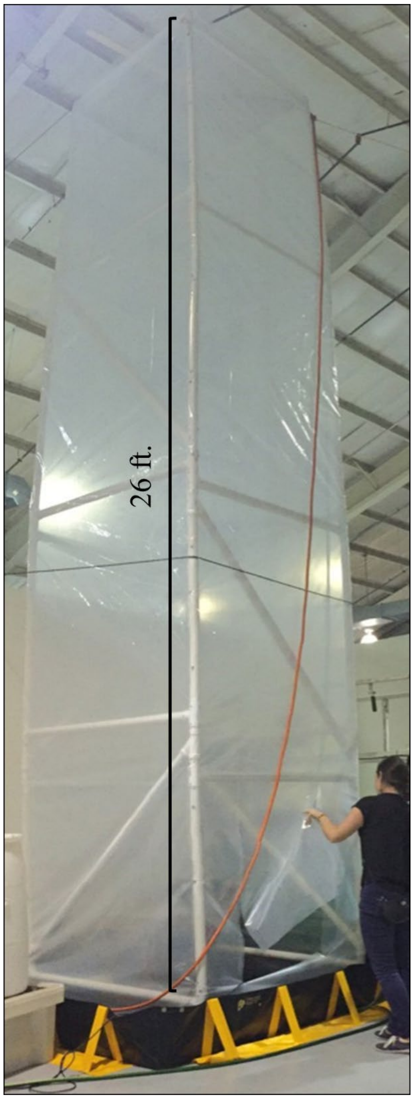

Figure 2. Rainfall simulator test apparatus to assess wash-off of spores from outdoor materials

Decontamination Efficacy Using Chemical-Based Decontaminants

Although the efficacy of a decontaminant is critical in its selection, there are other criteria for selecting a decontamination method. These may include whether the technology has been demonstrated at full-scale, its cost, its availability (technology, chemicals, expertise, personnel), material compatibility, health and safety issues (most decontamination chemicals are hazardous), and environmental impacts. The EPA has extensively evaluated the efficacy of decontamination technologies (mostly chemical based) for *B. anthracis* spore inactivation and in 2019, published a review of their and others' research in this area (Wood and Adrion, 2019). That review provided a synthesis of liquid and gaseous-based chemical decontaminants, as well as a few physical-based techniques, that are commercially available and could be used at a relatively large scale (e.g., following a wide-area event). In that review, decontamination efficacy data were discussed and presented as a function of material, environmental conditions, and decontaminant application conditions such as chemical concentration and contact time.

The most likely and effective decontaminant gases or fumigants that would be employed in a wide-area event would include chemistries such as chlorine dioxide (ClO_2, methyl bromide (MeBr), hydrogen peroxide vapor (HPV), and formaldehyde. The more common and effective liquid-based decontaminants that would likely be used include those utilizing hypochlorous-acid chemistry (diluted bleach, PAB, dichlor, and calcium hypochlorite) or peroxides (e.g., concentrated hydrogen peroxide (> 35%), peracetic acid (PAA), and activated sodium persulfate). Liquid decontaminants can be applied via numerous techniques, e.g., as a spray, immersion, gel, foam, fog, or wipe. Lesser-used but effective sterilant techniques that may have niche uses following a wide-area event include ultraviolet light (in the C range, e.g., produced from mercury lamps), ozone gas, ethylene oxide, and ionizing radiation.

Field Studies Conducted for Decontamination of Specific Infrastructure

Small Building Interiors

As mentioned above, in a wide-area release *of B. anthracis* spores, the interior of houses and buildings may become contaminated through various means of infiltration. Several field studies have been completed to demonstrate the decontamination of small structure interiors. In the large multiagency Bio-response Operational Testing and Evaluation (BOTE) study, the decontamination of a 2-story office building was demonstrated using three different decontamination techniques, which included ClO_2 gas, HPV, and the powered-spraying of PAB (US EPA, 2013; 600/R-13/168). The building was tented to minimize the loss of decontaminant chemicals to the exterior.

MeBr gas was effective in the field scale demonstration for the decontamination of a 1,444 m^3 building. In that demonstration, no damage to the building or its contents was observed (Serre et al., 2016). Following fumigation, the MeBr was collected with activated carbon (Wood et al., 2016) to minimize its release to the atmosphere.

The simple-to-use decontamination technology referred to as low concentration hydrogen peroxide vapor (LCHPV) was demonstrated in a full-scale test house (Mickelson et al., 2019). This technique is inexpensive and developed from commercial, off the shelf (COTS) equipment and chemicals, and if implemented by lay personnel (home or business owners), would greatly increase decontamination capacity following a wide-area release of *B. anthracis* spores.

Subway infrastructure

The decontamination of a mock subway tunnel and station was successfully demonstrated using two different decontamination techniques (fogging of diluted bleach and powered-spraying of PAB) as part of the large multiagency Underground Transport Restoration Operational Technology Demonstration (UTR-OTD) study (US EPA, 2017; EPA/600/R-17/272). Also, as part of the UTR project, the use of MeBr to decontaminate an out of service subway railcar was successfully demonstrated (US EPA, 2017; EPA OEM report March 15, 2017). Several other decontamination studies conducted under the UTR program for subway materials and systems etc., are summarized in a previous Tech Brief (US EPA, 2018; EPA/600/S-18/286). One laboratory study showed that PAB and diluted bleach could be used to successfully decontaminate concrete, ceramic tiles, painted steel surfaces, and ballast materials taken from a subway system. The study showed that efficacy depended on the free available chlorine (FAC) concentration, presence of grime, and other parameters (US EPA, 2018; EPA/600/R-18/251). In another study (US EPA, 2014; EPA/600/R-14/226), fumigating with either ClO_2 gas or HPV was successful in decontaminating subway concrete, with the presence of grime not impacting efficacy.

Maritime infrastructure

Under the Analysis for Coastal Operational Resiliency (AnCOR) program funded by the Department of Homeland Security, Science and Technology Directorate, the EPA conducted lab-, pilot- and field scale testing of decontamination options for the US Coast Guard (USCG) and maritime-related assets. In case of a wide-area release of *B. anthracis* at a port city, the US Coast Guard would likely be the lead federal agency for response activities within the coastal zone. The overall purpose of this multi-agency program was to develop and demonstrate capabilities and strategic guidelines to prepare the U.S. for a wide-area release of a biological agent, including mitigating effects on USCG facilities and assets.

Following an anthrax release impacting a USCG base or station, it would be imperative for the USCG to rapidly return to service their marine assets such as patrol boats and cutters. As part of the AnCOR program, the EPA conducted a field-level demonstration of three methods that could be used to decontaminate a USCG vessel contaminated with *B. anthracis*. Prior to the application of each decontamination procedure, PAB was applied to the exterior surfaces of the boat down to the water line. After spraying the PAB, the USCG boat was further decontaminated with either MB fumigation, PAA fog, or LCHPV. The MB and PAA fog decontamination rounds resulted in no positive samples for the *B. anthracis* surrogate being used, and with LCHPV, only a few samples were positive. In all three test rounds, none of the test electronics were impacted by the decontaminants (US EPA, 2021).

One of the lab studies conducted under the AnCOR program evaluated the efficacy of the Navy ship-based decontaminant calcium hypochlorite, aka high-test hypochlorite (HTH), on outdoor materials (asphalt and concrete) and USCG boat-related materials, using *B. atrophaeus* as a surrogate for *B. anthracis*. In 90% of the tests, the HTH solution (~ 24,000 parts per million FAC) decontaminated the material such that no spores were detected. This contrasts with PAB, in which only about 40% of the test results achieved no spores detected (US EPA, 2022A).

Figure 3. Field test demonstration of Coast Guard patrol boat decontamination

Difficult-to-Decontaminate Outdoor Materials and Conditions of Concern

Soil

The efficacy of a decontaminant in inactivating *B. anthracis* spores is highly dependent on the material with which the spores are associated, and soil remains one of the most difficult materials to decontaminate. This is due to its relatively high organic content, other variable chemical constituents and physical properties such as density, particle sizes, and porosity (Wood and Adrion, 2019). The EPA has been evaluating soil decontamination methods for over 10 years. Some oxidant-based decontaminants such as hypochlorous acid/hypochlorite and PAA (US EPA, 2014; EPA/600/R-14/189) performed poorly in decontaminating soil, while other oxidants such as ClO_2 gas and activated sodium persulfate (US EPA, 2017; R-17/343) were found to be relatively effective. Several alkylating decontaminants have been demonstrated to be effective in decontaminating soil, including MeBr (US EPA, 2017; R-17/343), metam sodium (US EPA, 2013), and formaldehyde (Richter et al., 2022). In general, decontamination efficacy has been shown to diminish with soil depth.

Ex-situ treatment of *B. anthracis*-contaminated soil (e.g., excavation/removal of soil followed by off-site treatment such as incineration) is another remediation option, although this approach may aerosolize and disperse the *B. anthracis* spores during the excavation and transport processes and cause further cross contamination. Thus, *in-situ* treatment of soil contaminated with *B. anthracis* spores, such as with the chemical decontaminants discussed above, or with the use of thermal techniques, are remediation options that would potentially avoid the aerosolization of spores. Wood et al. (2020) demonstrated the feasibility of using dry heat to decontaminate soils contaminated at the surface with *B. anthracis*. Lastly, the addition of chemicals to induce germination of *B. anthracis* spores to the vegetative cell form, which is known to be less resistant than spores to environmental stressors and chemical inactivation, has been investigated as a soil decontamination option as well.

<u>Dirt/grime on materials</u>

Like soil, the presence of organic material in the form of dirt/grime on the surface of other materials may diminish a decontaminant's efficacy, especially if the decontaminant is an oxidant-based liquid. However, lab-scale studies have shown mixed results from the impact of grime, possibly due to variations in the grime recipe used, materials, and the decontaminants evaluated. For example, three studies (EPA/600/R-12/591; US EPA, 2014; EPA/600/R-14/226; EPA/600/R-16/038) using either PAB, HPV, or ClO_2 gas demonstrated little to no impact of grime on decontamination efficacy, while a study investigating MeBr (EPA/600/R-17/187) showed that higher concentrations and/or longer contact times were required to achieve 6 LR on grimed materials. In a study investigating the use of bleach-based decontaminants for subway materials, the presence of grime diminished efficacy by 1-3 orders of magnitude.

<u>Vegetation</u>

A study was conducted to assess decontamination options for vegetative materials, and found that under some conditions, both dichlor- and PAA-based spray decontaminants were effective (no samples were positive for bacterial spores) for small plants (US EPA, 2022B). Pine bark and sod/grass were more difficult to decontaminate than the plants, although PAA was generally more effective than dichlor. Tests were also conducted to assess any detrimental impacts that the decontaminants (PAA and dichlor) may have on the plants (phytotoxicity). While none of the small plants died during the month-long observations following exposure to the decontaminant, there were some mixed results with respect to other phytotoxic effects that varied by plant type, decontaminant, and the type of phytotoxic effect. No obvious trends in effects were noted.

<u>Tests conducted specifically for outdoor materials (asphalt, concrete, brick, wood)</u>

Materials used in outdoor infrastructure are typically porous and may be comprised of organic matter, making their decontamination difficult. Two separate studies were conducted to evaluate decontamination efficacy for such materials, including asphalt, concrete, brick, and wood. In one study (US EPA, 2015; EPA 600/R-15/101), several conditions were found in which activated sodium persulfate was an effective decontaminant for the four materials, with concrete being the most difficult.

Concrete was also found to be the more difficult material to effectively decontaminate in another study to evaluate the efficacy of dichlor, PAB, and diluted bleach for the same four materials (US EPA, 2021; EPA 600 R-21/004). In that study, diluted bleach and dichlor produced similar efficacy results, while the PAB was generally less effective. Decontamination was most successful on the brick material.

Vehicles

Following a wide-area *B. anthracis* incident, many vehicles may become contaminated and left unattended in the impacted area. Vehicles contain a broad array of materials and components that may need to be decontaminated (EPA/600/R-19/068). In addition, many vehicle parts are electrical or mechanical, and contain sensitive materials, making decontamination even more difficult due to material compatibility issues.

Cold temperatures

Following a wide-area release of *B. anthracis* spores, decontamination may need to be undertaken at relatively colder temperatures. Several decontamination studies have confirmed that in most cases (not all), achieving sufficient efficacy at 10 °C or below typically requires longer contact times and/or higher concentrations of the decontaminant active ingredient than what would be required if the decontamination testing occurred at the more typical lab ambient test temperatures of 20-25 °C. This was found to be the case when fumigating with ClO_2 (US EPA, 2016; 600/R-16/038) and MeBr (US EPA, 2016; EPA/600/R-17/187). The efficacy of PAA fog diminished with lowering temperature as well (Richter et al., 2018). Tests with formaldehyde vapor showed that at 10 °C, lower concentrations were achieved, resulting in reduced efficacy (Choi et al., 2020). However, there were a few studies that showed minimal impact in reducing temperature. In one study evaluating PAB (using various formulations to lower the freezing point) at cold temperatures, it found minimal difference in efficacy for tests conducted at 0°, 10 °, and 25 °C (U.S. EPA, 2017; EPA/R-17/211). In a study evaluating formaldehyde solution to decontaminate soil, lowering the temperature from 24 to 10 °C did not affect efficacy in one set of conditions evaluated (Richter et al., 2022).

Figure 4. Laboratory tests to evaluate decontamination of vegetation

Expanding decontamination capacity with easy to use, readily available equipment and chemicals

Following a wide-area release of *B. anthracis* spores, the time required to recover from the incident will be limited by many factors, including the availability of decontamination resources (equipment, chemicals, expertise, personnel). One way to increase decontamination capacity is to develop techniques that can be implemented using readily available, COTS equipment and chemicals, and that don't require extensive expertise or training in their use. These techniques are sometimes referred to as "self-help" or "low-tech" approaches and may only require a trip to the local hardware store. These approaches could potentially be implemented by homeowners, small business owners, and/or their remediation contractors. Several examples of these techniques are summarized below.

<u>Low concentration hydrogen peroxide vapor</u>

The LCHPV approach (Wood et al., 2016) uses COTS aqueous solutions of hydrogen peroxide disseminated with COTS equipment such as humidifiers or foggers. In lieu of relatively high concentrations with short contact times, concentrations of 25-50 parts per million HPV coupled with contact times of several days have been shown to be effective in inactivating *B. anthracis* spores. As discussed above, this technique has been successfully demonstrated at full-scale for decontaminating a house, a Coast Guard boat, and a vehicle.

<u>Off the shelf cleaning products</u>

Several ready to use cleaning solutions comprised of at least 2% sodium hypochlorite were all effective against a *B. anthracis* surrogate on several types of materials (US EPA, 2015; EPA/600/R-15/228). In this same study, germicidal bleach with a dilution of 1:5 provided satisfactory sporicidal activity. Based on this research, subsequent decontamination studies involving diluted bleach typically utilize it with an FAC level of around 20,000 parts per million.

<u>Clothes washing and drying</u>

After a wide-area release, personal clothing may become contaminated with the biological agent. Clothes washers and dryers with a suitable decontamination solution are a potential self-help practice to reduce and/or inactivate biological spores from common clothing material. In a study to evaluate this, it found that a 1% chlorine bleach solution coupled with a laundry detergent was indeed effective in inactivating spore contamination from fabric materials when using an 18-minute wash cycle. The study also found that using a clothes dryer was not advised since it provided no additional spore reductions beyond using a washer and resulted in the reaerosolization of spores (US EPA, 2020; EPA/600/R-20/217).

<u>Pool and spa chemicals</u>

Sodium dichloro-s-triazinetrione, also known as dichlor, is a widely available granular pool disinfection chemical that can be prepared as a sporicide by simply mixing with water. When prepared at a concentration of 2% FAC, it was evaluated for decontamination efficacy for outdoor materials and compared to the more well-known decontaminants PAB and diluted bleach (US EPA, 2021; EPA/600/R-21/004). It was found in that study that dichlor and diluted bleach achieved similar levels of decontamination efficacy for the materials tested and were more effective than PAB.

Cleaning methods to remove spores

Although cleaning approaches are primarily meant to remove or trap bacterial spores and not necessarily inactivate them, lab tests have shown that floor cleaning cloths can remove up to 99.9% of bacterial spores from surfaces (US EPA, 2017; EPA/R17/126), and that wet-vacuum carpet cleaners removed up to 99.99% of spores from carpet (US EPA, 2013; EPA/600/R-13/217).

Use of solid-based decontaminants

The ability to timely remediate wide-area *B. anthracis* contamination will be limited by several factors, including a sufficient supply of decontaminant chemicals. The quantity of decontaminant chemicals available can be broadened by including the use of solid-phase bulk chemicals, in which water is added at the point where decontamination will take place. The use of dry chemical precursors will have the added benefit of reducing transportation costs and hazards. Several dry powder decontaminant chemicals (some are discussed above) include dichlor (US EPA, 2021; EPA 600 R-21/004), calcium hypochlorite (US EPA, 2022A), and sodium persulfate (US EPA, 2015; EPA/600/R-15/101). Sodium chloride (table salt) added to water can be used to generate a hypochlorous-acid based decontaminant by passing an electrical current through an electrochemical cell containing the brine solution (US EPA, 2011; EPA/600/R-11/124). This technology was found to be effective against *B. anthracis* spores on hard, non-porous inorganic materials. Other dry chemical decontaminant options include PAA precursor chemicals such as peracetyl borate and diperadipic acid (US EPA, 2018; EPA/600/R-18/157).

Spray Application of Liquid Decontaminants at Large Scale

Following a wide-area release of *B. anthracis* spores, large-scale commercial, agricultural, and industrial types of spray equipment would likely be used to apply liquid decontaminants to roadways, building exteriors, and the surfaces of other infrastructure. Such sprayers were evaluated for their potential use to apply decontaminants in a subway system (US EPA, 2017; EPA/600/R-17/156). Large radial fan type sprayers and a dust suppression spray cannon were down selected for further evaluation. While the equipment was found to adequately spray surfaces to obtain sufficient decontamination efficacy, the issue of material compatibility of sprayer components (e.g., pump diaphragm) with the corrosive decontaminants was another finding of the project.

A database of commercial equipment that could potentially be used in response to a wide-area *B. anthracis* contamination incident has been developed. (US EPA 2022C; https://radar.epa.gov/widget/11796291-7778-43ff-84d9-190ecc2db583). The equipment inventory includes that which could be used for sampling and decontamination (among other response categories), such as the use of large commercial sprayers. The intent was to pre-collect and rank equipment that could be used in the event of such an incident by already conducting market surveys and assessments. After an incident, responders can query the tool to identify equipment options.

Figure 5. Test demonstration of large radial fan sprayer

Wide-area decontamination related planning tools and models

Recovering from a wide-area release of *B. anthracis* spores becomes a large problem of resource allocation, optimization, and prioritization. Several tools and models have been developed to address these issues and are briefly summarized below.

The Prioritization Analysis Tool for All-Hazards and the Analyzer for Wide-area Effectiveness (PATH/AWARE) was developed under the Department of Homeland Security's Integrated Biological Restoration Demonstration program and was further demonstrated for the Wide-area Recovery and Resiliency Program (US EPA, 2021; EPA/600/R-21/096).

The Stochastic Infrastructure Remediation Model was developed to dynamically model the interdependencies of critical infrastructure sectors and allows the user to draw statistical conclusions specific to an incident. This model allows for all infrastructure sectors to be modeled, considers the realistic variability of the impact of an incident, and predicts the time required to restore each sector to its original operating efficiency (US EPA, 2021; EPA/600/R-21/096).

The Wide-Area Decontamination Tool (WADT) calculates cost, time, and other resource demands associated with the remediation (sampling, decontamination, waste disposal, etc.) of a wide-area biological incident (US EPA, 2022D). The model utilizes EPA's bio-decontamination compendium to provide estimates of decontamination efficacy for various decontaminants applied to different materials, to determine if multiple treatments are needed. The predicted costs and time requirements are based on actual costs and time requirements determined from previous field studies.

The Remediation Data Repository (RADAR) tool (US EPA, 2019; EPA/600/C-19/114, July 2019) provides a simple, online interface to search EPA's Homeland Security Research Program data. The purpose of RADAR is threefold: 1) to provide support to cleanup and recovery operations, 2) to inform research and facilitate use of results, and 3) to provide models and software tools with the most up-to-date research.

The Decon Strategy and Technology Selection Tool (US EPA, 2014) is used to support making recommendations on how to decontaminate buildings contaminated with chemical or biological agents. This tool is available upon request. Other response support tools, such as those for sampling and waste management, can be found at https://www.epa.gov/emergency-response-research.

Conclusions

In the event of a large outdoor release of *B. anthracis* spores, there are several tools and strategies that could be implemented in the lengthy and costly remediation process that would follow. Modeling and planning software has been developed by EPA and others to assist with prioritization and optimization of resources and the selection of decontamination approaches that would be needed for such an unprecedented event. These decontamination strategies and techniques could include natural attenuation of the spores, physical removal, and/or inactivation of the spores via chemical and physical based technologies. The EPA has conducted extensive bench-, pilot-, and field-scale testing of all these approaches. Studies have been conducted and technologies demonstrated for the decontamination of building interiors and other infrastructure, as well as for the decontamination of outdoor areas and materials. Many factors affect how efficacious a decontaminant is in inactivating or removing *B. anthracis* spores, with the material the spores are contaminating a primary consideration. Outdoor materials (e.g., soil, vegetation, concrete) and vehicles, as well as the outdoor environment itself (with issues like cold temperatures), present daunting challenges for remediation. Spores will move through the air and surface environments over time and may contaminate previously uncontaminated or decontaminated areas. Current research efforts include analyzing the availability and feasibility of using existing, commercially available, large-scale spray equipment that could be used to apply liquid decontaminants over large outdoor areas and infrastructure. The EPA has also taken the approach of trying to build decontamination capacity for such an event by emphasizing and evaluating the use of low-tech, low cost, readily available decontamination techniques.

Disclaimer

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