Appendix 15
Hart Senate Office Building HVAC Fumigation Final Report

APPENDIX 15

Hart Senate Office Building
Heating Ventilation Air Conditioning System
ClO_2 Fumigation (AH21/22 and associated ducting)

FINAL REPORT

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ACRONYMS

Anthrax	Bacillus anthracis
AH	Air handling
AHU	Air handling unit
AH21	Air handling system number 21
AH22	Air handling system number 22
AOC	Architect of the Capitol
B. st.	Bacillus stearothermophilus
B. s.	Bacillus subtilis
ClO_2	Chlorine dioxide
Ct	Concentration time
Daschle	Senator Daschle Office Suite
Design	Hart Senate Building, HVAC (AH21/22 Return) Fumigation, Remediation Design, prepared by USEPA, Region 3, dated December 6, 2001
ERT	Emergency Response Team
F	Fahrenheit
FDA	Food and Drug Administration
HSOB	Hart Senate Office Building
HVAC	Heating, ventilation, and air conditioning.
NAU	Negative air unit
NAUs	Negative air units
Rh	Relative humidity
USEPA	United States Environmental Protection Agency

INTRODUCTION

Bacillus anthracis (anthrax) was released in the Hart Senate Office Building (HSOB) on October 15, 2001 (See Figure 1 for building location). The anthrax spores were specifically released in Senator Tom Daschle's Office Suite (Daschle) and spores entered the return air handling system (AH21/AH22) servicing the office suite. The spores traveled through air return pickup vents and their lateral ducts to the vertical risers leading to the 9th floor air handling system. The spores did not pass through the filter banks located within the air-handling units. The supply-side of the AH21/AH22 systems was not known to have been contaminated and was not addressed. Decontamination of the heating, ventilation, and air conditioning (HVAC), return system was necessary to ensure the protection of human health. A series of planning documents was prepared that resulted in a remedial design that called for the introduction of chlorine dioxide (ClO_2) gas in concentrations and under humidity and temperature conditions documented to kill bacillus spores (Brentwood 2001, Daschle 2001).

HVAC fumigation was initially attempted beginning December 14th and ending December 17th 2001. Operational difficulties including equipment breakdown and an inability to monitor and control humidity resulted in an unsuccessful operation.

A second HVAC fumigation occurred between December 28th and December 31st 2001. Environmental samples and spore strip analysis indicated that the fumigation achieved an effective remediation of the HVAC system. The fumigation achieved Food and Drug Administration (FDA) standards for sterilizing levels of sporicidal effects (10^6 Bacillus subtilis (Bs) kill, 10^5 Bacillus stearothermophilus (Bst) kill), (Leighton 2002). Although the data did not prove the absence of viable spores in the treated system, they fully supported the resumption of the operation of the HVAC system (Leighton 2002). Post-fumigation environmental and air sampling suggested that the ClO_2 fumigation was successful in remediating the spore burden within the HVAC system (Leighton 2002).

This report provides a summary of actions taken during the HVAC fumigation. It highlights problems encountered, actions taken to minimize or eliminate the problems, and lessons learned during the planning and execution of the fumigation.

1.0 PLANNING DOCUMENTS

The following planning documents were prepared in anticipation of and in support of the ClO_2 fumigation:

A technology review document entitled **"Hart Senate Office Building HVAC Decontamination,"** was prepared by United States Environmental Protection Agency (USEPA), Region 3, on or about December 3, 2001 (USEPA 2001a). This document discussed technologies available for use in the remediation of the HVAC system and introduced the concept of using ClO_2 gas as a fumigant for the HVAC.

A conceptual design document entitled **"Conceptual Design – HVAC Fumigation", Draft 12/5/01 (rev 1),** (USEPA 2001b) was prepared to document a conceptual design using ClO_2 as a fumigant. The document presented tasks required to be completed, an associated design and application schedule, and a sketch that illustrated conceptual ClO_2 and steam application locations with operational and efficacy monitoring points.

A remedial design document entitled "**Hart Senate Building, HVAC (AH21/22 Return) Fumigation, Remediation Design**", prepared by USEPA, Region 3, dated December 6, 2001, (Design) (USEPA 2001c) was prepared to address the application of ClO_2 gas for the remediation of the HVAC system. Addenda were prepared to describe the installation of equipment and operations during fumigation.

A management plan**; "Hart Senate Building, HVAC (AH21/22 Return) Fumigation, Chlorine Dioxide Fumigation Operation Plan, Ground Floor Garage Management Plan",** prepared by USEPA, Region 3, dated December 10, 2001, was prepared to address equipment and operation isolation needs for the fumigation.

Addendum 1 to the Design; "**Hart Senate Building, HVAC (AH21/22 Return) Fumigation, Addendum 1, Return Air Grate and Duct Isolation, Steam and ClO_2 Fumigant Supply, and Monitoring Points and Sample Lines Installation Work Plan**", prepared by USEPA, Region 3, dated December 8, 2001, (USEPA 2001d) was prepared to address operational tasks necessary to isolate the vertical return air risers of the AH21/AH22 system from the horizontal return air ducts in office suites not documented to be contaminated. Addendum 1 also addressed the installation of steam and ClO_2 gas feed lines required to fumigant the AH21/AH22 system at the 2nd floor, in the Daschle suite return air ducts on the 5th and 6th floors, and in the return air plenum legs behind the filters located on the 9th floor. In addition, Addendum 1 addressed the installation of the lines required to convey sample air from specific monitoring points to a central manifold location and provided temperature and humidity monitoring access ports. Addendum 1 also included the placement of confirmatory spore sample strips in locations designed to document the efficacy of the fumigation.

Addendum 2 to the design, "**Hart Senate Building, HVAC (AH21/22 Return) Fumigation, Final Addendum 2, Chlorine Dioxide Fumigation, Operation Plan**", prepared by USEPA, Region 3, dated December 14, 2001, (USEPA 2001e) was prepared to address equipment installation and detail the operations necessary to conduct a preliminary operational test of the systems and to conduct the ClO_2 Fumigation, including air monitoring. Air monitoring in Addendum 2 included the operations necessary for monitoring:

- The ambient air inside the HSOB
- The air inside the AH21/AH22 HVAC system.
- The ambient air outside of the HSOB.

Addendum 3 to the Design, "**Hart Senate Office Building, HVAC (AH21/22 Return) Fumigation, Addendum 3, Change In Operations Of Chlorine Dioxide Stripper Temperature, and Establishment of Temperature Action Level**", prepared by USEPA Region 3 dated December 16, 2001, (USEPA 2001f) was prepared to address a modification in operating temperatures detailed in Section 3.3 of Addendum 2 regarding the ClO_2 stripper units. The maximum operating temperature of the ClO_2 stripper units originally planned at 85^o Fahrenheit (F) was increased to 100^o F. Addendum 3 also established a temperature "Action Level" of the ClO_2 fluid used in the ClO_2 strippers. If the operating temperature of the ClO_2 fluid used in the ClO_2 strippers exceeded 110^o F, the steam feed to the tank would immediately be reduced by adjusting the steam supply valves to bring the fluid temperature below 110^o F.

Addendum 4 to the Design, **"Hart Senate Office Building, HVAC (AH21/22 Return) Fumigation, Addendum 4, Chlorine Dioxide Fumigation, Operation Plan Modification"**, prepared by USEPA Region 3, dated December 27, 2001, (USEPA 2001g) was prepared to document operational changes and or modifications required to execute the ClO_2 fumigation as detailed in the Design. Addendum 4 documented the relocation of the negative air unit (NAU) on the 9th floor located in the return air plenum of the HVAC return air system and moved it to AH21. The new location provided better distribution and circulation of ClO_2 gas. Addendum 4 also addressed an additional spore strip array added to the horizontal return duct leading from the Daschle Suite on the 5th floor. Addendum 4 modified the dosimeter spore strip array sequence and composition and provided for the installation of corrosion coupons consisting of materials used in the manufacture of telephone handsets and switching equipment that were subsequently installed in AH21 and AH22. Addendum 4 described additional operational temperature and relative humidity (Rh) sampling probe locations and the final placement of an auxiliary fan in the horizontal duct leading to the south HVAC vertical riser.

2.0 FUMIGATION SYSTEM DESCRIPTION

The planning documents provided for a phased approach of the design and operation of the fumigation. The system developed in the planning documents consisted of the following elements:

- The isolation of the horizontal return air ducts to the north and south vertical return risers at floors 2, 4, 8, and the return air mechanical ductwork on the 9th floor from the supply side of the HVAC system and the outside air plenums used to bring makeup air into the HSOB.
- The injection of ClO_2 and steam at the bottom of the north and south vertical return risers, in the vents leading to the horizontal return air ducts on the 5th and 6th floor in the Daschle suite, and three points on the 9th floor.
- The removal of 150 cubic feet per minute of treated air from the isolated HVAC system via negative air machines (NAUs).
- Scrubbing residual ClO_2 from the NAU exhaust and venting it to the interior of the HSOB.
- Air monitoring and operational sampling for temperature, relative humidity (Rh), and ClO_2 gas concentration at critical points within the building.
- Air quality monitoring outside of building.
- Objectives of attaining 75%+Rh, 75^{o}+F temperature, 500 ppm_V + ClO_2, and 9000 ppm_V-hours concentration time (Ct) within the HVAC system.

The fumigation planning documents also described equipment, locations, and operational parameters. The equipment developed and used in the fumigation included:

- The construction and installation of two ClO_2 generator stations. The stations were located on the 9th floor and in the HSOB garage. The stations generated ClO_2 solution that was then used to feed four ClO_2 stripper columns.
- The construction and installation of four ClO_2 stripper columns that fed thirteen injection points.
- The installation of two steam supply lines that fed thirteen injection points. One of the supply lines was in the HSOB garage and the other was connected to the building steam supply on the 9th floor and then hard piped to the 6th floor.
- The installation of ten ClO_2 gas sample points feeding a centralized manifold in the HSOB garage.
- The installation of fourteen remote temperature and humidity points with data cables feeding a centralized command center in the HSOB garage.
- The installation of eleven spore strip sites containing a total of 428 spore strips.
- The installation of an on-site analytical laboratory in the HSOB garage.

An integral part of the development of the planning documents included the study of existing plans and drawings of the HSOB and its HVAC system. These drawings were used to prepare schematics graphically illustrating the HVAC system and the intended placement of operating and monitoring equipment. Limits on time and resources prohibited the preparation of detailed illustrations. Attached to this report are reproductions of various portions of existing drawings used to develop the fumigation. The reproductions have been edited to exclude extraneous detail and to include relevant information. Descriptions of the drawings are included below:

Figure 2a – ClO_2 Fumigation Process Flow Diagram

This figure illustrates the fumigation process developed for the HVAC system and identifies ClO_2 application points and operational monitoring locations. The circled numbers correspond to ClO_2 gas monitoring points; the numbers are consistent with locations illustrated in subsequent drawings and with the data reported in Table 1. The drawing depicts the north and south vertical return risers, the return air handling system on the 9th floor, and equipment used to generate and supply ClO_2 gas and their locations. Figure 2a is a combination plan and elevation view.

Figure 2b – 9th Floor Return Air Mechanical

This figure illustrates in detail AH21 and AH22 and the associated ducting located on the 9th floor of the HSOB. It also details the connections of the north and south return air vertical risers to AH21 and AH22. Circled numbers correspond to ClO_2 gas operational monitoring points and with the data reported in Table 1. Locations where the return air system was isolated from the supply portion of the HVAC system and outside air plenums are also shown. Figure 2b is a plan view with cross-sections.

Figure 3 – Return Air Risers

This figure illustrates the return air vertical risers that bring return air from floors 2, 4, 6, and 8 to AH21 and AH22 on the 9th floor. Because the two risers are identical only one is shown. Circled numbers correspond to ClO_2 gas operational monitoring points and with the data reported in Table 1. Locations where the risers were isolated from the horizontal return air ducts on floors 2, 4, and 8 are also shown. Figure 3 is an elevation view.

Figure 4 – 2nd Floor Core S6 and Return Air Duct System

This figure illustrates the horizontal return air duct system that feeds return air from the 2nd floor to the north and south vertical return ducts. The approximate location of where the horizontal ducts were isolated from the north and south vertical return risers are shown. Figure 4 is a plan view.

Figure 5 – 4th Floor Core S6 and Return Air Duct System

This figure illustrates the horizontal return air duct system that feeds return air from the 4th floor to the north and south vertical return ducts. The approximate location of where the horizontal ducts were isolated from the north and south vertical return risers are shown. Figure 5 is a plan view.

Figure 6 – 6th Floor Core S6 and Return Air Duct System

This figure illustrates the horizontal return air duct system that feeds return air from the 6th floor to the north and south vertical return risers. The 6th floor duct system was treated with ClO_2 gas and steam and was not isolated from the north and south vertical return risers. Circled numbers correspond to ClO_2 gas operational monitoring points and with the data reported in Table 1. Figure 6 is a plan view.

Figure 7 – 8th Floor Core S6 and Return Air Duct System

This figure illustrates the horizontal return air duct system that feeds return air from the 8th floor to the north and south vertical return risers. The approximate location of where the horizontal ducts were isolated from the north and south vertical return ducts are shown. Figure 7 is a plan view.

Figure 8a – 6th Floor ClO_2 and Steam Application Points

The figure illustrates the locations (with red blocks) on the 5th floor where ClO_2 and steam was applied. The vents were connected to the main horizontal return air duct system that is located on the 6th floor; vents and ducts that were isolated during the fumigation are also shown (with black blocks). Figure 8a is a plan view.

Figure 8b – 6th Floor ClO_2 and Steam Application Points

The figure illustrates the main horizontal return air duct system that is located on the 6th floor. The figure shows vents where ClO_2 and steam was applied (with red blocks) and vents that were isolated (with black blocks). Figure 8b is a plan view.

3.0 FUMIGATION TIMELINE

The development of the ClO_2 fumigation was done with competing tasks under a compressed schedule. This section details the tasks that were accomplished during the design, preparation, and application of the fumigation.

3.1 Initial Fumigation Preparation November 30 - December 14, 2001

November 30, 2001 (Friday)

- Advised by the Senate Sergeant of Arms that the HVAC system is to be remediated.
- Begin discussions on level and extent of contamination expected in the HVAC system.
- Advised that sample events have determined that the return portion of the HVAC system is contaminated, but that the supply side downstream of the filter banks is clean.
- Begin research on air handling system and heating, ventilation and air conditioning system.
- Secure drawings and descriptions of the system from the Architect of the Capitol (AOC).

December 1, 2001 (Saturday)

- Begin review of technologies applicable for HVAC decontamination.

- Begin development of options for HVAC decontamination.

December 2, 2001 (Sunday)

- Continue review of technologies and options for HVAC decontamination.

- Continue gathering information concerning the HVAC system.

- Meet with AOC air conditioning supervisor regarding HVAC system design.

- Review sample results from HVAC sampling events.

December 3, 2001 (Monday)

- Continue review sample results from HVAC sampling events.

- Examine technologies applicable for HVAC decontamination.

- Begin preparation of a technology review document for consideration by incident command.

- Conduct project scope meetings with AOC, contractors, and incident command.

December 4 – 5, 2001 (Tuesday – Wednesday)

- Five options considered for remediation of HVAC.
    - Manual fogging (sodium hypochlorite (bleach))
    - Gas fumigation (ClO_2 or other)
    - Nanocream
    - UV/Sonic
    - Vaporized hydrogen peroxide (VHP)
    - Conduct preliminary design meetings with personnel from the AOC, contractors, and incident command.

- Issue technology review document for consideration by incident command.

- Prepare conceptual design document for the fumigation of the HVAC using ClO_2 for consideration by incident command.

- Decision made by incident command to move forward with ClO_2 fumigation.

- Begin preparation of final design for the fumigation of the HVAC using ClO_2.

- Begin sourcing material to build ClO_2 fumigation equipment.

- Begin sourcing sampling and monitoring equipment.

December 6, 2001 (Thursday)

- Issue final design for the fumigation of the HVAC using ClO_2.
- Begin preparation of addenda to the design to describe isolation procedures and design and placement of equipment.
- Begin engineering of a scrubber system to remove ClO_2 from HVAC system during and after fumigation.
- Contact USEPA Emergency Response Team (ERT) about air monitoring needs.
- Continue sourcing material to build ClO_2 fumigation equipment.
- Continue sourcing sampling and monitoring equipment.

December 7-8, 2001 (Friday-Saturday))

- Issue Addendum 1 to the design for consideration by incident command.
- Discuss air-monitoring needs with ERT.
- Have access area of ductwork and Core S6 videotaped.
- Continue design of scrubber system.
- Begin development of Addendum 2 to the design for describing the operation plan for the fumigation.
- Continue sourcing material to build ClO_2 fumigation equipment.
- Continue sourcing sampling and monitoring equipment.

December 9, 2001 (Sunday)

- Obtained man-lift to access ductwork in 2 story suite offices to access high ceiling vents.
- Smoke tested vents on returns on floors 2 and 8. Second floor had good draft on both vents. Floor 8 had no draft in the horizontal duct but good flow in the vertical riser. Checked draft at the 7^{th} floor, which showed very little draft in horizontal duct, but good draft in the vertical riser.
- Measure dimensions on ductwork and the distance from the duct to the backside of vertical return risers. The dimensions were used to pre-cut spore strip array rods.
- Smoke tested various areas on the 9^{th} floor and filter boxes. Smoke test showed good isolation.
- Sealed the return duct in HAL-99A.

- Installed new access hatch in duct in the Shelby suite on the 1st floor.

- Documented isolation with photographs.

- Inventoried available spore strips and arranged for additional spore strips to be ordered on 12/10/02.

- Continued development of Addendum 2.

- Continue sourcing material to build ClO_2 fumigation equipment.

- Continue sourcing sampling and monitoring equipment.

- Begin building ClO_2 fumigation equipment.

December 10, 2001 (Monday)

- Inspected access hatch in Specter suite, determined that the existing hatch was not accessible and install new hatch on the bottom of the duct.

- Installed a new access hole in duct in 309 (Sarbanes).

- Installed isolation in the fresh air plenum on the 9th floor.

- Moved and installed new isolation in AH21 so that filters could be removed.

- Installed two “guide lines” from the 9th floor to the garage down the S6 Core shaft.

- Prepare request and garage floor management plan for exclusive access to garage area for Friday thru Sunday to the Senate Rules Committee.

- Conduct meetings with Washington D.C. Department of Health representative to discuss plans and concerns.

- Conducted meeting with site safety officer to modify existing site health and safety plan and air monitoring plan.

- Continued development of Addendum 2.

- Continue sourcing material to build ClO_2 fumigation equipment.

- Continue sourcing sampling and monitoring equipment.

- Continue building ClO_2 fumigation equipment.

December 11, 2001 (Tuesday)

- Installed additional “guide lines” in Core S6.

- Pulled sample tubing from the 9th floor to the garage down the S6 Core. Tape and identify the tubing numbers in the garage and on the 9th floor.

- Locate and isolate the elevator duct tie-in (TF-7) from the elevator shaft to the duct going to AF21.

- Verify that isolation was installed in AF22.

- Install isolation bladders in ducts on floors 1, 3, and 7.

- Install, verify, and document isolation of all outside air plenums.

- Install two sample tubes to vertical return risers on the 2nd floor.

- Install steam and emitter tubing to vertical risers on the 2nd floor.

- Isolation bladders installed in room 309 (Sarbanes) and room 311 (Byrd).

- Isolation bladders installed in the horizontal ducts in the 6th floor hallway.

- Located sample points, emitter, and steam injection locations, and monitoring probe locations.

- Installed access hole in the duct above AH21 for the manometer.

- Continued development of Addendum 2.

- Continue sourcing material to build ClO_2 fumigation equipment.

- Continue sourcing sampling and monitoring equipment.

- Continue building ClO_2 fumigation equipment.

December 12, 2001 (Wednesday)

- Installed isolation bladders in ducts in room 709 (Mikulksi), 711 (Specter), 110 (Shelby), and 112 (Boxer).

- Completed isolation of the 6th floor ducts.

- High ceiling vent isolations in room's 509A, 509, and 506 were completed.
- Isolation of the 9th floor fresh air plenums was completed.

- Isolation bladder was installed in the TF-7 duct.

- Manometer was installed on the 9th floor.

- Conducted airflow test using NAUs on 9th floor and manometers.

- Continued development of Addendum 2.
- Continue sourcing material to build ClO_2 fumigation equipment.
- Continue sourcing sampling and monitoring equipment.
- Continue building ClO_2 fumigation equipment.
- Begin installation of ClO_2 fumigation equipment.
- Begin installation of monitoring equipment.

December 13, 2001 (Thursday)

- Continued the installation and repair of steam delivery lines.
- Continued the installation of electronic data cables from the Daschle and Baucus suites.
- Inspected isolation bladders
- Reconnaissance of 9th floor HVAC area to determine the location of the steam and ClO_2 delivery lines.
- Continued development of Addendum 2.
- Continue sourcing material to build ClO_2 fumigation equipment.
- Continue sourcing sampling and monitoring equipment.
- Continue building ClO_2 fumigation equipment.
- Continue installation of ClO_2 fumigation equipment.
- Continue installation of monitoring equipment.

December 14, 2001 (Friday)

- Installed second mini NAU on the 9th floor.
- Installed three steam and ClO_2 delivery lines on the 9th floor (AH21, AH22, and overhead fresh air duct.)
- Modified steam manifold on the 5th floor to include the 4th steam delivery line.
- Installed temperature and relative humidity probes in the mixing box doorway.
- Installed temperature and relative humidity probe in duct from AH21 prior to joining the outside air plenum at the mixing box.

- Completed isolation of the two remaining 8 ft overhead ceiling vents on the 5^{th} floor.
- Installed spore strips in the 3^{rd} floor horizontal ducts and in AH21.
- Install sample tubing and electronic data cables from the 5^{th} and 6^{th} floors sampling and monitoring locations to the garage down the S6 Core.
- Installed steam and sample tubes in vertical risers at the 2^{nd} floor. Tied the same into steam header in garage.
- Program temperature and humidity probes.
- Installed telephone company corrosion coupons in AH21 and AH22.
- Installed test spore strips prior to steam test.
- Issued Addendum 2 describing ClO_2 operations during the fumigation.
- Continue sourcing material to build ClO_2 fumigation equipment.
- Continue building ClO_2 fumigation equipment.
- Continue installation of ClO_2 fumigation equipment.
- Continue installation of monitoring equipment.

3.2 Initial Fumigation December 14 - December 17, 2001

December 14, 2001 (Friday)

- Build containment area on 9^{th} and 6^{th} floor.
- Continue installation of ClO_2 fumigation equipment.
- Secure perimeter of operation area.
- Secure HSOB garage.
- Begin humidification of HVAC system at approximately 5:00 PM starting at the garage location.
- Continue humidification of the HVAC system at the garage and begin adding steam at the 5^{th}, 6^{th}, and floors at approximately 8:00 PM.
- Discontinue operations at approximately 00:00 AM.
- Inspected isolation of ducts for leaks.

- Recovered spore strips from the steam test and inspected them for steam damage.

December 15, 2001 (Saturday)

- Continued to troubleshoot ClO_2 delivery and humidification system.

- Installed fumigation spore strip arrays.

- Main steam lines from 9th floor to 6th and 5th floor found incompatible with high temperatures. Small 3/8" tubing from manifolds into steam application points found to be carrying condensate that blocks off steam supply.

- Re-stretched flexible steam line from 9th floor to 6th floor and protected it from kinks and collapse points.

- Restarted humidification of HVAC system at approximately 6:00 PM and continued to 00:00AM.

- Decided to abandon steam flexible tubing and hard pipe steam via a 1 inch steel supply line from the 9th floor supply to the manifold on the 6th floor. Contacted AOC and had them prefabricate iron pipe and fittings.

- New steam line to be installed in garage location using ¾ inch copper tubing and controlled with gate and ball valves from the medium steam supply on the drip leg in the mechanical room adjacent to the garage location to Core S6 and the vertical riser risers.

December 16, 2001 (Sunday)

- Continue troubleshooting ClO_2 delivery and humidification system.

- Continue the installation of the steel supply line from the 9th floor to the manifold on the 6th floor.

- Re-inspect isolation bladders. One found partially deflated on the 7th floor.

- Developed and issued Addendum 3 to the design describing modifications to operating parameters to the ClO_2 stripper temperatures.

- Humidification restarted at approximately 2:00 PM.

- ClO_2 operations begun at approximately 8:00 PM.

- North return duct ClO_2 supply believed blocked because of condensate in delivery hose.

December 17, 2001 (Monday)

- Continue ClO_2 operations until approximately 1:30 AM

- Continue steam operations until 3:00 AM.

- All operations halted at 0500.

- Garage ClO_2 equipment secured and de-energized.

- 9^{th} floor and 6^{th} floor equipment de-energized.

- Standby electrical generator and power lines removed.

- Garage ClO_2 liquid neutralized.

- Garage ClO_2 precursor chemicals removed.

- Garage opened for occupancy at 0700.

3.3 Second Fumigation Preparation December 17 - December 27, 2001

December 17, 2001 (Monday)

- Review results of initial fumigation.

- Advised by incident command that another attempt would be made to fumigate the HVAC.

- Inspect ClO_2 delivery hoses in garage to vertical return ducts. Found condensate water in hose feeding the north return duct that would have blocked ClO_2 delivery.

- Inspect balance of ClO_2 fumigation system and discover condensate blockages in the steam delivery system on 6^{th} and 5^{th} floors.

- Review HVAC drawings with AOC and discover drawings depicting the presence of deflector vanes in the bottom of the return vertical shafts. These deflector vanes contributed to the accumulation of condensate at the bottom of the shafts blocking off the ClO_2 delivery hoses from the ClO_2 strippers.

December 18, 2001 (Tuesday)

- Continue review of initial fumigation and begin planning operations for next fumigation.

- Source new steam condensate traps and additional steam flexible tubing from AOC.

- Source additional temperature and humidity probes and arrange for shipment to site.

- Develop new operation schedule.

- Recover spore strips and inspect isolation.

- Continue repair and re-installation of steam and ClO_2 equipment.

December 19, 2001 (Wednesday)

- Advised by incident command that second attempt on the fumigation would be done the weekend following Christmas.
- Advise ERT of new schedule for air monitoring operations
- Continue development of system changes.
- Continue sourcing of equipment for system modifications.
- Continue installation of equipment modifications.

December 20, 2001 (Thursday)

- Source and arrange for additional ClO_2 precursor chemicals for delivery on Monday, December 24, 2001.
- Continue development of system changes.
- Continue sourcing of equipment for system modifications.
- Develop new isolation systems for vents.
- Continue installation of equipment modifications.

December 21, 2001 (Friday)

- Continue development of system changes.
- Continue sourcing of equipment for system modifications.
- Continue installation of equipment modifications.

December 22 - 25, 2001 (Saturday-Tuesday) Christmas Break

- New steam supply line and valves installed in the garage area.
- Additional precursor chemicals delivered to the site.

December 26, 2001 (Wednesday)

- Personnel remobilized to the site.
- Received new monitoring equipment.
- Continue installation of equipment and modifications to system.
- Installed temperature and humidity probe in the horizontal duct in the Daschle suite.

- Installed three new temperature and humidity data cables from the 9th floor to the garage down Core S6 shaft.

- Installed sample probes in the AHUs on the 9th floor.

- Installed small recirculating fan in the horizontal duct in the Baucus suite.

December 27, 2001 (Thursday)

- Installed new ERT temperature and Rh probes.

- Installed perimeter air monitoring equipment.

- Installed new temperature and Rh probes in AH21, AH22, and mixing box.

- Installed new sample points so that ClO_2 gas intakes tubes are near the midpoint of the ducts.

- Relocated NAU to AH21.

- Reprogrammed all probes.

- Installed double contained flexible duct from NAU to scrubber.

- Installed new flexible hose from steam delivery pipe to distribution manifolds on 5th and 6th floors.

- Installed and reconfigured new steam condensate traps on 5th and 6th floors.

- Installed new sample tubes from AH22 to sample manifold in the garage.

- Inspected and resealed all isolation points.

- Relocated ClO_2 and steam supply lines from fresh air plenum to allow access door to close.

- Develop and issue Addendum 4 to the Design concerning modifications to the operation plan.

- Update site security plan and garage management plan.

- Conducted steam test of steam delivery system in the garage.

- Installed spore strip arrays.

3.4 Second Fumigation December 28 - December 31, 2001

December 28, 2001 (Friday)

- Downloaded data from humidity and temperature probes and restarted probes.
- Setup analytical laboratory in HSOB garage.
- Setup operation command center in HSOB garage.
- Secured perimeter for operations.
- Verified isolation in place on the 5^{th}, 6^{th}, and 9^{th} floors.
- Start humidification of HVAC system on 9^{th} and 6^{th} floor at approximately 9:00AM.
- Shutdown steam for leak repair and restart humidification at approximately 10:00AM.
- Installed new ERT probe in the duct in the Daschle suite.
- Probes overcome by humidity exceeding 96% Rh on or about 12:00 PM.
- Shut down of the system at approximately 2:00 PM to dry and replace temperature and humidity probes and remove excess humidity from the HVAC system.
- Restarted humidification of the system at approximately 4:00 PM.
- Started ClO_2 fumigation operations at approximately 5:30 PM.
- Installed bypass/shorcircuit pipes and valves in containment above NAU to slow suspected stack effect.

December 29, 2001 (Saturday)

- Inspected isolation bladder in room 711. Bladder found to be deflated and replaced.
- Inspected bypass/shortcircuit pipes in AH21. Found that system was under positive pressure and that pressure increased as the NAU speed was increased. Also found that system was under positive pressure when the NAU was turned off.
- Tested bypass valves under various 9^{th} floor conditions as AOC turned off various fans in other HVAC systems impacting airflow in the building. No effect on bypass under various conditions with NAU operating at 220 feet per minute.
- Curtailed humidification and ClO_2 operations at approximately 5:00 PM for repair of isolation.

December 30, 2001 (Sunday)

- Installed foam board on horizontal transitions in the mixing box. Occluded approximately 90% of the opening to reduce stack effect in the vertical risers.

- Install new isolation in ductwork leading from mechanical room on the 9th floor.

- Humidity operations re-started at 3:00 AM.

- ClO_2 operations re-started at 8:00 AM.

December 31, 2001 (Monday)

- Humidification and ClO_2 operations ended at approximately 3:00 AM.

- Secured and verified ClO_2 Ct data and determined credit and deducts as relates to humidification objectives.

- De-commissioned and de-energized ClO_2 equipment.

- Began removal of HVAC fumigation equipment.

- Returned HSOB garage for stakeholder occupancy.

4.0 FUMIGATION RESULTS

Review of the operational results and monitoring data collected during the fumigation revealed that for the most part the objectives detailed in Section 2.0 were eventually achieved. Some objectives presented challenges that were not completely overcome. This section presents the fumigation results according to observations and data collected and reviewed.

4.1 Isolation of the HVAC Return Air System

The design called for the isolation of the horizontal return air ducts to the north and south vertical return risers at floors 2, 4, 8; the return air mechanical ducts on the 9th floor from the supply side of the HVAC system; and the system from the outside air plenums (See Figures 2b, 3, 4, 5, 6, and 7 for locations). Hard isolation materials (foam board covered by plastic sheeting and duct tape) proved, for the most part, resilient to the effects of the fumigation. Prolonged exposure to high temperatures and humidity caused degradation of duct tape seals. The primary problems encountered in isolation efforts proved to be the existance of undiscovered return air vents, inherent leakages of the duct system, and the expansion failure due to temperature increases of the air filled bladders used to isolate the horizontal ducts. The leakages caused ClO_2 gas and steam containment issues and prolonged the fumigation time period that also contributed to additional degradation and increased leakages.

4.2 Injection of ClO_2 and Steam

The design called for the injection of ClO_2 and steam at the bottom of the north and south vertical return ducts, in the vents leading to the horizontal return air ducts on the 5th and 6th floor in the Daschle suite, and three points on the 9th floor (See Figure 2a for locations). ClO_2 and steam was introduced into the system at all of the objective points and the success of each was varied.

ClO_2 gas was applied to application points at concentrations that would have allowed increasing accumulations within the system had it not been for system leaks and the dilution contributed by stack effect attributed to the steam being applied into the bottom of the system and rising 9 stories. This effect was particularly noticeable during the second fumigation when outside air temperatures where significantly colder than the first effort. During the second effort, occlusions were installed at the top of the vertical shafts during a system shutdown to inhibit stack effect.

Steam condensate was problematic for all of the locations during the initial fumigation. Observations during that effort led to installation of hard piped, larger capacity, primary feed lines, condensate traps, and shorter secondary feed tubes that eliminated most of the condensate issues in the second attempt. During the second fumigation, steam was delivered to all of the application points in impressive amounts. Because of the lack of operating experience and the crude control available, the prodigious amounts of steam occasionally overwhelmed temperature and Rh probes. This made effective monitoring of conditions within the HVAC system difficult.

4.3 Negative Air Machines

The design called for the removal of 150 cubic feet per minute (cfm) of treated air from the HVAC system via negative air machines (NAUs). During the initial fumigation a small NAU was installed in AH22 and the exhaust was vented via flexible conduit to the scrubber also installed on the 9th floor. This NAU removed approximately 165 cfm during the initial fumigation. A ClO_2 scrubber was attached to the discharge and was designed to accommodate up to 500 cfm. Observations of the system during the initial fumigation indicated that airflow in the 9th floor duct system was not as effective as anticipated. The second fumigation provided for movement of the NAU to AH21 that provided better sweeping efficiency. The removal of small amounts of air within the closed system was intended to keep it under negative pressure, thus prohibiting ClO_2 from escaping the system and allowing ClO_2 concentrations to accumulate. Stack effect and system leakages combined with building interior environmental airflows caused a positive pressure on the system to be observed on the 9th floor during the second fumigation. The effect was documented when observation tubes where installed above the NAU that were intended to short circuit air flowing up the system. The tubes indicated that air was flowing out of the system on the 9th floor, even with the NAU turned off.

4.5 ClO_2 Scrubber

The design called for scrubbing residual ClO_2 from the NAU exhaust and venting it to the interior of the HSOB, specifically the atrium area. During the second fumigation the scrubber effectively removed ClO_2 from the NAU exhaust when the scrubber chemicals were within operating parameters. Because of the increase of time the fumigation required and the stack effect pushing more air out of the system than was intended, the scrubber was overwhelmed on at least two occasions. Interior air monitoring teams picked up spikes of ClO_2 gas on the 9th floor and it was traced to the discharge of the scrubber. Once the situation was appraised, operating teams extended the discharge ducting further into the atrium and readjusted the scrubber chemicals to bring them in line with proper operating parameters.

4.6 Air Monitoring and Operational Sampling

The design called for air monitoring and operational sampling for temperature, relative humidity, and ClO_2 gas concentration at critical points within the building. This section presents the results of these operations.

Air Monitoring

Interior air monitoring was accomplished according to the Air Monitoring Plan prepared for the operation. Roving teams of personnel carrying ClO_2 monitoring instruments monitored ambient air at specific locations on a set schedule. There was at least one team in the building at all times during fumigation operations. Readings were radioed to a support team located at the operation center in the HSOB garage. If data received in the HSOB garage support station exceeded standards indicated in the plan, then project management was advised, and repair parties were dispatched to repair equipment and contain excursions. There were a number of occasions that data collected during the sampling proved to be indicative of problems associated with containment within the HVAC system and/or failure of scrubbing equipment. Air monitoring equipment, however, was unable able to pick up low concentrations of ClO_2 gas near the command center of the HSOB garage during the fumigation. This became known because it was discovered near the end of the operation.

Operational Sampling

Operational sampling consisted of recording data supplied by remotely installed temperature and humidity probes and the collection of ClO_2 gas samples from near these same locations. Data feed cables from the remote instruments were terminated at laptop computers located in the HSOB garage operation center and were used to provide real time observations. The ClO_2 gas samples were collected at a central manifold also near operation center in the HSOB garage and analyzed according to procedures outlined in the design at an onsite analytical laboratory.

The remote temperature and humidity probes proved to be unreliable when exposed to humidity levels that approached 95% Rh. Monitoring probes supplied by ERT and purchased specifically for the fumigation both proved to be susceptible to high humidity. The probes would essentially peg themselves and became nonfunctioning. This became problematic during the course of the fumigation as Ct time credit was deducted for humidity levels that were either below 70% Rh or that were un-verifiable because of probe failure. There were heroic efforts employed by project management and entry team personnel to replace, repair, and keep the instrumentation functioning. The ability of the instruments to provide real time monitoring results at a remote location where personnel were not required to wear restrictive personal protection equipment was extremely beneficial. The equipment also allowed data to be manipulated with commercially available spreadsheet programs.

The ClO_2 gas sample collection and analytical effort functioned as was anticipated. There were problems encountered with sample tubes becoming blocked due to condensate. Blocked tubes were blown out with compressed air periodically. Because of the increased time duration there were analytical chemical supply difficulties. Stocks of chemicals became low and efforts to replenish them during non-business hours and weekends were difficult. Personnel manning the analytical lab were also over-worked because of the extended schedule. Substitute personnel were quickly trained as replacements.

Data collection and coordination was not as seamless as anticipated. Merging temperature and humidity data with ClO_2 Ct data was cumbersome and inefficient. There was unconstructive time spent in merging the data towards the end of the fumigation when personnel were fatigued.

Air Quality Monitoring Outside of the Building

Air quality monitoring outside of the building was conducted according to the site-specific monitoring plan. Air monitoring personnel communicated ClO_2 levels outside of the building to operational command in a timely and efficient manner. At no time did excursions exceed allowable levels provided for in the plan.

4.7 Fumigation Objectives

The design objectives called for the fumigation to attain 75%+ of Rh, 75^{o}+F temperature, 500 ppm_V + ClO_2, and 9000 ppm_V-hours Ct within the HVAC system. Based on previous laboratory and field experience (Brentwood 2001), these parameters were expected to produce sporicidal effects within the HVAC system. This section describes the results of the fumigation as it relates to these objectives.

Relative Humidity Parameter

During the first fumigation attempt the Rh parameter was not achieved in a majority of the monitored locations. There were various mechanical and operational problems associated with steam feed, condensate accumulation, isolation, and equipment. The failure to achieve the humidity objective terminated the first attempt. Observations made during that attempt were incorporated in the planning and operation of the second fumigation. The adjustments made during the preparation for the second attempt resulted in the modified humidity parameter of greater than 70% being achieved in five of the six locations considered critical for success. During the second fumigation a 70% Rh cutoff was employed because there were numerous values between 70-75% Rh, and the available scientific data supporting a 75% Rh cutoff was not strong. The only area not achieving the 70% Rh objective was AH21. Because of this, the area was topically treated with ClO_2 solution following the fumigation.

Temperature Parameter

The temperature parameter was consistently achieved in both fumigation attempts. Temperature control was not a significant issue in the terms of attainment.

Chlorine Dioxide Concentration Parameter

The ClO_2 ppm_v concentration parameter was not achieved during the first fumigation because of the failure to achieve the humidity parameter and the resulting fumigation termination. The second fumigation also did not consistently achieve this parameter. ClO_2 ppm_v concentrations were both over and under the objective at all locations at some point during the fumigation. The critical parameter for success of the fumigation was the chlorine dioxide concentration time, Ct parameter. If ClO_2 ppm_v concentration was below the objective, the time of the fumigation was extended to compensate for the lower value.

Chlorine Dioxide Concentration Time Parameter

The ClO_2 ppm_v – hrs Ct parameter was not achieved during the first fumigation because of the failure to achieve the humidity parameter and the fumigation termination. The adjustments made during the preparation for the second attempt resulted in the parameter being achieved in five of the six locations considered critical for success. The Ct values for the sample locations were corrected for times that relative humidity did not attain the design objectives. The only critical area not achieving the Ct objective was AH21 and that was due to the non-attainment of the humidity parameter. Because of this, AH21 was topically treated with ClO_2 solution following the fumigation. The actual values achieved during the second fumigation are detailed in Table 1. Sample point numbers are consistent with locations detailed in Figures 2a, 2b, 3, 4, 5, 6, and 7.

TABLE 1
Chlorine Dioxide Concentration Time (Ct)

Sample Point	Description	Total Ct	Corrected Ct	Comments
1	511 Horizontal Duct	13700+	9404	
2	509A Horizontal Duct	14415+	9349	
3	South Return Vertical Riser	10988+	6623	
4	North Return Vertical Riser	13286+	9179	
5	Mixing Box 9th floor	11056+	Approximately 7000	For calculation of Ct locations 5 and 6 were combined
6	AH 21/22 after Mixing Box	11161+		
9	AH22	9966+	9431	
10	AH21	9255+	0	Corrected Ct value due to humidity problems

<u>Spore Strip Dosimeter Results (Leighton 2002)</u>

A total of 440 spore dosimeter indicator strips were placed at eleven locations within the HSOB HVAC system directly impacted by the anthrax release from the 6th floor. A total of 395 Strips were initially recovered following the second fumigation. An additional 33 strips were subsequently recovered (total recovered = 428). The purpose of the spore strip arrays was to monitor sporicidal bioeffects during the fumigation. Spore strip arrays were suspended across the horizontal lengths of the HVAC air-handling units at locations on the 2nd, 4th, 8th, and 9th floors. Each spore strip array contained; 2 or 3 Bst Steri-Charts containing strips with 10^3, 10^4, 10^5, 10^6, and 10^7 spores; 2 sterile control strips; 6 Bs strips, containing 10^6 spores, in clusters of 3 strips; and 6 Bst strips, containing 10^5 spores, in two clusters of three strips. The spore strips were usually contained in glassine envelopes. In some cases, Steri-Charts and individual spore strips contained in Tyvek envelopes were also included to assess the effects of envelope materials on sporicidal effects. Table 2 indicates a summary of the spore strip analytical results.

TABLE 2

Spore Strip Data Summary

HVAC Vertical Return	Floor	Steri-Chart	Bs	Bst
North Riser	2	-5 kill (v)	-6 kill (v)	-5 kill
South Riser	2	-6 kill (v)	-6 kill (v)	-5 kill (v)
North Riser	4	-7 kill	-6 kill	-5 kill
South Riser	4	-7 kill	-6 kill	-5 kill
North Riser	6	-7 kill	-6 kill	-5 kill
South Riser	6	-7 kill	-6 kill	-5 kill
North Riser	8	-7 kill (2NR)	-6 kill	-5 kill
South Riser	8	-7 kill	-6 kill	-5 kill
North Riser	9	-6 kill (v)	-6 kill	-5 kill
South Riser	9	-7 kill	-6 kill	-5 kill
AH22 Mixing Box	9	-7 kill	-6 kill	-5 kill

Notes: Steri-Chart = Mini-arrays containing *Bacillus stearothermophilus* strips in glassine envelopes with 10^3, 10^4, 10^5, 10^6, and 10^7 spores; Bs = *Bacillus subtilis* 10^6 spore indicator strips in glassine envelopes (FDA sporicidal test species); Bst = *Bacillus stearothermophilus* 10^5 spore indicator strips in glassine envelopes (FDA gas phase sporicidal test organism); Sterile Control strips in glassine envelopes were also used a placement and handling sterility controls; Positive control strips (not exposed to fumigation conditions) were used to verify culture system performance; (v) = Variable data from individual components of the spore dosimeter array. Composite log spore killing is indicated for each sample location (example – 6 kill = a 10^6 sporicidal effect). 2NR = Two Steri-Charts not recovered at this location

The spore strip dosimeter array data suggest the FDA standard for pervasive sterilizing sporicidal effects (10^6 Bs kill and 10^5 Bst kill) was achieved during the fumigation. The data do not prove the absence of viable spores in the treated system but they fully supported the resumption of the operation of the HVAC system. Post-fumigation environmental and air sampling suggest that the ClO_2 fumigation was successful in remediating the spore burden within the HVAC system.

5.0 LESSONS LEARNED

Although many challenges were overcome, the fumigation of the HSOB HVAC revealed opportunities for adjustment if similar projects are anticipated in the future. Evaluation of operations after the fumigation combined with interviews of participating project managers and contractors indicated that future projects would benefit from the lessons learned at the HSOB. This section presents the cumulative knowledge of both challenges overcome and those unsolved as related to the fumigation of the HSOB.

5.1 Plan for Redundancy

- Prepare for breakdowns, stockpile spare parts including pumps, compressors, valves, fittings and pipe. Anticipate what parts may fail and have spares on-hand. The cost of the parts will likely be insignificant compared to the cost of standby time while parts are located.

- Stock quantities of chemicals and analytical reagents in excess of the anticipated needs. The experience at the HSOB is that fumigation events take much longer than originally planned and consumption of chemicals, including laboratory reagents, was greater than anticipated. Biological demand, leakage of gas, degradation, unanticipated weather effects, and partitioning to other media contribute to operational chemical consumption. The extended time period caused increases in analytical chemical consumption because the number of time dependant samples increased. Trying to source supplies of scarce or unique analytical reagents becomes problematic during non-normal work schedules, weekends, and holidays.

- Critical monitoring points should be installed in duplicate. At the HSOB; gas sampling, relative humidity, and temperature monitoring points were lost for various reasons. Duplicate probes and sample lines can minimize loss of data.

- A process operability review is recommended before construction to determine suitability of components. Thorough research of operating parameters of rotating equipment and instrumentation will keep equipment failures to a minimum.

- For critical path, high profile or potentially dangerous operations, dry runs and operational choreography is recommended. Provisions for training and process review should be accommodated in the schedule to minimize confusion and enhance effectiveness.

5.2 Preposition Materials for Repairs

- Prepare for breakdowns; stockpile tools and construction materials where they will likely be needed.

- Tool kits should be tagged for location so they are not removed and a procedure and record keeping system devised so that they are returned to their specified location after use.

- The location, a map of the location, and an inventory of pre-positioned tools, equipment, and material should be available at incident command.

- Large equipment or material spares that are difficult to move should also be pre-positioned near to where they are anticipated to be used.

5.3 Personnel

- All positions should have redundant personnel that can be substituted in a short period of time with no interruption in assigned tasks. If the project demands 24-hour a day operations, make sure there is a handover procedure at crew change so that relevant information is transferred and not lost.

- There should be sufficient depth of senior and mid level contractor personnel that are qualified for and willing to do hot zone entry work for all anticipated work shifts.

- All personnel should work reasonable shifts; over-extended working hours, particularly for key personnel, is detrimental to operational efficiency.

- Key personnel should be stationed at local hotels during off duty hours and provided with dedicated communication equipment so that they can be reached in an emergency.

- Qualified personnel should be appointed to set up communications and to provide training to incident command, managerial, and entry personnel.

5.4 Treatment Zone Selection, Preparation, and Isolation

- Treatment zone selection criteria should include consideration for isolation requirements. Isolation should be done with ridged materials where possible, particularly avoid inflatable bladders in ducts. Temperature increases during treatment cause inflatable bladders to expand beyond their design strengths.

- Use HVAC rated equipment, (ducting, insulation, transitions, T's, connections, straps, tape, etc) where possible.

- Avoid imparting artificial airflows or pressures within an HVAC system.

- Do not rely on "as built" drawings as the absolute authority on HVAC or building construction. Direct inspection is required for all critical points and isolations.

- Use tape or flags to identify and label valves, switches, critical lines, sample points, and pathways in the hot zone.

- Develop a map for the operations center with locations of critical items and access pathways marked.

- Extensive use of video reconnaissance is recommended for briefing incident command and non-entry personnel.

- The use of real time audio and video equipment should be considered for directing and monitoring entry teams during critical and or special operations.

5.5 Monitoring

- Position critical sensor monitors and insertions in level D areas if possible. Terminate the remote monitoring data cable feed to this location. This area should also have a location that provides for consolidated sample lines and sampling apparatus.

- Additional research needs to be completed on validating automated "real time" chlorine dioxide analytical instruments.

- Integrated data management needs to be employed for process monitoring information.

- When sample lines are employed they need to be tested and standardized before operation

- Minimize data points by effective testing of the system to determine requirements. This can be accomplished by use of test gases, smoke, or low-level chlorine dioxide dosages. Testing frequency can also be minimized as the process operations level out.

- Set testing personnel on shift schedules regardless of anticipated or actual start time to insure adequate staffing levels during operations.

- Appoint dedicated personnel whose sole function is record operation changes during fumigation events and utilize additional personnel as a master data recorder – coordinator.

5.6 Treatment

- Allow time for normal construction practices (i.e. let the glue dry) before testing or operations.

- All equipment, controls, analytical instrumentation and communication should be tested prior to treatment start up and assigned personnel trained in the use.

- The treatment schedule should not be finalized until after construction and final testing is completed. The inherent unknowns in HVAC systems and building mechanical systems provide sufficient variables to make process projections difficult.

- Designs should allow for condensate traps, check valves, flow indicators, and other process control aids.

- Humidity and temperature control should be established at least 24 hours prior to start of fumigation and then maintained for the entire operation. Longer periods may be required if there is a high potential for moisture absorption.

- Emitter/stripper temperature control should only be used to help maintain humidity levels, not to establish them.

6.0 CONCLUSION

The fumigation of the HSOB HVAC revealed that adjustments are most likely necessary if similar projects are expected in the future. Given there was little precedence concerning the use, efficacy, and application of ClO_2 gas as a fumigant against anthrax, and the fact it had never been distributed in a public building's HVAC system, the outcome of the operation can be considered a success. Through diligent effort by EPA project managers, the innovative skills of a select cadre of private companies, and the coordinative efforts of Washington D.C. public safety officials the suppression of the anthrax contamination in the HSOB HVAC was completed. The experience proved that ClO_2 gas could be applied safely, that knowledgeable personnel must apply it, and that successful operation integration requires patience and professional management.

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