

Assessment of the Impact of Decontamination Fumigants on Electronic Equipment

INTRODUCTION

In response to Homeland Security Presidential Directive 10, the U.S. Environmental Protection Agency (EPA) Office of Research and Development and the Department of Homeland Security Science and Technology Directorate (DHS) coordinated efforts to develop capabilities to respond to incidents involving biological agents. One capability needed is effective methods to decontaminate areas that may contain sensitive equipment or high value materials. These items may be harmed in the decontamination process by the decontamination agent (e.g., the fumigant). Therefore, often the compatibility of sensitive materials and decontamination agents should be understood when deciding on a cleanup approach.

To address this needed capability, EPA has completed a number of material compatibility studies, some in collaboration with DHS, using the following four fumigation techniques:

- Chlorine dioxide (ClO_2) gas has been used successfully for the remediation of several federal buildings contaminated by *Bacillus anthracis* (*B. anthracis*) spores contained in letters and shown to be highly effective in EPA laboratory studies for use on porous and non-porous materials.¹⁻⁸
- Hydrogen peroxide (H_2O_2) vapor was employed effectively as part of the overall remediation strategy used for a government facility in 2001. It has also been shown to be effective against *B. anthracis* spores, particularly on non-porous materials, in laboratory testing conducted by EPA.^{1,3-6,9}
- Methyl bromide (MeBr) gas has been shown to be effective against *B. anthracis* spores on porous and non-porous materials in laboratory testing.^{1,4-5,10}
- Ethylene oxide (EtO) gas is a commercially available fumigation technology used widely in the medical industry for sterilization. It has also been shown to be effective against *B. anthracis* spores in laboratory testing.¹¹

Material compatibility was directly assessed by observing the impact of these fumigation technologies on sensitive electronic components and materials. The materials and electronic systems used in this study were chosen to be characteristic of equipment, components, and materials found in critical infrastructure or high-value items. For example, computer systems were employed that included sub-components often found in high-end medical, communication, and security equipment.

Laboratory Facility Description

The material compatibility testing was performed at the EPA's research facility in Research Triangle Park, NC. Target conditions varied by fumigant and are discussed below. The materials and equipment evaluated stayed as identical as possible for each subsequent test.

Material and Equipment Evaluated

Three categories of materials were examined in these studies:

- Category 2 materials included low surface area structural materials such as metal coupons, stranded wires, circuit breakers, gaskets, smoke detectors, printed paper, color pictures, and photographs. The experimental objective for this category of materials was to assess the aesthetic (visual) and/or functionality (as appropriate) impact of the fumigation process on the materials.
- Category 3 materials included small, personal electronic equipment such as fax machines, cell phones, Personal Digital Assistants (PDAs), CDs, and DVDs. The experimental objectives for this category were to determine aesthetic (visual) and functionality impacts on the equipment as a function of time post-fumigation.
- Category 4 materials included desktop computers and monitors. The experimental objective of testing this category of equipment (and materials) was to assess the impact of the fumigation conditions using a two- tiered approach: (1) visual inspection and functionality testing using a personal computer (PC) software diagnostic tool, and (2) detailed analysis for a subset of the tested equipment.

PC-Doctor® Service Center™ 7.5 (Version 6 was used in earliest testing), a commercially available software used to diagnose and detect computer component failures, was used to test the functionality of each computer pre- exposure, immediately post-exposure, and then monthly thereafter for a period up to one year. If any particular test failed the first time, the computer was tested a second time to correct for possible human error.

FUMIGANT: CHLORINE DIOXIDE (ClO₂)¹²⁻¹⁴

Fumigation conditions were chosen based upon use in the field or demonstration of effectiveness in laboratory based testing. The fumigation conditions studied were as follows, and included the effect of relative humidity (RH) and ClO₂ gas concentration:

- 3,000 ppmv ClO₂ at 75% RH with a total product of concentration and time (CT) of 9000 ppmv-hrs;
- 750 ppmv ClO₂ at 75% RH with a total CT of 9000 ppmv-hrs;
- 75 ppmv ClO₂ at 75% RH with a total CT of 900 ppmv-hrs;
- 5 ppmv ClO₂ at 40% RH with a total CT of 900 ppmv-hrs;
- 3,000 ppmv ClO₂ at 90% RH with a total CT of 9000 ppmv-hrs

Exposures to 40% and 90% RH without ClO₂ fumigant were performed to determine the effect of RH alone.¹² All tests were conducted at 72-75 °F.¹²⁻¹⁴

ClO₂ Results Summary

Category 2 and 3 Materials

The observed effects were a direct function of the conditions to which the material or equipment was exposed.¹²⁻¹⁴

Fumigation at levels of RH exceeding standard fumigation conditions (i.e., 75% RH) resulted in the most significant material impacts.¹² In general, the effects were directly related to the ClO₂ gas concentration, RH, and type of material or equipment exposed.¹²⁻¹⁴ Results obtained in this study show that RH during fumigation should be maintained between 65 percent and 75 percent to maximize compatibility for most materials.¹²

Materials with the potential for damage include, but are not limited to, the following:

- Unpainted and unlubricated carbon steel;
- Ferritic and martensitic chromium alloys of stainless steel (Type 400 series);
- Certain alloys of aluminum;
- Devices with exposed copper contacts, including battery-powered devices (see Figure 1);
- Any device with optical plastic components, such as consumer-grade cameras, CD/DVD drives, and laser pointers;
- Equipment containing extensive color-coded wire insulation.

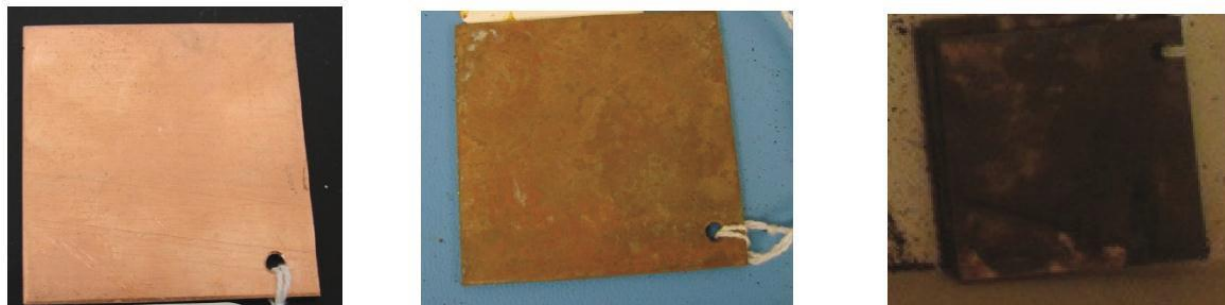


Figure 1. Copper coupon before (left photo), immediately after (center photo), and 12-months post-exposure (right photo) to high RH fumigation with ClO₂.

Category 4 Materials - Visual Assessment

Pre-2010 desktop computers models exhibited some significant effects when exposed to ClO₂ fumigation.¹² As a result of the fumigation with ClO₂, the aluminum heat sink produced in a light powder which coated the motherboard and chassis. Significant corrosion was seen on any exposed metal edges, as shown in Figures 2 and 3. This effect was seen throughout the internal PC components. At higher concentrations of ClO₂ gas, wire insulation became discolored (compare Figures 4 and 5). Similar wiring is used in many other applications where wire color may be very important. A critical note here with regard to PCs is that components are not always consistent across models of different lots; component types change often.¹²⁻¹⁴



Figure 2. CD-ROM Casing (Control PC)



Figure 3. CD ROM Casing (3000 ppmv)



Figure 4. Unaffected Internal Wires (75 ppmv)

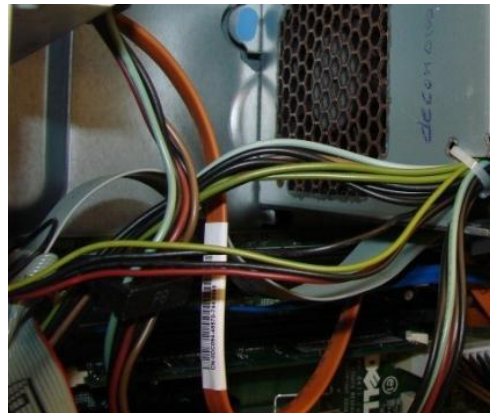


Figure 5. Discolored Internal Wires (3000ppmv)

Category 4 Materials - Functionality Assessment

The vast majority of failed components (83.7%) were related to the CD/DVD drive.¹²⁻¹⁴ A significant number of the remaining failures were related to the floppy drive, and many were an intermittent network loopback failure which appeared to be an issue with all computers, even controls. Analysis showed that the CD/DVD subsystem is not reliable even under normal circumstances (without decontamination), with one of three failing in two of the control condition computer sets. However, exposure to fumigants clearly did reduce the reliability of the CD/DVD subsystems.

Total PC failures over the course of PC testing with ClO₂ gas compared to controls are shown in Figure 6. For a test to “fail”, the test had to have a negative result two consecutive times to mitigate the effect of intermittent trouble or user error. For each test “failure”, a score of 1000 was added to a cumulative total, and for each test that passed on the second try, a score of 1 was added to the total. The cumulative score at each month of evaluation is shown in Figure 6.

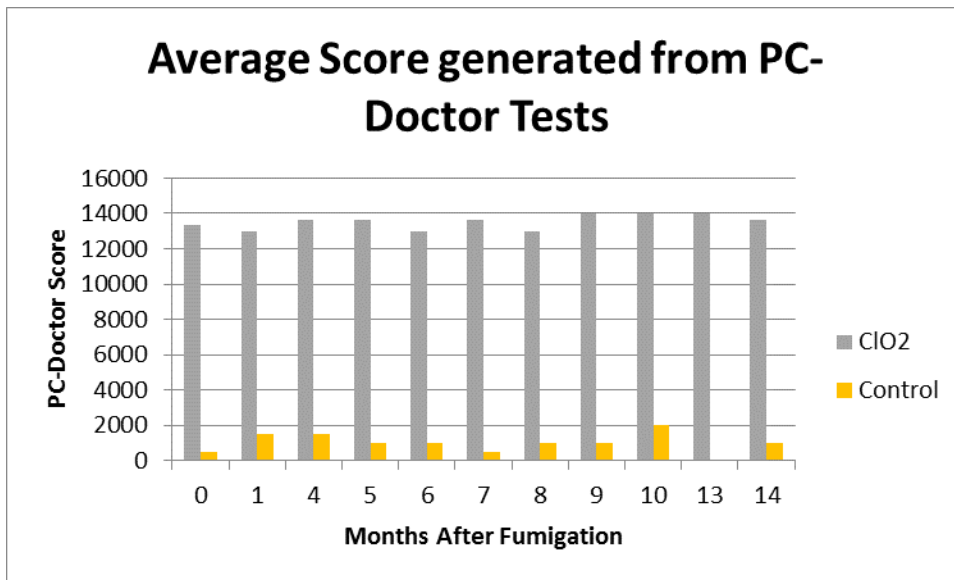


Figure 6. PC Doctor test results.

CIO₂ Summary

- The tested equipment exhibited more frequent failures after fumigation at 3,000 ppmv CIO₂ and 90% RH than under other test conditions.
- The results for computers exposed to 3,000 ppmv CIO₂ and 75% RH were notably better for those computers that were “ON”, though the fumigation was not as effective at killing the spores inside the computers.
- The failure rate for fumigation at standard conditions was slightly elevated for “OFF” computers.
- Many of the computer subsystems held up well to the fumigation process, including, importantly, the hard drive and the motherboard.
- Many of the significant issues were caused by the hygroscopic dust, which may be specific to a few metal alloys.
- Removal of this dust through vacuuming and drying of the dust (over time in a relatively dry office atmosphere) ameliorated effects.
- Significant failures included the DVD drive and floppy drive, lending credence to effects of fumigation on optical plastics.
- Despite these effects and visible corrosion, the computers, with the exception of some DVD drives, were still in operation with no replacement parts one year after fumigation.

FUMIGANT: HYDROGEN PEROXIDE (H₂O₂)¹³

The following H₂O₂ scenarios were conducted on all three categories of materials:

- BioQuell HPV (hydrogen peroxide vapor) with a 35% starting RH and a 1 hour dwell time;
- STERIS 1000ED at 250 ppm H₂O₂ concentration for 4 hours with initial RH of 35% (total cumulative exposure of 1000 ppm-hr);
- Additional tests were conducted to determine the effect of varying the operating conditions (RH, concentration, and exposure time) on aesthetic (visual) and functionality impacts on targeted material and equipment.

H₂O₂ Results Summary

Category 2 and 3 Materials

Visual inspection and operational testing showed that Category 2 and 3 materials maintained their pre-exposure physical and functional characteristics throughout a 12-month observation period following both BioQuell HPV and STERIS VHP® fumigations (Figure 7).



Figure 7. Exposed stranded wire and PDAs powered 12 months after H₂O₂ gas exposure.

Category 4 Materials - Visual Assessment

No changes were noted for Category 4 equipment (desktop computers and monitors) that had been exposed to H₂O₂ using either BioQuell HPV or STERIS VHP® fumigation technologies. The same type of Category 4 equipment, when exposed to ClO₂ fumigation, exhibited some visually observed effects. These effects included corrosion on the inside and outside, and the presence of a powdery residue. Corrosion to an internal grid following ClO₂ fumigation is shown in Figure 8.

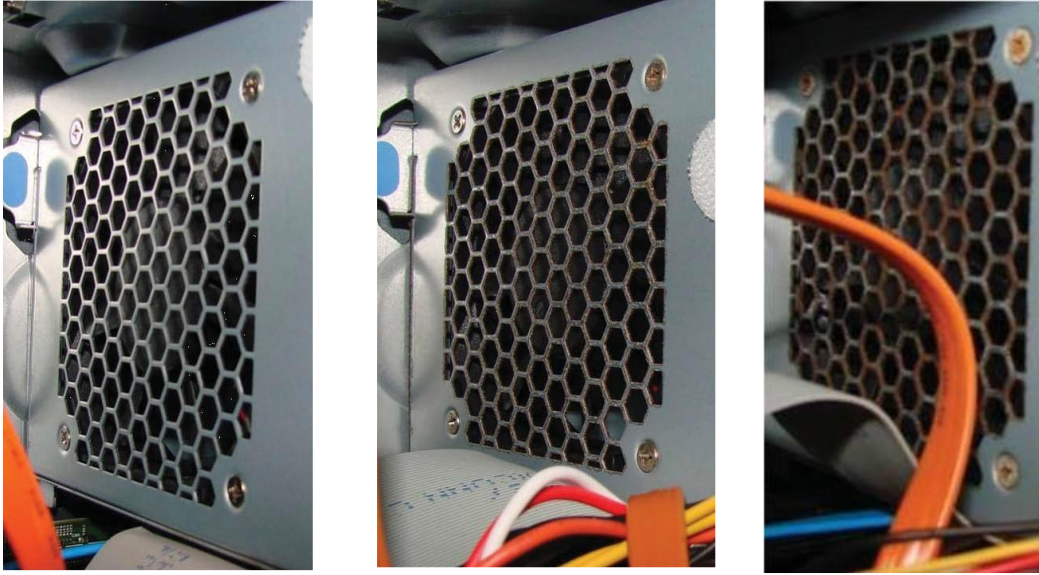


Figure 8. An unexposed power supply case with no corrosion (left photo) compared to a corroded grid seen on computers fumigated with ClO_2 at (center photo) 3000 ppmv and (right) 750 ppmv.

Category 4 Materials - Functionality Assessment

Regardless of the fumigation scenarios, the vast majority of failures (83.3%) were found to be related to the DVD drive, 14% were related to the floppy drive, and the remaining 3.7% to other failures (such as broken USB ports, power supply, etc.). In most cases, comparison of the results from fumigated computers to the control computers did not suggest that fumigation significantly affected the performance of the computer. Computers exposed to ClO_2 were found to be more prone to physical/functional deterioration than the ones that were exposed to H_2O_2 fumigation, confirming the earlier test results.

H_2O_2 Summary

- Category 2 and 3 materials and equipment appear to be unaffected by fumigation with H_2O_2 .
- Computer performance does not appear to be significantly affected by up to 12 months following fumigation with H_2O_2 .
- Confirming earlier results, computers fumigated with ClO_2 were more prone to physical/functional deterioration.

FUMIGANT: METHYL BROMIDE (MeBr)¹⁴

MeBr is toxic to humans, but colorless and odorless, so it is frequently mixed with 2 percent chloropicrin (tear gas) which serves to warn users of exposure (hereafter referred to as “98-2 MeBr ”). Target conditions for the MeBr fumigations were 300 mg/L MeBr with 2% chloropicrin (98-2) for 9 hours at 37 °C and 75% RH. The determination of these conditions was based upon EPA testing of the efficacy of MeBr for inactivation of *B. anthracis* spores on building materials (USEPA, 2010; USEPA, 2011).

MeBr Results Summary

Category 2 and 3 Materials

Methyl bromide itself is an alkylating fumigant that should not cause corrosion. However, the chloropicrin component did cause oxidation of many materials, including steel and zinc-plated metals.

Category 2 materials had varying physical responses throughout the 12 month observation period following the 98-2 MeBr fumigation, but seemed to maintain their pre-exposure functional characteristics, with the exception of low carbon steel and the steel outlet/switch box, which showed signs of corrosion (Figure 9).

Category 3 materials showed no visual or functional changes after fumigation with 98-2 MeBr.



Figure 9. Low carbon steel before (left) and after (right) fumigation showing significant corrosion.

Category 4 Materials - Visual Assessment

Figure 10 shows evidence of corrosion on zinc-coated stamped metal of the computer power supply, similar to the results seen in Category 2 materials.

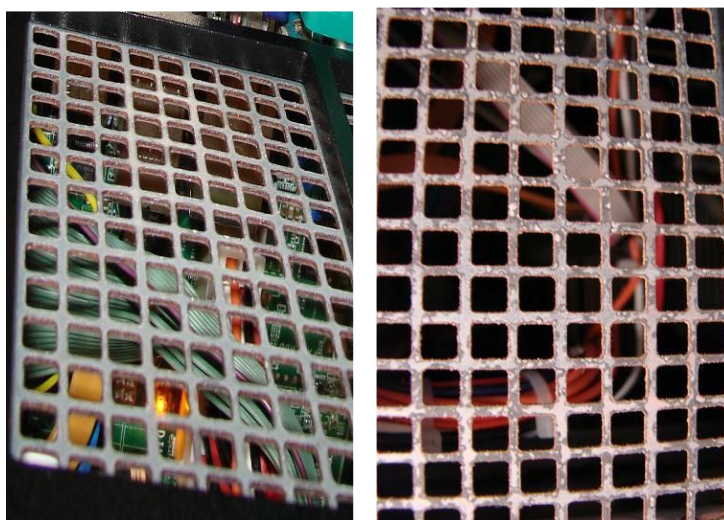


Figure 10. Comparison of the metal grids on the back of tested computers: (left photo) control PC at test conditions, no exposure and (right photo) exposed to 74,000 ppm 98-2 MeBr.

Category 4 Materials - Functionality Assessment

Regardless of the fumigation scenarios, the vast majority (83.7%) of failures were found to be related to the DVD drive. A significant amount of the remaining failures were related to the floppy drive, and many were an intermittent network loopback failure which seems to be an issue with all computers, even controls. The intermittent “Pass 2” results also point to vulnerabilities in the same subsystems (DVD and floppy drives). Figure 11 shows the average score, clearly indicating the fumigated computers performed worse than the control computers. Overall, 98-2 MeBr resulted in less failures when the computers were maintained powered on compared to when they were not powered during fumigation. Fumigation with 98-2 MeBr with the computers powered off resulted in similar failure analysis scores as to when the computers were fumigated with ClO₂ (750 ppmv at 75% RH for 12 hours).

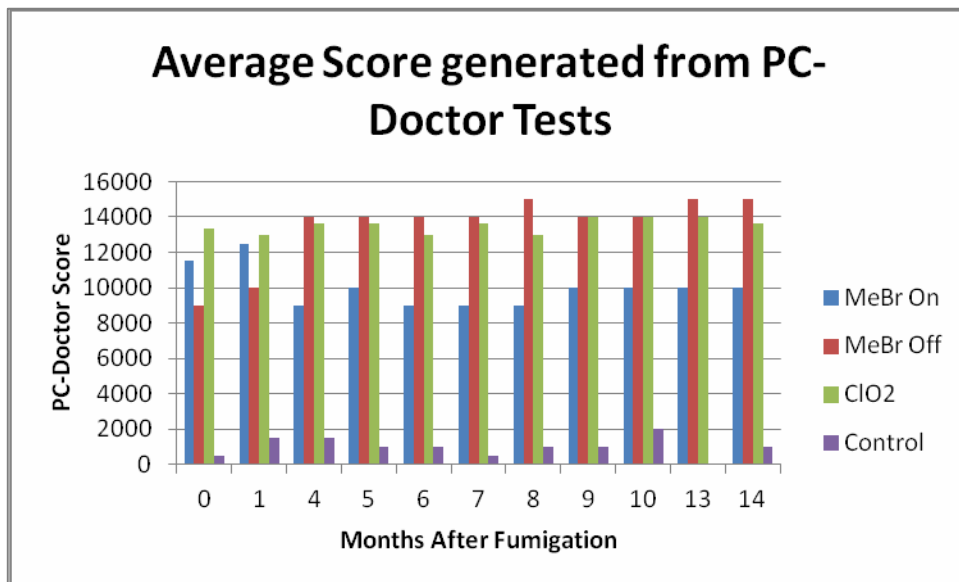


Figure 11. Average PC-Doctor Score per Exposure Type. MeBr ON refers to fumigation with 98-2 MeBr with the computers powered On; MeBr Off refers to fumigation with 98-2 MeBr with the computers powered Off; ClO₂ fumigation as a reference to previous testing (750 ppmv ClO₂ at 75% RH for 12 hours).

All computers exposed to 98-2 MeBr exhibited problems with the power supply, some catastrophically. The power supply to one began failing a few days after fumigation by tripping ground fault circuits and with burning smells. These effects were eventually detected in all 98-2 MeBr fumigated computers, and all power supplies needed to be replaced. These failures were traced to exposure to the chloropicrin component of the fumigant.¹⁵

MeBr Summary

- Low carbon steel and the steel outlet/switch box showed signs of corrosion following 98-2 MeBr fumigation. No other Category 2 and 3 materials and equipment were affected.
- Power supplies in all 98-2 MeBr fumigated computers failed, some catastrophically. The chloropicrin component of the fumigant was found to be the cause.
- Materials with the potential for damage include, but are not limited to, power supplies, metal bearings, and CD/DVD drives.

FUMIGANT: ETHYLENE OXIDE (EtO)¹⁶

The target (manufacturer-suggested) fumigation method for the Andersen EOGas 333 system was an 11 gram EtO cartridge activated within a specialized selectively-permeable bag. The bag also contains humidichips, which contain water to humidify the environment inside the bag as the ventilation cabinet containing the bag heats to the manufacturer suggested temperature of 50 °C. As EtO is released from the cartridge (EtO is very volatile), the EtO slowly permeates through the bag wall into the ventilation cabinet over an 18-hour cycle. The cabinet removes the EtO through an abator, and it is safe to retrieve the bag at the conclusion of the 18-hour cycle. The study also investigated the use of a higher EtO concentration with the use of an 18 gram cartridge.

EtO Results Summary

The effects of EtO on all tested materials were minimal (Figure 12), with no recorded visual impacts on any of the materials. All fumigated electronic components maintained the same functionality as the control equipment.

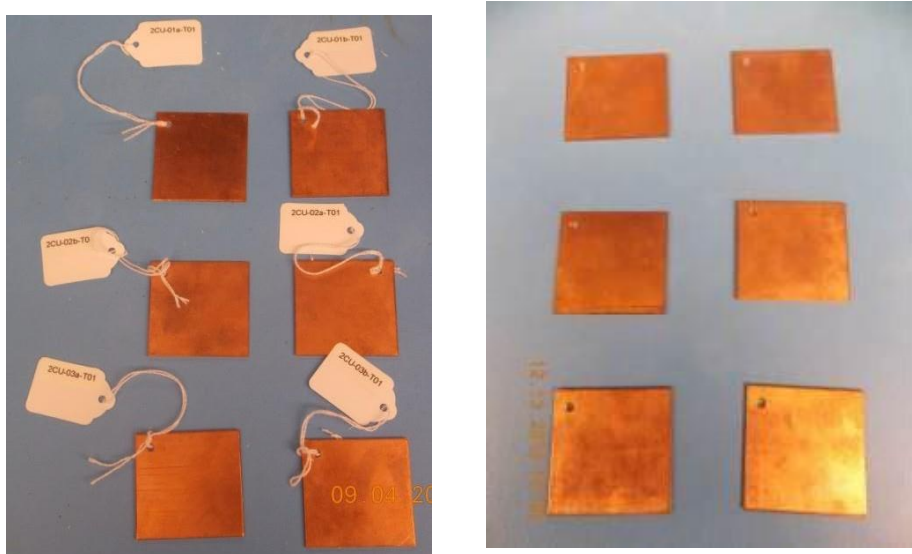


Figure 12. Copper coupons pre-fumigation (left photo) and 2 months post-fumigation (right photo).

EtO Summary

- There was little-to-no impact recorded for any materials or equipment tested following fumigation with EtO.
- EtO is very difficult to scale up. Its safe use is generally limited to what can fit inside a manufacturer-supplied permeable bag (though it has been scaled up for use on bee hives and entire hospital rooms).
- EtO is also both highly toxic and flammable and, therefore, must be used in an extremely well-ventilated area (use of an abator is also strongly recommended). EtO is not suitable for wide area fumigations, such as a building or in any environment where a flame might be present or possible.

REFERENCES

1. U.S. EPA. [Compilation of Available Data on Building Decontamination Alternatives](http://cfpub.epa.gov/si/si_public_record_Report.cfm?dirEntryId=222706). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-11/012, 2005
(http://cfpub.epa.gov/si/si_public_record_Report.cfm?dirEntryId=222706)
2. U.S. EPA. [Evaluation of Sporicidal Decontamination Technology: Sabre Technical Services Chlorine Dioxide Gas Generator](http://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=154826&fed_org_id=1253). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-06/048, 2006.
(http://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=154826&fed_org_id=1253)
3. U.S. EPA. [Persistence Testing and Evaluation of Fumigation Technologies for Decontamination of Building Materials Contaminated with Biological Agents](http://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=223584). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-10/086, 2010.
(http://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=223584)
4. U.S. EPA. [Determining the Efficacy of Liquids and Fumigants in Systematic Decontamination Studies for Bacillus anthracis using Multiple Test Methods](http://cfpub.epa.gov/si/si_public_record_report.cfm?address=nhsr&dirEntryId=227175). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-10/088, 2010.
(http://cfpub.epa.gov/si/si_public_record_report.cfm?address=nhsr&dirEntryId=227175)
5. U.S. EPA. [Systematic Investigation of Liquid and Fumigant Decontamination Efficacy against Biological Agents Deposited on Test Coupons of Common Indoor Materials](http://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=235044). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-11/076, 2011.
(http://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=235044)
6. U.S. EPA. [Evaluation of Fumigant Decontamination Technologies for Surfaces Contaminated with Bacillus anthracis Spores](http://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=239584). U.S. Environmental Protection Agency, Washington, DC, EPA/600/S-11/010, 2011. (http://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=239584)
7. U.S. EPA. [Decontamination of a Mock Office Using Chlorine Dioxide Gas](http://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=283842). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-14/208, 2014.
(http://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=283842)
8. U.S. EPA. [Evaluation of Chlorine Dioxide Gas and Peracetic Acid Fog for the Decontamination of a Mock Heating, Ventilation, and Air Conditioning Duct System](http://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=269357). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-14/014, 2014.
(http://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=269357)
9. U.S. EPA. [Evaluation of Hydrogen Peroxide Fumigation for HVAC Decontamination](http://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=269357). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R/12/586, 2012.
(http://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=269357)
10. U.S. EPA. [Methyl Bromide Decontamination of Indoor and Outdoor Materials Contaminated with Bacillus anthracis Spores](http://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=282882&fed_org_id=1253). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-14/170, 2014. (http://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=282882&fed_org_id=1253)
12. U.S. EPA. [Compatibility of Material and Electronic Equipment with Chlorine Dioxide Fumigation](http://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=219487). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-10/037, 2010.
(http://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=219487)

13. U.S. EPA. [Compatibility of Material and Electronic Equipment with Hydrogen Peroxide and Chlorine Dioxide Fumigation](http://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=231565), U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-10/169, 2010. (http://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=231565)
14. U.S. EPA. [Compatibility of Material and Electronic Equipment with Methyl Bromide and Chlorine Dioxide Fumigation](http://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=246831). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R/12/664, 2012. (http://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=246831)
15. LGS Innovations LLC, Alcatel – Lucent; Assessment and Evaluation of the Impact of Fumigation with Methyl Bromide Fumigation on Electronic Equipment. Final Report, Alcatel – Lucent 600 Mountain Avenue, Murray Hill, NJ 07974; December 28, 2010.
16. U.S. EPA. Compatibility of Material and Electronic Equipment with Ethylene Oxide Fumigation. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R/14/TBD, 2014.

DISCLAIMER

The U.S. Environmental Protection Agency through its Office of Research and Development funded and managed the research described here under EP-C-09-027 to Arcadis-US, Inc. It has been subjected to the Agency's review and has been approved for publication. Note that approval does not signify that the contents necessarily reflect the views of the Agency. Mention of trade names, products, or services does not convey official EPA approval, endorsement, or recommendation.

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

CONTACTS

For more information about biological agent decontamination using fumigation, visit the [NHSRC Web site](http://www2.epa.gov/homeland-security-research) (<http://www2.epa.gov/homeland-security-research>), or view [the full report](http://www.epa.gov/nhsrc/tte_fumdecontech.html) for each technology (http://www.epa.gov/nhsrc/tte_fumdecontech.html).

Principal Investigator: Shannon Serre (919) 541-3817

Feedback/Questions: Kathy Nickel (513) 569-7955

U.S. EPA's Homeland Security Research Program (HSRP) develops products based on scientific research and technology evaluations. Our products and expertise are widely used in preventing, preparing for, and recovering from public health and environmental emergencies that arise from terrorist attacks or natural disasters. Our research and products address biological, radiological, or chemical contaminants that could affect indoor areas, outdoor areas, or water infrastructure. HSRP provides these products, technical assistance, and expertise to support EPA's roles and responsibilities under the National Response Framework, statutory requirements, and Homeland Security Presidential Directives.

September 2014
EPA/600/R-14/316