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Practical Experiences with Technologies for Decontamination of *B. anthracis* in Large Buildings

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ABSTRACT

In the Fall of 2001, a number of buildings were contaminated with *B. anthracis* (*B.a.*) from letters processed through United States Postal Service and other mail handling facilities. All of the buildings have now been decontaminated using a variety of technologies. In a number of cases, large buildings have been decontaminated by introduction of either chlorine dioxide or hydrogen peroxide, in a manner and at scales not previously attempted. The practical application of these technologies in a safe and effective manner presented a number of technical challenges all of which were successfully overcome.

This paper will summarize observations on the events that need to occur during a decontamination event and the engineering experience gained during the decontaminations. Observation of the total process suggests that the time and cost associated with the actual fumigation process is a fraction of the duration and total cost of the entire decontamination event. The paper also discusses some of the "lessons learned" during the decontamination events and subsequent tests.

INTRODUCTION

In the Fall of 2001, an unknown person, or persons, mailed a number of letters containing *B. anthracis* (*B.a.*) spores, resulting in the contamination of a number of buildings in Washington, DC, and elsewhere. In some cases, where the extent of contamination was very limited, surface cleaning and materials external decontamination or disposal were used to remove the contamination. In other cases the spores were widely distributed as an aerosol or by "tracking". In these cases, fumigation of the entire facility was ultimately required. The author observed various fumigation events connected with the decontamination of a number of these buildings, specifically; the Brentwood Processing & Distribution Center (P&DC) in DC, the Hamilton P&DC near Trenton, NJ, the State Department SA-32 mail facility in Sterling, VA, and the American Media International (AMI) Building in Boca Raton, FL. From all indications, the spores in these facilities were easily converted into an aerosol, and thus required fumigation following source reduction and surface cleaning activities The volumes fumigated at these

facilities ranged from about 700,000 cubic feet at AMI to over 14,000,000 cubic feet at Brentwood.

The author has also observed three other tests of fumigation processes conducted on uncontaminated buildings: Methyl bromide was tested at a small house in Big Pine Key, FL, using a tent to contain the fumigant and spore strips to evaluate the effectiveness Chlorine dioxide was tested on a mold contaminated house in Utica ,NY, using tenting to contain the gas. And a portable chlorine dioxide system has undergone preliminary testing at a 350,000 cubic foot site in Anniston, AL, and more tests are planned.

The author's observation of the decontamination, as well as subsequent conversations with other individuals closely involved with the total decontaminations process, suggests that the time and cost associated with the actual fumigation process is a fraction of the total duration and cost of the entire decontamination event. The paper will present the author's view of the activities associated with the entire event from detection to clearance. It will also discuss his views of lessons learned and ways in which the overall process might be improved based on the cumulative experience to date.

ELEMENTS OF A DECONTAMINATION EVENT

The scope of the decontamination event, from detection to final clearance, goes far beyond the ultimate fumigation process installation and operation, with a number of activities that can and must proceed in parallel. However there are certain critical decision points that must be reached before other activities can take place. One approach is to categorize the activities into six areas: decision process; characterization and monitoring; building related activities; decontamination process; waste disposal; and stakeholder communication. The discussion below attempts to place these activities in an approximate temporal relationship; however, the order shown does not necessarily reflect relative priority of the areas. Note that no two decontamination events follow exactly the same path, so this paper is an attempt to capture the range and types of activities that the author has observed to date. Each activity category is discussed below.

Decision Process

The decision process may involve complex interactions with a variety of federal, state and local government organizations, advisory groups and private sector contractors. There are discrete decisions that must be reached before other related activities can commence. The elements of the decision process include:

1. Site and structure security must be provided to ensure that the contamination is contained, the risk to the community at large is minimized, and potentially valuable property is secure. This may also involve selection of a contractor to seal and maintain the facility for the duration of the decontamination event.

2. Appropriate federal state and local environmental, health and safety agencies must be contacted immediately to establish a working relationship and to determine the applicable

regulations and jurisdictions. The EPA Environmental Response Team (ERT) and Regional On-Scene Coordinators (OCSs) also have an essential role in the entire decontamination activity. If a proposed decontamination chemical is not registered by EPA under the Federal Insecticide' Fungicide, and Rodenticide Act (FIFRA), then a request must be sent to the EPA Office of Pesticides Programs and Toxic Substances (OPPTS) for issuance a "crisis exemption" before the product can be sold, distributed or used for this purpose. (Note that no products are currently registered for inactivation of *B.a.*) Other Federal agencies that have been involved in past events include Center for Disease Control (CDC), Occupational Safety and Health Administration (OSHA), National Institute of Occupational Safety and Health (NIOSH), and several Department of Defense Organizations. In addition to the FIFRA requirements, approvals may be necessary from state or local agencies (e.g., environmental, health, safety, police and fire departments, and city councils).

3. The command structure for control and coordination of the site activities should be established. Incident command or unified command structures have been used in previous events.

4. A review needs to be established for technical documents (see 7. below) that will be required to support the federal decision making process. Two approaches have been used in the past. In some cases the reviews were conducted by employees of the EPA and other federal agencies, and in other cases a technical working group (TWG) composed of federal and private sector experts was brought together to review the overall plans with an environmental sampling subcommittee (ESS) to review the sampling plans. In some cases an environmental clearance committee (ECC) performed interim and final data reviews to provide advice on clearance of the building for occupancy. Several events used some combination of these groups.

5. Selection of the contractor(s) to perform the decontamination is another critical step. The command structure needs to clearly define criteria against which the technologies will be evaluated, including the time to complete the fumigation. The selection of the contractor(s) to perform the decontamination has also been accomplished based on available information or past performance on other decontaminations, by presentations by several vendors, and input by the TWG or other technical reviewers to the command structure or the building owner. Selection can also be by the building owner based on a competition between vendors.

Note that the selection of the technology may also be based on the characteristics of the structure or its contents, particularly if sensitive items are involved.

6. The decision as to the technology(ies) to be used and the approach to selecting a contractor is a *critical step* since several other activity categories can not proceed until the contractor is in place Once the decision is made, several critical negotiations must be initiated: the terms and conditions of the contract must be negotiated; intellectual property rights must be established if there is an issue; insurance must be arranged; and indemnity conditions must be established.

7. The crisis exemption process has required the preparation of several documents, including: the remedial action plan (RAP); sampling and analysis plan (SAP); and the ambient air monitoring plan(AAMP). The RAP provides complete details on the facility and the implementation of the

fumigation technology approach, including: fumigation conditions, process control, and process provisions to ensure the safety of workers and residents of the surrounding community.

The SAP covers all aspects of measurement activities, including: characterization sampling to establish the location and extent of the contamination, placement of biological indicator (BI) spore strips to aid in evaluating the efficacy of gas distribution, measurement of temperature, relative humidity, and gas concentration in representative locations throughout the building, and clearance sampling for *B.a*. spores after fumigation to evaluate the effectiveness of the fumigation and provide a basis for clearance for re-occupancy.

The AAMP provides for ambient monitoring in the vicinity of the structure to ensure worker safety, and at the fence line and in the community to ensure resident safety. Appropriate ambient concentrations have been established based on the toxicity of the fumigant in conjunction with OSHA occupational standards.

8. Once the reviews of the various plans have been completed and necessary modifications have been satisfactorily completed, OPPTS issues the crisis exemption. This is a *critical step* that must be completed prior to the fumigation.

9. When the fumigation and all the clearance sampling has been completed, the contractor prepares and submits a FIFRA report to the EPA that documents the entire fumigation process. The ECC, if one has been created, will be a key reviewer to determine that all conditions have been met. The *critical condition* is that all clearance samples are "negative for growth of *B.a.* spores". Note that if any samples are positive, additional sampling, spot treatment or another fumigation would be required.

Characterization and Monitoring

The characterization and monitoring process includes forensics sampling for *B.a*. spores to support the criminal investigation, screening and characterization sampling to determine the extent and location of contamination, monitoring of ambient concentrations during periods when the fumigant is being generated, placement , removal and analysis of BIs, and CIs if used, and clearance sampling for *B.a.* spores. Note that, in some cases, the capacity to analyze the volume of samples generated may become a resource limitation that affects the time required to complete the process.

1. Forensics sampling has been conducted by the Federal Bureau of Investigation (FBI) in cooperation with the CDC to characterize the spore type and extent of contamination. The results of this sampling are closely held and not generally made available to those in charge of the remediation effort. The FBI must release the scene before additional sampling can occur.

2. Characterization sampling is required to establish the contaminated area within the building and to quantify the concentration of spores for the various contaminated locations. Sampling has been done with surface wipes or HEPA vacuuming. The selection of sampling locations may be guided by information on the movement of mail and personnel through the facility. Analysis of

the samples should allow quantification of spores at each sample location, which also provides guidance for later clearance sampling.

3. The BIs are placed throughout the building as an indicator that the required fumigation conditions were achieved at all locations. The type of spore distributed on the coupons has been selected as the best known *B.a.* surrogate for the fumigant being used. The coupons have typically been paper or stainless steel inoculated with 6 log of spores and contained in Tyvec or glassine envelopes. Spore placement has been based on a random distribution of one strip per 100 square feet of floor area, with focused placement in areas of high contamination and in selected "hard to reach" locations. Strips may be placed at different elevations, on surfaces, above drop ceilings, in HVAC ducts and plenums, and inside furniture or machines. The three dimensional location of each sample must be carefully documented (in some cases computer generated maps have been constructed using CAD drawings of the building). Depending on the size of the facility, thousands of strips may be required. Following the fumigation the strips are removed and cultured for seven days to determine if there is any growth of surviving spores. Both positive and negative controls are analyzed to provide quality assurance for the collection, handling and analysis of the strips.

4. The ambient fumigant gas monitoring has involved some combinations of three methods:

> Hand held monitors have been used to monitor concentrations in the vicinity of the workers and to detect leaks that need to be patched.
>
> Fenceline remote monitoring has been used to provide an alert if ambient concentrations approach or exceed specified levels.
>
> The environmental response team's (ERT) Trace Atmospheric Gas Analysis (TAGA) van has been used to monitor extremely low ambient concentrations (low parts per trillion) of the fumigant both outside the fenceline and in proximity to the building. The TAGA has clearly demonstrated its value not only for ambient monitoring, but also for providing early warning of fumigant leakage and help in diagnosis of the source of the leaks. The ambient concentration limits *at the nearest receptor* have typically been set at three 15-minute rolling averages exceeding one quarter of the OSHA occupational standard, or one 15 minute rolling average exceeding the OSHA standard. Exceeding these levels can lead to pausing or terminating the fumigation.

5. Clearance sampling starts with collection of surface samples throughout the facility and in known areas of contamination and cultured for seven day culturing to ensure that there are no live spores in the sample. Air sampling and aggressive air sampling using leaf blowers to stir up any residual spores is required to determine the existence of residual airborne spores. If positives were found, additional characterization would be required to determine if the growth was *B.a.*, or only an artifact produced by sample collection or handling. If *B.a.* positives were found, surface cleaning or re-fumigation may well be required.

6. The FIFRA report documents the results of all sampling and analysis and serves as one basis

for clearance of the facility for re-occupancy.

Building Related Activities

The building related activities can account for a significant investment of effort and time for a variety of activities, including:

Closure of the facility following confirmation of contamination.

Containment of the contamination by sealing or maintaining a slight negative pressure inside the building.

Accumulation of available information on building design and layout (if the CAD drawings are available and current, the process can be expedited).

Assessment of the building contents to make removal and decontamination decisions.

Structural modifications that may be required for effective fumigation, or other reasons

Removal of additional contents post fumigation

Restoration or reconstruction of the building prior to re-occupancy.

Security and maintenance activities must be performed on a continuing basis over the entire period from closure to re-occupancy. Personnel entering the building will be required to wear appropriate personal protective equipment (PPE) and breathing protection, which can significantly limit the amount of time for performing physical activity. Staging areas and decontamination facilities must be provided for all personnel exiting the contaminated area.

1. As soon as the determination is made that the building is potentially contaminated, it needs to be shut down in an orderly fashion. The personnel will need to be decontaminated to minimize their exposure and to prevent the spread of contamination beyond the facility. Provision of alternative space is a high priority to maintain the function of the organization and the jobs of the workers, but imposes additional costs on the decontamination.

2. The contamination needs to be controlled within the building to the maximum extent possible. This has been accomplished by sealing the doors and windows, securing the HVAC system by shutting it down or placing it in the 100% recirculation mode and turning off any vent fans, locating and sealing any other leaks that can be identified. In some cases, the building has been maintained at a slight negative pressure with a large fan withdrawing air through a HEPA filter to minimize exfiltration of the contaminant through any remaining leaks.

3. The documentation of the building design and interior layout needs to be assembled, in computer aided design (CAD) format if it is available. Details of the HVAC systems also need to be assembled.

4. The building contents need to be assessed and any sensitive or valuable property needs to be inventoried and secured. Certain items may need to be properly packaged as medical waste and removed from the building for decontamination or safe disposal, while other items may be fumigated in place for either reuse or subsequent removal and disposal. Note that after fumigation, items and contents can be removed with minimum PPE and can probably be treated using normal waste handling and disposal procedures.

5. Building materials may also need to be removed before fumigation, in particular porous materials such as; carpet, ceiling tile, and fabric surfaces. This decision may be substantially influenced by the choice of fumigation technology and the fumigant's potential interaction with materials. The decision may also be influenced by the plans for restoration after the fumigation.

Note that for both contents and building materials, the items that must be removed may depend on the fumigation technology chosen. Factors that need to be considered include: the ability of the fumigant to penetrate porous materials; the destruction of the fumigant by the materials making it difficult to maintain the required concentrations in the building; and, the potential damage to the material that may be caused by the fumigant. Disposal costs can be a very significant component of the overall costs. In addition personal effects, unique items, and sensitive or high value items are special cases and may require non-destructive decontamination for return the owner.

6. The site plan needs to be prepared showing the layout for the decon equipment and all related support facilities. It needs to specify containment around all chemical and waste use and storage areas. It also needs to provide for the location of support equipment; storage for equipment and supplies, and provisions for safety and comfort of the workers.

7. Restoration of the building may simply involve replacing building materials, machinery, and contents in the original configuration, or may involve a substantial reconfiguration to better serve the needs of the organization, including provisions to mitigate the future potential for contamination.

Decontamination Process

Once the decontamination contractor has been selected a number of activities can commence, including building assessment for interfacing the decontamination process and related support equipment and supplies, RAP, SAP or AAMP preparation, system design, purchase, installation, testing, the fumigation event and, documentation. Some of these activities can proceed in parallel, while others will be sequential pending reviews by and approvals from the appropriate participants.

1. The initial activity is a detailed assessment of the method of interfacing the decontamination system with the building. The contractor should have submitted a conceptual design for consideration during the *decision process.*

2. The design of the generation system is dependent on the technology selected. One or more

approaches may be considered. The fumigant can be generated in an external system, and introduced and distributed through the air handlers of the existing HVAC systems, or the fumigant may be generated externally, and introduced at discrete locations within the building without using the HVAC. In all cases, additional fans or blowers may be used to further promote distribution and mixing within the volume. Since highly effective distribution of the fumigant through the volume is a *critical issue* additional studies of gas distribution may be conducted with computational fluid dynamics (CFD) models; tracer studies; or smoke tests.

Another necessary design element is the part of the system that assists in containing the fumigant in the building. In spite of the extensive sealing that has been done, there has been sufficient leakage that a supplemental method was required to prevent the exfiltration that might occur from the natural tendency for buildings to operate under slight positive pressure (0.02 to 0.05 inches of water). The method used in most of the decontaminations to date has been to use the scrubber system induced draft (ID) fan to draw a slight negative pressure (- 0.03 to 0.05 inches of water) on the building. (Details of the scrubber systems are discussed in the later section dealing with the actual decontamination events to date.)

3. Once the design is reviewed and approved, procurement or fabrication of the long lead time components (e.g., gas generators and emitters) needs to start immediately. (Note that this step may take several months, but some or all of that time can be avoided if appropriate equipment were to be stockpiled and be ready for immediate deployment.) The system interface with the building can begin immediately, including: placement of sensors for temperature, relative humidity and fumigant concentrations; installation of ducts and piping to transport the fumigant to the point(s) of distribution; containment berms for chemicals, foundations for equipment, if required; and placement of existing equipment. Many of the pieces of equipment may be available on a rental basis, with appropriate lead time.

4. A number of system tests have been conducted during the decontamination events to date, including:

> A test of the effectiveness of processes for control of temperature and relative humidity at all measurement points is needed.
>
> Scrubber tests are needed to verify the ability of the fans to achieve and maintain the required negative pressure in the building.
>
> Tracer or smoke tests can evaluate the distribution of the gas in the building and to guide the placement of fans to assist in distribution of the gas.
>
> A long term scrubber test (up to the expected duration of the fumigation event) with the fumigant at the expected building concentration introduced directly into the duct will verify system performance.
>
> If an auxiliary carbon bed is to be used, the capacity and performance needs to be tested with the scrubber chemicals turned off to evaluate the performance and the life of the bed.

Finally, the overall performance of all systems should be tested by a low level introduction of the fumigant into the building (this can also provide insights on the effectiveness of sealing and negative pressure in containing the gas in the building).

These tests should be conducted prior to, and as part of, approval of the RAP and issuance of the crisis exemption .

5. After the crisis exemption, the actual fumigation can be conducted at an appropriate time, which may be affected by a variety of factors, such as presence of people in close proximity to the site during the week. The fumigation will require some volume of chemical reagents for fumigant generation or scrubbing to be transported to the site and stored with appropriate safety and security measures. (Note that this will require close coordination with local fire and police organizations.) The duration of the event will be impacted by the approach being used. If the whole building is being fumigated at once, the event may be completed in less than 24 hours. If the subsections of building are being fumigated sequentially and the negative results of the BIs from one section must be received before the next section is fumigated, several weeks or months may be required to complete the fumigation.

6. When the building is cleared for occupancy, the system must be disassembled for disposal or storage for future use. All residual chemicals and process wastes must be disposed of appropriately.

Disposal

Disposal activities will probably occur throughout the duration of the project. However, there will be certain periods where the volume increases significantly, including removal and disposal of materials or contents prior to fumigation; disposal of material following fumigation; and disposal of residual chemicals, process wastes, or components of the decontamination process. Consideration of timing and disposal approaches early in the process has the potential to minimize the associated cost.

1. The amount and types of materials that need to be removed prior to decontamination will depend, at least in part, on the decontamination process(es) chosen, as well as other factors. At a minimum, paper products will need to be removed, but other contents composed of porous furnishings, such as upholstered furniture, wall and window coverings, and partitions, may also need to be removed. Porous building materials, such as carpet, ceiling tiles and insulation, may need to be removed. The removal may be based on either reaction of the fumigant with the materials, or adverse effects on the materials themselves. The other consideration is for high value items (e.g., artwork, historic documents, personal mementoes) or sensitive equipment (e.g., electronics) which may need to be decontaminated externally with compatible methods Note that the time and expense of removal of materials prior to fumigation will probably be considerably greater than it would be if the same materials were to be removed after the fumigation due to the need for the workers to use a high level of PPE. In addition, the wastes will need to be packaged, transported and treated as infectious medical waste and transported in accordance with applicable

Department of Transportation requirements.

2. Additional materials or contents may be removed from the building subsequent to clearance of the building for re-occupancy and can probably be disposed of as conventional waste. The residual chemicals, residuals (e.g., PPE and decontamination fluids) from personnel decontamination activities, and any waste materials must be handled appropriately. The residues from fumigant and scrubber operations, as well as HEPA filters and carbon bed materials, also need to be handled appropriately.

Communication

Timely and effective communication with a wide variety of organizations and constituencies is a critical function throughout the entire decontamination event. Information must be provided to the various recipients in the appropriate form and level of detail. The affected groups include the workers or occupants of the building, the community at large, the state and local agencies, advisory groups, and federal government health and regulatory agencies.

1. The workers and occupants of the building who may have been exposed to the contaminant are a priority group that needs to receive immediate and continuing information about the event. They need to be notified immediately on suspicion or confirmation of the nature and extent of the contamination. To the extent possible, the individuals and their belongings need to be decontaminated prior to leaving the facility to protect them and to prevent the spread of the contamination to the maximum extent possible. They need to receive health information and, if appropriate, medication to mitigate the effects of the exposure. The workers can also provide very useful information on potential spread of contamination by recounting their recent movements in the building or elsewhere. Continuing communication and periodic meetings over the course of the event can also be helpful.

2. The residents and surrounding commercial establishments should receive prompt notification and periodic updates through “town meetings” and other means. They should be informed as the decontamination plans are developed and after the building is cleared for re-occupancy.

3. State or local environmental and health agencies will play key roles in the event and effective communication mechanisms need to be established as soon a s possible. During their preparation, applications for permits and other requirements should be closely coordinated with the agencies to expedite the process. Representatives of these agencies are valuable participants in or members of various advisory or review panels. They may also be present during any tests and the actual fumigation event(s).

4. Advisory groups should be continuously informed through electronic communications, conference calls, and periodic meetings. Advanced notice on schedule needs to be provided when documents need to be reviewed or advice on decisions is required.

5. Federal health and regulatory agencies are also involved on a “realtime” basis, particularly the EPA OSCs who monitor the event on a day to day basis, and the NIOSH and CDC

representatives who should have first hand knowledge of events. The EPA crisis exemption process can be expedite by frequent communication and consultation during preparation of the RAP, SAP and AAMP. These agencies also play key roles in the various sampling events before, during and after the decontamination.

6. The FFIRA report provides the final documentation of the event; however, additional documents may be required for use by state or local agencies.

Observations at Decontamination Events and Tests.

While there have been a number of building decontaminations events, the discussion in this paper is based on the author's observation of various stages of testing and use of fumigation processes and participation in advisory functions related to the technology. Since many aspects of the technologies and the detailed results of the fumigation have not been published, the discussion is qualitative based on these observations. Design details and specific operating conditions are not discussed. The observations are based on three *B.a.* fumigations with chlorine dioxide and one with hydrogen peroxide. Two tests with spore strips in small residential buildings have also been observed, including one with methyl bromide, and one with chlorine dioxide.

Chlorine Dioxide Fumigations

The chlorine dioxide fumigations occurred at the: Brentwood Processing & Distribution Center (P&DC) in Washington, DC; the USPS Hamilton P&DC near Trenton, NJ; and the former American Media International (AMI) Building in Boca Raton, FL. In all cases the chlorine dioxide was generated by the proprietary Sabre Oxidation Technology wet method and distributed into the building through "emitters" connected to the building air handlers. At Brentwood and Trenton, the emitters were located inside the space being fumigated, whereas at AMI they were located outside the space. The target fumigation conditions for the building was to maintain 750 ppm for 12 hours for a minimum "concentration time " (CT) clock of 9000 ppm-hours based on various small scale tests of efficacy for *B.a.* .The minimum temperature was specified as 75 degrees Fahrenheit and the minimum relative humidity as 75% with the values monitored at a number of points within the building The chlorine dioxide was monitored at numerous points in the building, with each sample drawn hourly through multiple arm "spiders" and transported to external impingers for wet chemical analysis.

Spore strips were placed throughout the building as previously described above. The fumigation event consisted of: a conditioning phase to achieve the targeted temperature and humidity; an induction phase to establish the minimum chlorine dioxide concentration; a fumigation phase to achieve the 9000 minimum ppm-hours CT requirement; and a aeration phase where the chlorine dioxide concentration was reduced to 0.1 ppm through natural decomposition in the space, ventilation through the scrubber and active scrubbing with the emitters. In all cases, the actual chlorine dioxide concentration in the buildings ranged from 750 up to 1500 ppm, and the CTs at various locations in the buildings ranged from 12,500 to over 20,000 ppm-hrs. During the fumigation the ambient concentrations were monitored by the TAGA van and the standards were

not exceeded at the nearest receptor in the vicinity. In all cases, there were no clearance samples that showed any growth of *B.a.* The main differences between the three locations were the building volumes and the scrubbing approach as described below.

1. The volume of the Brentwood P&DC was about14,000,000 cubic feet, and most building contents, machinery and materials were left in place for the fumigation. The two scrubber systems consisted of: a HEPA filter, demister ; forced draft fan; wet scrubber tower using sodium bisulfite and sodium hydroxide; and a carbon bed as a polishing step. One of the two scrubbers underwent a number of tests, including: three scrubber performance tests, two associated carbon bed tests to simulate the ability of the bed to remove chlorine dioxide in the event of a scrubber failure. These tests also demonstrated the ability of the system to maintain a slight negative pressure (-0.03 inches of water) at all points in the building. Both scrubbers were demonstrated with a low level (about 400 ppm) chlorine dioxide introduced into the building.

2. The volume of the Hamilton P&DC was about 7,000,000 cubic feet, and more materials (e.g., carpet) were removed prior to fumigation. The two scrubber systems were moved to Hamilton from Brentwood (after it was cleared), but the configuration was somewhat rearranged to remedy some small problems; specifically, the demister and the fan (converted to an induced draft configuration) were moved to a position after the scrubber tower to eliminate the potential for a chlorine dioxide leak on the high pressure side of the fan, and the tower was reinforced to accommodate the induced draft pressure. A scrubber test and a low level test were conducted prior to the fumigation.

3. The volume of the AMI building was about 750,000 cubic feet, distributed approximately evenly over three floors, and only paper and photographs were removed. All operable electronic equipment, including computers, printers, copiers, fax machines, and a telephone system, were left on during the fumigation. The two negative air systems consisted of a HEPA filter and a carbon bed with two integral induced draft fans. The external placement of the emitters and the air handlers resulted in problems with leakage of chlorine dioxide in a number of unexpected places, which required additional sealing prior to and during the fumigation. Note that some of the leaks were in locations that required extensive penetration of the gas to escape the building. A combined scrubber and low level test was performed before the fumigation.

Hydrogen Peroxide Fumigation

The hydrogen peroxide fumigation occurred at the Department of State (DoS) SA-32 1,400,000 cubic foot mail facility in Sterling VA. DoS had decided to extensively reconfigure the facility after the decontamination, therefore all building contents including equipment and all non-structural building materials were removed prior to fumigation. The materials were decontaminated at remote facilities with either ethylene oxide, steam sterilization, or incineration. The building was initially separated into seven zones of about 200,000 cubic feet each using floor-to-ceiling, triple layer plastic film barriers between zones. Each zone was fumigated individually with the zone being fumigated having a single point hydrogen peroxide supply duct at one end and a single point return duct at the other. The vaporized hydrogen peroxide (VHP) generation system flow path consisted of: the return duct from the building,

HEPA filter; catalyst to destroy returned VHP; de-humidifier; four to six hydrogen peroxide vaporizers, and a supply duct to the building.

The generators were fed with a 35% hydrogen peroxide solution at a controlled rate and the vaporizers could be operated in combination to achieve the required concentration in the zone. The zones where VHP was not being introduced also had a duct to draw a negative pressure and take the exhausted air containing residual hydrogen peroxide to a decomposition catalyst before discharge to the atmosphere. The fumigation consisted of four phases: dehumidification to less than less than 30% ; conditioning to reach the targeted VHP concentration in the volume; four hour fumigation with all hydrogen peroxide monitors and temperature monitors indicating values above the minimum (however relative humidity was allowed to increase over the fumigation cycle); and an aeration phase to reduce the residual concentration to a safe entry level.

Each zone had six to eight monitors for VHP concentration, temperature and relative humidity. The target conditions for the fumigation were that the VHP concentration be above 216 ppm at all monitors for four hours, that there be 30% relative humidity at the start, and a minimum of 30 degrees Celsius. Each zone had a number of BIs and chemical indicators(CIs) distributed throughout. After a zone was fumigated, the CIs were read and the BIs were cultured and shown to be negative for growth (which took 3 to 7 days) before the next zone was fumigated.

Once the fumigation of the first zone began, it became apparent that the target concentration could not be achieved. After several attempts, it was decided to reduce the zone volume to about 100,000 cubic feet. At about the same time, the supply duct was changed from galvanized steel to high density polyethylene (HDPE). Between these two changes, the concentration requirements were met for the first subdivided zone. The building was ultimately divided into 10 zones ranging from about 40,000 cubic feet up to four of the original 200,000 cubic foot zones. All zones achieved the necessary conditions, although one zone had to be re-fumigated because one BI came back positive for growth. From start to finish, the fumigations requires almost two months.

The average VHP concentration in the zones was around 275 plus or minus 25 ppm, with maximum concentrations ranging fro 225 to near 400 ppm at individual monitors during the 11 fumigations. In some zones, the concentration dropped below the 216 ppm level at some point requiring generation to be increased. This indicates a substantial decomposition of the hydrogen peroxide somewhere in the system. Several explanations have been postulated, including: decomposition on surfaces; and decomposition in the supply duct.

In an attempt to explain the losses, EPA did a limited set of measurements in the supply duct about 20 feet after the point of generation which indicated only about 40% of the concentration that was expected from the 35% hydrogen peroxide feed and air flow rates. If we accept this as a generation efficiency factor, based on stirred reactor calculations, the concentration in individual zones should have equilibrated in the range of 750 to 1438 ppm, well above the actual levels. Two monitors in the zones and located close to the duct discharge indication the VHP entering the space was at least 600 to 800 ppm. No measurements in the duct near the discharge were made. The 10 zones show only a modestly increasing trend line with decreasing surface area

(estimated to be between 8000 and 31,000 square feet), or with decreasing inlet duct length (estimated to be between 50 and 450 feet). If the final small zone closest to the point of generation is excluded, there is almost no effect of either surface area or inlet duct length. Therefore some other explanation for loss of nearly 90% of the hydrogen peroxide supply must be sought. It appears possible that some homogeneous decomposition or condensation mechanisms exist. Note that some testing is being conducted at an Edgewood Chemical & Biological Command (ECBC) experimental facility where the generators are placed directly into individual spaces to address these issues.

Small Scale Tests

Two small scale tests of alternative approaches have been conducted on residential structures. Methyl bromide was tested in Big Pine Key, FL, and chlorine dioxide was tested in Utica, NY. While they are not actual decontamination of *B.a.* they provide valuable insights on the fumigation process.

1. The Big Pine Key test was conducted in a two-story house that was triple tented with the same tarps that are used for dry wood termite fumigations. Methyl bromide was released into the house on two occasions during a 48 hour period to maintain an average concentration of about 75,000 ppm at 37 degrees Celcius and 75% relative humidity. Spore strips were placed in a number of locations and are reported to show no growth on any sample. There are indications that the methyl bromide leakage was significant with concentrations of up to 30 ppm at the tent surface and 1 to 5 ppm at 20 to 50 feet. Should future tests be conduced, another tarp with a different inner material, or an effective scrubber system to maintain a slight negative pressure in the building, would be necessary.

2. The chlorine dioxide technology used in the *B.a.* fumigations was tested on a three-story house in Utica, NY. A single termite tarp was used to inclose the house and a slight negative pressure was applied with a small blower which vented through a carbon bed. Chlorine dioxide concentrations in the building ranged from 750 ppm at the beginning of the fumigation to about 1300 ppm at the end. The TAGA van monitored ambient chlorine dioxide and chlorine concentrations in the vicinity of the house. the maximum chlorine dioxide or chlorine concentration spikes of 2.5 ppb were detected in the down wind direction. In general the steady state concentration of either gas was below the detection limit in the low ppt range.

Conclusions

The author's observations of these events and extensive conversations with others provides a number of insights on the overall process and on the technologies in specific. While the efforts to date have resulted in a number of successful *B.a.* decontaminations, the experience can also provide suggestions to expedite and simplify the process, should it be necessary in the future. The author has assembled a number of "lessons learned" that may contribute to this goal.

Observation of these events and tests clearly demonstrates the potential for decreasing both the

time and financial resources necessary to decontaminate buildings. It is also important to observe that although the experience is specific to spore forming organisms such as *B.a.*, many of the observations about the steps in the overall process may be equally applicable to both chemical and other biological agents. Specific observations are as follows.

1. It appears that a major potential source of cost savings is to reduce the time necessary to conduct the decontamination event This can reduce the direct cost of on site labor and other expenses, as well as indirect costs (e.g., lease of replacement facilities). The other potential source of savings is to increase the efficiency and timeliness of installation and operation of the decontamination itself.

2. If the whole building can be fumigated at once, the time and cost associated with the actual fumigation itself is a very small part of those for the overall event (e.g., 1 to 2 days out of an overall event lasting months to years). It has been suggested that decreasing the time and or concentration of the fumigation might result in savings; however, the data to support such a suggestion does not yet exist. Furthermore the relatively short time necessary to achieve this part of the overall event suggests that the fumigation conditions should be specified to ensure effective kill. And, reducing the standard of "cleanliness" (i.e,. no growth on any clearance sample) does not show major potential. Furthermore, it has been stated by building owners that occupant confidence in the cleanliness of the building or facility is an important factor for re-occupancy.

3. It appears that labor is the major cost element, particularly for activities that must be performed in a high level of protective gear (PPE). Therefore reducing the duration of the overall decontamination event alone has the potential to substantially reduce cost.

4. The level of experience with the technology influences the amount of documentation and system testing required to obtain the crisis exemption which potentially decreases the time required for this step. For instance, the time from set up of the chlorine dioxide decontamination equipment to completion of the fumigation has been progressively shorter as experience with implementation has progressed.

5. Negotiation of insurance and indemnity agreements can be another major time consuming step.

6. Effective and timely communication with all involved regulatory agencies is essential. The applicable regulatory agencies will depend on the particular location and the requirements imposed by the state and local groups. Identification of the requirements, and preparation and review of the necessary documentation can be a time consuming part of the decontamination process. The OSCs have an essential role in the event and should be engaged as soon as possible.

7. Certain documents, such as the RAP, SAP and AAMP, will be required for any decontamination using a chemical not registered by EPA under FIFRA for use in inactivating the target biological agent. For certain critical infrastructure, draft documents might be prepared in advance and reviewed by the EPA and others. Ready availability of current CAD drawings for

such facilities is a high priority both for planning the decontamination and for documentation of placement of the spore strips.

8. Communication with the various stakeholder groups also has high priority. This includes the affected employees, the residents in the neighborhood and the community at large.

9. The ready availability of long lead time components of the fumigation system or of the need for a large number of generation units is a key to the ability to conduct a rapid decontamination event. Consideration should be given to creating a stockpile of equipment or systems for ready availability, possibly on a regional basis.

10. The TAGA van has proven to be invaluable both in providing the capability to monitor ambient concentrations in the vicinity of the site and to diagnose locations of fumigant leaks from th process or the building. The availability of a sufficient number of TAGA vans with highly trained crews is an essential asset for response in case of multiple events. Note that the vans not only have many uses outside of decontamination events, but also are a key element in ambient monitoring to provide early warning of any chemical release during high profile events.

11. Installing and maintaining adequate sealing of a contaminated building is time consuming and costly; however, this step has been essential to minimize the spread of *B.a.* and to allow the decontamination system to maintain a negative pressure ion the building during the fumigation. Recent experience suggests that "tenting" the building has the potential to significantly decrease the time and cost of providing these functions. The technique used for dry wood termite fumigation appears to be suitable for containment of chlorine dioxide, and can significantly reduce the amount of air that must be removed from the building to maintain a slight negative pressure. Remaining issues include the durability of the tarps necessary to provide containment for longer periods of time under potentially adverse weather conditions and demonstration that the technique can be employed on large complex structures and provide the necessary containment of the gas.

12. The HVAC system should receive particular attention, since it can be an important part of the decontamination system. It may be used to introduce the fumigant into the building or to promote circulation and distribution within it. If the air handler is external to the building, it can also be a major source of leaks, many of them in hard to reach places requiring careful sealing. Also note that the system should be placed in 100% re-circulation mode as soon as possible after the contamination is detected to minimize any release to the vicinity. Furthermore, if climate control can be maintained in the building, it can reduce the heat stress on personnel working in PPE, as well as potentially reduce collateral damage to the contents.

13. The capacity of the generating system must be sufficient to maintain the specified concentration in the building and to provide enough excess capacity to compensate for unanticipated loss of fumigant due to decomposition in the system or building. The fumigant will be removed from the building by destruction in the scrubbing system, and by natural decomposition in the space due to interaction with materials or homogeneous mechanisms.

14. Porous materials (e.g.. carpets, paper, drop ceiling tiles) appear to be one cause of decomposition of the fumigant gas in the building. While it appears that it is a greater concern for hydrogen peroxide than for chlorine dioxide, both fumigants are affected to some extent.

15. The amount of materials that must be removed from a building prior to fumigation impacts the time and costs for the event. Therefore, the nature of the building contents may impact both the fumigant choice and the system capacity required.

16. The compatibility of the materials with the fumigant has the potential to adversely impact the building and contents. This is another factor that may influence fumigant choice.

17. The scrubbing system must have the capacity to provide the required level of negative pressure in the building and to destroy the fumigant removed during the event. Stack emissions have typically been quite low (i.e., below 1 ppm).

18. The chlorine dioxide scrubbing systems used to date have consisted of either a wet scrubber followed by a carbon bed, or a carbon bed alone. Based on carbon bed capacity testing conducted at Brentwood, two carbon beds were used at AMI. Carbon beds alone demonstrated the capacity to effectively destroy 1000 to 1500 ppm of chlorine dioxide for an extended period of time (e.g., over 12 hours). However, additional information is needed on the capacity of the carbon, and the size of building where this approach is feasible has not been demonstrated. Note that elimination of the scrubber eliminates the spent reagent waste that would be generated by the scrubber.

19. Process wastes for chlorine dioxide decontamination may include neutralized generation solution and wet scrubber waste. The HEPA filters used in advance of the scrubber system may also need to be handled as if they were contaminated. Disposal may be an issue.

20. The time and expense of sampling for *B.a*. can significantly impact the timeliness and cost of the decontamination. If the sampling process be simplified savings might result. Access to the forensics sampling might reduce the characterization sampling that would be required.

21. The locating, placement, recording, harvesting and analysis of numerous spore strips takes time and increases cost. Consideration should be given to reducing the number of spore strips. The criteria one BI per 100 square feet might be replaced by a reduced number of strips and concentrated them in known areas of contamination and in “hard to reach” places. This would reduce time for placement, recovery and analysis.

22. The decomposition of hydrogen peroxide may limit the applicability of a potentially good fumigant. The decomposition mechanism need to be established to determine if the predominate mode is homogeneous, or are surfaces reactions involved.

23. The ambient concentration that will shut down a fumigation is 25 ppb for three consecutive 15 minute rolling averages (or a total of 43 minutes) at the nearest receptor as measured by the TAGA van. This is one quarter of the OSHA eight hour occupational standard. Consideration might be given to using a less stringent standard if it were judged to be sufficiently protective of

human health.