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Remediating Sites with Anthrax Contamination: Building on Experience

Dorothy A. Canter, Ph.D.
US Environmental Protection Agency,1200 Pennsylvania Avenue, N.W., Washington, D.C., 20460

ABSTRACT

Prior to the anthrax attacks on the civilian population in late 2001, bioterrorism experts believed that the remediation of large urban areas or buildings contaminated with anthrax spores was not a viable option. The cleanup experience from the 2001 attacks, in which letters containing *Bacillus anthracis* spores were mailed to media outlets and two Senators, has demonstrated that buildings in the civilian sector can be effectively remediated and returned to productive use. This paper discusses the key roles of the US Environmental Protection Agency (EPA) in the remediation process. It summarizes the remediation process for decontaminating sites, focusing on sites at which fumigations have been/will be performed and the agents chosen for those fumigations. It identifies the factors that must be addressed before undertaking fumigations and presents information on agents being used for fumigations. Finally, it presents key lessons learned to date from anthrax cleanups that will enhance future cleanups, should they be needed.

INTRODUCTION

In 1999 the Working Group on Civilian Biodefense issued its Consensus Statement on Anthrax as a Biological Weapon.[1] In that document, the Working Group concluded that "decontamination of large urban areas or even a building following exposure to an anthrax aerosol would be extremely difficult and is not indicated." Although that was the prevailing opinion at that time, EPA and the other agencies have demonstrated that civilian structures can be successfully remediated.

Late in 2001, three known terrorist attacks occurred in which *Bacillus anthracis* (*B.a.*) spores were transmitted in letters through the U.S. mail system. In the first attack, letters mailed to media outlets in New York City entered the mail system in Trenton, N.J. on or about September 18. The second attack involved a letter or package sent in late September to American Media Incorporated (AMI), a publisher of weekly newspapers, in Boca Raton, FL. In a third wave, letters to Senators Daschle and Leahy entered the mail system in Trenton, N.J. on or about October 9. Four letters were recovered by the Federal Bureau of Investigation; the letter to Tom Brokaw, the letter to the New York Post, and the letters to Senators Daschle and Leahy.

Twelve cases of cutaneous anthrax and 11 cases of inhalational anthrax resulted from these attacks. Five of the persons with inhalational anthrax died.[2,3]

Numerous sites were contaminated either directly or through secondary (cross) contamination. Among these were media offices, postal facilities, the Capitol Hill Anthrax Site, and residences.

The contaminated postal facilities included large Processing and Distribution Centers (P&DC) such as the Hamilton P&DC in Trenton, NJ, the Brentwood P&DC in Washington, D.C., and the Morgan P&DC in New York City. Numerous smaller U.S. Postal Service facilities also experienced contamination, as did a number of federal government mail facilities downstream of the Brentwood facility.

REMEDIATION OF SITES CONTAMINATED WITH ANTHRAX SPORES

The remediation process for each of the sites has consisted of up to eight steps: site assessment including environmental sampling to characterize the contamination, isolation of contaminated areas, artifact and critical item removal, source reduction, remediation of contaminated areas/articles, post-remediation environmental sampling, further remediation and sampling if the initial post-remediation sampling indicated continuing areas of contamination, and disposal of decontamination waste.

Environmental sampling is important at a number of phases of the remediation process, from identifying the nature and extent of the contamination (characterization sampling) , to assessing the usefulness of specific source reduction activities prior to implementing the main remediation, to ultimately evaluating whether the remediation has been effective and the site is ready for re-occupancy (characterization sampling). Environmental sampling as a discipline has evolved significantly since the initial sampling events after the attacks, and consensus exists that in-depth environmental sampling should be performed to characterize the nature and extent of contamination before any cleanup activities are undertaken.[4] In addition, for sites at which primary aerosolization events have taken place, aggressive air sampling should be a part of the post-remediation environmental sampling strategy.

The roles of the US Environmental Protection Agency (EPA) in the remediation process have been twofold. First, EPA has ensured that the cleanups are performed in accordance with the Comprehensive Environmental Restoration Compensation and Liability Act (Superfund Law), either by performing all of or part of the cleanups or by providing technical assistance to the organizations conducting the cleanups. The extensive experience that EPA staff in the waste program have gained over a quarter of a century from cleanups of chemical spills and hazardous waste sites was an important asset in planning and implementing the remediations of anthrax-contaminated sites.

Second, EPA has granted crisis exemptions for treatments with pesticidal agents not registered under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). No chemical agent has ever been registered specifically to kill *B.a.* spores. Hence, organizations responsible for the cleanup of sites and chemical manufacturers have had to submit crisis exemption requests to EPA that are supported by data on the expected efficacy and safety of the remediation process, in order to receive approval to use the chemical agents proposed for that process. The expertise of staff in the EPA antimicrobials program in treating microbiological contamination with antimicrobial chemicals has added substantially to the efficacy of the remediation process.

Chemical agents that have been approved for cleanups of non-porous surfaces are chlorine bleach

(sodium hypochlorite), aqueous chlorine dioxide, and mixtures of hydrogen peroxide and peroxyacetic acid. Three chemical agents have received crisis exemptions for use in fumigating contaminated sites - gaseous chlorine dioxide, paraformaldehyde, and vaporized hydrogen peroxide. Of these, paraformaldehyde has a long history of usage to decontaminate biologic safety cabinets and laboratories.[5]

Fumigation of Sites

At least six of the contaminated sites will have been fumigated, by the time that all remediation activities are completed. They are the Hart Senate Office Building of the Capitol Hill Anthrax Site, the Brentwood P&DC, the Hamilton P&DC, the Department of Justice (DOJ) postal facility, the General Services Administration (GSA) Building 410, and the Department of State (DOS) Annex-32. A seventh site, the building previously owned by AMI but recently purchased by White Palm Real Estate, Inc., is currently being evaluated as to the remediation approach that will be used.

Gaseous chlorine dioxide was/will be used for the first three sites, paraformaldehyde was used at the DOJ mail facility, and vaporized hydrogen peroxide (VHP) was used at GSA Building 410 and is currently being used to remediate DOS Annex-32. At two of the sites, fumigation was/will be performed of the entire site at one time (Brentwood, Hamilton), while at two other sites (GSA Building 410, DOS Annex-32), the entire site was /is being fumigated, but in sub-sections treated one at a time. At two of the sites (Hart Senate Office Building, DOJ postal facility) only a portion of the entire facility was fumigated, and other areas judged not to be contaminated with *B.a.* spores, received no treatment at all. Five of the sites are mail facilities, while two are office buildings. Table 1 summarizes information on the six sites with fumigation remedies.

Table 1: Sites with Fumigation Remedies

Sites with Fumigations	**Nature of Contamination**	**Fumigant**	**Volume of Space Fumigated**	**Fumigation Approach**
Hart Building (Daschle Suite)/ Capitol Hill Anthrax Site	aerosolized	chlorine dioxide	90,000 ft^3on two floors	all at one time
DOJ mail facility	secondary	paraformaldehyde	4,000 ft^3 (tented space containing mail sorting machine)	all at one time

GSA Building 410	secondary	VHP	1.6 million ft^3	fumigation of 9 zones individually
Brentwood P&DC	aerosolized	chlorine dioxide	14.5 million ft^3 on two floors	all at one time
DOS Annex-32	aerosolized	VHP	1.4 million ft^3	fumigation of 11 zones individually
Hamilton P&DC	aerosolized	chlorine dioxide	5.8 million ft^3	all at one time

The selection of the fumigant for a particular facility results from a consideration of the following factors: effectiveness of the agent, both historically and in anthrax attack cleanups to date; its toxicity and environmental safety; generation of the agent; penetrability; materials compatibility; post-fumigation aeration of fumigant and potential by-products from absorbing materials; nature of the site to be treated; cost; and time expended to complete cleanup. Each agent has its advantages and disadvantages; there is no silver bullet.[6] For example, paraformaldehyde is heated to generate formaldehyde to fumigate facilities. Formaldehyde is an animal carcinogen and probable human carcinogen. It is also genotoxic.[7] Chlorine dioxide and vaporized hydrogen peroxide have not been tested for carcinogenicity. Chlorine dioxide, however, is the most acutely toxic of the three fumigants with a permissible exposure limit (PEL) of 0.1 parts per million (ppm) and an Immediately Dangerous to Life or Health (IDLH) value of 5 ppm. The PELs for formaldehyde and hydrogen peroxide are 0.75 and 1.0 ppm, respectively, while the IDLHs for formaldehyde and hydrogen peroxide are 20 ppm and 75 ppm, respectively.[8]

The process variables that must be effectively controlled for successful fumigations are fumigant concentration, exposure time, relative humidity, and temperature. For each fumigant, specified ranges exist for each of the variables. For example, the relative humidity for chlorine dioxide fumigations should be in the range of 70 - 95% throughout the process, while the relative humidity prior to introduction of VHP into the space to be fumigated should be no greater than 40%.

The effectiveness of a fumigation process is judged both by its meeting the specified ranges of the above process variables and by its killing the prescribed numbers of spores of a surrogate species on a biological indicator. Spores from a species within the *Bacillus* family that is not pathogenic to humans, but that is both genetically very similar to, and as difficult to kill as, *Bacillus anthracis* spores, are placed on carriers such as paper strips or metal coupons. The species utilized will depend upon the fumigant being used. Fumigation processes are considered fully successful when there is no growth of spores on any biological indicators following fumigation.

Representative Sites with Fumigation Remedies

At the Capitol Hill Anthrax Site, EPA fumigated the Daschle suite in the Hart Senate Office Building with chlorine dioxide gas on December 1, 2001. That suite consists of 90,000 cubic feet on two floors. The fumigation significantly reduced the load of spores resulting from the opening on October 15 of the highly contaminated letter to Senator Daschle in the mail receiving area. Thereafter, a surface treatment with aqueous chlorine dioxide was performed, and all post-remediation environmental samples in the suite were negative for growth of *B.a.* spores. Two air handling units that service the tier of the building containing the Daschle suite were also fumigated. Surface cleanups with aqueous chlorine dioxide were performed in other areas of the building demonstrated to have lesser amounts of secondary contamination. No cleanup activities were undertaken in other parts of the building in which characterization environmental sampling for *B.a.* spores was negative. The entire Hart Building was re-opened for productive occupancy on January 22, 2002.[9]

The Brentwood P&DC consists of 14.5 million cubic feet of interior space on two floors. A total of four workers at the facility contracted inhalational anthrax, of whom two died. Following its closure on October 21, 2001, the site was demonstrated to have widespread *B.a.* contamination. Most of the contamination, however, was clustered on the first floor at zero to six feet above the floor level in the immediate vicinity of mail sorting machine #17.[10] The USPS decided to fumigate the entire site at one time, using chlorine dioxide gas. That fumigant was chosen to be consistent with the remedial process for the Capitol Hill site. Surface cleaning of specific parts of the facility using bleach and High Energy Air Particulate-vacuuming was performed prior to the fumigation, which took place on December 14, 2002. The USPS had to resolve a number of key safety and efficacy issues prior to the fumigation, given the large size of the facility and the decision to fumigate the entire facility at one time.

The Department of State mail facility, Annex-32, is believed to have been contaminated as a result of the letter to Senator Leahy being misdirected there from the Brentwood P&DC. The contamination was discovered after one worker developed inhalational anthrax. The facility, which was closed on October 22, 2001, consists of 1.4 million cubic feet on one level. Limited characterization environmental sampling was performed at the facility following its closure. After evaluating the three available fumigants, the State Department selected VHP as the fumigant for the facility and decided to subdivide the facility into zones of about 200,000 ft^3 each and perform separate fumigations of each zone. These fumigations are currently underway.

Addressing the Safety and Efficacy Issues for Fumigations

Before EPA will issue a crisis exemption for the use of a particular fumigant, the organization with responsibility for the cleanup must submit a site-specific remediation action plan that describes how the fumigation can be performed both safely and effectively.

There are several critical safety issues. First is the containment of the space to be fumigated. Containment may be achieved by maintaining negative air pressure within the facility or by tenting the facility. Prior to fumigation it is important that studies be performed to test the effectiveness of the containment. This testing is particularly crucial for sites at which the entire facility is to be fumigated at one time. During fumigation, it is also necessary to monitor for

leakage of fumigant from the facility. For each fumigant, action levels for ambient concentrations of the fumigant need to be set in the event of significant leakage or of releases due to equipment failures or other emergencies. The action levels, both for temporarily pausing the fumigation and for terminating it, will depend on the acute toxicity of the fumigant. In addition, an emergency response plan addressing worst case and reasonably expected failure scenarios needs to be in place prior to the start of fumigation. It is important to run pre-fumigation tests of the equipment to be used during the fumigation process, including the fumigant generation equipment, the fumigant removal equipment, and the monitoring equipment for key process variables, so that any needed safety modifications can be made before the actual fumigation takes place. At the end of fumigation, it is important to remove/destroy the fumigant and process by-products quickly and efficiently. The nature and extent of equipment used for this purpose will depend on the fumigant and the volume of space fumigated at one time.

In terms of the efficacy of the fumigation process, it is critical to maintain the key process variables - concentration, exposure time, relative humidity, and temperature - within the ranges specified for each phase of fumigation process, as approved in the crisis exemption issued by EPA. It is also important to ensure appropriate distribution of the fumigant within the space being treated. This can be achieved by the usage of an adequate number of fans arranged to deliver the fumigant to hard to reach locations. The presence of materials that serve as absorbers of the fumigant within the space to be treated also must be taken into account to ensure the maintenance of the specified fumigant concentration throughout the treatment process. Where possible, such materials (e.g., carpets, draperies) should be removed prior to the fumigation. Adequate numbers of monitors to measure fumigant concentration, relative humidity and temperature on a real time basis need be placed in hard to reach locations. Experience to date emphasizes the need for redundancy of key equipment, especially monitoring equipment, given the equipment failure rates that have been observed.

Another critical factor in assessing the efficacy of the fumigation process is the selection of the biological indicator. The surrogate *Bacillus* species selected will vary with the fumigant used. For example, *Geobacillus stearothermophilus* was selected as the indicator species of choice for the remediation of DOS Annex-32 with VHP. In general, strips containing one million spores of the surrogate species are used. The number and placement of the spore strips within the space to be fumigated are important decisions. A number of the organizations performing fumigations have followed the US Army Medical Research Institute of Infectious Diseases' (USAMRIID) regulations for fumigations which specify the use of one spore strip for every 100 square feet fumigated.[11] The spore strips are placed in locations that are hard for the fumigant to reach, to ascertain whether high enough fumigant levels are reached in those locations to kill all the surrogate spores. It is useful to select a laboratory to analyze growth of the biological indicators that is independent of the organization conducting the fumigation to prevent potential conflicts of interest. The laboratory should have sufficient expertise and experience in analyzing biological indicators, so as to decrease the potential for adventitious contamination, that will compromise the results of the fumigation.

The decision to fumigate all of the facility at once rather than to fumigate smaller subsections one at a time has ramifications on both the potential safety and efficacy of the process. The larger the

space to be fumigated at one time, the greater the need to assure effective containment and to have a safe, reliable and efficient system for removing the fumigant after or during the process. Moreover, the larger the space, the greater the challenges to achieving adequate distribution of the fumigant throughout the space and to maintaining the process parameters in the specified ranges throughout each phase of the process.

A readiness demonstration is an important step prior to the fumigation(s) for both safety and efficacy purposes. During such a demonstration, the fumigant is introduced into the facility at a lower concentration and for a shorter duration than in the actual fumigation. The functioning of the equipment generating, monitoring, and destroying the fumigant is measured. Distribution and circulation of the agent are also checked as is the adequacy of the containment in preventing leaks. The demonstration may be performed without obtaining a crisis exemption, as long as biological indicators are not used to monitor effectiveness of killing surrogate spores. Results from the readiness demonstration can be used to make necessary modifications to the process and can make the difference between a successful and failed fumigation.

Judging the Effectiveness of Fumigations

Two criteria should generally be met for a fumigation to be considered fully successful. First, the key process variables of concentration, relative humidity, temperature, as measured by real-time monitoring equipment, should be within the specified ranges for the prescribed time periods for each phase of the fumigation process. Second, there should be no growth of spores from all the biological indicators. At the DOS facility, if either or both of these criteria are not met, individual fumigations will be repeated. The same was the case at GSA Building-410, where several fumigations were repeated. As noted above, a number of spore strips demonstrated growth of bacteria following the fumigation of the Daschle suite. Likewise, at the Brentwood P&DC, a small percentage of the surrogate spore strips showed bacterial growth.

Judging the Effectiveness of the Overall Remediation Process

The criterion currently being used for judging the effectiveness of the overall remediation process for a site is zero growth of *B.a.* spores from all post-remediation environmental samples. This applies to all sites, regardless of whether the contamination occurred through a primary aerosolization event, such as in the Daschle suite or at the DOS mail facility, or as the result of secondary contamination.[11] Thus, clearance environmental sampling is performed following fumigations, even when the fumigations have been judged to be fully successful. In the Daschle suite, an additional surface treatment was performed following the fumigation. All subsequent clearance samples, which included both surface and air samples, were negative for growth of *B.a.* spores. At the Brentwood facility, all clearance environmental samples collected following the completion of the fumigation were negative for growth of *B.a.* spores. In those instances in which one or more clearance environmental samples yield positive growth of *B.a.* spores, further remedial work will need to be undertaken. The nature and extent of such additional remediation activities will depend upon the results of the post-remediation environmental sampling.

DISCUSSION

As a result of EPA's continuing contributions to and oversight of numerous anthrax remediation activities, EPA staff have learned a number of lessons that will assist the remediation process, should there be additional attacks in the future. Key among these lessons are the following:

- The emergency response experience that EPA has gained in cleaning up accidental releases of hazardous chemicals and performing time critical removals of such chemicals has been important in the Agency's ability to respond to the anthrax attacks, but expertise in microbiological agents and antimicrobial chemicals to treat such agents has been equally as important.
- A multi-disciplinary team should be assembled to assess and remediate sites contaminated with biological agents of terrorism. Expertise in sterilization science is critically needed. For sites at which fumigations of large spaces are planned, chemical engineering support should also be brought to bear.
- All contaminated sites have unique features that need to be evaluated on an individual basis.
- Environmental sampling is important throughout the remediation process The advances in sampling approaches and techniques need to be incorporated in future sampling activities.
- Existing epidemiological data for each site (e.g., following the mail trail to confirm source of contamination, disease distribution data) should be evaluated and combined with the characterization environmental sampling results to help delineate the cause and effects of the contamination.
- A number of chemical fumigants are available; they all have their advantages and disadvantages. More data are needed on their safety, efficacy, optimal use parameters, and costs
- At sites that use fumigations, real-time ambient air monitoring is needed, particularly when businesses and residential areas are adjacent to the property. Prior to the start of the fumigation, concentrations of fumigant in ambient air need to be established, above which the fumigation process will either be temporarily paused or terminated. Emergency response plans also need to be developed to address worst case and reasonably expected failure scenarios.
- Long down times occur when fumigation is needed to achieve effective remediation of the site. The shortest clean up time to date - about three months - was at the Hart Building on Capitol Hill, where extensive resources were available to the Legislative Branch. Other fumigation cleanups involving sites with extensive, aerosolizable contamination are taking well over a year to complete.
- It is key to coordinate with relevant State and local health and environmental agencies throughout the process.
- It is important to provide continuing outreach to involved workers and the public, and to keep them informed as the remediation activities progress.

CONCLUSIONS

After the completion of the remediation of the Capitol Hill Anthrax Site in January 2002, the

Working Group on Civilian Biodefense updated its Consensus Statement on Anthrax as a Biological Weapon to reflect that remediation of civilian sites with anthrax contamination can be carried out effectively. Since remediation of contaminated buildings or parts of buildings is technically difficult, the revised document advises that "decisions about methods for decontamination following an anthrax attack follow full expert analysis of the contaminated environment and the anthrax weapon used in the attack and be made in consultation with experts on environmental remediation."[13] This advice is consistent with the lessons learned from remediations performed to date.

REFERENCES

1. Inglesby, T.; et al., *JAMA*. **1999**, 281,1735-1745.

2. *MMWR Morb Mortal Wkly Rep;* Centers for Disease Control and Prevention: **2001**,50 (47):1049-1051.

3. *MMWR Morb Mortal Wkly Rep;* Centers for Disease Control and Prevention: **2002**, 51(13):279-281.

4. *Summary Report: Peer Review Workshop on Environmental Sampling for Anthrax Spores at Morgan Postal Processing and Distribution Center;* U.S. Environmental Protection Agency. Washington, D.C., February 2003; EPA 500-R-03-001.

5. U.S. Environmental Protection Agency. Summary of Meeting on Anthrax Remediation Issues, Washington, D.C., January 10, 2002.

6. Whitney, E.A. et al.; *Emerging Infectious Diseases*. **2003**, 9(16), 623-627.

7. *IARC Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Humans, Supplement 7*; International Agency for Research on Cancer. **1987**; 211-216.

8. National Institute for Occupational Safety and Health. Documentation for Immediately Dangerous to Life or Health Concentrations (IDLHs), Revised IDLH Values (as of 3/1/95) webpage (http://www.skcgulfcoast.com/nioshdbs/idlh/intridl4.htm).

9. *Challenges Faced During the Environmental Protection Agency's Response to Anthrax and Recommendations for Enhancing Response Capabilities: A Lessons Learned Report*; U.S. Environmental Protection Agency. Washington, D.C. September 2002.

10. U.S. Environmental Protection Agency. Summary of Meeting of Representatives of Johnson & Johnson with US Postal Service Staff/Contractors on Chlorine Dioxide Fumigation of Brentwood Facility, Washington, D.C. February 27, 2002.

11. US Army Medical Research Institute of Infectious Diseases. UAMRIID Regulation 385-17, Decontamination of Containment Areas with Formaldehyde, Fort Detrick, MD., February 19, 1999.

12. National Response Team. Technical Assistance for Anthrax Response, Interim-Final Draft. Chapter 7. September 2002, webpage (http://www.nrt.org)

13. Inglesby, T., et al; *JAMA*. **2002**, 287, 2236-2252.