www.epa.gov/nhsrc

technical BRIEF

Evaluation of Fumigant Decontamination Technologies for Surfaces Contaminated With *Bacillus anthracis* Spores

EPA investigates the effectiveness of fumigant technologies to decontaminate surfaces contaminated with biological agents

Background

Because of their potential use as weapons of mass destruction, biological agents are a significant terrorist threat. Once released, certain bacteria and viruses can spread through the air, water distribution systems, and the food supply and cause disease or death in humans, animals, and plants. According to the Centers for Disease Control and Prevention, *Bacillus anthracis,* which causes anthrax, is one of the most important pathogens on the list of bioterrorism threats. In the United States, twenty-three people became infected with anthrax and five died after envelopes containing *B. anthracis* spores were mailed to governmental and news media offices during the months following the Sept. 11 terrorist attacks. Sites where letters were received and many U.S. Postal Service facilities became contaminated with spores.

As part of U. S. EPA's Office of Research and Development, the National Homeland Security Research Center (NHSRC) provides products and expertise to improve our nation's ability to respond to environmental contamination caused by terrorist attacks on our nation's water infrastructure, buildings and outdoor areas.

NHSRC conducts research related to:

- Detecting and containing contamination from chemical, biological, and radiological agents
- Assessing and mitigating exposure to contamination
- Understanding the health effects of contamination
- Developing risk-based exposure advisories
- Decontaminating and disposing of contaminated materials.

Although person-to-person transmission has not been demonstrated, humans can acquire anthrax by contact with spores on surfaces and in the air. Anthrax is a naturally occurring disease most commonly found in grazing animals such sheep, cattle, and goats. Spores can be found in the tissues from infected animals or in contaminated products made from bone, hide, wool, or hair.

Spores pose a significant threat because they may remain viable for decades, depending on the environmental conditions. *B. anthracis* spores can be processed or weaponized and delivered through the air over wide areas. A major attack using *B. anthracis* spores could cause many deaths and interrupt vital civilian and government operations.

One of the key challenges following an attack with biological agents is remediating contaminated areas for re-entry and re-use. The primary goal is to reduce the cost and time it takes to effectively remediate an area while protecting workers and nearby residents.

EPA/600/S-11/010
November 2011

One challenge: to find fumigants effective against *B. anthracis* spores

B. anthracis forms spores that are highly resistant to severe environmental conditions, including exposure to harsh chemical and physical treatments. In 2001, when remediation of facilities contaminated by *B. anthracis* spores began, there were no EPA-registered products specifically for use against the spores. EPA's Office of Pesticide Programs had to issue crisis exemptions for the sporicidal products needed for remediation.

The Federal Insecticide, Fungicide, and Rodenticide Act Scientific Advisory Panel[1] was convened in 2007 to provide guidance on test methods for determining the efficacy of antimicrobial products for inactivating *B. anthracis* spores. The Panel recommended that, in order to be registered as a sporicidal decontaminant against *B. anthracis* spores, a decontaminant technology had to achieve a mean (average) 6 $\log_{10}$ reduction in the number of viable spores in relevant laboratory testing via approved protocols.

EPA's fumigation technology evaluation research

EPA has conducted several tests to collect performance (efficacy) data on several fumigant technologies that might be used to decontaminate facilities contaminated with *B. anthracis* spores [1, 2, 3, 4, 5, 6, 7]. EPA continues to evaluate fumigation technologies for inactivation of *B. anthracis* spores and will issue reports and summaries as additional studies are completed.

Fumigants are sometimes referred to as volumetric decontamination technologies, since they can be applied to decontaminate hard-to-reach places (such as ventilation ductwork) or large and irregular surfaces or open areas that might be time-consuming and prohibitively expensive to decontaminate using liquid or foam technologies.

The following fumigant technologies were tested for efficacy against *B. anthracis* spores:

Decontamination Technology	Active Component	Vendor or Source	Abbreviations
Cloridox-GMP ™	Chlorine dioxide	ClorDiSys Solutions, Inc.	Cloridox
Sabre ClO_2	Chlorine dioxide	Sabre Technical Services LLC	Sabre
CERTEK ® Model 1414RH Formaldehyde Generator/Neutralizer	Formaldehyde	CERTEK, Inc.	CERTEK
Bioquell Clarus C HPV/Bioquell Clarus S HPV	Hydrogen peroxide	Bioquell, Inc.	BioQ C/BioQ S
STERIS VHP ® 1000ED	Hydrogen peroxide	STERIS Corp.	STERIS
Methyl bromide	Methyl bromide	Unknown	MeBr
Ozone Generator AC-2045	Ozone	IN USA, Inc.	Ozone
ProFume ®	Sulfuryl fluoride	Dow Agro Sciences LLC	SuFl

[1] *Final Meeting Minutes for July 17 – 18, 2007 Scientific Advisory Panel: Guidance on Test Methods for Demonstrating the Efficacy of Antimicrobial Products for Inactivating Bacillus anthracis Spores on Environmental Surfaces*

Generally, the major factors influencing fumigant choice are the ***effectiveness of the fumigant against the biological contaminant*** on the materials being decontaminated; the ability to achieve the necessary fumigation requirements (for example, fumigant concentration, temperature, relative humidity) in the field-use condition, ***compatibility with materials*** (to minimize damage and reduce cost); ***ventilation requirements*** for fumigant application; containment of the fumigant; the ***type of aeration and fumigant capture approaches*** required

to clear the fumigant once decontamination has been achieved; availability of personnel or companies with expertise and the needed equipment to meet required fumigation parameters; health, safety, and environmental considerations or regulatory requirements; and cost. Once a fumigant is chosen, the key process variables that must be effectively controlled for successful fumigation are fumigant concentration, contact time with materials, and, for some, relative humidity (RH) and temperature.

Summary of Major Conclusions From Cited EPA Research on Fumigant Technologies

(see **Technology Evaluation Materials Referenced** for the studies that serve as the basis for this technical brief)

Fumigant	Major Conclusions From Cited Studies
Chlorine dioxide	Material type: Fumigation efficacy was a strong function of material type [1,2,7]; effectiveness has been demonstrated on all porous and non-porous material tested. Relative humidity: Fumigation efficacy was greater at 75% RH than at 40% [5]; and at 80-84 % than at 71-75% [7] Inoculant quantity: Decrease in fumigant efficacy on all coupon material types was seen with 1 x 10^8 colony forming units (CFU) per coupon compared with 1 x 10^7 or 1 x 10^6 CFU per coupon [2] Organism: Efficacy varied with strain of *B. anthracis* [Ames or NNR1Δ1] [7] Organic burden: Added organic burden had "negligible" effect on fumigation efficacy [2, 7] Other: For some materials, the time required to achieve successful fumigation was determined to be independent of fumigant concentrations used; mean $\log_{10}$ reductions were independent of ClO_2 generation methods (wet versus dry) [1]
Hydrogen peroxide	Material type: Mean $\log_{10}$ reductions were observed to be a strong function of material type [2]; efficacious fumigation to achieve a 6 $\log_{10}$ reduction is a function of material type and contact time [7]; greater mean $\log_{10}$ reductions were seen on non-porous surfaces [4] Inoculant quantity: Significant decrease in the effectiveness observed when the spore inoculation was increased to 1 x 10^8 CFU per coupon from 10^7 or 1 x 10^6 [2]
Formaldehyde	Material type: Mean $\log_{10}$ reductions varied according to coupon material type; under study conditions, material porosity did not appear to affect fumigant efficacy [3] Organism: Efficacy against *B. anthracis* was higher than against *B. subtilis* [3]
Methyl bromide	Material type: Mean $\log_{10}$ reductions varied according to coupon material type, fumigant concentration, and contact time [7]; effectiveness has been demonstrated on all porous and non-porous material tested. Relative humidity or temperature: fumigant efficacy was marginally (not practically significantly) greater at 75% RH than at 40% [7]; efficacy was higher at 36° C than at 25 ° C [7] Organism: Under different conditions, which achieved from 1 to 6 mean $\log_{10}$ reductions in *B. anthracis* on glass, little or no efficacy was observed against *B. subtilis* (this non-pathogenic spore is significantly more difficult to inactivate than *B. anthracis*)
Ozone	Relative humidity: Mean $\log_{10}$ reductions were higher at 85% RH than at 75% [6]
Sulfuryl fluoride	Other: Mean $\log_{10}$ reductions were less than 1.5 [6]

Summary of Major Fumigant Technology Results Against *Bacillus anthracis* Spores on Coupons of Various Common Indoor Materials

Coupon Materials	Fumigant Technologies Tested												
	Chlorine Dioxide				Hydrogen Peroxide					Formal-dehyde	Methyl Bromide	Ozone	Sulfuryl Fluoride
	Sabre [5]	Sabre [1]	Sabre [7]	Cloridox [1]	BioQC [4]	BioQC [5]	BioQS [5]	STERIS [5]	STERIS [7]	CERTEK [3]	MeBR [7]	Ozone [6]	SuFl [6]
Aluminum	✓	nt	nt	nt	nt	nt	⊘	✓	✓	nt	nt	nt	nt
Carpet (industrial grade)	✓	✓	✓	✓	⊘	✓	⊘	✓	✓	✓	✓	nt	nt
Ceiling Tile	nt	✓	nt	✓	nt	⊘	nt	⊘	✓	nt	✓	nt	nt
Cinder Block (painted)	nt	nt	✓	nt	✓	⊘	nt	✓	✓	✓	✓	nt	nt
Cinder Block (unpainted)	nt	✓	nt	✓	nt	nt	nt	nt	nt	nt	nt	nt	nt
Computer Keyboard Keys	✓	nt	nt	nt	nt	nt	✓	✓	✓	nt	nt	nt	nt
Glass	nt	nt	✓	nt	✓	✓	nt	✓	✓	✓	✓	✓	⊘
Insulation (cellulose)	nt	nt	✓	nt	nt	nt	nt	nt	⊘	nt	✓	nt	nt
Joint Tape Paper or Wallboard Paper (painted)	✓	✓	nt	✓	✓	nt	✓	✓	✓	✓	nt	nt	nt
Laminate (decorative)	nt	nt	✓	nt	✓	✓	nt	✓	✓	✓	✓	nt	nt
Metal Ductwork (galvanized)	nt	nt	✓	nt	✓	✓	nt	✓	✓	✓	✓	nt	nt
Particle Board	nt	nt	✓	nt	nt	nt	nt	nt	⊘	nt	nt	nt	nt
Pine Wood (bare)	nt	✓	nt	✓	⊘	⊘	nt	⊘	✓	✓	✓	✓	⊘
Steel (painted I-beam)	nt	✓	nt	✓	nt	nt	nt	nt	nt	nt	nt	nt	nt

✓ A mean 6 $\log_{10}$ or greater reduction of *B. anthracis* spores was observed on this material in at least one test condition in this study

⊘ A less than 6 $\log_{10}$ reduction of *B. anthracis* spores was observed on this material for all test conditions in this study

nt Material was not tested in this study

Technology Evaluation Materials Referenced

[1] Rastogi, V., Ryan, S., Wallace, L., Smith, S., Shah, S., and Martin G. 2010. *Systematic Evaluation of the Efficacy of Chlorine Dioxide Decontamination of Building Interior Surfaces Contaminated with Anthrax Spores*. Applied and Environmental Microbiology. 76(10):3343-3351.

[2] Rastogi, V., Wallace, L., Smith, L., Ryan, S., and Martin, B. 2009. *Quantitative Method To Determine Sporicidal Decontamination of Building Surfaces by Gaseous Fumigants, and Issues Related to Laboratory-Scale Studies*. Applied and Environmental Microbiology. 75(11):3688-3694.

[3] Rogers, J., Choi, Y., Richter, W., Rudnicki, D., Joseph, D., Sabourin, C., Taylor, M., and Chang, J. 2007. *Formaldehyde gas inactivation of Bacillus anthracis, Bacillus subtilis, and Geobacillus stearothermophilus spores on indoor surface materials.* Journal of Applied Microbiology. 103(4):1104-1112.

[4] Rogers, J., Sabourin, C., Choi, Y., Richter, W., Rudnicki, D., Riggs, K., Taylor, M., and Chang, J. 2005. *Decontamination assessment of Bacillus anthracis, Bacillus subtilis, and Geobacillus stearothermophilus spores on indoor surfaces using a hydrogen peroxide gas generator*. Journal of Applied Microbiology. 99(4):739-748.

[5] Ryan, S. 2010. *Persistence Testing and Evaluation of Fumigation Technologies for Decontamination of Building Materials Contaminated With Biological Agents.* Washington, D.C.: U.S. Environmental Protection Agency. EPA/600/R-10/086.

[6] U.S. EPA. 2010. *Evaluation of Sulfuryl Fluoride and Ozone Fumigation Technologies to Inactivate Bacillus anthracis Spores.* Technology Evaluation Report. Washington, D.C.: U.S. Environmental Protection Agency. EPA/600/X-10/032.

[7] U.S. EPA, 2011. *Systematic Investigation of Liquid and Fumigant Decontamination Efficacy Against Biological Agents Deposited on Test Coupons of Common Indoor Materials.* Investigation and Technology Evaluation Report. Washington, D.C.: U.S. Environmental Protection Agency. EPA/600/R-11/076.

See Also for Related Information

Canter, D., Gunning, D., Rodgers, P., O'Connor, L., Traunero, C., and Kempter, C. 2005. *Remediation of Bacillus anthracis Contamination in U.S. Department of Justice Mail Facility.* Washington, D.C.:U.S. Environmental Protection Agency. EPA/600/R-10/154. 2005.

Estill, C., Baron, P. , Beard, J., Hein, M., Larsen, L., Rose, L., Schaefer, F., Noble-Wang, J., Hodges, L., Lindquist, H., Deye, G., and Arduino, M. 2009. *Recovery efficiency and limit of detection of aerosolized B. anthracis Sterne from environmental surface samples*. Applied and Environmental Microbiology. 75(13):4297-4306.

U.S. EPA. 2010. *Biological Sample Preparation Collaboration Project: Detection of Bacillus anthracis Spores in Soil.* Washington, D.C.:U.S. Environmental Protection Agency. EPA/600/R-10/177.

U.S. EPA. 2010. *Determining the Efficacy of Liquids and Fumigants in Systematic Decontamination Studies for Bacillus anthracis Using Multiple Test Methods*. Washington, D.C.:U.S. Environmental Protection Agency. EPA/600/R-10/088.

Contact Information

For more information, visit the EPA Website (www.epa.gov/nhsrc)

Technical Contacts: Joseph Wood (wood.joe@epa.gov)
Shawn Ryan (ryan.shawn@epa.gov)

General Feedback/Questions: Kathy Nickel (nickel.kathy@epa.gov)

If you have difficulty accessing this PDF document, please contact Kathy Nickel (Nickel.Kathy@epa.gov) or Amelia McCall (McCall.Amelia@epa.gov) for assistance.