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Compatibility of Electronic Equipment and Other Materials with Peracetic Acid Fog and Low Concentration Hydrogen Peroxide Vapor

Office of Research and Development
Homeland Security Research Program

EPA 600/R-20/171

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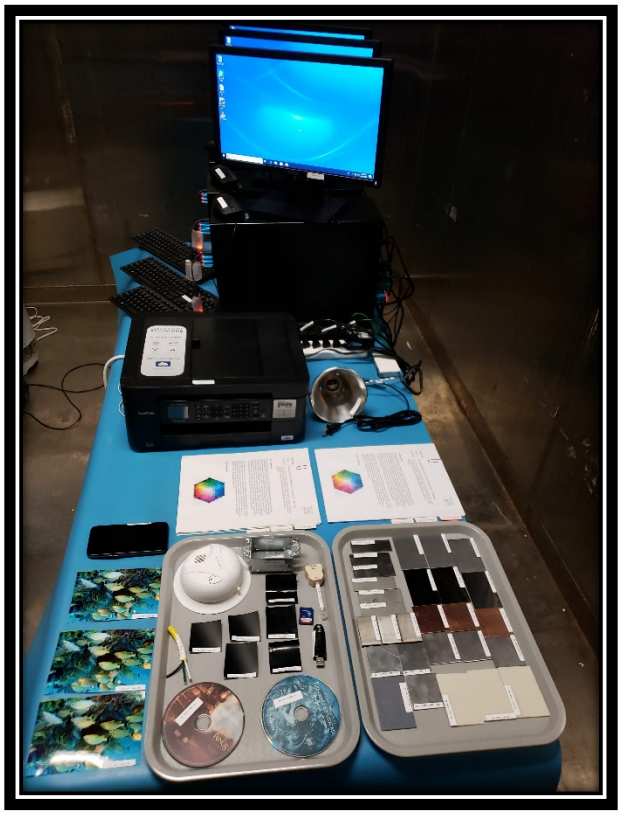

Center for Environmental Solutions and Emergency Response
Office of Research and Development
U.S. Environmental Protection Agency
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Disclaimer

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Foreword

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The Center for Environmental Solutions and Emergency Response (CESER) within the Office of Research and Development (ORD) conducts applied, stakeholder-driven research and provides responsive technical support to help solve the Nation’s environmental challenges. The Center’s research focuses on innovative approaches to address environmental challenges associated with the built environment. We develop technologies and decision-support tools to help safeguard public water systems and groundwater, guide sustainable materials management, remediate sites from traditional contamination sources and emerging environmental stressors, and address potential threats from terrorism and natural disasters. CESER collaborates with both public and private sector partners to foster technologies that improve the effectiveness and reduce the cost of compliance, while anticipating emerging problems. We provide technical support to EPA regions and programs, states, tribal nations, and federal partners, and serve as the interagency liaison for EPA in homeland security research and technology. The Center is a leader in providing scientific solutions to protect human health and the environment.

Gregory Sayles, Director

Center for Environmental Solutions and Emergency Response

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Acronyms and Abbreviations

ATI	Analytical Technology, Inc.
BI	biological indicator
CD	compact disc
CESER	Center for Environmental Solutions and Emergency Response
COMMANDER	Consequence Management and Decontamination Evaluation Room
COTS	commercial off-the-shelf
CFL	compact fluorescent Light
DSL	digital subscriber line
DVD	digital versatile disc
EPA	U.S. Environmental Protection Agency
ESD	electrostatic discharge
HDPE	high-density polyethylene
HEPA	high-efficiency particulate air filter
HP	hydrogen peroxide
HPV	hydrogen peroxide vapor
hr	hour
L	liter
LCHP	low concentration hydrogen peroxide
LCHPV	low concentration hydrogen peroxide vapor
LDPE	low-density polyethylene
m	meters
min	minute
mL	milliliter
NIST	National Institute of Standards and Technology
ORD	Office of Research and Development
PAA	peracetic acid
PC	personal computer
pDAQ	personal data acquisition
PEL	permissible exposure limit
ppm	parts per million
PVC	polyvinyl chloride
QA	quality assurance
QC	quality control
RSD	relative standard deviation
RH	relative humidity
ROM	read-only memory
RW	rewritable
SCADA	supervisory control and data acquisition
SD	secure digital
TSA	tryptic soy agar
UPS	uninterruptable power supply

USB	universal serial bus
w/w	weight/weight

Executive Summary

The U.S. Environmental Protection Agency (EPA) and others have evaluated and demonstrated numerous decontamination techniques that can be used effectively to inactivate *Bacillus anthracis* (*B. anthracis,* the causative agent for anthrax) spores on a wide variety of materials and in different environments. In addition to efficacy, other criteria such as material compatibility, may be used to select which decontaminant to employ in the event of a *B. anthracis* contamination incident. The fogging of peracetic acid (PAA) has been shown to be an effective decontaminant against *B. anthracis* spores. Similarly, the generation of low concentrations of hydrogen peroxide vapor (LCHPV) by vaporizing either 3% or 8% aqueous hydrogen peroxide solutions in off-the-shelf humidifiers, is also an effective decontamination technique. These decontamination approaches are effective as well as relatively simple to use, although the detrimental effects they may have on various types of materials and equipment are unclear.

Thus, the purpose of this study was to determine the impacts of PAA fog and LCHPV on representative indoor materials and electronic equipment. This effort examined the impact of each decontaminant on the physical appearance and functionality of various materials and electronic equipment. Visual assessments and functionality inspections of equipment were performed before and after exposure to each decontaminant over a 12-month post-exposure observation period. During the fogging of PAA and the generation of LCHPV, *Geobacillus stearothermophilus* biological indicators (*B. anthracis* surrogates) were used to ensure the decontaminants were effective in inactivating bacterial spores.

The decontaminants' impacts were evaluated against three categories of materials. These materials included coupons (excised samples) of metal and plastic materials; small electrical items or electronics such as a light switch, smoke detector, mobile phone, and USB flash drive; and computers and related peripheral equipment.

The fogging of PAA solution caused visually-observed appearance changes (e.g., discoloration, oxidation, residue) on the copper, low-carbon steel, 304 stainless steel, and aluminum metal coupons. Some minor corrosion and/or residue was also observed on the electrical switch box, incandescent light, and the smoke detector battery terminals. For the computers, the external, non-metal surfaces had a moderate amount of white, powdery residue. Internal and external metal surfaces showed small amounts of rusting and a significant amount of white residue. Some functionality incompatibilities with the PAA fog included issues with the power button on the mobile phone and the smoke detector giving a false "low battery" alert. For the computers, there were a total of six subsystem test failures that were not observed in the control set of computers; four were related to the +- rewrite (RW) drive and two related to the read-only memory (ROM) drive.

For the LCHPV exposure generated from the 3% aqueous hydrogen peroxide solution, there were minimal compatibility issues with the materials and equipment. Visually-detected appearance changes were limited to the low-carbon steel, which showed some minor oxidation. The exposure did not affect the functionality of any equipment, except for a few issues with computers. Four unique subsystem test failures, not observed in the control computer set, were observed, and all were related to the +-RW drive.

For the LCHPV exposure generated using the 8% HP solution, there were minimal compatibility issues as well. As with the LCHPV exposure with 3% HP solution, visually-observed changes in material and equipment were observed on low-carbon steel which, as before, showed rust on exposed surfaces. The exposure did not affect the functionality of equipment. Three unique subsystem test failures, not observed with the control computers, were observed in the exposed computers and included minor issues with the sound card, +-RW drive, and universal serial bus (USB).

For all three decontaminants evaluated, all biological indicators were inactivated.

Introduction

The U.S. Environmental Protection Agency (EPA) and others have evaluated and demonstrated numerous decontamination techniques that can be used effectively to inactivate *Bacillus anthracis* (*B. anthracis*, the causative agent for anthrax) spores on a wide variety of materials and in different environments. In addition to efficacy, other criteria such as material compatibility, may be used to select which decontaminant to use in the event of a *B. anthracis* contamination incident (Wood et al., 2019). The fogging of peracetic acid (PAA) has been shown to be an effective decontaminant against *B. anthracis* spores (Richter et al., 2018; Wood et al., 2013). Similarly, the generation of low concentrations of hydrogen peroxide vapor (LCHPV) via the vaporization of 3% or 8% aqueous hydrogen peroxide (HP) solutions in off-the-shelf humidifiers, is also an effective decontamination technique (Wood, et al., 2016; Mickelsen et al., 2019). These decontamination techniques are effective as well as relatively simple to use, although their impact on various types of materials and equipment is unclear.

1.0 Project Description

The purpose of this study was to determine the impacts of PAA fog and LCHPV on representative indoor materials and electronic equipment. This effort examined the impact of each decontaminant on the physical appearance and functionality of materials and electronic equipment.

Visual assessments and functionality inspections of equipment were performed before and after exposure to each decontaminant over a 12-month post-exposure observation period. Visual assessments were performed at a 1-, 3-, 6- and 12-months post-exposure. Functionality assessments were completed once per month for 12-months after exposure. All tests were conducted at the U.S. EPA facility located in Research Triangle Park, NC.

The study described in this report builds on and is consistent with previous other U.S. EPA studies to examine the material compatibility of decontaminants (Adrion, et al., 2019; U.S. EPA, 2010; U.S. EPA 2017a; U.S. EPA 2012; U.S.EPA, 2014).

2.0 Materials and Methods

2.1 Indoor Material and Equipment Categories

The decontaminants' impacts were evaluated against three categories of materials.

In general, Category 2 materials are representative of materials that may be present in limited amounts in indoor areas. Category 3 materials are representative of personal electronic equipment that are typical of a commercial or government office setting. Category 4 materials were chosen to be representative not only of computers typical of commercial/ government use, but also as a collection of subsystems representative of a broad range of technological equipment, from printed circuit boards to optical devices to fan bearings. Note that Category 1 materials, such as those used for building structures, were evaluated in previous material compatibility assessment, but were not included in this assessment. Most of the EPA material compatibility assessments have excluded structural materials (Adrion et al. 2019). Further details on each category of materials is discussed below.

2.1.1 Category 2 Materials

Category 2 materials include those that are likely to be used in limited amounts as building materials or electronic equipment components. Specifically, Category 2 materials are of small surface area within a building, have a minimal fumigant material demand, and have functionality and use that could be impacted by the decontaminant exposures. Table 2-1 provides a description of the Category 2 materials. The visual inspections were directed toward areas where corrosion or material changes are expected from the decontamination treatment. Printed documents and pictures were inspected for possible changes in the appearance (color and legibility) and the integrity of the paper. Inspections occurred monthly over a 12-month observation period, with materials stored at ambient conditions in an environmentally controlled facility throughout the observation period. Visual inspections included digital photography to document the appearance of each material before and after each decontamination event.

Table 2-1. Category 2 Materials

Material	Description	Supplier/ Manufacturer	Part No.	Coupon Size and/or No. of replicates for each test
1100 Aluminum	Corrosion-resistant, Textured 0.063 inch thick sheet	McMaster Carr	88685K93	2 x 2 inches, 3 coupons
Super-conductive 101 copper	0.063 inch thick, 1/8 Hard Temper	McMaster Carr	89675K751	2 x 2 inches, 3 coupons
Low-carbon steel	0.0625 inch thick	McMaster Carr	6544K53	1½ x 2 inches, 3 coupons
Type 316 stainless steel	Highly-corrosion resistant, 0.063 inch thick	McMaster Carr	9090K1	1 x 2 inches, 3 coupons
Type 304 stainless steel	Brushed, 0.0625 inch thick, #3 finish	McMaster Carr	9085K1	1 x 2 inches, 3 coupons
Type 410 stainless steel	Tight-tolerance, wear-resistant, 0.063 inch thick	McMaster Carr	9524K69	2 x 2 inches, 3 coupons
Type 430 stainless steel	0.025 inch thick	McMaster Carr	1294T33	2 x 2 inches, 3 coupons
Type 309 stainless steel	High-temperature, 0.25 inch thick	McMaster Carr	9205K15	1 x 2 inches, 3 coupons
Digital subscriber line (DSL) line conditioner	Telephone and DSL connectors embedded within	McMaster Carr	1522T23	1 replicate
Portable light	With electrical switch	McMaster Carr	1627K12	1 replicate
Steel outlet/switch box	2 x 3 x 1½ inches	McMaster Carr	71695K81	1 replicate
Silicone caulk	Mildew-resistant sealant	McMaster Carr	7582T15	1 x 1 inch
Yellow SJTO 300 VAC service cord	16/3 American wire gauge, 0.33 inch outer diameter	McMaster Carr	8169K32	3 replicates
Smoke detector	Battery-powered ionization sensor with battery	First Alert	SA304	1 replicate
Laser-printed paper	Stack of 15 color printed pages	RTO-H206- HP 4730 Color LaserJet	NA	8½ x 11 inches
Ink Jet colored paper	Stack of 15 color printed pages (see Appendix B)	HP Desk Jet 932C	NA	8½ x 11 inches
Color photograph	4 x 6 inches, Kodak processing	Walgreens	NA	4 x 6 inches, 3 replicates
Static intercept bags	20 x 24 x 0.003 inches	Dasal Technical Products	NA	1 replicate
Acrylonitrile butadiene styrene plastic	0.125 inch thick, beige	McMaster Carr	8586K101	1½ x 2 inches, 3 replicates
HDPE plastic film	4 mil HDPE stretched across PVC tube	McMaster Carr	86255K61	2 x 4 inches, 3 replicates
LDPE plastic film	4 mil LDPE stretched across PVC tube	McMaster Carr	8553K814	2 x 4 inches, 3 replicates
Duct tape	2 inch wide, premium duty, Fed. Spec. PPP-T-60E, Type IV, Class I, used to seal plastic films onto PVC tube	McMaster Carr	7612A7	1 inch long, 3 replicates
PVC plastic	High-strength PVC sheet	McMaster Carr	87025K116	1 inch length, 3 replicates

HDPE: high-density polyethylene, LDPE: low-density polyethylene, No.: number

2.1.2 Category 3 Equipment

Category 3 equipment included small personal electronic equipment. As with Category 2 materials, changes in appearance and functionality of the equipment were monitored over the 12-month observation period. The exposure impact assessment involved visual inspections for aesthetic effects and documentation with digital photographs. Functionality evaluations were performed by operating the equipment as intended by the manufacturer. The ability to successfully complete the desired operation and notable changes in the production quality were assessed by comparison to similar, unexposed equipment. Table 2-2 lists the Category 3 equipment.

Table 2-2. Category 3 Materials

Equipment	Description	Manufacturer or Supplier	Model or Item No.	No. of replicates per test
Mobile phone	ZTE Maven 3	ZTE	Z835	1
Fax/phone/copier machine	Color Inkjet All-in-One Printer with Mobile Device and Duplex Printing	Brother	MFCJ497DW	1
Data CD	*Best of the Most Relaxing Classical Music in the Universe*, Music CD	Walmart Inc.	Walmart, 000873479	1
Data DVD	*The Lord of The Rings: The Two Towers*, (2002) Standard DVD video	Walmart Inc.	Walmart, 0088392945298	1
USB flash drive	4GB flash drive	SanDisk	SDCZ36-004G-A11	1

CD: compact disc, DVD: digital video disc, No.: number, SD: Secure digital, USB: universal serial bus

2.1.3 Category 4 Equipment

Category 4 equipment included desktop computers and ancillary equipment. The objective for this category of equipment (and materials) was to assess the impact of the test conditions using visual inspection, functionality testing, and a personal computer (PC) diagnostic tool (PC-Doctor Service Center™ 11 software). Components and specific parts of components susceptible to corrosion due to the decontamination process were assessed. This information could be used to make informed decisions about the compatibility of other equipment that has similar components (at least similar in operation or material makeup) to reduce further testing and uncertainty in a field application. Table 2-3 lists the Category 4 equipment.

Table 2-3. Category 4 Materials

Equipment	Description	Manufacturer	Item No.	No. of replicates per test
Personal Computer	Dell Precision Tower 3620 XCTO base	Dell	210-ALFI	3
Monitor	Dell 19" Monitor – E1916H	Dell	210-AGND	3
Mouse	Dell MS116 Wired Mouse	Dell	275-BBBW	3
Keyboard	Dell KB216 Wired Multi-Media Keyboard - English	Dell	580-ADJC	3

2.2 Environmental Control Chamber

All decontamination tests were conducted in, and materials placed within, the Consequence Management and Decontamination Evaluation Room (COMMANDER). COMMANDER consists of a stainless steel–lined inner chamber built specifically for decontamination testing, with internal dimensions of approximately 2.4 meter (m) wide, 2.5 m deep, and 2.8 m high. At the entrance to the chamber is an airlock compartment, and enclosing the chamber and airlock is an exterior steel shell. When desired, all three components can be kept under cascading slightly negative pressure (with the greatest negative pressure in the inner chamber) by using separate air streams with valve controls on the inlet and outlet of each component. Air entering the decontamination chamber passes through a high-efficiency particulate air (HEPA) filter, and exhaust air from the chamber is ducted to an activated carbon bed and HEPA filter prior to being released into the facility exhaust system. Fans were used inside the chamber to provide internal mixing during fogging. The inner chamber inlet and outlet ducts were closed and fans turned off during fogging activities (Wood et al., 2013). A piping and instrumentation diagram of COMMANDER can be found in Appendix A.

Temperature (T), relative humidity (RH), air pressures, and flow rates within the decontamination chamber are controlled and/or their data logged continuously using a supervisory control and data acquisition (SCADA) system. Temperature and RH within the chamber were measured using a temperature and RH transmitter (model HMD40Y, Vaisala Inc., Helsinki, Finland). This instrument was calibrated prior to each test by comparing its RH data with known RH values generated in the sealed headspace above individual saturated solutions of various salt compounds. The RH meters were replaced if calibration criteria could not be met. During dissemination of the PAA and HP solutions and subsequent dwell time, the RH and temperature within the chamber were monitored, but not controlled. (All tests were conducted at lab ambient temperatures of approximately 72 °F.) This approach to not controlling RH is consistent with previous studies using foggers or humidifiers for decontamination (Richter et al., 2018; Wood et al., 2013; Wood, et al., 2016; Mickelsen et al., 2019). Typically, maximum RH measurements for the LCHPV exposures using a commercial off-the-shelf (COTS) humidifier neared or exceeded the maximum range of the RH meter during the fogging events.

2.3 PAA Fog and LCHPV Exposure Events

2.3.1 Overview of the PAA Fog Procedure

PAA fog was produced using a Sani-Tizer™ ultra-low volume fogger (Curtis Dyna-fog, Ltd., Westfield, IN). The fogger consisted of a motor/blower assembly, nozzle system, nozzle housing, 1-gallon formulation tank, and metering a valve. The PAA solution (MinnCare Cold Sterilant, Mar Cor Purification, Lowell, MA; EPA Registration Number 52252-4) was drawn from the formulation tank through the control valve and into the nozzle system where it was pneumatically sheared into an aerosol or mist with a mean droplet size of 31.0 µm. The droplets were then disseminated throughout the chamber by ambient air passing through the nozzle system. The fogger is shown in Figure 2-1.

Figure 2-1. Fogger used to disperse PAA.

From a previous study (U.S. EPA, 2016), it was determined that fogging 31.25 milliliter (mL) PAA per m^3 of volume to be decontaminated was the minimum amount required for effective decontamination against *B. anthracis* spores. Based on this amount and the volume of COMMANDER, a volume of 750 ml of PAA solution was fogged. The fogger was transferred to COMMANDER and placed on the floor in front of the chamber door, facing the back wall with the nozzle positioned at an angle of approximately 70°. The metering valve knob was positioned on the low flow setting which allows for reduced droplet size. The fogger was plugged into an unenergized power outlet and the fogger's power switch placed in the ON position. A 12-inch (in), 3 speed, oscillating fan (Pelonis Technologies Inc., Exton, PA) was placed in COMMANDER with the speed setting set to the HIGH position in order to promote even fog distribution throughout the chamber. The COMMANDER chamber was sealed and an approximate zero air exchange rate was set by adjusting the chamber's air supply and exhaust valves. The fogger was activated remotely using the SCADA system. Active fogging is defined for this report as the duration of time the unit generated fog output, continued until the volume of solution in the fogger tank was insufficient to support fog production. The fogger was remotely turned off and the chamber allowed to dwell overnight, consistent with a previous study in which PAA was fogged and shown to be effective for *B. anthracis* (U.S. EPA 2016). At the start of the following day, the chamber was aerated. The materials and equipment were collected for photo documentation and evaluation. The remaining solution in each fogger was transferred to a graduated cylinder and measured. The volume of solution dispersed as fog was determined volumetrically.

2.3.2 Overview of the LCHPV Exposure Procedure

The two LCHPV tests were performed using the Honeywell QuietCare Cool Mist Console Humidifier, HCM-6009 (Honeywell, Morristown, NJ). The humidifier was a cool mist evaporative humidifier that used a small fan to pull air through a wicking filter saturated with aqueous solution from the reservoir to disperse. Each humidifier had two 1 ½ gallon tanks for a total capacity of 3 gallons with 9 possible combinations of output settings. Figure 2-2 shows the Honeywell, HCM-6009 humidifier.

Figure 2-2. Honeywell HCM-6009 humidifier.

LCHPV was produced from prepared solutions of 3% weight/weight (w/w) and 8% (w/w) HP solution using a 35% HP aqueous stock solution (Hi Valley Chemical, Inc., Centerville, UT). The HP concentration in solution of both the stock and prepared solutions were measured using the analysis method detailed in Section 3.1. The temperature and pH of the prepared HP solutions were measured using the procedure outlined in Section 3.2. The total required volume of prepared HP solution, 4 liter (L) of 3% HP and 3 L of 8% HP, was determined based on a previous study (U.S. EPA, 2017b). The HP solution was divided evenly between the two humidifier tanks and the humidifier weight was obtained. The output settings used for this investigation were the lowest fan setting (the single blade icon) and the highest humidistat setting (the 4-drop icon). As with the fogger, the humidifier was plugged into an unenergized power outlet and the humidifier settings adjusted to the appropriate configuration. A 12-inch oscillating fan was placed in the COMMANDER with the speed setting set on HIGH to promote even mixing during the exposure. COMMANDER was sealed and an approximate zero air exchange rate was maintained by adjusting the chamber's air supply and exhaust valves. The humidifier was activated remotely using the SCADA system. Vapor production continued until the humidifier's internal floating switch deactivated the unit. The HPV concentration was allowed to passively fall below the permissible exposure limit (PEL) prior to re-entry. The total exposure time was approximately 3 days for the LCHPV using 3% HP solution and 2.5 days for the LCHPV exposure with 8% solution, consistent with previous studies (Wood et al., 2016; Mickelsen et al., 2019) The humidifier was then removed from the chamber and the final weight recorded. The remaining solution in each tank and the reservoir was combined in a graduated cylinder and measured. Due the significant portion of the residual test solution that remained in the wicking filter, the volume of solution remaining in the wick was determined gravimetrically.

2.3.3 Category 4 Equipment Exposure Preparation

Prior to exposure, Category 4 computer operation systems were configured for PC-Doctor Service Center™ 11 software (PC Doctor, Reno, NV), and a burn-in-test protocol hardware/software diagnostic program (PassMark, Sydney, Australia). Each computer was assessed with PC-Doctor™ software to establish pre-exposure baselines for the computer subsystems detailed in Section 3.7.2. Installed burn-in-test software was programmed to imitate typical office use during a work week (i.e., on and active 5 days per week, 8 hours per day) during exposure and the 12-month observation period following exposure.

A HOBO® RH/temperature logger and five *Geobacillus stearothermophilus* biological indicators (BIs) (Mesa Laboratories, Inc, Bozeman, MT) were mounted in each computer chassis. The HOBO® logger recorded real-time internal temperature and RH data from inside the functioning computer during the exposure (active fogging or humidifying and dwell). The tower chassis were closed during each exposure.

The exposed BIs were processed in the microbiological laboratory for qualitative spore viability. Figure 2-3 shows the placement of the BIs (circled in red) and the HOBO® logger (circled in yellow) inside each.

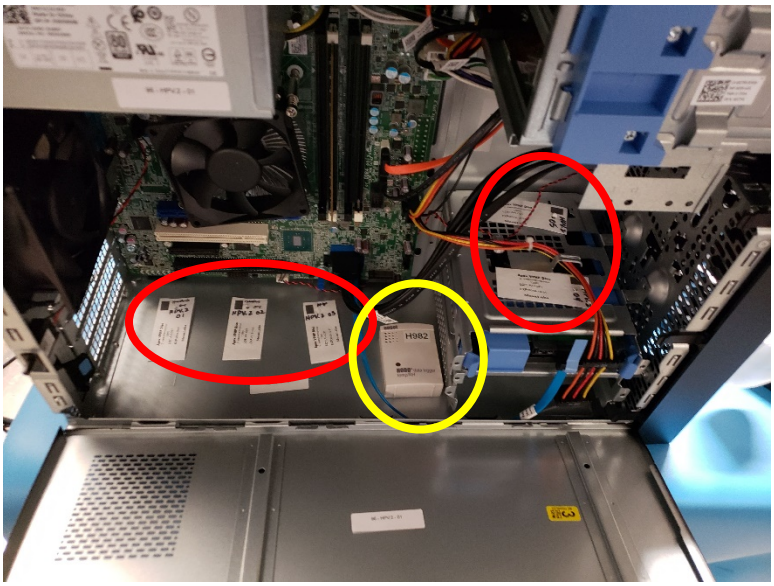


Figure 2-3. 5 Biological indicators (circled in red) and 1 HOBO® logger (circled in yellow) positioned inside the central processing unit chassis.

Category 4 equipment was ON and executing a PassMark burn-in-test session during the exposure. All other electronic equipment, with the exception of the light switch, were powered ON during each exposure.

2.3.4 PAA Fog and HPV Exposure Event Sequence

The piping and instrumentation of the control chamber is in Appendix A. The general procedure for each exposure is as follows:

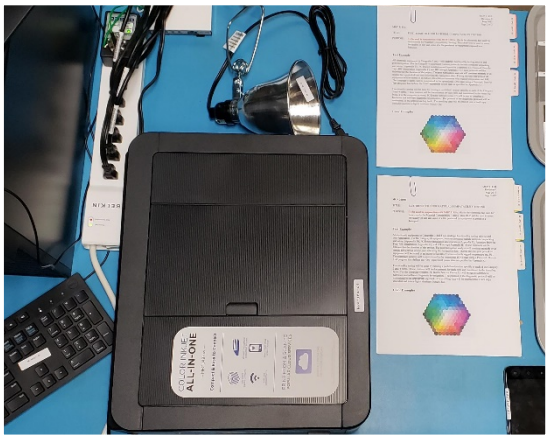
1. Within 1 week of fogging or humidifying the decontaminant, a hydrogen peroxide vapor (HPV) sensor (Section 3.3), and a temperature and humidity probe (Section 3.4) were calibrated.

2. Test facilities were prepared with two electrostatic discharge (ESD) workstations for computer work and/or storage (Section 3.5). An onsite laboratory was outfitted with a permanent ESD workstation that was used for long-term computer storage and monthly evaluations. A temporary workstation was assembled inside of the COMMANDER chamber and was used for staging the computers during fog and vapor exposures.

3. Category 4 computers were assembled, configured, and photographed at the permanent ESD workstation located onsite in Highbay Building Room 106. Baseline functionality testing was completed using PC Doctor Inc.'s PC-Doctor Service Center 11 software. Computers were disassembled, packaged in 4 mil Static Intercept® bags (Xtend Packaging, Inc., Houston, TX), transported on a grounded steel conductive cart (McMaster Carr®, Santa Fe Springs, CA), then reassembled on the temporary ESD workstation located inside of the exposure chamber. Categories 2 and 3 materials underwent baseline testing and photography, were transported to the exposure chamber, then staged as shown in Figure 2-4.

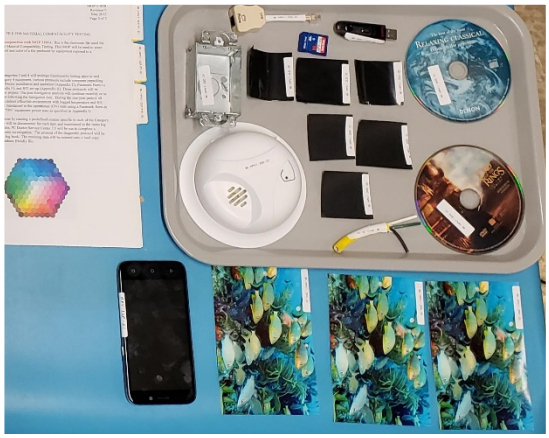
(a)

(b)



(c)

(d)



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4. Figure 2-4. General setup of Categories 2, 3, and 4 materials and equipment for PAA fog and HPV exposure. Photo a: Category 4 equipment; Photos b, c, and d were Categories 2,3, and 4 materials and personal electronics. Three computers designated as controls for Category 4 remained at the permanent ESD workstation. The control materials and equipment for Categories 2 and 3 remained in the same onsite laboratory as the permanent ESD workstation for long-term storage during the observation period.

5. Five BIs and 1 HOBO logger were placed outside of COMMANDER in the enclosure area for use as controls (unexposed to the treatment conditions).

6. The fogger or humidifier containing prepared aqueous decontaminant solutions were placed inside the COMMANDER. Figure 2-5 shows the humidifier and fan placement during testing.

a) b)

Figure 2-5. Placement of test materials, humidifier, and mixing fan inside the COMMANDER (a) facing the back wall and (b) facing the entrance.

7. The COMMANDER chamber was sealed and decontamination initiated. The foggers or humidifiers operated for the minimum time required to empty the tanks before being remotely deactivated. After the conclusion, the chamber was allowed to dwell for the time required for the HPV to naturally decompose to levels below the permissible exposure limit (PEL). After the contact time was reached, aeration of the chamber was started.

8. When the chamber was verified safe for entry, Category 4 materials were repackaged in the static intercept bags and the Categories 2 and 3 materials returned to trays.

9. All materials were transported on the grounded cart to the anti-static workstation for a series of monthly post-exposure functionality assessments and visual observations. Foggers or humidifiers were removed, humidifiers weighed, and the remaining solution in the foggers collected and measured.

10. The BIs were collected and relinquished to the microbiological laboratory for qualitative analysis. The HOBO loggers were removed, and the digital data files saved on EPA servers.

3.0 Sampling Approach

Prior to dissemination of PAA or HPV, the active ingredient concentration of the test solution was tested using the measurement procedures described in Section 3.1. During exposure, chamber HPV measurements were collected in real time using an Analytical Technology, Inc. (ATI) B-12 series transmitter for HPV (p/n B12-11-6-0100-1, Analytical Technology Inc., Collegeville, PA) that was positioned in the center of the chamber.

The testing strategy for the impact of the decontamination processes on material and electronic equipment requires monitoring the environment in COMMANDER and inside the computers for the testing of Category 4 equipment. The sampling locations of the temperature and RH loggers (HOBO® data logger, p/n U10-003, Onset Computer Corp., Bourne, MA) inside the computers were consistent among test runs to avoid measurement bias.

Table 3-1 provides information on the monitoring method, test location, scope, and frequency for the measurement techniques needed for this material compatibility study.

Table 3-1. Monitoring Methods

Monitoring Method	Scope	Frequency/Duration
Visual Inspection	Effects of fogging PAA or HPV	Monthly
RH/temperature sensor	0 to 100% RH, -20 to 80 °C	Real time/6 per minute
PC-Doctor Service Center 11 (PC Doctor Inc.) diagnostic software	Computer functionality and hardware compatibility	Monthly
Category 3 functionality testing	Basic functionality of Category 3 materials	Monthly

HPV: hydrogen peroxide vapor, PAA: peracetic acid, RH: relative humidity, RH: relative humidity

3.1 Aqueous Hydrogen Peroxide Analysis

Minncare® Cold Sterilant was used, undiluted, as the PAA fog test solution and a stock of 35% aqueous hydrogen peroxide (HP) was used to prepare 3% and 8% aqueous HP solutions for the LCHPV tests. Both stock solutions were received within four months of use and were stored, unopened in an environmentally controlled laboratory.

For the PAA fog test, hydrogen peroxide vapor (HPV) was monitored as a surrogate indicator for PAA. From the Minncare® EPA product label, the solution contains 4.5% PAA and 22.0% HP; an approximate 1:5 ratio. (Peracetic acid is manufactured and sold in a solution with hydrogen peroxide and acetic acid. In this report as well as the literature, PAA always refers to this solution mixture. This approach to measuring HPV to indicate presence of PAA in vapor is recommended in the Minncare EPA registration label. We also note that the EPA label for Minncare allows for fogging applications, and does not recommend controlling RH.)

Prior to testing, the HP concentrations in both the PAA solution and the 35% stock solution were verified using an internal operating procedure summarized as follows: by transferring 5 grams (g) of PAA was transferred to a 250-milliliter (mL) flask then, 40 mL of H2SO4 and 150 mL of deionized water added. The sample was titrated to permanent pink with 1 Normal (N) KMnO4. The volume of KMnO4 is used to calculate the percent HP (w/w). The accuracy criterion for the measured HP concentration in solution was ± 10% of the manufacturer label for the stock solution and ± 10% of the calculated value for the prepared solution.

The type, volume, and concentration of the test used for fogging were some of the independent variables for this investigation. The solutions used for this effort are detailed in Table 3-2.

Table 3-2. HP Based Fogging Solutions

Test Solution	Active Ingredient
Minncare® Cold Sterilant	4.5% Peracetic acid, 22.0% hydrogen peroxide
HP solutions	3% and 8% solutions prepared from 35% stock solution

3.2 HPV Monitoring

Two electrochemical HPV sensors were used for this investigation: a sensor capable of detecting 0-1000 parts-per-million (ppm) HPV (Analytical Technology, Inc. [ATI] Model B12-34-1-1000-1, Collegeville, PA) used during fogging of PAA and a sensor ranged 0-100 ppm HPV (Model B12-34-1-0100) for the LCHPV exposures. The low-range transmitter was wired to an Iotech 56 Series personal data acquisition (pDAQ) module (Measurement Computing, Norton, MA) while the high-range was wired to the COMMANDER SCADA system. Both had a variable output that was monitored in real time.

3.3 Temperature and RH Monitoring

During fogging of PAA or LCHPV exposures, real-time temperature and RH measurements were collected using a Vaisala® model HMD53 temperature and RH transmitter. The Vaisala transmitter was placed approximately 3 feet from the chamber walls inside the COMMANDER chamber. Repeated exposure to fogging conditions degrades the transmitter. The RH sensor became corroded; the higher resistance results in inaccurate RH readings. The Vaisala transmitter was calibrated before and after each exposure. Damaged sensors were evaluated and replaced before each test.

Table 3-3. RH and Temperature Sensor Specifications

Instrument	Vaisala transmitter	HOBO Logger
RH Range	0 to 98%	25 to 95%
RH Accuracy – 0 to 90%	+/- 3%	+/- 3.5%
RH Accuracy – 90 to 98%	+/- 5%	Unknown
RH Resolution	0.001%	0.07%
Temperature Range	-10 to 60 °C	-20 to 70 °C

Temperature Accuracy	+/- 0.6 °C @ 20 °C	+/- 0.4 °C @ 25 °C
Temperature Resolution	0.001 °C	0.1 °C

3.4 Biological Indicators (BIs)

BIs were used to provide an assessment of decontamination efficacy, and were obtained from Apex Discs (Mesa Labs, Bozeman, MT) loaded with nominally $1x10^6$ *Geobacillus stearothermophilus* spores on stainless steel disks in Tyvek™ (Dupont, Wilmington, DE) envelopes. The BIs provided a qualitative result of growth or no growth after an incubation period of seven days, following exposure to the decontaminant. The tube results were validated by plating the sample.

It was expected that the higher local temperatures inside the computer chassis would be associated with lower RH values compared to the external, COMMANDER environment. Insufficient RH could possibly result in a failure to achieve appropriate decontamination conditions inside the computer chassis. Therefore, five BIs were placed on a table inside COMMANDER and five BIs were placed inside each computer, for comparison. Thus, a total of 20 BIs were exposed to the decontaminant in each test. Additionally, 5 BIs were placed just outside COMMANDER as positive controls. Upon completion of the exposure test, the BIs were collected in a sterile sample bag and transferred to the Microbiology Lab for processing.

During processing, each BI was transferred aseptically from the Tyvek envelope to a sterile conical tube containing 25 mL of nutrient broth. Positive and negative controls were processed in conjunction with each test group for quality assurance. The tubes were incubated at 23 °C for seven days, and then recorded as either “growth” or “no growth” based upon visual inspection. Tubes with growth turned the nutrient broth a cloudy color and consistency. All tubes were plated on tryptic soy agar (TSA) to confirm that any growth in the tube was indeed *G. stearothermophilus* and not contamination from another organism. Using aseptic techniques, the TSA plates were incubated overnight at 32 °C. A visual inspection of the plates was performed the following day to determine if the *G. stearothermophilus* had grown; *G. stearothermophilus* grows leaving a reddish tint on the agar. Both positive and negative controls were used to confirm *G. stearothermophilus* growth on TSA was consistent.

3.5 Electrostatic Discharge (ESD) Workstation

To prevent damage to electronic components that was unrelated to the treatment conditions, precautions were taken to minimize static electricity while performing test activities. Precautions included the use of two ESD workstations for computer work and/or storage: a permanent workstation located in an onsite laboratory used for storage and monthly evaluations and, a temporary workstation located inside the COMMANDER chamber used for staging the electronic equipment during fog and vapor exposures. ESD workstations included static safety equipment such as an ESD work mat, an electrostatic monitor, and ESD wrist bands. These sets of equipment worked in concert to dissipate static electricity of the equipment and of the technician while handling the equipment; as well as to prevent static electricity buildup in the workstation during the 12-month observation period. A second, smaller sub-station was set up inside the COMMANDER for use during PAA fog and HPV exposures. All computers were inspected, photographed, and operated on a certified ESD workstation. During

operation, all computers were energized using surge protectors (BELKIN 7 Outlet Home/Office surge protector with 6-foot cord, Part # BE107200-06; Belkin, Playa Vista, CA).

3.6 Visual Inspection

Visual inspection focused on the observed physical changes in the Categories 2, 3, and 4 materials and equipment resulting from each decontaminant exposure event including changes in color and legibility of print, and in material degradation resulting from corrosion or rust. Photo documentation of the materials and equipment exposed to the decontaminant were taken prior to exposure to serve as the baseline (along with materials and equipment not exposed to the decontaminant. Comparable digital photographs were taken to document any changes that occurred over the 12-month period following exposure. Time points documented include pre-exposure (baseline), 1-week, 3-months, 6-months, and 12-months post-exposure. Photo-documentation of the Category 4 computers was completed on the permanent ESD workstation in Highbay Building Room 106.

Care was taken to avoid or minimize physical contact with surfaces to maintain the integrity of the specimen over the duration of the 12-month observation period. Metal coupons (excised samples) were staged and remained on a tray during exposure and throughout the observation period to minimize physical manipulation. When handling the materials, powder-free nitrile exam gloves were donned for Categories 2 and 3 materials and equipment and anti-static gloves were also donned for Category 4 equipment.

3.7 Functionality Testing

After exposure to the PAA fog or LCHPV, materials from all categories were tested for changes in appearance and functionality over a 1-year observation period. After exposure to test conditions, Category 3 equipment were tested for basic functionality and Category 4 personal computers were tested using PC-Doctor Service Center 11 software (PC Doctor, Reno, NV, http://www.PC-Doctor.com).

All electronic equipment underwent functionality testing before and after exposure as did Category 2 materials as appropriate (e.g. incandescent light switch and smoke detector). Computers were set-up and tested using procedures developed under a previous material compatibility study (U.S. EPA, 2010). Category 2 material coupons and Category 4 computers were tested in triplicate. Category 3 equipment were tested individually.

3.7.1 Category 3 Materials

Testing protocols were specific for each material and were intended to assess functionality by operating the equipment as intended by the manufacturer. Table 3-4 details the assessments performed on Category 2 and 3 materials and equipment.

Table 3-4. Assessment Criteria for Categories 2 and 3 Equipment

Material	Test Description
DSL line conditioner	Tested with landline phone: Pass - unit has verified dial tone and successful call. Fail - unit has unsuccessful dial tone and call or successful call without a dial tone.

Material	Test Description
Incandescent light	Tested with compact fluorescent light (CFL) bulb, 100-watt equivalent. Pass – unit can be switched on and off as indicated by the CFL. Fail - if the unit fails to switch CFL (and subsequently a replacement bulb) on and off.
Smoke detector	Tested with smoke check spray. Pass - Unit receives a pass if the audible alarm is activated. Fail - Unit is assigned a fail if the alarm is not activated after the first attempt and after replacing the battery.
Ink Jet All-In-One	Print, copy, fax, and scan functions tested and assessed individually. Pass – successful execution of all the above functions. Fail - unsuccessful execution for any one of the above functions resulted in a FAIL for the unit.
Mobile phone	Voice calls, text messages, and receiving data were assessed individually. Pass – successful execution of all the above functions. Fail – unsuccessful execution for any of the above functions resulted in a FAIL for the unit.
Data CD	Audio functions were assessed by inserting CD into a designated host computer and playing initial 10 second of each track. Pass – the host computer successfully performed seek and read functions; played first 10 seconds of each track Fail – host computer unable to complete seek and read function
Data DVD	Audio and visually-observed performance was assessed by inserting the DVD into a designated host computer and playing the initial 10 seconds of each scene. Pass – the host computer successfully performed seek and read functions; completed first 10 seconds of each scene Fail – host computer unable to complete seek and read functions.
SD Memory Card	Device was inserted into a designated host computer. Checks included ability to access the external drive by navigating file explorer, open the drive, and move documents to and from drive. Pass – successful completion of the above checks.

Material	Test Description
	Fail – unsuccessful complete of the above checks.
USB Storage Device	Device was inserted into a designated host computer. Checks included ability to access the external drive by navigating file explorer, open the drive, and move documents to and from drive. Pass – successful completion of the above checks. Fail – unsuccessful complete of the above checks.

3.7.2 Category 4 Materials

The protocol for the Category 4 equipment setup procedures was developed under a previous study (U.S. EPA, 2010). Post-decontamination analysis on Category 4 equipment was performed monthly for a duration of 12-months following exposure to test conditions. The computer systems were maintained in the operational (ON) state and a burn-in-test sequence was performed five days a week, 8 hours per day, to simulate real world working conditions.

PC-Doctor Service Center™ 11 software was commercially available software designed to diagnose and detect computer component failures. For every monthly test, standard protocol for each test was performed once. If any particular test failed the first time, the computer was retested a second time to correct for possible human error(s). A test that failed the second time was labeled "Fail." If the test failed the first time, but passes the second time, it was labeled "Pass2." For tabulation, a score of 1,000 is assigned to each "Fail," and a "Pass2" is assigned a score of 1. A "Pass" is assigned a score of 0. During each pre- and post-exposure testing period, a total PC Doctor score was tallied for each computer based on the number of tests that failed on the first or second attempt. Scores were evaluated only relative to controls.

While the exact number and type of tests depends on the system being tested, for the case of the Category 4 materials a total of 93 tests were run. A complete list of the PC Doctor Service Center™ 11 subsystem tests is shown in Figure 3-1.

Test ID	Test Name
Realtek Audio	
1	Rough Audio Test
2	Sound Interactive Test
OS - C:	
3	Linear Seek Test
4	Linear Read Test
5	Random Seek Test
6	Funnel Seek Test
7	Targeted Read Test
8	Targeted Read Test - 2
9	SMART Status Test
10	SMART Thresholds Test
11	SMART Short Self Test
12	SMART Extended Self Test
13	SMART Conveyance Self Test
HL-DT-ST DVD+-RW GHB0N	
14	DRAM Test
15	Flash ROM Test
16	Main IC Test
17	OPU Test
18	Spindle Test
19	Tray Out Test
20	Tray In Test
21	CD Linear Seek Test
22	CD Linear Read Compare Test
23	CD Random Seek Test
24	CD Funnel Seek Test
25	CD Read Performance Test
26	DVD Linear Seek Test
27	DVD Linear Read Compare Test
28	DVD Random Seek Test

Test ID	Test Name
29	DVD Funnel Seek Test
30	DVD Read Performance Test
HL-DT-ST DVD-ROM DH50N	
31	DRAM Test
32	Flash ROM Test
33	Main IC Test
34	Spindle Test
35	Tray Out Test
36	Tray In Test
37	CD Linear Seek Test
38	CD Linear Read Compare Test
39	CD Random Seek Test
40	CD Funnel Seek Test
41	CD Read Performance Test
42	DVD Linear Seek Test
43	DVD Linear Read Compare Test
44	DVD Random Seek Test
45	DVD Funnel Seek Test
46	DVD Read Performance Test
HL-DT-ST DVD+-RW GHB0N	
47	CD Audio Test
48	CD Linear Seek Test
49	CD Linear Read Compare Test
50	CD Random Seek Test
51	CD Funnel Seek Test
52	CD Read Performance Test
HL-DT-ST DVD-ROM DH50N	
53	CD Audio Test
54	CD Linear Seek Test
55	CD Linear Read Compare Test
56	CD Random Seek Test

Test ID	Test Name
57	CD Funnel Seek Test
58	CD Read Performance Test
HL-DT-ST DVD+-RW GHB0N	
59	CD-R Read Write Test
60	CD-RW Read Write Test
61	DVD-R Read Write Test
62	DVD-RW Read Write Test
63	DVD+R Read Write Test
64	DVD+RW Read Write Test
USB Drive M	
65	Linear Read Test
USB Drive K	
66	Linear Read Test
USB Drive F	
67	Linear Read Test
USB Drive G	
68	Linear Read Test
USB Drive H	
69	Linear Read Test
USB Drive J	
70	Linear Read Test
USB Drive I	
71	Linear Read Test
USB Drive L	
72	Linear Read Test

Test ID	Test Name
Intel(R) HD Graphics 630	
73	Shader Rendering DX11 Test
74	Multiple Rendering DX9 Test
75	Thermal Cycle Test
76	Shader Rendering DX10 Test
77	Wireframe Shader Rendering Test
78	Shader Rendering Test
79	GPU Pipeline Data Test
80	Transformation and Lighting Stress Test
81	Wireframe Stress Test
82	Fixed Transformation and Lighting Test
83	Wireframe Line Test
84	Primary Surface Test
85	Video Memory Test
AVI Test	
86	AVI Interactive Test
DELL E1916H (Generic PnP Monitor)	
87	EDID Checksum Test
88	Monitor Interactive Test
HID Keyboard Device	
89	Keyboard Interactive Test
HID-compliant mouse	
90	Mouse Interactive Test
Intel(R) Ethernet Connection (2) I219-LM	
91	Network Link Test
92	TCP/IP Internal Loopback Test
93	Network External Loopback Test

Figure 3-1 PC Doctor Service Center™ system tests and test identification codes.

3.8 Location of Control Equipment

The control group accompanied the test group throughout the process (except inside the chamber) however; the controls were isolated from the test group by placing each in separate primary containment (i.e., trays for Cat. 2 and 3 materials and static intercept bags for Cat. 4 materials). Control materials remained outside the COMMANDER chamber during release of the PAA fog or LCHPV to avoid exposure.

3.9 Representative Samples

Categories 2 and 3 materials are representative of materials present in limited amounts in areas or buildings that may require fumigation. Category 2 coupons were cut to avoid the factory edge, which may not have been representative of the bulk material.

Category 4 materials were chosen to be representative not only of computers typical of commercial/ government use; but also as a collection of subsystems representative of a broad range of technological equipment, from printed circuit boards to optical devices to fan bearings. Each material and equipment type were tested in triplicate to estimate variability within each. Figures 3-1 through 3-5 show control samples (not exposed to decontaminant) of the Categories 2, 3, and 4 materials and equipment.

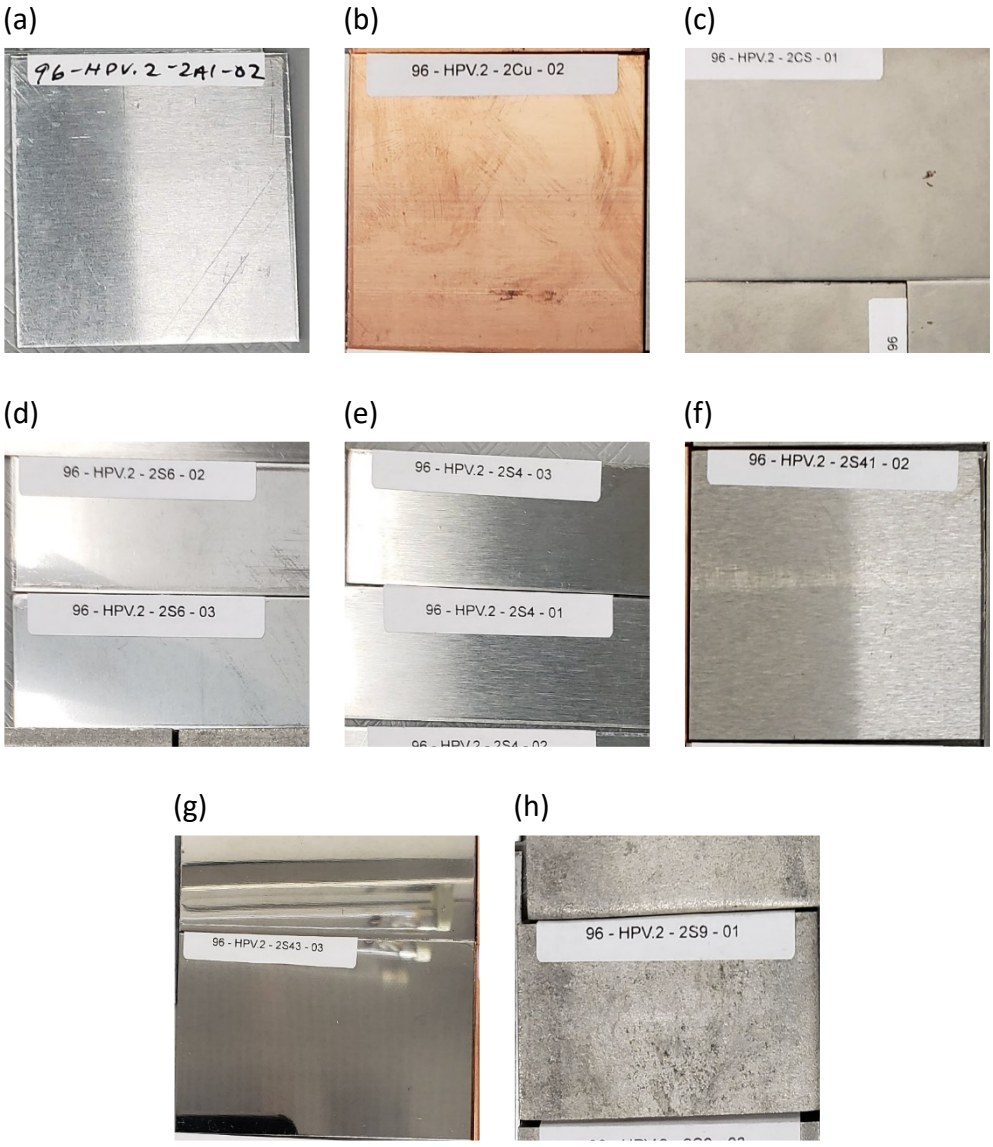


Figure 3-2. Category 2 metal coupon controls (a) 3003 aluminum, (b) 101 copper, (c) low-carbon steel, (d) 316 stainless steel, (e) 304 stainless steel, (f) 410 stainless steel, (g) 430 stainless steel, and (h) 309 stainless steel.

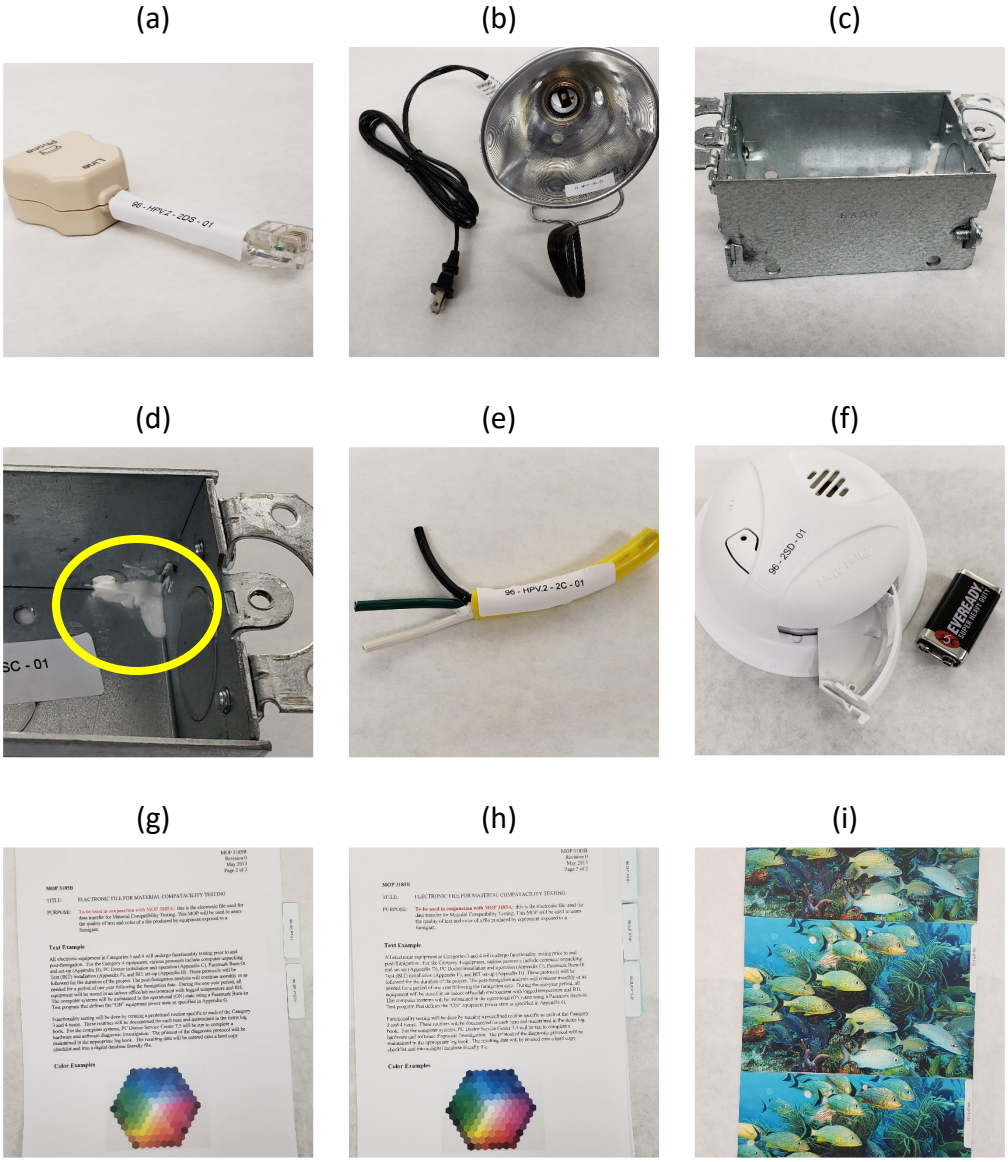


Figure 3-3. Category 2 material controls (a) DSL line conditioner, (b) switch (incandescent light), (c) steel outlet/switch box, (d) silicone caulk (circled in yellow), (e) yellow SJTO 300 VAC service cord, (f) smoke detector (cover removed), (g) laser-printed paper, (h) ink Jet colored paper, and (i) a color photograph.

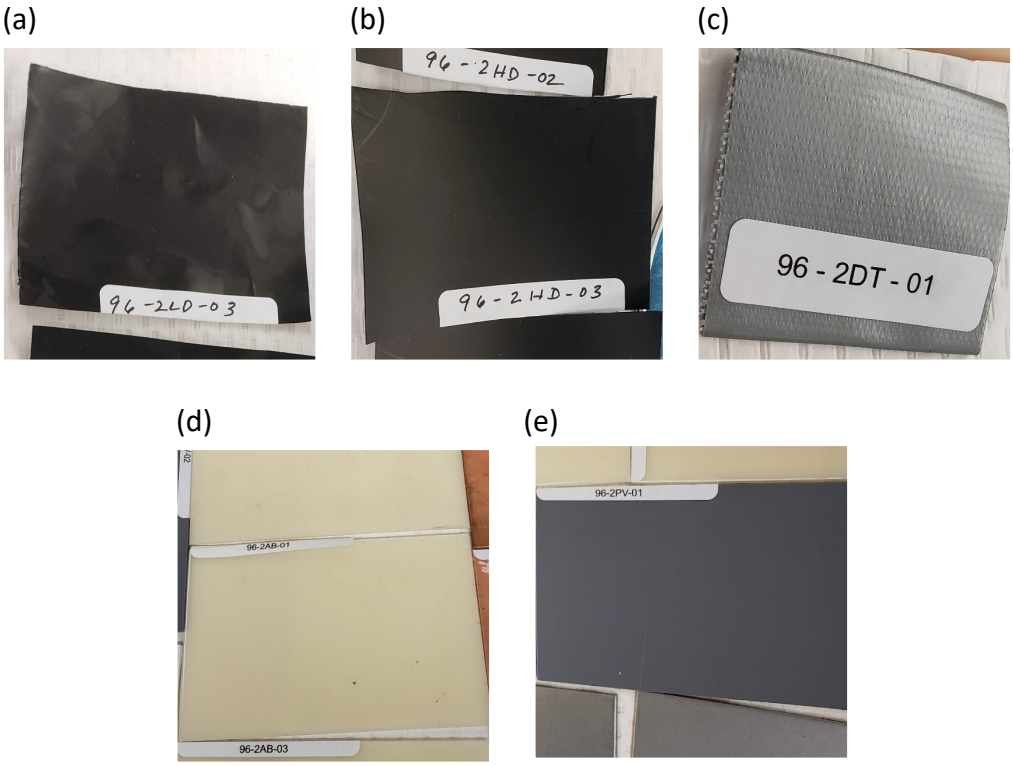


Figure 3-3. Category 2 plastic material controls: (a) low-density polyethylene, (b) HDPE plastic film, (c) duct tape, (d) acrylonitrile butadiene styrene plastic, and (e) PVC plastic.

(a) (b) (c)

(d) (e) (f)

Figure 3-4. Category 3 equipment controls: (a) mobile phone, (b) printer/fax/scanner/copier machine, (c) data CD, (d) data DVD, (e) USB flash drive, and (f) SD memory card.

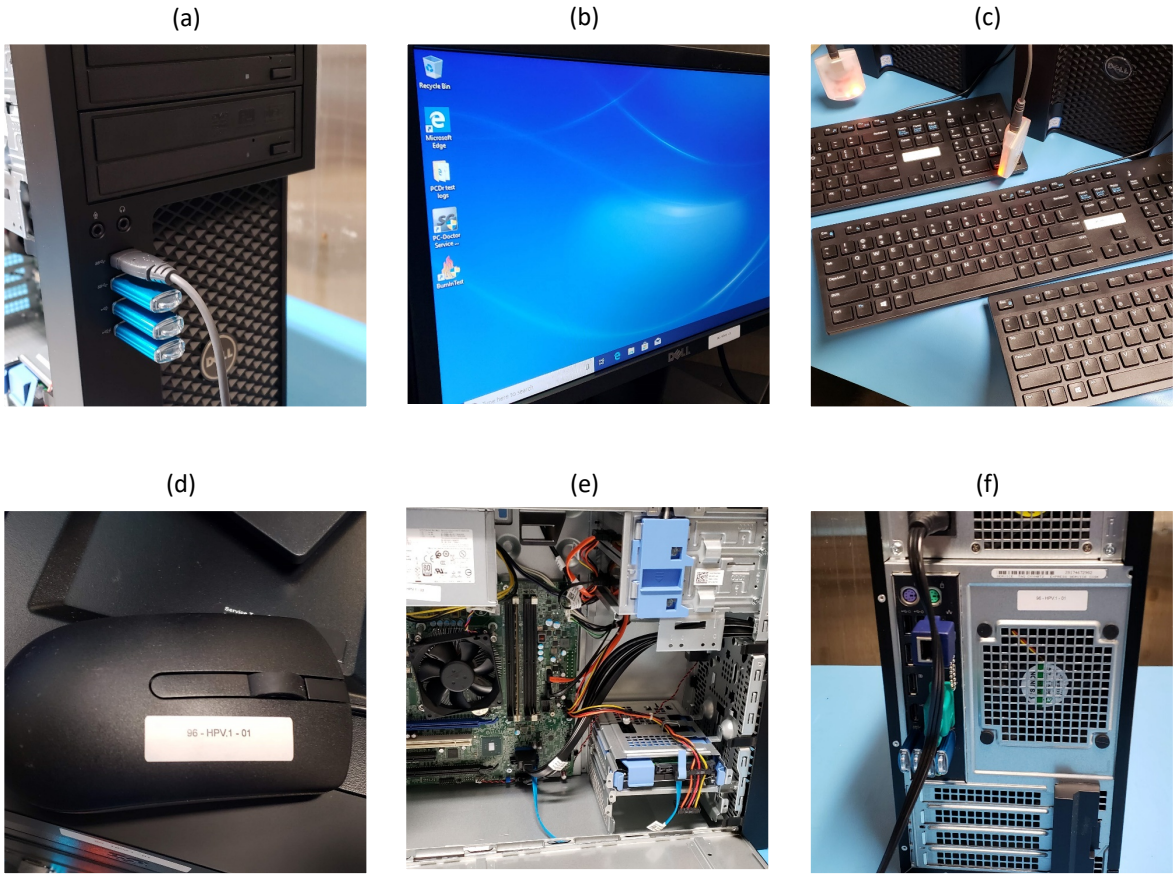


Figure 3-5. Category 4 equipment controls: (a) front external tower components (front ports), (b) monitor, (c) keyboard, (d) mouse, (e) internal tower components, and (f) rear external tower components.

3.10 Material and Equipment Storage and Preservation Methods

Test samples (i.e., materials and equipment) were stored in T/RH controlled, indoor ambient lab conditions. Both test and control samples were stored at the same conditions before and after the fogging or LCHPV event.

The Category 4 equipment, specifically the computers and monitors, were placed in anti-static and anti-corrosion bags (Static Intercept® Technology, http://www.staticintercept.com) during transport. These bags were developed by Bell Labs and recommended by Alcatel-Lucent. These bags are specifically designed to protect the bagged equipment from exposure to potentially damaging electrostatic charge or corrosive gases (Intercept Technology, Inc., 2020). The computers and monitors were removed from their original packaging, labeled with a designated sample number. The Category 4 equipment along with Categories 2 and 3 equipment and materials were transferred to an appropriate area (ESD workstation) in which the computers and monitors could remain energized and operated over the course of a year to continually assess delayed effects due to the exposure conditions.

The inside of the desktop computers were digitally photographed. To maintain the integrity of the computer, static electricity was avoided with the use of an ESD Station. An ESD station was set-up in a separate, onsite laboratory in Highbay Building Room 106. The station consisted of an electrostatic discharge work mat, an electrostatic monitor, and electrostatic discharge wrist bands. All computers were inspected and operated (e.g., diagnostic testing, long-term operation of computers for analysis of residual effects) on the certified ESD workstations according to certified procedures. During operation of the computers, all computers were energized using surge protection receptacles.

4.0 Results and Discussion

4.1 Exposure Test Matrix and Summary of Test Conditions

A total of three decontaminant exposure tests were performed. Test T1 dispersed 750 mL of PAA with a fogger. The subsequent tests, T2 and T3, utilized a humidifier to disperse 3% HP aqueous and 8% HP aqueous, respectively. Table 4-1 summarizes the test matrix.

Table 4-1. Test Matrix

Test Number	Dissemination Equipment	Sporicidal Liquid	Prescribed Volume
1	COTS Fogger	PAA[1]	750 mL
2	COTS Humidifier	3% hydrogen peroxide[2] (aq)	3000 mL
3	COTS Humidifier	8% hydrogen peroxide[2] (aq)	2000 mL

[1] Used as received from the manufacturer: 4.5% PAA, 22% H_2O_2

[2] Prepared from a stock of 35% HP (aq)

Aq: aqueous, COTS: commercial off-the-shelf, PAA: peracetic acid

Fogging approximately 300 mL of PAA in a mock office environment in COMMANDER was shown to be efficacious on nonporous surfaces such as stainless steel and glass with ≥ 6 log reduction of *Bacillus atrophaeus* (a surrogate for *B. anthracis*), in addition to certain porous materials such as paper and wood (U.S. EPA, 2017c). (A decontaminant achieving ≥ 6 is considered effective [U.S. EPA, 2018]). However, the conditions proved insufficient to achieve the required 6 log reduction for other porous materials, such as ceiling tile, carpet, and concrete. In a subsequent study, more rigorous decontamination conditions were achieved for subway railcar materials by disseminating 31.25 mL/m^3 of PAA solution using a comparable fogger (U.S. EPA, 2016). To replicate the HPV conditions in the railcar, 750 mL of PAA were disseminated in COMMANDER (24 m^3) for this investigation.

Similarly, low concentrations of hydrogen peroxide (LCHP) concentrations and volumes disseminated were consistent with previous studies that utilized a comparable humidifier for HPV decontamination and demonstrated efficacy against B. anthracis and surrogate spores on both porous and nonporous materials. A summary of the test conditions is shown in Table 4-2.

Table 4-2. Summary of Test Conditions During Dissemination

Test ID	Aqueous H_2O_2 %	Sporicidal Liquid Volume Disseminated (mL)	Active Dissemination Time (hr)	Dwell Time (hr)	Mean HPV (ppm)	Max HPV (ppm)	Mean RH (%)	Max RH (%)	Mean T (°C)	Max T (°C)
1	22.0[a]	746	0.2	19.7	97.8	150.8	60.6	65.9	27.1	28.4
2	2.9	3100	66.6	8.4	3.46	7.71	93.7[b]	97.3[b]	24.3[b]	25.5[b]
3	8.6	2200	48.7	10.3	10.2	25.3	91.2	95.2	24.0	25.2

[a] Per the manufacturer's label; PAA concentration 4.5%

[b]HOBO data used for temperature (T) and relative humidity (RH), since the SCADA RH and temperature data were unavailable due to malfunction.

HPV: hydrogen peroxide vapor, hr: hour

4.1.1 PAA Fog Test

The PAA fog test was performed with the fogger (Section 2.4.1) having the mist setting on LOW. Preliminary flow rate checks with deionized water showed the LOW setting disseminated approximately 59 mL/minute (min). A total of 746 mL of PAA were disseminated during the exposure; 750 mL of PAA were added to the fogger prior to activation and 4 mL of PAA were retrieved upon re-entry the following day. Active PAA fog generation continued for approximately 11 minutes prior to shutting off the fogger, followed by a dwell time of approximately 19 hours prior to starting chamber aeration. Figure 4-1 shows the HPV concentration over the duration of the exposure and during the initial 2 hours of the PAA fog test.

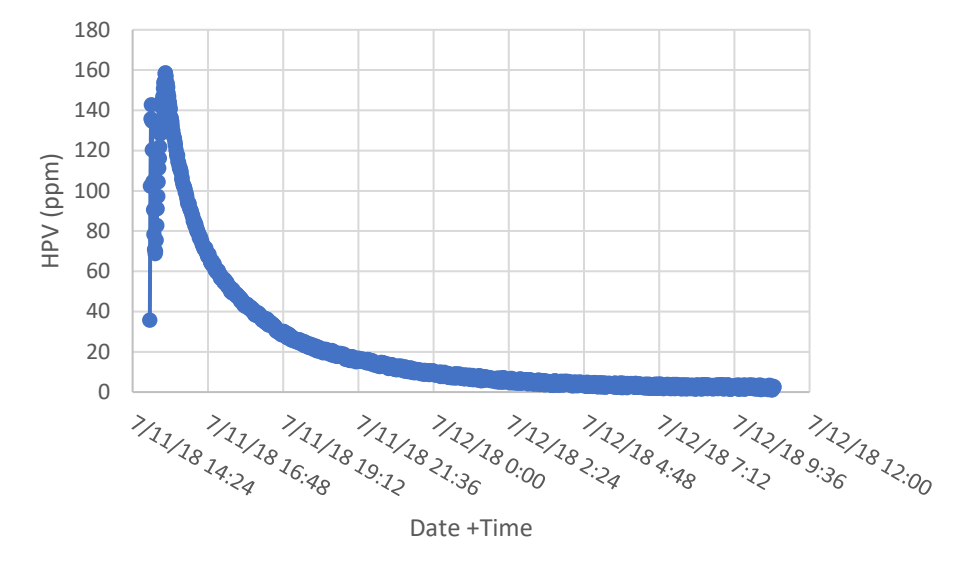


Figure 4-1. HPV concentration during PAA fog test.

4.1.2 3% LCHP Test

The COTS humidifier used for the preliminary test was reused for the 3% LCHP test with a new, unused replacement filter installed. With the information from the preliminary test, approximately 1 L was expected to remain in the fogger upon re-entry. 3% LCHP solution was prepared and analyzed to be 2.93% HP (aq). To achieve the targeted 3-L dissemination volume, 4-L of the prepared solution were equally divided between the humidifier tanks. The humidifier was transferred to the COMMANDER chamber and placed on the chamber floor. The humidifier settings were configured for high humidity and low fan output. A new oscillating fan was installed in the chamber and plugged into the circuit controlled by the SCADA system. The COMMANDER chamber was sealed and configured for zero air exchanges. The humidifier and mixing fan were powered on remotely activating the humidifier using the SCADA system. Figure 4-2 shows the HPV concentration over the duration of the exposure event.

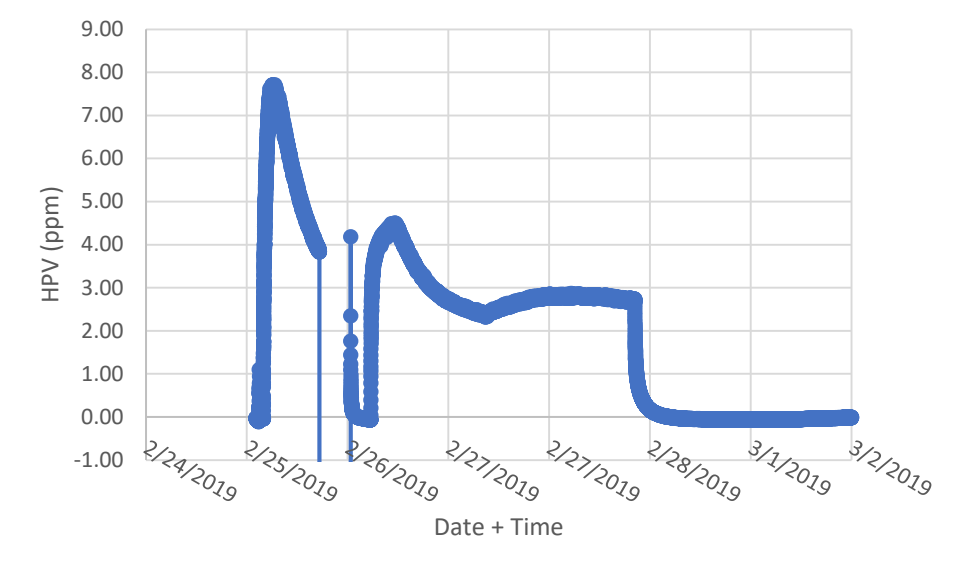


Figure 4-2. HPV concentration during 3% LCHP test.

The COMMANDER uninterruptible power supply (UPS) failed approximately 9 hours into the exposure. The UPS powered the SCADA system which, powered the humidifier, mixing fan and the, personal data acquisition (pDAQ) system used to power and record readings from the HP Analytical Technology, Inc. (ATI) 2-wire gas transmitter, Viasala humidity probe, and the thermocouple. Approximately 9 ½ hours after power was lost, the humidifier, fan, and pDaq were restored by moving the power source to an unaffected circuit. This "dark" period of lost power is shown in Figure 4-2 during Days 1 and 2. The reported RH and temperature data were collected from the deployed HOBO logger positioned on the table with the test materials and equipment. Although we lost HPV data during this time period, from Figure 4-2, it appears the HPV concentration remained in the range of approximately 4-5 ppm, and so we can reasonably conclude that the lost power did not affect the equipment and materials' exposure to the HPV.

4.1.3 8% LCHP Test

A new COTS humidifier (same brand) was used for the 8% LCHP test. The target volume for dissemination was 2 L, therefore, 3 L were added. The solution was prepared from 35% stock. Analysis of the HP (aq) concentration of prepared solution returned 8.6%. The prepared solution was transferred to the humidifier by adding 1.5 L to each of the two tanks. As with the previous HPV test, the humidifier settings were configured for high humidity and low fan output. A new oscillating fan was installed in COMMANDER and powered on. The 8% LCHP dissemination began by remotely activating the unit via the SCADA system. Figure 4-3 shows the HPV concentration inside the COMMANDER chamber during the exposure test.

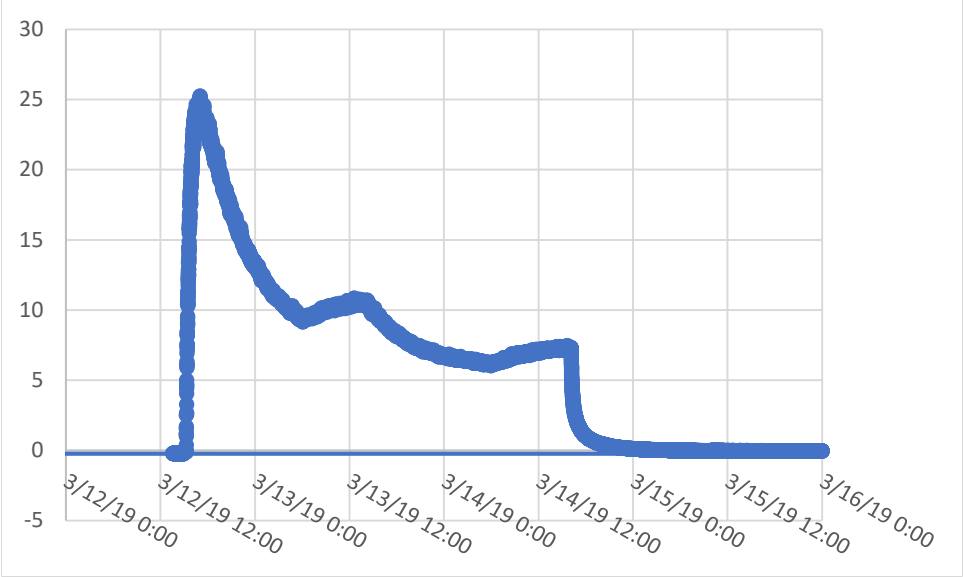


Figure 4-3. HPV concentration during 8% LCHP test.

The total duration of the exposure was 59 hours (2.4 days) including 48.7 hours of active dissemination and 10.3 hours of dwell time. The maximum HPV concentration during dissemination was 25 ppm and the average over the duration of the exposure was 10 ppm (± 4 ppm SD). The amount of 2.2 L was found to have been disseminated through gravimetric analysis. The amount of 206 mL was collected from the unit and the remainder was assumed to be left in the filter.

4.2 Visual Inspections

All Category 2,3, and 4 materials and equipment were inspected and photo-documented before and, on months 1, 3, 6, and 12 after the exposure events. Additionally, an unexposed, control set of materials and equipment were inspected and photographed for comparison. This section details the documented physical changes over the 12-month observation period. Unless noted otherwise, materials/decontaminant combinations not specifically mentioned below were not visually impacted.

4.2.1 Category 2 Materials

The PAA fog exposure resulted in the most observed changes of the three decontaminant methods evaluated in the study, in terms of number the materials affected and the severity of the impact. Category 2 metals that showed visually-observed impacts from the PAA fog included copper, low-carbon steel, 304-stainless steel, and the aluminum switch box. Refer to Table 4-3 and Figures 4-4 through 4-10. The exposed surface of the copper material showed a thin green layer typical of patina. Low-carbon steel materials were severely oxidized resulting in complete coverage of a thick layer of rust. The 304 stainless-steel showed minimal effects with a thin layer of residue on the exposed surfaces. Aluminum surfaces showed a thin layer of crystalized salt residue. The switchbox had the same residue that appeared on the aluminum material in addition to the rust on the cut edges. The base of incandescent light was layered with what appeared to be the same residue found on the aluminum material and switch box. Additionally, the internal surface of the socket showed a layer of green residue resembling patina. The visual observations documented on month 12 were the same as those documented on Day 7

after exposure. The conditions of these materials were consistent throughout the observation period; they neither worsened nor improved.

Both the laser and inkjet-printed papers were also affected by the PAA exposure. The first page of each stack was the most affected as expected. Fully exposed to the test environment, the condition of the first page deteriorated over time. Over the initial 3 months of inspection, the edges of the page were progressively more brittle with each inspection. The damage appeared to be consistent between months 6 and 12. It was difficult to manipulate the page without causing further damage. Traveling further into the stack of paper reveals less of this damage. Pages 7 and 15 of both laser and inkjet papers did not share these effects. A notable difference between laser and inkjet copies is the inkjet ink traveled through the page; this occurred for images throughout the entire stack. Ink bleed was not observed with the laser copies.

With regard to the LCHPV exposures, low-carbon steel showed no sign of physical changes from the 3% exposure on Day 7. Trace levels of oxidation were observed during month 1 after the 3% exposure and Day 7 after the 8% exposure. For both HP exposures, the initially small active areas grew and appear to stabilize after month 6.

The remaining Category 2 materials exposed to the 3% and 8% LCHPV exposures were visually unaffected. A description of the visually-observed changes documented in Category 2 materials are detailed in Table 4-3 and shown in Figures 4-4 through 4-10. Materials not discussed in this Section showed no indication of change.

Table 4-3. Summary of Visually-Observed Changes for Impacted Category 2 Materials

Treatment	Material	Visually-Observed Changes
PAA Fog	Copper	Moderate amount of green patina formed on surfaces of each replicates
	Low-carbon steel	Gross oxidation; rust formed on the surfaces of each replicate
	304-stainless steel	Thin layer of white opaque discoloration
	Aluminum	Small amount of white crystalized residue
	Switchbox	Rust formed on cut edges, white crystalized residue on majority of surfaces
	Incandescent Light	Green residue on interior surface of socket. Moderate oxidation (rust) and green residue on plug. White, chalky residue on metal surfaces of the base.
	Printed paper	Significant deterioration around the edges of the 1st sheet. Pages 7 and 15 do not show any of the physical impacts of page 1. Bleeding though the page of inkjet printed pages.
	Smoke detector	Corrosion on battery terminals
3% HP	Low-carbon steel	Mild/moderate oxidation – rust formation on the surfaces of each replicate
8% HP	Low-carbon steel	Mild/moderate oxidation – rust formation on the surfaces of each replicate

Materials not included in this table were visibly unaffected during the observation period.

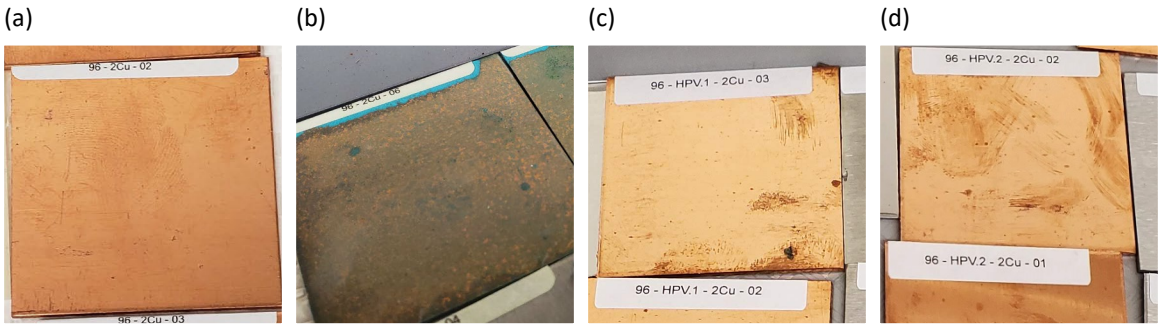


Figure 4-4. Copper coupons at month 12 after: (a) control, (b) PAA, (c) 3% LCHP, and (d) 8% LCHP exposures.

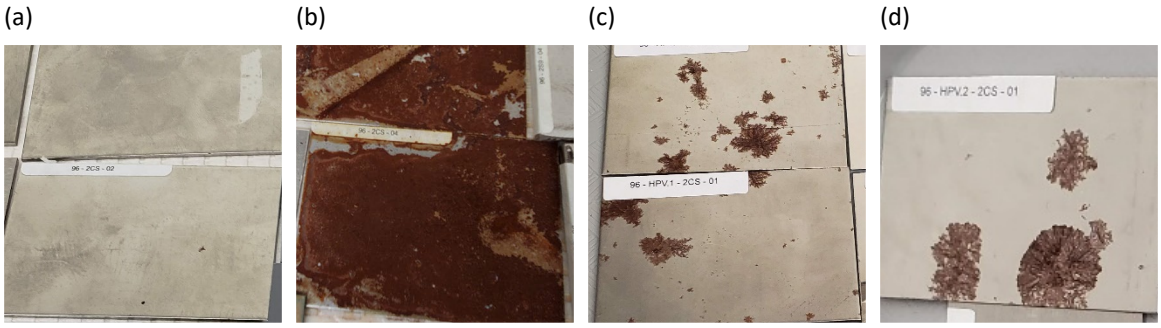


Figure 4-5. Low carbon steel at 12-months post-exposure: (a) control, (b) PAA, (c) 3% LCHP, and (d) 8% LCHP solutions.

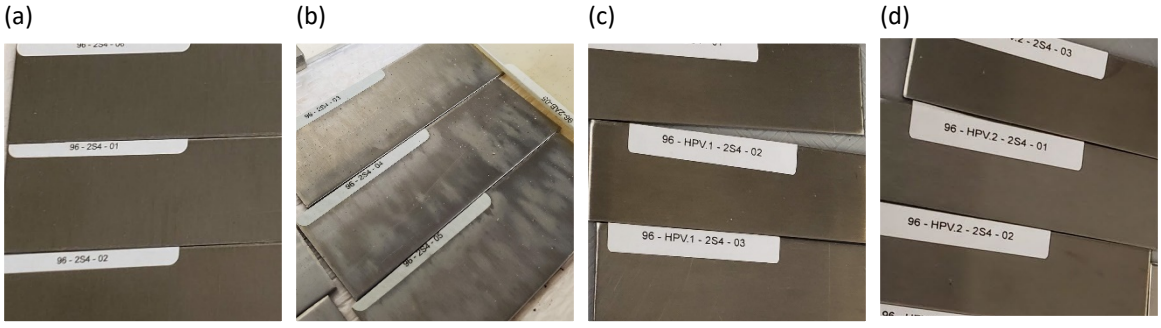


Figure 4-6. Type 304 stainless steel coupons at 12-months post-exposure: (a) control, (b) PAA, (c) 3% LCHP, and (d) 8% LCHP solutions.

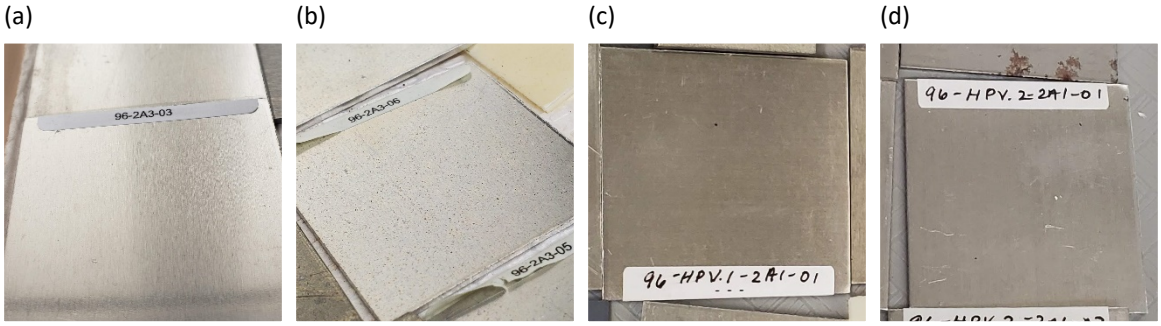


Figure 4-7. Aluminum at 12-months post-exposure: (a) control, (b) PAA, (c) 3% LCHP, and (d) 8% LCHP solutions.

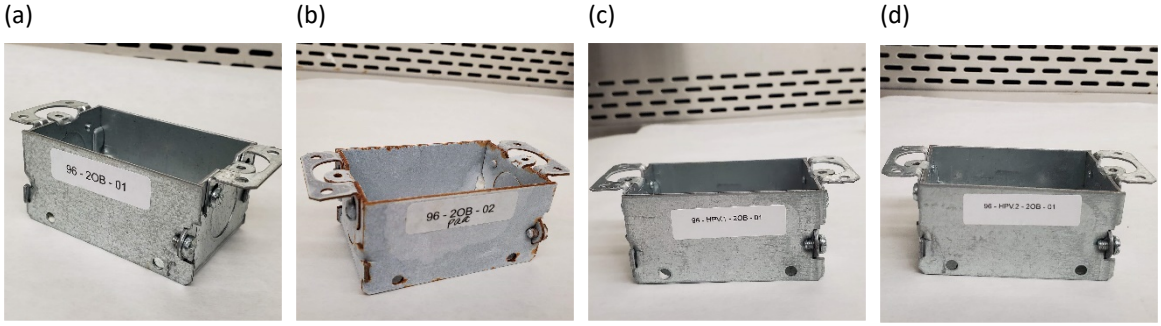


Figure 4-8. Switch box at 12-months post-exposure: (a) control, (b) PAA, (c) 3% LCHP, and (d) 8% LCHP solutions.

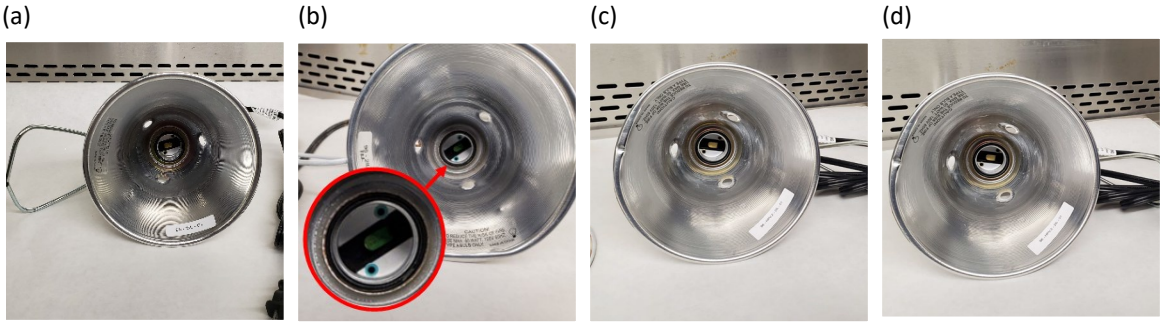


Figure 4-9. Light with switch at 12-months post-exposure: (a) control, (b) PAA, (c) 3% LCHP, and (d) 8% LCHP solutions.

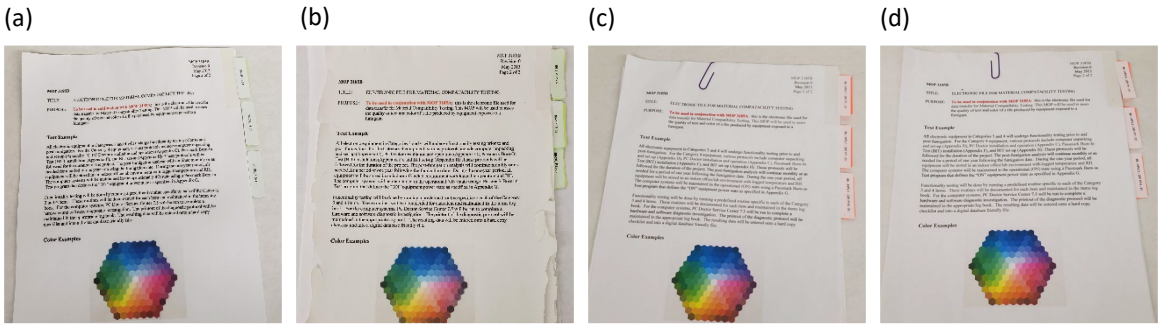


Figure 4-10. Inkjet-printed paper at 12-months post-exposure: (a) control, (b) PAA, (c) 3% LCHP, and (d) 8% LCHP solutions.

4.2.2 Category 3 Equipment

As with Category 2 materials, the PAA fog exposure produced more visually-observed changes in Category 3 equipment than the two LCHP exposures. The PAA-affected equipment included the SD memory card, USB flash drive, and the all-in-one printer. Changes observed on the SD card include green residue on the metal pins. The USB flash drive also showed a small amount of residue on the metal surfaces. As with the switch box, the all-in-one printer had rust on the cut edges of the metal component of the roller assembly.

The Category 3 materials exposed to the 3% and 8% LCHP exposures were visually unaffected. A description of the visually-observed changes documented in Category 3 materials are detailed in Table 4-4. Visually-observed changes are shown in Figures 4-11, 4-12, and 4-13.

Table 4-4. Summary of Visually-Observed Changes for Category 3 Equipment

Treatment	Equipment	Visual Observations
PAA fog	SD Memory Card	Green residue on external surfaces
	USB flash drive	Slight corrosion on exposed metal
	All-In-One Printer	Gross color fading on printed label, diminished coating

Visually-observed changes were not observed in Category 3 equipment exposed to LCHPV from 3% or 8% LCHP

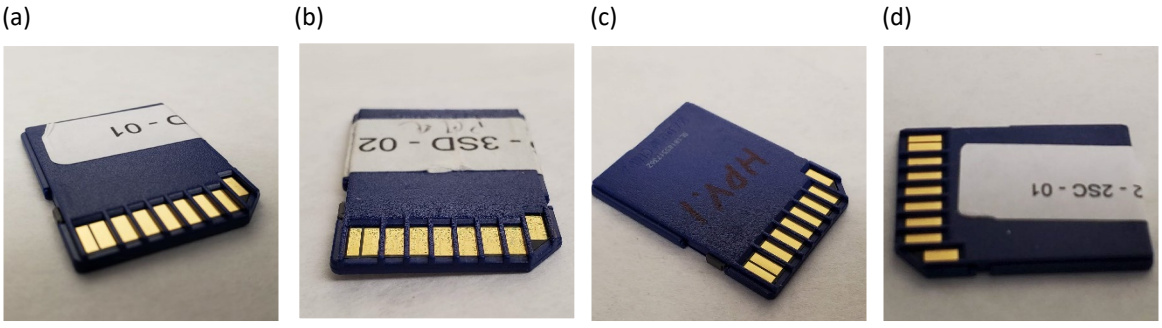


Figure 4-11. SD Cards at 12-months post-exposure: (a) control, (b) PAA, (c) 3% LCHP, and (d) 8% LCHP solutions.

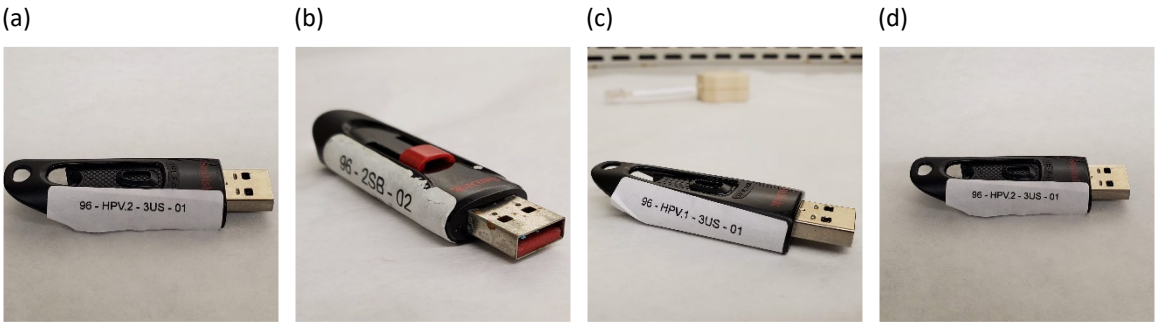


Figure 4-12. USBs at 12-months post-exposure: (a) control, (b) PAA, (c) 3% LCHP, and (d) 8% LCHP solutions.

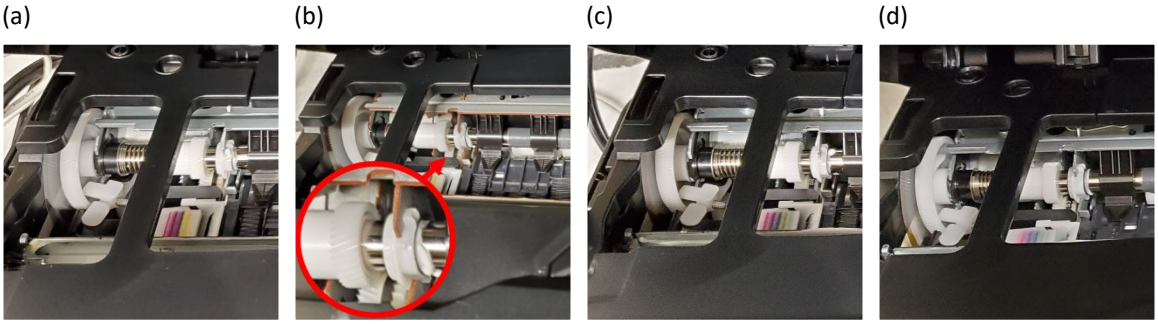


Figure 4-13. All-In-One printers at 12-months post-exposure: (a) control, (b) PAA, (c) 3% LCHP, and (d) 8% LCHP solutions.

4.2.3 Category 4 Equipment

The PAA fog treatment produced similar physical visually-observed changes for Category 4 equipment as were observed for Category 3 materials. Most notably was the white residue seen on nearly all of the computer surfaces (internal and external). The build-up of residue on the synthetic surfaces such as cords and the tower casing suggest it is likely a salt that formed as the PAA droplets dried as opposed to corroded or oxidized metal surfaces. The residue was also observed in significant quantities on the internal surfaces of the tower chassis. In addition to the white residue, a relatively small amount of rust had developed on the cut edges of the external metal surfaces.

There were no significant visually-observed changes observed in the Category 4 computers exposed to either LCHP treatment.

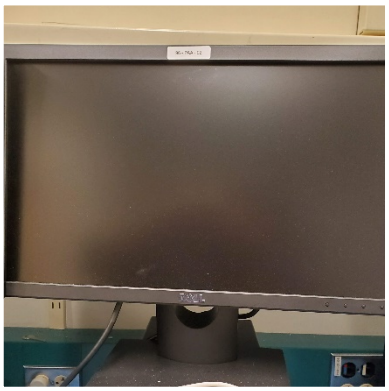
A description of the visually-observed changes documented in Category 4 materials are detailed in Table 4-4. Computer components for the control set and each exposure are shown in Figures 4-14 through 4-17.

Table 4-5. Summary of Visually-Observed Changes in Category 4 Materials

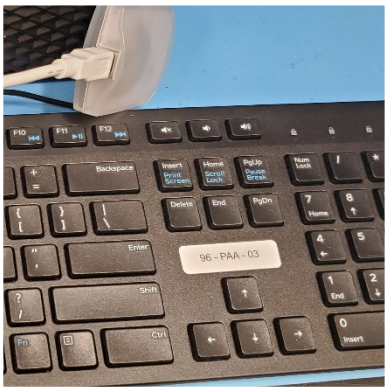
Treatment	Computer Component	Visual Observation
PAA Fog	Monitor	White residue
	Keyboard	None
	Mouse	None
	Tower Exterior	Rust on cut edges of metal material and white residue
	Tower Interior	White residue

Visually-observed changes were not observed in Category 4 equipment exposed to LCHPV from 3% or 8% LCHP

(a)



(b)

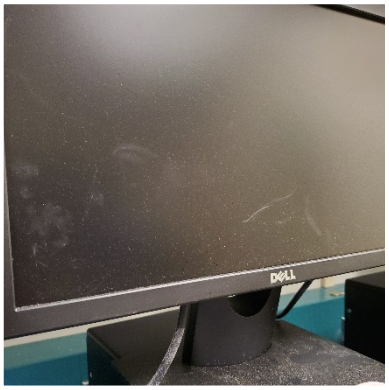


(c)

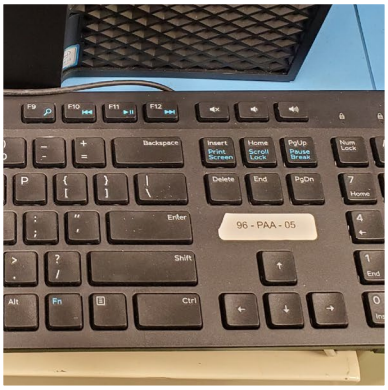
(d)

Figure 4-14. Control desktop computer at month 12 of the observation period: (a) monitor, (b) keyboard, (c) computer exterior, and (d) computer interior.

(a)



(b)



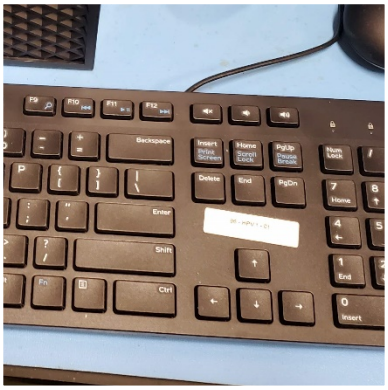
(c)

(d)

Figure 4-15. T01 desktop computer 12 months after PAA exposure: (a) monitor, (b) keyboard, (c) computer exterior, and (d) computer interior.

(a)

(b)



(c)

(d)

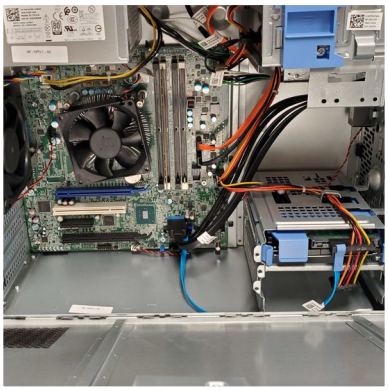
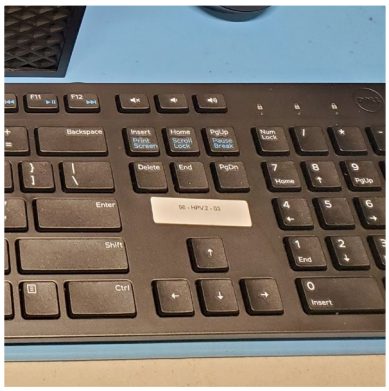


Figure 4-16. T02 desktop computer 12-months after 3% LCHP exposure: (a) monitor, (b) keyboard, (c) computer exterior, and (d) computer interior.

(a)

(b)



(c)

(d)

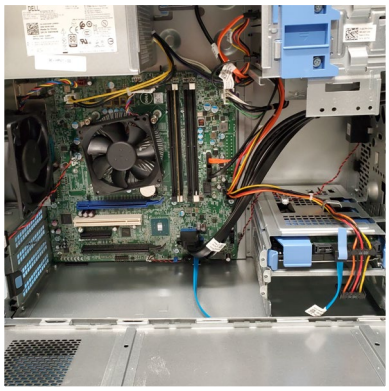


Figure 4-17. T03 desktop computer 12-months after 8% LCHP exposure: (a) monitor, (b) keyboard, (c) computer exterior, and (d) computer interior.

4.3 Functionality Assessments

Functionality assessments were performed on Category 2, 3, and 4 materials and equipment once each month over the 12-month post-exposure observation period. Assessments were performed by operating the equipment as intended and specified by the manufacturer. Equipment was assessed on the successful completion of basic functions in an average operating environment. This section will detail the results of Category 2, 3, and 4 functionality assessments.

4.3.1 Categories 2 and 3 Equipment

Categories 2 and 3 equipment were powered off and unplugged when not in use. Mobile phones were fully charged prior to testing. All equipment was stored in an environmentally controlled facility typical of an indoor office environment. The following is a summary of functionality issues encountered with equipment exposed to PAA fog. No functionality issues were encountered with the positive control equipment or with equipment exposured to the LCHPV.

One month following the PAA fog exposure, the mobile phone power button would successfully power the device on and off, but would not wake the phone from hibernation. To wake the mobile device, an incoming call had to be placed and the call either ignored or answered. This failure repeated for the duration of the 12-month observation period.

The incandescent lamp that was exposed to PAA fog failed to switch on the CFL bulb at the 3-month test. A second attempt was made with a new bulb, but proved unsuccessful. It was later determined that the power outlet used was likely not energized. There were no failures observed before or after this instance.

During the 7-day post-exposure assessment, the smoke detector that was exposed to PAA fog would periodically produce a chirp-like beep typical of a low battery alert. The alert continued after replacing the battery. The unit ceased to produce the alert at the 4-month post exposure assessment, but otherwise functioned properly. Table 4-6 summarizes the functionality issues observed in the Category 2 and 3 materials during the 12-month observation period. Since only one replicate of each piece of equipment was exposed, it is not possible to determine statistical significance.

Table 4-6. Functionality Issues Found for Category 2 and 3 Equipment

Treatment	Equipment	Functional Change
PAA fog	Incandescent Light Switch[1]	Inability to power light source on and off, tested by installing a CFL light bulb. This failure only occurred during month 3 post-exposure.
	Mobile phone	The power button would not wake the phone or power the phone off.
	Smoke detector	Unit would produce an unprompted chirp typical of a low battery alert and continued after a new battery was installed.

[1] Failure is inconclusive. There is a strong possibility that the power outlet was not energized when the failure occurred.
PAA: peracetic acid

4.3.2 Category 4 Materials Functionality Assessment

PC Doctor™ functionality testing was conducted prior to the decontaminant exposure event and monthly thereafter. The temporal evaluation of the computers provided information about the progression and extent of damage to the computer subsystems over time.

A number of failed diagnostic tests occurred in the set of control computers, and these issues also occurred with the test group of computers. Failures observed in the decontaminant-exposed computers that were observed in the control set are detailed in the following sections.

Except for the few minor issues with the PAA fog exposure as noted in the following sections, there were no other functionality impacts of Category 4 equipment from exposure to the PAA fog. There were no additional functionality impacts to Category 4 equipment from exposure to either of the LCHPV exposures apart from what was observed with the control computers.

As previously mentioned, a test that failed the first trial was tested a second time to correct for possible human error. A test that failed the second trial was labeled "Fail." If the test failed the first time, but passes the second time, it was labeled "Pass2." For tabulation, a score of 1,000 is assigned to each "Fail," and a "Pass2" is assigned a score of 1. A "Pass" results in a score of 0.

4.3.2.1 Control Set Assessments

A set of triplicate, unexposed computers (PC-01, PC-02, and PC-03) provided a baseline for comparison with the decontaminant-exposed computers. PC Doctor tests for the untreated, control set were conducted in parallel with the PAA fog treated computers. Although the control set was not exposed to treatment conditions, a number of system failures were reported in the optical drives over the observation period. It is important to note that the computers used for this study were configured with 2 separate optical drives: a rewritable drive (+- RW) and a read-only memory (ROM). The rewritable drive experienced the most test failures with a total of 122 failures for the three control computers. Observed failures in this drive began on Day 202 of the observation period and, with few exceptions, consistently failed both test trials for each subsequent assessment. The ROM drive totaled 7 failures, all from PC-02. The first instance occurred on Day 146 with both test trials failing. Subsequent failures occurred on Days 202 and 321; the tests on these days failed the initial trial, but passed the second. Infrequent sub-system failures included the sound card, USB, and network card. The sound card failure occurred in PC-02 on Day 70; the initial test trial failed and the second passed. The USB Drive for PC-03 failed both test trials on Day 39, but performed without further incident thereafter. Two network card failures were detected on Day 108 for PC-01. For both tests, the initial test trial failed, but the second test trial passed.

Table 4-7 provides a summary of the failed test and their corresponding subsystems for the control set of computers. Tables 4-8, 4-9, and 4-10 provide monthly assessment scores, test failures and the frequency of the failures over the observation period for the control set.

Table 4-7. Summary of Failed Tests and Corresponding Subsystems for the Category 4 Control Set

Failed Test ID	Test Description	Sub-System	Total Failures
1	Rough Audio Test	Sound Card	1
26	DVD Linear Seek Test	+- RW Drive	11
27	DVD Linear Read Compare Test	+- RW Drive	11
28	DVD Random Seek Test	+- RW Drive	11
29	DVD Funnel Seek Test	+- RW Drive	11
30	DVD Read Performance Test	+- RW Drive	11
42	DVD Linear Seek Test	ROM Drive	3
44	DVD Random Seek Test	ROM Drive	2
45	DVD Funnel Seek Test	ROM Drive	2
60	CD-RW Read Write Test	+- RW Drive	1
61	DVD-R Read Write Test	+- RW Drive	20
62	DVD-RW Read Write Test	+- RW Drive	15
63	DVD+R Read Write Test	+- RW Drive	17
64	DVD+RW Read Write Test	+- RW Drive	14
70	Linear Read Test	USB	1
91	Network Link Test	Network Card	1
93	Network External Loopback Test	Network Card	1

Table 4-8. PC-Doctor™ Scores and Failed Test IDs for PC-01 (Control)

Monthly Scores			Failed Test ID								
Month	*Elapsed Time (Days)*	*Score*									
Baseline	-22	0									
Jul	7	0									
Aug	39	0									
Sep	70	0									
Oct	108	2	91[a]	93[a]							
Nov	140	1000	63								
Dec[1]	N/A										
Jan	202	2000	63	64							
Feb	227	3000	61	62	63						
Mar	259	8001	26	27	28	29	30	60[a]	61	62	63
Apr	284	9000	26	27	28	29	30	61	62	63	64
May	321	9000	26	27	28	29	30	61	62	63	64
Jun	355	9000	26	27	28	29	30	61	62	63	64

[a] Test failed the first trial and passed the second trial

[1]Data is not available. The test facility could not be accessed. Blank cells indicate no failed tests.

Table 4-9. PC-Doctor™ Scores and Failed Test IDs for PC-02 (Control)

Monthly Score Summary			Failed Test ID									
Month	***Elapsed Time (Days)***	***Score***										
Baseline	-22	0										
Jul	7	0										
Aug	39	0										
Sep	70	1	1[a]									
Oct	108	0										
Nov	146	0	42	44	45							
Dec[1]	N/A											
Jan	202	1004	42[a]	44[a]	45[a]	62[a]	63					
Feb	227	3000	62	63	64							
Mar	259	3000	62	63	64							
Apr	284	9000	26	27	28	29	30	61	62	63	64	
May	321	9001	26	27	28	29	30	42[a]	61	62	63	64
Jun	355	9000	26	27	28	29	30	61	62	63	64	

[a] Test failed the first trial and passed the second trial

[1]Data is not available. The test facility could not be accessed. Blank cells indicate no failed tests.

Table 4-10. PC-Doctor™ Scores and Test Failure IDs PC-03 (Control)

Monthly Scores			Failed Test ID								
Month	***Elapsed Time (Days)***	****Score***									
Baseline	-4	0									
Jul	7	0									
Aug	39	1000	70								
Sep	70	0									
Oct	108	0									
Nov	140	1000	64								
Dec[1]	NA										
Jan	202	4000	61	62	63	64					
Feb	227	4000	61	62	63	64					
Mar	259	9000	26	27	28	29	30	61	62	63	64
Apr	284	9000	26	27	28	29	30	61	62	63	64
May	321	9000	26	27	28	29	30	61	61	61	61
Jun	355	9000	26	27	28	29	30	61	61	61	61

[1]Data is not available. The test facility could not be accessed. Blank cells indicate no failed tests.

4.3.2.2 PAA Test Assessments

Computers PC-04, PC-05, and PC-06 were exposed to the PAA fog. The computers successfully completed diagnostic testing without failures up to observation Days 108, 244, and 202, respectively. As subsystems began to fail, failed tests and the frequency of failure were consistent with the control set of computers, with the majority of failures associated with the +-RW drive (119 total tests). Failed subsystems that also occurred in the control group included the sound card (total of 1 failure). There were three +-RW test failures that occurred with PAA fog exposure that did not occur in the control set. They include the Spindle, Tray In, and CD Linear Seek tests. The Spindle and Tray In tests failed the initial test, but passed the second on Day 244 for PC-04. Additionally, these failures were unique for this set of computers; they did not occur a second time. The CD Linear Seek test was performed as Tests 21 and 48 for the +-RW and both failed for PC-04. The two failures occurred on days 202 and 271, and only failed the initial test trial. The ROM drive failures include CD Funnel Seek and CD Linear Seek tests. The CD Linear Seek test failure occurred at Day 202 for PC-06. The CD Funnel Seek test also occurred at Day 202 for PC-04. Table 4-11 provides a summary of the failed test and their corresponding subsystems for the computers exposed to PAA fog. Tables 4-12, 4-13, and 4-14 provide monthly assessment scores, test failures and the frequency of the failures over the observation period.

Table 4-11. Summary of Failed Tests and Corresponding Subsystems for the PAA Fog Test Category 4 Set

Test ID[1]	Test Description	Subsystem	Total Failures
1	Rough Audio Test	Sound Card	1
18*	Spindle Test	+- RW Drive	1
20*	Tray In Test	+- RW Drive	1
21*	CD Linear Seek Test	+- RW Drive	1
26	DVD Linear Seek Test	+- RW Drive	12
27	DVD Linear Read Compare Test	+- RW Drive	11
28	DVD Random Seek Test	+- RW Drive	11
29	DVD Funnel Seek Test	+- RW Drive	11
30	DVD Read Performance Test	+- RW Drive	11
40*	CD Funnel Seek Test	ROM Drive	1
48*	CD Linear Seek Test	+- RW Drive	1
54*	CD Linear Seek Test	ROM Drive	1
61	DVD-R Read Write Test	+- RW Drive	15
62	DVD-RW Read Write Test	+- RW Drive	17
63	DVD+R Read Write Test	+- RW Drive	15
64	DVD+RW Read Write Test	+- RW Drive	12

[1] Test failures that did not also occur in the control set are highlighted and have an asterisk.

Table 4-12. PC-Doctor™ Scores and Failed Tests for PC-04 (PAA)

Monthly Scores			Failed Test ID[2]									
Month	*Elapsed Time (Days)*	*Score*										
Baseline	-22	0										
Jul	7	0										
Aug	39	0										
Sep	70	0										
Oct	108	2	1[a]	61[a]								
Nov	140	2000	62	63								
Dec[1]	N/A											
Jan	202	1005	48[a*]	54[a**]	61[a]	62[a]	63[a]	64				
Feb	227	4000	61	62	63							
Mar	244	8002	18[a*]	20[a*]	26	27	28	29	30	61	62	63
Apr	271	9001	21[a*]	26	27	28	29	30	61	62	63	64
May	316	9000	26	27	28	29	30	61	62	63	64	
Jun	355	9000	26	27	28	29	30	61	62	63	64	

[a] Test failed the first trial and passed the second trial

[1] Data is not available. The test facility could not be accessed.

[2] Test failures that did not also occur in the control set are highlighted and have an asterisk. Blank cells indicate no failed tests.

Table 4-13. PC-Doctor™ Scores and System Failures for PC-05 (PAA)

Monthly Scores			Failed Test ID								
Month	*Elapsed Time (Days)*	*Score*									
Baseline	-22	0									
Jul	7	0									
Aug	39	0									
Sep	70	0									
Oct	108	0									
Nov	140	0									
Dec[1]	N/A										
Jan	202	0									
Feb	227	0									
Mar	244	1000	62								
Apr	271	1000	62								
May	316	6003	26	27	28 [a]	29 [a]	30 [a]	61	62	63	64
Jun	355	9000	26	27	28	29	30	61	62	63	64

[a] Test failed the first trial and passed the second trial

[1] Data is not available. The test facility could not be accessed. Blank cells indicate no failed tests.

Table 4-14. Monthly PC-Doctor™ Scores and System Failures for PC-06 (PAA)

Monthly Scores			Failed Test ID[2]								
Month	*Day*	*Score*									
Baseline	-22	0									
Jul	7	0									
Aug	39	0									
Sep	70	0									
Oct	108	0									
Nov	140	0									
Dec[1]	N/A										
Jan	202	4002	26	40 a*	61 [a]	62	63	64			
Feb	227	9000	26	27	28	29	30	61	62	63	64
Mar	244	9000	26	27	28	29	30	61	62	63	64
Apr	271	9000	26	27	28	29	30	61	62	63	64
May	316	9000	26	27	28	29	30	61	62	63	64
Jun	355	9000	26	27	28	29	30	61	62	63	64

[a] Test failed the first trial and passed the second trial.

[1] Data is not available. The test facility could not be accessed.

[2] Test failures that did not also occur in the control set are highlighted. And have an asterisk. Blank cells indicate no failed tests.

4.3.2.3 3% LCHP Test Assessments

Computers PC-07, PC-08, and PC-09 were exposed to the HPV from 3% LCHP. The computers were assessed without subsystem failures until Days 82, 37, and 177, respectively. When failures occurred, the majority were associated with the +-RW drive. Upon completion of the observation period, the +-RW drive test failures totaled 107, of which only 5 were not represented in the control set. These included the OPU, Spindle, Tray In, and CD Linear Seek tests. An OPU test failure was recorded for PC-07 and PC-08, both on Day 246. PC-07 failed the initial test trial and passed the second while, PC-08 failed both test trials. The Spindle and Tray In failures were recorded for PC-07 on assessment Day 246. The spindle test failed the first test trial and passed the second while the Tray In test failed both test trials. The CD Linear Seek test failed for PC-08 on Day 37; the initial test trial failed and the second passed. Additional test failures include the Rough Audio and DVD Linear Seek tests, which are associated with the sound card and ROM drive, respectively. Both tests failures also occurred in the control set. Table 4-15 provides a summary of the failed test and their corresponding subsystems for the control set of computers. Tables 4-16, 4-17, and 4-18 provide monthly assessment scores, test failures and the frequency of the failures over the observation period.

Table 4-15. Summary of Failed Tests and Corresponding Subsystems for the Category 4 3% LCHP Test Set

Test ID[1]	Test Description	Subsystem	Total Failures
1	Rough Audio Test	Sound Card	2
17	OPU Test	+- RW Drive	2
18	Spindle Test	+- RW Drive	1
20	Tray In Test	+- RW Drive	1
21	CD Linear Seek Test	+- RW Drive	1
26	DVD Linear Seek Test	+- RW Drive	8
27	DVD Linear Read Compare Test	+- RW Drive	8
28	DVD Random Seek Test	+- RW Drive	7
29	DVD Funnel Seek Test	+- RW Drive	7
30	DVD Read Performance Test	+- RW Drive	7
42	DVD Linear Seek Test	ROM Drive	1
60	CD-RW Read Write Test	+- RW Drive	4
61	DVD-R Read Write Test	+- RW Drive	14
62	DVD-RW Read Write Test	+- RW Drive	10
63	DVD+R Read Write Test	+- RW Drive	17
64	DVD+RW Read Write Test	+- RW Drive	20
67*	Linear Read Test	USB Device	7

[1] Test failures that did not also occur in the control set are highlighted and have an asterisk.

Table 4-16. Monthly PC-Doctor™ Scores and System Failures for PC-07 (3% LCHP)

Monthly Score Summary			Failed Test ID[1]											
Month	*Elapsed Time (Day)*	*Score*												
Baseline	-11	0												
Mar	9	0												
Apr	37	0												
May	82	1000	67											
Jun	114	3000	63	64	67*									
Jul	136	3000	63	64	67*									
Aug	177	5000	61	62	63	64	67*							
Sep	213	5000	61	62	63	64	67*							
Oct	246	11002	17[a*]	18[a*]	20*	26	27	28	29	30	60	61	62	63	64
Nov	276	12000	26	27	28	29	30	59	60	61	62	63	64	67*	
Dec	298	10000	26	27	28	29	30	61	62	63	64	67*			
Jan	325	11000	26	27	28	29	30	60	61	62	63	64	67*		
Feb	360	11000	26	27	28	29	30	60	61	62	63	64	67*		

[a] Test failed the first trial and passed the second trial

[1] Test failures that did not also occur in the control set are highlighted and have an asterisk. Blank cells indicate no failed tests.

Table 4-17. Monthly PC-Doctor™ Scores and System Failures for PC-08 (3% LCHP)

Monthly Score Summary			Failed Test ID[1]								
Month	*Elapsed Time (Days)*	*Score*									
Baseline	-11	0									
Mar	9	0									
Apr	37	1	21 [a*]								
May	82	0									
Jun	114	0									
Jul	136	1	64 [a]								
Aug	177	3000	61	63	64						
Sep	213	3000	61	63	64						
Oct	246	3000	17*	61	63						
Nov	642	2003	1 [a]	26 [a]	27 [a]	63	64				
Dec	664	4000	61	62	63	64					
Jan	325	9000	26	27	28	29	30	61	62	63	64
Feb	360	9000	26	27	28	29	30	61	62	63	64

[a] Test failed the first trial and passed the second trial

[1] Test failures that did not also occur in the control set are highlighted and have an asterisk. Blank cells indicate no failed tests.

Table 4-18. Monthly PC-Doctor™ Scores and System Failures for PC-09 (3% LCHP)

Monthly Score Summary			Failed Test ID[1]				
Month	*Elapsed Time (Days)*	*Score*					
Baseline	-11	0					
Mar	9	0					
Apr	37	0					
May	82	0					
Jun	114	0					
Jul	136	0					
Aug	177	1000	64				
Sep	213	1000	64				
Oct	246	0					
Nov	276	0					
Dec	664	1	64 [a]				
Jan	325	0					
Feb	360	1004	1 [a]	42	61 [a]	63 [a]	64 [a]

[a] Test failed the first trial, but passed the second. Blank cells indicate no failed tests.

4.3.2.4 8% LCHP Test Assessments

Computers PC-10, PC-11, and PC-12 were decontaminated with HPV from 8% LCHP. PC-10 experienced a failed CD Linear Seek test (+-RW drive) on Day 9 however, the next failure did not occur until the assessment performed on Day 122. Assessments for PC-11 and PC-12 were completed without failures until Days 100 and 163, respectfully. A total of 90 subsystem failures occurred in this set of computers including 82 +-RW, 1 sound card, and 2 USB subsystem failures. Test failures that did not occur with the control PCs were minor, but included the Sound Interactive (sound card), CD Linear Seek (+-RW drive), and the Linear Read (USB) tests.

A Linear Read Test failure occurred in a USB drive, which was likely caused by an improperly seated USB device. The initial test trial failed, however, physical adjustment to the USB device resulted in a successful second test trial.

Table 4-19 provides a summary of the failed tests and their corresponding subsystems for the computers exposed to the HPV generated from the 8% HP. Tables 4-20, 4-21, and 4-22 provide monthly assessment scores, test failures and the frequency of the failures over the observation period.

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Table 4-19. Summary of Failed Tests and Corresponding Subsystems for the Category 4 8% LCHP Test Set

Test ID[1]	Test Description	Subsystem	Total Failures
2*	Sound Interactive Test	Sound Card	1
21*	CD Linear Seek Test	+- RW Drive	1
26	DVD Linear Seek Test	+- RW Drive	7
27	DVD Linear Read Compare Test	+- RW Drive	7
28	DVD Random Seek Test	+- RW Drive	7
29	DVD Funnel Seek Test	+- RW Drive	7
30	DVD Read Performance Test	+- RW Drive	7
59*	CD-R Read Write Test	+- RW Drive	1
61	DVD-R Read Write Test	+- RW Drive	8
62	DVD-RW Read Write Test	+- RW Drive	10
63	DVD+R Read Write Test	+- RW Drive	15
64	DVD+RW Read Write Test	+- RW Drive	14
65	Linear Read Test	USB	1
67*	Linear Read Test	USB	5

[1] Test failures that did not also occur in the control set are highlighted and have an asterisk.

Table 4-20. Monthly PC-Doctor™ Scores and System Failures for PC-10 (8% LCHP)

Monthly Scores			Failed Test ID[1]								
Month	*Day*	*Score*									
Baseline	-25	0									
Mar	9	1	21*[a]								
Apr	36	0									
May	73	0									
Jun	100	0									
Jul	122	0									
Aug	163	0	61	63							
Sep	199	2000	61	63							
Oct	232	2001	62[a]	63	64						
Nov	262	1	63[a]								
Dec	284	4004	26[a]	27[a]	28[a]	29[a]	30	61	62	63	
Jan	311	9000	26	27	28	29	30	61	62	63	64
Feb	346	9000	26	27	28	29	30	61	62	63	64

[a] Test failed the first trial and passed the second.

[1] Test failures that did not also occur in the control set are highlighted and have an asterisk. Blank cells indicate no failed tests.

Table 4-21. Monthly PC-Doctor™ Scores and System Failures for PC-11 (8% LCHP)

Monthly Scores			Failed Test ID[1]		
Month	*Elapsed Time (Day)*	*Score*			
Baseline	-11	0			
Mar	9	0			
Apr	36	0			
May	73	0			
Jun	100	2000	63	64	
Jul	122	2000	63	64	
Aug	163	0			
Sep	199	0			
Oct	232	1002	2*[a]	64 [a]	67*
Nov	262	1000	67		
Dec	284	1000	67		
Jan	311	1001	64 [a]	67	
Feb	346	9000	62 [a]	63	67*

[a] Test failed the first trial and passed the second.

[1] Test failures that did not also occur in the control set are highlighted and have an asterisk. Blank cells indicate no failed tests.

Table 4-22. Monthly PC-Doctor™ Scores and System Failures for PC-12 (8% LCHP)

Monthly Scores			Failed Test ID[1]									
Month	***Elapsed Time (Days)***	***Score***										
Baseline	-11	1	65 [a]									
Mar	9	0										
Apr	36	0										
May	73	0										
Jun	100	0										
Jul	122	0										
Aug	163	1000	64									
Sep	199	1000	64									
Oct	232	1002	62 [a]	63 [a]	64							
Nov	262	2006	26 [a]	27 [a]	28 [a]	29 [a]	30 [a]	62 [a]	63	64		
Dec	284	9001	26	27	28	29	30	59* [a]	61	62	63	64
Jan	311	9000	26	27	28	29	30	61	62	63	64	
Feb	346	9000	26	27	28	29	30	61	62	63	64	

[a] Test failed the first trial and passed the second

[1] Test failures that did not also occur in the control set are highlighted and have an asterisk. Blank cells indicate no failed tests.

4.4 Decontaminant Effectiveness

Table 4-23 shows the number of BIs inactivated by each test decontaminant for each of the test locations.

Table 4-23. Inactivated Biological Indicator (BIs) for Each Location

Test Solution	BI Location	Total BIs	No. Inactivated (No Growth)
PAA	PC-04	5	5
	PC-05	5	5
	PC-06	5	5
	Table[a]	5	5
	Airlock[b]	5	0
3% LCHP	PC-07	5	5
	PC-08	5	5
	PC-09	5	5
	Table[a]	5	5
	Airlock[b]	5	0
8% LCHP	PC-10	5	5
	PC-11	5	5
	PC-12	5	5
	Table[a]	5	5
	Airlock[b]	5	0

[a] Located inside of COMMANDER; fully exposed

[b] Located outside of COMMANDER; unexposed to decontaminant

No.: Number

BIs not exposed to the PAA fog or LCHPV conditions (i.e. positive controls placed in the air lock) were positive for growth for each decontamination event. All BIs were inactivated for each of the 3 exposures.

5.0 Quality Control/ Quality Assurance

Quality assurance (QA)/quality control (QC) procedures were performed in accordance with the quality requirements detailed in an approved quality assurance project plan.

5.1 Sampling, Monitoring, and Equipment Calibration

Approved operating procedures were used for the maintenance and calibration of all laboratory equipment. All equipment was verified as being certified calibrated or having the calibration validated by EPA's metrology laboratory at the time of use. Standard laboratory equipment such as balances, pH meters, biological safety cabinets, and incubators were routinely monitored for proper performance. Calibration of instruments was done at the frequency shown in Tables 5-1 and 5-2. Any deficiencies were noted. Any deficient instrument was adjusted to meet calibration tolerances and recalibrated within 24 hours. If tolerances were not met after recalibration, additional corrective actions were taken, including recalibration or/and replacement of the equipment.

Table 5-1. Sampling and Monitoring Equipment Calibration Frequency

Equipment	Calibration/Certification	Expected Tolerance
RH and temperature sensor	Compare RH to the head space of three calibration salt solutions in an enclosed space within 1 week of use; thermistor (for temperature) part of RH sensor and calibrated by manufacturer	**± 5%**
ATI HPV transmitter	Compare HPV reading to the head space of a calibration solution of known concentration within 1 a week of use	**± 5%**
Stopwatch	Compare against National Institute of Standards and Technology (NIST) Official U.S. time at http://nist.time.gov/timezone.cgi?Eastern/d/-5/java once every 30 days	± 1 min/30 days

Table 5-2. Analysis Equipment Calibration Frequency

Equipment	Calibration Frequency	Calibration Method	Responsible Party	Acceptance Criteria
Pipettes	Annually	Gravimetric	Carter Calibrations, Manassas, VA	± 1% target value
Scale	Before each use	Compared to Class S weights	Laboratory staff	± 0.01% target

5.2 Acceptance Criteria for Critical Measurements

QA/QC checks associated with this project were established in a quality assurance project plan. A summary of these checks is provided in Table 5-3.

Table 5-3. QA/QC Acceptance Criteria for Critical Measurements

Matrix	Critical Measurement	QA/QC Check	Frequency	Accuracy	Precision
Test Chamber air	COMMANDER chamber HPV concentration	2-point calibration	Once per test	± 5%	5% of the target concentration
Test Chamber air	COMMANDER chamber RH	Three-point calibration (Vaisala, HMK15 humidity calibrator)	Once per test (Vaisala calibration salt with certificate)	± 3% RH	± 15% RH
Test Chamber air	COMMANDER chamber temperature	Five-point calibration	Annually	± 0.5 °C	± 5.0 °C

5.3 Data Quality

The accuracy of a measurement is expressed in terms of percent bias and precision in relative standard deviation (RSD). Span values collected during calibrations were used to measure the precision and accuracy of the ATI HP gas transmitter. For this effort, multiple cell HPV concentrations were used for the span and, therefore, a precision value is not available. Calibration requires adjustment of both zero and span. The zero point was set when the sensor is known to be in an environment free of the target

gas. The span was set by exposing the transmitter to the head space of a known concentration and temperature of hydrogen peroxide solution. Table 5-4 details the precision and accuracy of the ATI gas sensor.

Table 5-4. Precision (RSD) and Accuracy (% Bias) Assessments of the ATI HP Gas Sensor

Calibration Cell (wt/wt% HP)	Calibration Cell Headspace (ppm HPV)	Calibration Cell Temperature (°C)	Adjusted ATI Reading (ppm HPV)			Precision (RSD)	Accuracy (% error)
			T01	T02	T03		
Baseline[1]	0	-	0	0	0	NA	NA
8%	32.2	22.4	-	31	-	NA	3.7
16.6%	46.1	15	-	-	49	NA	6.3
48.6%	545[a]	23.8	545	-	-	NA	0

[1] HPV reading in ambient air at ambient temperature.

[a] 0-1000 ppm range ATI

RSD: relative standard deviation

Precision and accuracy assessments for the Vaisala transmitter's RH sensor were performed prior to each exposure test. The sensor was calibrated using a HMK15 humidity calibrator (Vaisala, Helsinki, Finland) placed in selected cells of saturated salt solutions of known relative humidity (Greenspan, 1976) for a duration of at least 2 hours. The first hour was provided for the response to stabilize; data collected during the final hour was used for data quality indicator assessments. LabView data acquisition software was used to digitally record the data. Precision and accuracy assessments for the Vaisala transmitter's sensor are reported in Table 5-5.

Table 5-5. Precision (RSD) and Accuracy (% Bias) Assessments of the Vaisala Transmitter's RH Sensor

Salt	Calibration Cell RH[1] (%, ± SD)	Mean Sensor Measurement (%, ±SD)			Precision (RSD)	Accuracy (% bias)
		T01	T02	T03		
MgCl	33.07 ± 0.48	33.4 ± 0.03	32.9 ± 0.05	33.2 ± 0.01	0.008	-0.29
$Mg(NO_3)_2$	54.38 ± 0.23	54.1 ± 0.01	-	-	NA	0.51
NaCl	75.47 ± 0.14	75.4 ± 0.05	75.3 ± 0.01	74.9 ± 0.14	0.004	0.36
K_2SO_4	97.59 ± 0.53	-	97.6 ± 0.003	97.8 ± 0.35	0.001	-0.11

[1] Equilibrium relative humidity of saturated salt cell at 20°C

RSD: relative standard deviation

6.0 Summary and Conclusions

6.1 PAA Fog Exposure

In terms of decontamination efficacy, fogging 750 ml of PAA into COMMANDER inactivated all the BIs.

Fogging of PAA solutions has potential as a relatively easy-to-use decontamination technology in the event of contamination with *Bacillus anthracis* or other spore-forming infectious disease agents (Wood et al., 2013), however, there are a few notable material incompatibilities to be aware of. Visually-

observed changes (e.g., discoloration, residue) were observed on the following metal coupons: copper, low-carbon steel, 304 stainless steel, and aluminum. Some corrosion and/or residue was also observed on certain locations of the electrical switch box, incandescent light, and the smoke detector battery terminals. For the computers, the external, non-metal surfaces had a moderate amount of white, salt residue. Internal and external metal surfaces showed small amounts of rusting and a significant amount of white residue.

Changes in equipment functionality or impacts include:

- Printed paper – The PAA fog solution appeared to soak through the top few pages. For those pages, the integrity of the standard printer paper was shown to deteriorate overtime; becoming too brittle to handle or use within 6 months of exposure.
- Mobile smart phone - One month following exposure, the power button failed to power the device on and off or wake the phone from hibernation
- Smoke detector – The unit would give a false "low battery" alert.
- Category 4 computers - A total of six subsystem test failures, not observed in the control set, were observed in the Category 4 computers; 4 were related to the +-RW drive and 2 to the ROM drive.

6.2 LCHPV generated with 3% HP

Disseminating 3-L of 3% HP using a COTS humidifier resulted in the inactivation of all 20 BIs. The dissemination phase required approximately 2.75 days and the dwell phase, 8 hours. During dissemination, the HP levels reached 7.7 ppm and averaged 3.5 ppm.

The LCHPV exposure resulted in minimal compatibility issues with the Category 2, 3, and 4 materials and equipment. Visually-observed changes in material and equipment were limited to low-carbon steel, which showed some minor oxidation as rust on exposed surfaces. While the amount of visible rust was initially minute, affected areas continued to progress over the surface of the material until approximately 6-months post-exposure.

The exposure did not affect the functionality of Category 2 or 3 equipment. Four unique subsystem test failures, not observed in the control set, were observed in the Category 4 computers; all were related to the +-RW drive.

6.3 LCHPV generated with 8% HP

Disseminating 2-L of 8% HP using a COTS humidifier successfully inactivated all BIs. The dissemination phase lasted approximately 2 days and the dwell phase, 10 hours. During dissemination, the HP levels reached 25 ppm and averaged 10 ppm.

The LCHPV exposure using the 8% HP had minimal compatibility issues with the Category 2, 3, and 4 materials and equipment. As with the 3% LCHP exposure, visually-observed changes in material and

equipment were observed on low-carbon steel, which, as before, showed rust on exposed surfaces. The amount of visible rust also increased over time until approximately 6-months post-exposure.

The exposure did not affect the functionality of Category 2 or 3 equipment. Three unique subsystem test failures, not observed with the control computers, were observed in the Category 4 computers and included minor issues with the sound card, +-RW drive, and USB.

6.4 Summary of impacts on personal computers

The impacts on personal computers after exposure to the decontaminants are summarized in Table 6-1, in terms of the number of second-trial failures that occurred. As previously mentioned, a diagnostic test on a system that failed the first trial was tested a second time to correct for possible human error. The number of tests that failed the second trial are summarized below for the positive control computers and those computers exposed to a decontaminant, and are a more realistic assessment of material compatibility. Table 6-1 presents the number of occurrences of second-trial failures over the year, in which the total number of tests conducted was 33 (3 replicate computers for each test condition times 11 assessments over the year). As can been seen in the table, for the PAA fog exposure, there were only two tests which had more second trial failures compared to the controls; for the 3% LCHP, there were only three tests which had more second trial failures compared to the controls; and for the 8% LCHP, there was only one test which had more second trial failures compared to the controls.

Table 6-1. Number of Second-Trial Failures on Personal Computers

Test ID	Test Name	2nd Trial Failures*			
		Control	PAA	3% LCHP	8% LCHP
17	OPU			1	
26	DVD linear seek	11	12	7	5
27	DVD linear read compare	11	11	7	5
28	DVD random seek	11	10	7	5
29	DVD funnel seek	11	10	7	5
30	DVD read performance	11	10	7	6
42	DVD linear seek	1		1	
44	DVD random seek	1			
45	DVD funnel	1			
60	CD-RW read write			4	
61	DVD-R read write	20	12	13	8
62	DVD-RW read write	14	16	10	6
63	DVD+R read write	17	14	16	13
64	DVD+RW read write	14	12	17	12
67	USB drive F linear read				5
70	USB drive J linear read	1			

*out of a total of 33 tests

7.0 References

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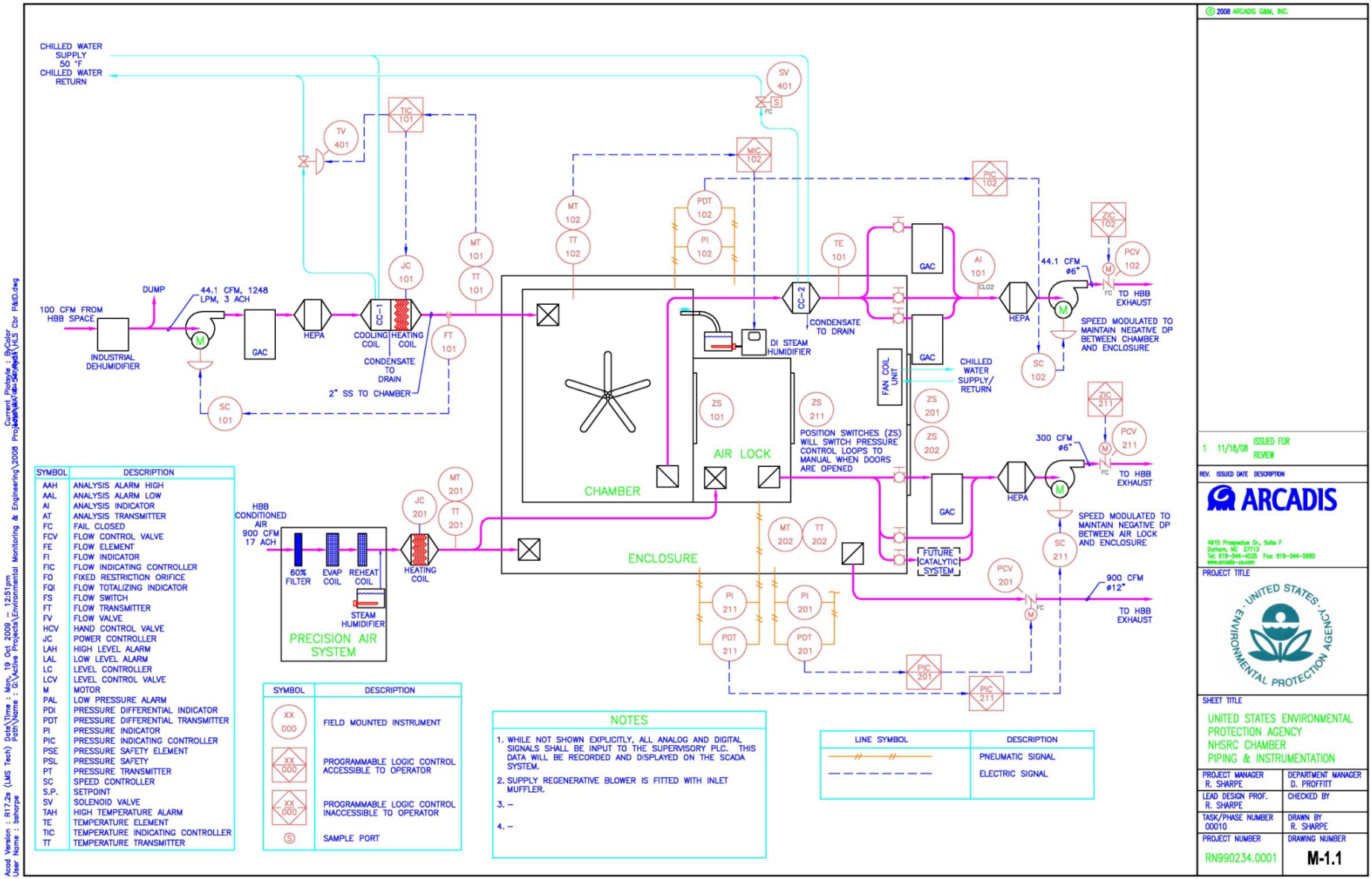
Appendix A

COMMANDER PIPING AND INSTRUMENTATION



SYMBOL	DESCRIPTION
AAH	ANALYSIS ALARM HIGH
AAL	ANALYSIS ALARM LOW
AI	ANALYSIS INDICATOR
AT	ANALYSIS TRANSMITTER
FC	FAIL CLOSED
FCV	FLOW CONTROL VALVE
FE	FLOW ELEMENT
FI	FLOW INDICATOR
FIC	FLOW INDICATING CONTROLLER
FO	FIXED RESTRICTION ORIFICE
FQI	FLOW TOTALIZING INDICATOR
FS	FLOW SWITCH
FT	FLOW TRANSMITTER
FV	FLOW VALVE
HCV	HAND CONTROL VALVE
JC	POWER CONTROLLER
LAH	HIGH LEVEL ALARM
LAL	LOW LEVEL ALARM
LC	LEVEL CONTROLLER
LCV	LEVEL CONTROL VALVE
M	MOTOR
PAL	LOW PRESSURE ALARM
PDI	PRESSURE DIFFERENTIAL INDICATOR
PDT	PRESSURE DIFFERENTIAL TRANSMITTER
PI	PRESSURE INDICATOR
PIC	PRESSURE INDICATING CONTROLLER
PSE	PRESSURE SAFETY ELEMENT
PSL	PRESSURE SAFETY
PT	PRESSURE TRANSMITTER
SC	SPEED CONTROLLER
S.P.	SETPOINT
SV	SOLENOID VALVE
TAH	HIGH TEMPERATURE ALARM
TE	TEMPERATURE ELEMENT
TIC	TEMPERATURE INDICATING CONTROLLER
TT	TEMPERATURE TRANSMITTER

SYMBOL	DESCRIPTION
XX 000	FIELD MOUNTED INSTRUMENT
XX 000	PROGRAMMABLE LOGIC CONTROL ACCESSIBLE TO OPERATOR
XX 000	PROGRAMMABLE LOGIC CONTROL INACCESSIBLE TO OPERATOR
S	SAMPLE PORT

NOTES

1. WHILE NOT SHOWN EXPLICITLY, ALL ANALOG AND DIGITAL SIGNALS SHALL BE INPUT TO THE SUPERVISORY PLC. THIS DATA WILL BE RECORDED AND DISPLAYED ON THE SCADA SYSTEM.
2. SUPPLY REGENERATIVE BLOWER IS FITTED WITH INLET MUFFLER.
3. –
4. –

LINE SYMBOL	DESCRIPTION
// //	PNEUMATIC SIGNAL
– – – – – –	ELECTRIC SIGNAL

1 11/18/08 ISSUED FOR REVIEW

REV. ISSUED DATE DESCRIPTION

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PROJECT TITLE

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

SHEET TITLE

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
NHSRC CHAMBER
PIPING & INSTRUMENTATION

PROJECT MANAGER	DEPARTMENT MANAGER
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TASK/PHASE NUMBER	DRAWN BY
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PROJECT NUMBER	DRAWING NUMBER
RN990234.0001	M-1.1

Figure A-1. COMMANDER Piping and Instrumentation.

Appendix B

COMMERCIAL OFF-THE-SHELF (COTS) HUMIDIFIER PRELIMINARY TEST

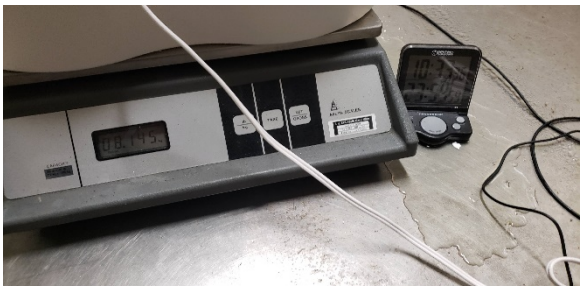
The LCHPV tests were performed with the commercial off-the-shelf (COTS) humidifier described in Section 2.3.2. Prior to testing with prepared LCHP solution, a preliminary test was performed with deionized water to characterize chamber conditions and the performance of the humidifier during testing. Approximately exactly 5 L of deionized water were added to the humidifier; 2500 mL per tank. The humidifier fan was set to level 1 and the humidistat was set to level 4. The humidifier was placed on a top Mettler PM30 top loading balance (Mettler Toledo; Columbus, OH) in an empty COMMANDER chamber with a 12-inch oscillating fan operating set on the highest of 3 speed settings. The COMMANDER chamber was sealed and configured for zero air exchanges. The humidifier was activated using the SCADA system and recovered on the sixth day. During the preliminary test, the COMMANDER chamber was entered periodically to retrieve the mass of the humidifier. Table B-1 details the dissemination rate of the humidifier over the 6-day period of operation.

Table B-1. Total and Average Water Disseminated by COTS Humidifier Over 6 Day Period

Time (Days)	Total Volume Disseminated (L)	Dissemination Rate (L/day)
0	0	0
1.0	1.095	1.095
2.0	1.690	0.845
5.7	3.635	0.638

The humidifier lost a total of 1.095, 1.690, and 3.635 liters on Days 1,2, and 6, respectively. The dissemination rate decreased over time. The initial rate was 1.095 L/day as of 1 day then, dropped to an average of 0.845 L/day on Day 2 and finally, was an average of 0.638 L/day by Day 6. Approximately 3.6 L of deionized water were disseminated, and 1.4 L remained in the humidifier. Further analysis indicated approximately 0.6 L of the volume remaining in the humidifier were absorbed in the wicking filter.

Upon re-entry on Day 6, significant amounts of condensation were observed on several chamber surfaces including the floor, ceiling, and walls. Figure B-1 shows a few areas with a significant collection of condensation after Day 6.

(a) 

(b) 

(c) 

Figure B-1. Condensation after Day 6 of preliminary test (a) next to the humidifier, (b) on the COMMANDER floor and, (c) on the COMMANDER walls.

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