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# Compatibility of Material and Electronic Equipment with Methyl Bromide and Chlorine Dioxide Fumigation

## Assessment and Evaluation Report

**Office of Research and Development**
National Homeland Security Research Center

EPA 600-R-12-664

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National Homeland Security Research Center
Office of Research and Development
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

## Disclaimer

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## List of Acronyms and Abbreviations

| | |
|---|---|
| Ag | silver |
| Al | aluminum |
| APPCD | Air Pollution Prevention and Control Division |
| AVI | audio visual interleave |
| AWWA | American Water Works Association |
| *B.* | *Bacillus* |
| BI(s) | biological indicator(s) |
| BIOS | basic input/output system |
| BIT | burn-in test |
| BW(s) | biological weapon(s) |
| CD | compact disk |
| CD/DVD | compact disk/digital video disk |
| CD-ROM | Compact Disk - Read Only Memory |
| $Cl_2$ | chlorine |
| $ClO_2$ | chlorine dioxide |
| CMOS | complementary metal-oxide semiconductor |
| COC | Chain of Custody |
| CODEC | compression decompression module |
| CPU | central processing unit |
| CRBTA | Chemical, Biological, and Radiological Technology Alliance |
| CT | The product of multiplying the factors Concentration and Time. Has the units of mass*time/volume |
| Cu | copper |
| CW(s) | chemical weapon(s) |
| DAS | data acquisition system |
| DCMD | Decontamination and Consequence Management Division |
| DHS | Department of Homeland Security |
| DIMM | Dual In-Line Memory Module |
| DQI(s) | Data Quality Indicator(s) |
| DQO(s) | Data Quality Objective(s) |
| DSL | digital subscriber line |
| DTRL | Decontamination Technologies Research Laboratory |
| DVD | digital video disk |
| EMS | ClorDiSys Solutions, Inc. Environmental Monitoring System |
| EPA | U.S. Environmental Protection Agency |
| ESD | electrostatic discharge |
| FIFRA | Federal Insecticide, Fungicide, and Rodenticide Act |
| GFCI | Ground Fault Circuit Interrupter |
| $H_2O_2$ | hydrogen peroxide |
| HCl | hydrochloric acid |
| HPV | Hydrogen peroxide vapor |
| HSPD | Homeland Security Presidential Directive |
| IA&E | Independent Assessment and Evaluation |
| IPC | industrial printed circuit (boards) |

| | |
|---|---|
| KI | potassium iodide |
| KIPB | phosphate buffered potassium iodide solution |
| LCD | liquid crystal display |
| MeBr | methyl bromide |
| MEC | material/equipment compatibility |
| MFGB | Midget Fritted Glass Bubbler |
| MSDS | Material Safety Data Sheet |
| N | Normal(ity) |
| N/A | not available |
| NA | not applicable |
| NB | nutrient broth |
| NGA | National Geospatial-Intelligence Agency |
| NHSRC | National Homeland Security Research Center |
| NIST | National Institute for Standards and Technology |
| NOMAD® | Omega Engineering, Inc. RH and T data loggers |
| OSHA | Occupational Safety and Health Administration |
| PC | personal computer |
| PCI | peripheral component interconnect |
| PDA | Personal Digital Assistant |
| PDAQ | personal data acquisition (system) |
| PEL | permissible exposure limit |
| PVC | polyvinyl chloride |
| QA | Quality Assurance |
| QAPP | Quality Assurance Project Plan |
| RAM | random-access memory |
| RH | relative humidity |
| RSD | Relative Standard Deviation |
| S&T | Department of Homeland Security, Directorate for Science & Technology |
| SCA | system control accuracy |
| SD | Standard Deviation |
| Sn | tin |
| SPI | Serial Peripheral Interface |
| SVGA | Super Video Graphics Array |
| T/RH | temperature/relative humidity (sensor) |
| TAGA | trace atmospheric gas analyzer |
| TIC(s) | toxic industrial chemical(s) |
| TLV | Threshold Limit Value |
| TSA | tryptic soy agar |
| UV-VIS | ultraviolet-visible |

## List of Units

| | |
|---|---|
| °F | degree Fahrenheit |
| °C | degree Celsius |
| $ft^3$ | cubic feet |
| hr | hour |
| L/min | liters per minute |
| mg/L | milligrams per liter |
| mL | milliliter |
| $oz/ft^3$ | ounce per cubic foot |
| ppb | parts per billion |
| ppm | parts per million |
| ppmv | parts per million by volume |
| scfm | standard cubic feet per minute |

## Executive Summary

In response to Homeland Security Presidential Directive 10 (HSPD-10), the Department of Homeland Security (DHS) and the U.S. Environmental Protection Agency (EPA), through its National Homeland Security Research Center (NHSRC), coordinated to develop a comprehensive program to provide scientific expertise and evaluation of actual and future decontamination technologies that could potentially be used to recover and restore buildings and sensitive equipment contaminated by biological warfare agents.

Building decontamination following a possible terrorist attack using chemical weapons (CWs), biological weapons (BWs), or toxic industrial chemicals (TICs) can be performed using different decontamination techniques, such as fumigation of the building with chlorine dioxide ($ClO_2$), vaporous hydrogen peroxide ($H_2O_2$), or methyl bromide (MeBr). Unlike $H_2O_2$ and $ClO_2$, MeBr is not an oxidizing agent and is much less reactive. However, information on the compatibility of materials and equipment with typical MeBr fumigation conditions effective against anthrax spores has not been determined in a reproducible way. As part of an ongoing evaluation of the MeBr decontamination method, this study was initiated by NHSRC and DHS and conducted at EPA's Decontamination Technology Research Laboratory (DTRL) in Research Triangle Park, North Carolina. The goal was to provide information on the effects of MeBr on sensitive electronic components and materials, which substituted for the types of components also found in high-end (high cost) military and commercial equipment such as medical devices and airport scanners.

$ClO_2$ fumigation has been used successfully for the remediation of several federal buildings contaminated by *B. anthracis* spores contained in letters (Canter, 2003). To tie in the results of this study with previous research (US EPA, 2010) on this alternative fumigation technique, $ClO_2$ fumigation was used on some materials (e.g., desktop computers and monitors) in this study.

Four categories of materials were defined for use in this program. Not included in this study were Category 1 materials, which are structural materials with a large surface area inside a typical building. While the field experience and subsequent NHSRC laboratory testing have clearly demonstrated that these materials in the building can have a significant effect on the ability to achieve and maintain the required concentration of fumigant, fumigation has not been shown to affect their functionality (LGS, 2010) . The three categories examined in this study were:

- Category 2 materials included low surface area structural materials that were expected to have minimal impact on the maintenance of fumigation conditions during the decontamination event; however, their functionality and use may be affected by the fumigation. The materials that were tested are listed in Table ES-1

**Table ES-1. Category 2 Materials**

| | | | |
|---|---|---|---|
| Type 3003 Aluminum | Type 410 Stainless Steel | Incandescent Light | Circuit Breaker |
| Alloy 101 Copper | Type 430 Stainless Steel | DSL Conditioner | Smoke Detector |
| Low Carbon Steel | Yellow VAC Service Cord | Drywall Screw | Laser Printed Paper |
| Type 304 Stainless Steel | Steel Outlet/Switch Box | Drywall Nail | Ink Jet Colored Paper |
| Type 309 Stainless Steel | Silicone Caulk | Copper Services | Color Photograph |
| Type 316 Stainless Steel | Gasket | Aluminum Services | |

- Category 3 materials included small, personal electronic equipment such as a personal digital assistant (PDA) , cell phone, fax machine, data DVD, and data CD.

- Category 4 materials included desktop computers and monitors. A list of the components is shown in Table ES-2.

**Table ES-2. Category 4 Components**

| Computer Component | Description |
|---|---|
| Dell™ OptiPlex™ 760 | Desktop computer |
| Dell™ E1910H flat panel monitor | Desktop monitor |
| USB keyboard and mouse | Desktop keyboard and mouse |
| Super Video Graphics Array (SVGA) | Computer display standard. |
| Metal coupons for fumigations | Copper (Cu)<br>Aluminum (Al)<br>Silver (Ag)<br>Tin (Sn) |
| Cables | Computer power cord<br>Monitor power cord<br>Analog video cable |
| Industrial printed circuit board (IPC) | Circuit board |

By using visual inspection and tests of equipment function, this study documented the effects of MeBr fumigation on all three categories of materials and equipment and of $ClO_2$ fumigation on Category 4 materials, commonly found inside large buildings and offices. The target MeBr fumigation conditions were 300 mg/L MeBr at 75 percent relative humidity (RH) and 37 °C (99 °F) for nine hours. The determination of these conditions is based upon ongoing NHSRC testing of the efficacy of MeBr for inactivation of *B. anthracis* spores on building materials (USEPA, 2010; USEPA, 2011).

Additionally, exposure to 75 percent RH without MeBr was performed to determine the effect of the initial higher RH alone.

To allow for comparison of the effects of using MeBr and $ClO_2$ fumigants on Category 4 materials (high-end equipment substitutes), the following tests were conducted:

- $ClO_2$ fumigation at 3000 ppmv $ClO_2$ at 75% RH and 75 °F (24 °C) with a total concentration·time (CT) of 9000 ppmv-hr (the basis for remediating sites contaminated with *B. anthracis* spores).

- Different power states (on and off) for the Category 4 equipment for MeBr and $ClO_2$ fumigated computers, as well as for controls.

MeBr is available as a compressed gas. MeBr is toxic to humans but colorless and odorless, so it is frequently mixed with 2 percent chloropicrin (tear gas) to warn users of exposure (hereafter referred to as

“98-2 MeBr”). In a wide area fumigation the decision of whether to add chloropicrin would be made by the site safety person. Without extensive monitoring, chloropicrin provides a warning of the presence of MeBr. Chloropicrin, unlike MeBr itself, could be a mild oxidant.

The results of this study indicate that there were no physical or functional effects on any of the Category 2 or 3 materials tested following 98-2 MeBr exposure, with two exceptions. Rusted edges were observed on the steel outlet/switch box. The surface of the low carbon steel coupons showed severe corrosion following exposure.

The only adverse effect of the 98-2 MeBr fumigations on the Category 4 computers and equipment was slight corrosion on metal edges on the interior and exterior of the computer chassis. One run – aborted due to a power failure and likely reaching a much higher 98-2 MeBr concentration – showed heavy interior and exterior corrosion, internal powder, and yellow liquid residue on the motherboard and chassis. Detailed analysis by Alcatel-Lucent (LGS, 2010) indicated that it was the chlorine (chloropicrin) component of the 98-2 MeBr that actually caused the corrosion.

The light corrosion and powder seen in the $ClO_2$-fumigated computers agrees with previous research conducted on this fumigant (US EPA, 2010).

The power state of the computers did not make any difference with respect to the effects of fumigation. Any changes observed were present immediately after fumigation and did not appear to progress over the 12 month period of equipment observation and testing, with the exception of one floppy drive failure at the two month mark.

The biological indicator (BI) data support the theory that the fumigant concentration was much higher during the third 98-2 MeBr fumigation. The BIs inside the computers were at the lowest location in the Material Equipment Compatibility (MEC) chamber and may have been subject to higher concentrations due to gravimetric settling of the 98-2 MeBr gas, resulting in total kill. Biological Indicators have been shown not to correlate directly with achieving target fumigation conditions for inactivating *B. anthracis* spores on common building surfaces (Rastogi, 2010).

No corrosion was observed on either the central processing unit (CPU) or the graphics processing unit (GPU) heat sinks of the 98-2 MeBr or $ClO_2$ fumigated computers (thought to be the primary, if not sole, source of corrosion in the previous $ClO_2$ study (US EPA, 2010)). Alactel-Lucent (LGS, 2010) determined that, in this new generation of computers, the heat sinks were made from a single aluminum alloy. They found no evidence of chlorine or bromine on the surface of the fins on either heat sink, which means that native aluminum oxide on the CPU surface is sufficiently robust to resist attack by both MeBr and chloropicrin. As no visible corrosion could be seen on the computers exposed to $ClO_2$, these surfaces now appear to be sufficiently robust to also resist attack by $ClO_2$ under standard conditions.

All computers exposed to 98-2 MeBr exhibited problems with their power supply, some catastrophically. For instance, one computer began failing a few days after fumigation by tripping ground fault circuits and exhibited a burning odor. These same effects were eventually detected in all 98-2 MeBr fumigated computers, and all power supplies were replaced. Alcatel-Lucent (LGS, 2010) traced these failures to exposure to the chloropicrin component of the fumigant.

Effects of fumigation for each category of material/equipment are summarized below.

**Category 2:**

No visual or functional changes were noted for Category 2 materials throughout the 12 month observation period following the 98-2 MeBr fumigation, with two exceptions.

The surface of the low carbon steel coupons showed a drastic transformation from smooth and metallic to severe corrosion following 98-2 MeBr exposure. The effects on low carbon steel were comparable to those observed with $ClO_2$ fumigations at high RH (US EPA, 2010). Because of this corrosion, a resistance reading could not be obtained from these corroded coupons.

Rusted edges were observed on the steel outlet/switch box.

Each of the remaining sets of metal remained tarnish free, with no signs of rust or corrosion.

Color pigments do not appear to be adversely affected by the 98-2 MeBr exposure, in marked contrast to the color pigment fading observed with $ClO_2$ fumigations.

Each exposed smoke detector remained fully operational throughout the year after exposure; the battery terminals, resistors, and other components showed no signs of physical damage.

Exposed stranded wires remained tarnish-free 12 months after exposure.

None of the breakers or services from any test fell outside of the acceptable testing range.

**Category 3:**

No visual or functional changes were noted for Category 3 materials throughout the 12 month observation period following the 98-2 MeBr fumigation.

The CDs and DVDs were all unaffected by 98-2 MeBr exposure.

There were no signs of damage to any of the mechanical parts of the fax machine, and the same level of operation was maintained throughout the year.

No visual or functional changes were noted for the cell phones. Screen quality and operational parameters were unaffected.

There were no visual or functional changes noted for the Personal Digital Assistants (PDAs).

**Category 4:**

The 98-2 MeBr fumigation resulted in slight corrosion on metal edges on the interior and exterior of the computer chassis. In a previous study with $ClO_2$, the aluminum heat sink oxidized and resulted in a light powder which coated the motherboard and chassis (USEPA, 2010). In this work, there was no visible powder on the motherboard from corrosion of the aluminum heat sink as had been seen in earlier work with $ClO_2$.

The third fumigation, suspected to be at a much higher concentration of MeBr, showed heavy interior and exterior corrosion, internal powder, and yellow liquid residue on the motherboard and chassis.

Parts affected by the 98-2 MeBr and $ClO_2$ fumigations included external and internal stamped metal grids, external metal slot covers, and any internal cut metal edges.

The CPUs of these computers were not impacted by either fumigant. The new generation of computer Heat sinks are being made from a single aluminum alloy which is sufficiently robust to resist attack by MeBr, chloropicrin, and $ClO_2$.

The power state of the computer did not seem to have an effect on the material compatibility.

The vast majority of failed components (83.7%) were related to the CD/DVD drive. A significant number of the remaining failures were related to the floppy drive, and many were an intermittent network loopback failure which seems to be an issue with all computers, even controls. Analysis shows that the CD/DVD subsystem is not reliable, with one of three failing in two of the control condition computer sets. Exposure to fumigants clearly reduced the reliability of the CD/DVD systems.

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

- Power supplies
- Metal bearings
- CD/DVD drives

# 1.0 Project Description and Objectives

Building decontamination following a possible terrorist attack using chemical weapons (CWs), biological weapons (BWs), or toxic industrial chemicals (TICs), can be performed using different decontamination techniques, e.g., fumigation of the building with chlorine dioxide ($ClO_2$), hydrogen peroxide ($H_2O_2$) vapor, or methyl bromide (MeBr).

Unlike $H_2O_2$ and $ClO_2$, MeBr is not an oxidizing agent and is much less reactive. However, information on the compatibility of materials and equipment with typical MeBr fumigation conditions effective against anthrax spores has not been determined in a precise way. Future guidance on selection and operation of decontamination technologies is dependent upon such information. This work determined the impact of fumigation with MeBr (with 2% chloropicrin) under sporicidal conditions on materials and electronic equipment.

## 1.1 Purpose

The main purpose of this work was to provide information to decision makers about the potential impact, if any, of the MeBr decontamination process on materials and electronic equipment. This effort examined the impact on the physical appearance, properties, and functionality of certain types of materials and equipment. While the impact on specific items was addressed, the purpose was to also consider some items – particularly the computer systems and electronic components – as substitutes for high-end equipment such as medical devices and airport scanners.

To provide comparative information and to tie this research into a previous study using $ClO_2$ as the potential decontamination technique (US EPA, 2010), desktop computers and monitors (Category 4 materials) were also fumigated with $ClO_2$. This fumigation allowed for 1) comparison of the effects of each technique on these high-end equipment substitutes, and 2) provide additional $ClO_2$ data for "identical" computers manufactured one year later, with subsequent industry substitutions of less-costly components. In the original research with $ClO_2$, inexpensive plastic compact disc (CD) and digital video disk (DVD) components were found to experience the most frequent and serious failures.

## 1.2 Process

To investigate the impact of 98-2 MeBr and $ClO_2$ gases on materials and equipment under specific fumigation conditions, material was divided into four categories. Category 1 materials were not addressed in this study. Materials in Categories 2 and 3 (low surface area structural materials and small personal electronic equipment, respectively) were evaluated on-site before and for one year after the date of exposure. Category 4 materials (desktop computers and monitors) were evaluated on-site before and immediately after fumigation. The sample set was then divided with one of the samples being sent to Alcatel-Lucent for in-depth analysis. The other samples remained on-site for evaluation over the course of a year.

### *1.2.1 Overview of the MeBr Fumigation Process*

MeBr is a broad spectrum pesticide registered under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) as a fumigant for termites, insects, and rodents in buildings and as a fumigant for agricultural applications. While not registered as a sporicide, laboratory (Kolb, 1950; USEPA, 2010; USEPA, 2011) and field research (Scheffrahn, 2003) has shown MeBr to be effective against *Bacillus* spores, including *B. anthracis*. As an alkylating agent, MeBr could be effective against chemical warfare agents as well, though more research needs to be done in this area to determine dosing.

MeBr is available as a compressed gas. MeBr is toxic to humans, but is colorless and odorless, so it is frequently mixed with 2 percent chloropicrin (tear gas) to warn users of exposure. For the remainder of this report, this MeBr mixture – which was used for the MeBr fumigations – will be referred to as "98-2 MeBr". Chloropicrin, unlike MeBr itself, could be a mild oxidant.

The target fumigation conditions for this work were 300 mg/L MeBr at 75 percent relative humidity (RH) and 37 °C (99 °F) for 9 hours. The determination of these conditions is based upon on-going National Homeland Security Research Center (NHSRC) testing of the efficacy of MeBr for inactivation of *B. anthracis* spores on building materials (Ryan, 2010).

### *1.2.2 Overview of the $ClO_2$ Fumigation Process*

Fumigation with $ClO_2$ was added to the test matrix to relate results of the 98-2 MeBr compatibility tests to previous research (US EPA, 2010). Fumigation with $ClO_2$ has been shown in other efforts to be effective for the decontamination of biological threats on building material surfaces (Rastogi, 2007), (Ryan, 2007). In past fumigation events for *B. anthracis* decontamination, the conditions set by FIFRA crisis exemptions required that a minimum concentration of 750 ppmv be maintained in the fumigation space for 12 hours until a minimum multiplication product of concentration and time (CT) of 9,000 ppmv-hours was achieved. Other important process parameters included a minimum temperature of 24 °C (75 °F) and a minimum RH of 75 percent.

While the minimum effective CT has been maintained in subsequent events, substantial improvement in the $ClO_2$ fumigation process technology allowed for higher concentrations to be achieved in large buildings. The baseline fumigation with $ClO_2$ for *Bacillus* spores for the previous research was 3,000 ppmv within the volume for three hours to achieve the CT of 9,000 ppmv-hr (Ryan, 2010). During this present study, this condition was repeated for Category 4 materials.

$ClO_2$ is generated commercially by two methods: wet and dry. The wet method, such as the one used by Sabre Technical Services, LLC. (Slingerlands, N.Y), generates the gas by stripping $ClO_2$ from an aqueous solution using emitters. The dry method, such as that used by ClorDiSys Solutions, Inc. (Lebanon, N.J.), passes a dilute chlorine gas (i.e., 2% in nitrogen) over solid hydrated sodium chlorite to generate $ClO_2$ gas. No differences in the effectiveness of either of the two generation techniques to inactivate *B. anthracis* spores on building materials have been observed in laboratory-scale investigations (Rastogi, 2007). Note that the wet technology is potentially "self-humidifying", while the dry technique requires a secondary system to maintain RH. The ClorDiSys method was used in this study to be consistent with the previous research with $ClO_2$,

### *1.2.3 Material/Equipment Compatibility (MEC) Chambers*

This task required that materials (computers and other potentially sensitive equipment) be exposed to 98-2 MeBr and $ClO_2$ – under conditions shown to be effective for decontamination of biological and chemical agents on building materials and/or in facilities – to assess the impact (hence, compatibility) of the fumigation process with the material/equipment. Two identical isolation chambers (material/equipment compatibility (MEC ) chambers ) were used for these compatibility tests.

The MeBr MEC chamber served as the isolation chamber for the MeBr-exposed material/equipment. The $ClO_2$ MEC chamber served as the isolation chamber for the $ClO_2$-exposed material/equipment. Figure 1-1 shows the dimensions of the MEC chambers; a photograph of the MEC test chamber is shown in Figure 1-2. The three computer installation setup used for $ClO_2$ fumigations can be seen in Figure 1-1. For the 98-2 MeBr fumigations, only two computers were inside the chamber at a time, one open (OFF power; see Figure 1-3) and one closed (ON power).

Power is supplied within the chambers by the inclusion of two seven-outlet surge protectors (BELKIN seven-outlet home/office surge protector with six-foot cord, Part # BE107200-06; Belkin International, Inc.; Compton, CA) inside each chamber (not shown in Figure 1-1). The power cord from each surge protector penetrated the polyvinyl chloride (PVC) chamber material on the bottom back wall of the chamber and was sealed to the chamber to prevent the fumigant from leaking out.

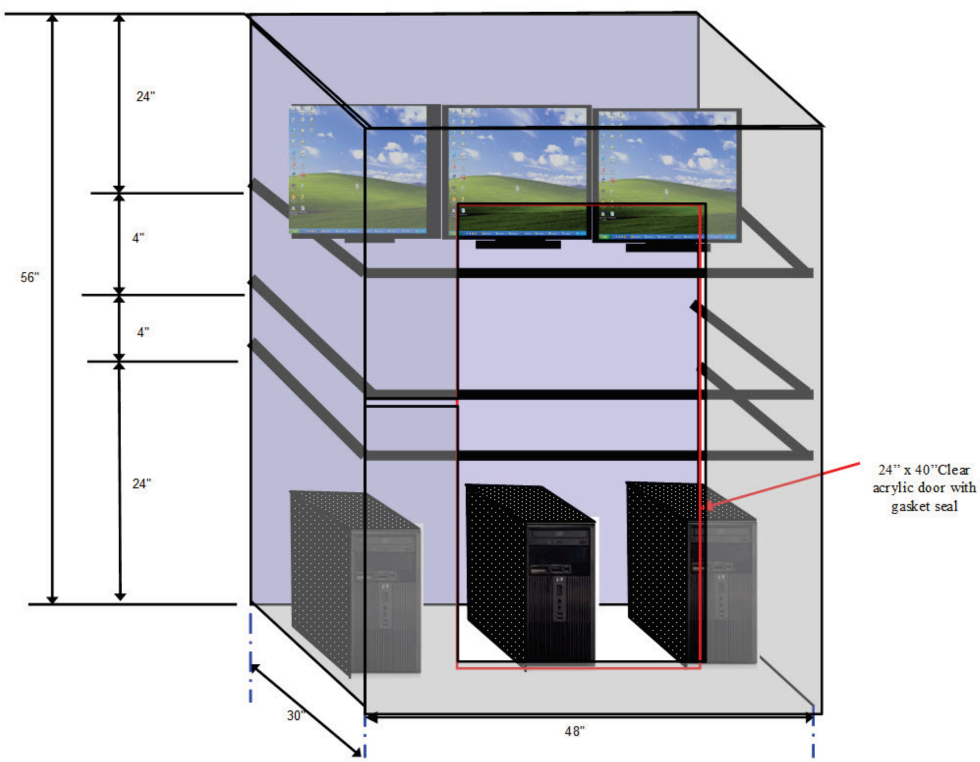



**Figure 1-1. Schematic Diagram of the MEC Chambers**

**Figure 1-2. Photograph of the MEC Test Chamber**

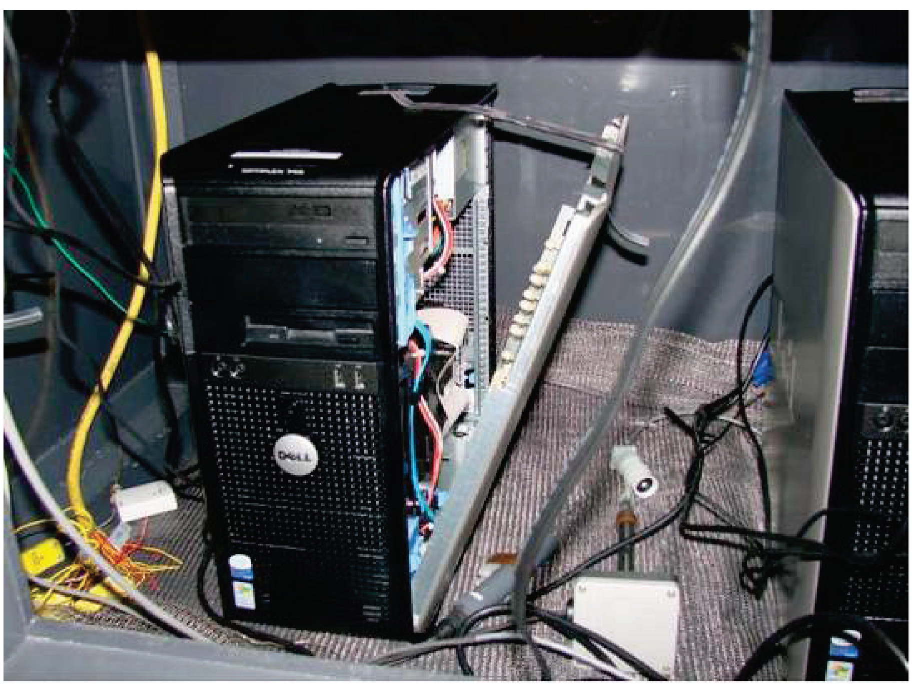


**Figure 1-3. Open Computer in MeBr MEC Chamber**

### *1.2.4 Laboratory Facility Description*

The material compatibility testing was performed in the EPA's NHSRC Decontamination Technologies Research Laboratory (DTRL) located in Research Triangle Park, NC. This facility is equipped with multiple fumigation generation systems; the MeBr and $ClO_2$ facilities are described below.

Measurement capabilities within DTRL include Dräger Polytron 7000 remote electrochemical sensors ($ClO_2$ /chlorine ($Cl_2$)), a HACH AutoCAT 9000 Amperometric Titrator (to facilitate wet chemical analysis for $ClO_2$ concentration measurements via a modification of American Water Works Association (AWWA) SM-4500-$ClO_2$-E), an Interscan Corporation LD223 dual range $ClO_2$ monitor (0-200 ppb; 0-20 ppm), and an Ion Chromatograph for use with the Occupational Safety and Health Administration (OSHA) ID-202 Method.

The chambers are made of opaque polyvinyl chloride (PVC) with a clear acrylic door, which is fastened with a bolted flange. The door is covered with an opaque material during tests to prevent light-catalyzed reactions from taking place during exposure. The three removable shelves within the chamber are made of perforated PVC. Grounded woven wire mesh (Type 304 Stainless steel, 0.011" gauge wire) was placed on each shelf to dissipate any potential static electricity. The ground wire penetrated the chamber wall and was attached to the electrical service ground. Three fans were placed in each chamber to facilitate mixing.

#### 1.2.4.1 MeBr Facility

The 98-2 MeBr was provided by a compressed gas cylinder from Great Lakes Chemical Corp. The concentration was monitored in real time with a Key Equipment Fumiscope 5.0 thermal conductivity analyzer, calibrated to MeBr. When the MeBr concentration fell below the set-point, a valve to the compressed gas cylinder was opened to inject more 98-2 MeBr. Injection was automated through a data acquisition system (DAS). The DAS was also used to control the temperature (37 °C; 99 °F) and RH (75%) during exposure.

A PureAire Monitoring Systems, Inc. Methyl Bromide Monitor was used during the aeration phase. Once the bulk concentration fell below 10 ppm, the PureAire monitor began sampling.

#### 1.2.4.2 $ClO_2$ Facility

This facility is equipped with a ClorDiSys Solutions, Inc., MiniDox $ClO_2$ gas generation system (and ancillary sampling/monitoring equipment, test chambers, and support equipment). This system automatically maintains a constant target $ClO_2$ concentration in an isolation chamber (e.g., MEC Chamber) and injects $ClO_2$ (20 L/min of ideally 40,000 ppmv $ClO_2$ in nitrogen) when the concentration inside the chamber falls below a pre-set condition. The MEC chamber is maintained at a set $ClO_2$ concentration, temperature, and RH. The $ClO_2$ concentration inside the chamber is measured by a ClorDiSys Solutions, Inc., photometric monitor located in the MiniDox unit, providing feedback to the generation system. A similar ClorDiSys Solutions, Inc. Environmental Monitoring System (EMS) photometric detector is used to confirm $ClO_2$ concentrations.

## 1.3 Project Objectives

The primary objective of this study was to assess the impact of fumigation on materials, electrical circuits, and electronic equipment. Specifically, the fumigation conditions of interest use 98-2 MeBr or $ClO_2$ at conditions thought to be effective for decontamination of materials and/or facilities contaminated with specific biological or chemical threats. Visual appearance of all items was documented before and after fumigation exposure. Most materials were not tested for complete functionality due to the multiplicity of potential uses. Specifically, this study focused on:

- 98-2 MeBr and $ClO_2$ fumigation technologies,
- Fumigation conditions, and
- State of operation of the equipment (OFF, ON and idle, and ON and active).

Three categories of material and equipment were tested under the different fumigation conditions discussed in detail in Section 3.8; the categories are separated based upon the conditions of testing and analysis to be performed to assess the impacts. Category 1 materials are structural materials with a large surface area inside a typical building. While the field experience and subsequent NHSRC laboratory testing have clearly demonstrated that these materials in a building can have a significant effect on the ability to achieve and maintain the required concentration, fumigation has not been shown to affect their functionality (Bartram, 2008). This type of material was not included in this study. The three categories of materials that were investigated are described below.

### *1.3.1 Category 2 Materials*

Category 2 materials include low surface area structural materials expected to have minimal impact on the maintenance of fumigation conditions within the volume. However, the functionality and use of Category 2 materials may be impacted by the fumigation event. The objective for this category of materials was to assess the visual and/or functional (as appropriate) impact of the fumigation process on the materials. The impact was evaluated in two ways:

1. Through visual inspections under each fumigant condition (concentration, temperature, RH, and time). These inspections were directed toward the locations thought to be most susceptible to corrosion and possible material defects due to the fumigation process.

2. Functionality was assessed, as appropriate, for the material. Resistance was measured for metal coupons and stranded wires; circuit breakers and copper and aluminum services were overloaded to determine the time prior to tripping the breaker; sealants were checked for leaks; gasket elasticity was tested with a simple stress test; lamps were tested to see if the bulb would light; the digital subscriber line (DSL) conditioner was tested for transmission on a telephone or fax; and the smoke detector batteries and lights were checked and put through a smoke test. Printed documents and pictures were inspected for possible alteration of their content.

The visual inspections were documented in writing and by digital photography for each material prior to and after exposure in each fumigation event. Visual inspections were not conducted on a monthy basis as the functional tests were. Functional testing of materials was assessed before and after 98-2 MeBr treatment, then periodically after exposure, and again at year’s end. Table 1-1 lists specifics of these materials and details the post-test procedures, where applicable. Appendix A includes the part number and vendor information for each of the materials used. Items not tested for functionality after exposure are shown as "not tested" in the *Functionality Testing Description* column.

**Table 1-1. Category 2 Material Information and Functionality Testing Description**

| Material Name | Sample Dimension / Quantity | Description | Functionality Testing Description |
|---|---|---|---|
| Type 3003 Aluminum | 2" x 2" x 0.0625" / 3 pieces | Metal Coupon | Triplicate coupons were stacked and the resistance was measured between the top and bottom coupon using an ohmmeter. |
| Alloy 101 Copper | 2" x 2" x 0.64" / 3 pieces | | |
| Low Carbon Steel | 1.5" x 2" x 0.0625" / 3 pieces | | |
| Type 304 Stainless Steel | 2" x 2" x 0.0625" / 3 pieces | | |
| Type 309 Stainless Steel | 1.5" x 2" / 3 pieces | | |
| Type 316 Stainless Steel | 2" x 2" x 0.0625" / 3 pieces | | |
| Type 410 Stainless Steel | 2" x 2" x 0.0625" / 3 pieces | | |
| Type 430 Stainless Steel | 1" x 2" x 0.012" / 3 pieces | | |
| Yellow SJTO 300 VAC Service Cord[1] | 12" long, 16 gauge, 3 conductor/ 3 pieces | Stranded Wire | The resistance of each wire was measured and recorded. |
| Steel Outlet/Switch Box | 2" x 3" x 1.5" / 1 piece | Steel box | Functionality was not tested. |
| Silicone Caulk | Approximately 1" long bead on the inside of a rectangular steel outlet/switch box | Sealant | Water was run into the corner of the outlet box with the sealant and the box was observed for leaks. |
| Gasket | 0.125" thick flange foam rubber / 3 pieces | Gasket | Gasket was folded in half and examined for cracks. |
| Incandescent Light | 60 Watt bulb / 3 pieces | Switch | A halogen light bulb was placed into the socket and the lamp was turned on. If the lamp failed to light the bulb, a new bulb was tested to verify that the switch was inoperable. |
| DSL Conditioner | NA / 1 piece | - | Simple connectivity was tested using a laboratory telephone through the conditioner. |
| Drywall Screw | 1" fine thread, coated / 3 pieces | - | Not tested. |
| Drywall Nail | 1.375" coated / 3 pieces | - | Not tested. |
| Copper Services | NA / 3 pieces | Copper and Aluminum Services | Services were tested at 15 amps (150% capacity) and timed to failure. |
| Aluminum Services | NA / 3 pieces | | |
| Circuit Breaker | NA / 10 pieces | - | Breakers were tested at 20 amps (200% capacity) and timed to failure. |
| Smoke Detector | NA / 1 piece | 9 Volt Smoke Detector | Battery was tested by pressing the button on the detector. In the hood, the alarm was tested by spraying the "Smoke Check-Smoke Alarm Tester" directly at the alarm. The light was checked to see if it was functioning. |
| Laser Printed Paper[2] | 8.5" x 11" (15 pages) | - | Visually assessed for legibility. |
| Ink Jet Colored Paper[2] | 8.5" x 11" (15 pages) | - | Visually assessed for legibility. |
| Color Photograph | 4" x 6" / 3 pieces | - | Visually assessed for content. |

Notes: "-" indicates "Material Name" and "General Description" are the same. NA = not applicable.
[1] The outside of the cord served as Housing Wire Insulation, and the three-stranded interior wires served as the Stranded Wires.
[2] Test page can be found in Appendix E of the EPA Quality Assurance Project Plan (QAPP) entitled, "Compatibility of Material and

Electronic Equipment with Chlorine Dioxide Fumigation," dated July 2007.

### *1.3.2 Category 3 Materials*

Category 3 Materials include small personal electronic equipment. The objectives for this category were to determine aesthetic (visual) and functionality impacts on the equipment as a function of time post-fumigation. The assessment of the impact was visual inspection for aesthetic effects and evaluation of functionality post-fumigation. Inspection occurred immediately after fumigation and then again at the one-year period, with the equipment stored at room temperature ambient conditions throughout that time period. Visual inspections of the equipment were documented in writing and by digital photographs. Any indications of odor emissions were also documented. The functionality of each piece of equipment was assessed comparatively with similar equipment that was not subjected to the fumigant exposure. Category 3 materials are listed in Table 1-2, with Table 1-3 detailing the post-test procedures. Appendix A includes the part number and vendor information for each of the materials used.

**Table 1-2. Category 3 Materials**

| Materials | Description | Manufacturer | Model Number | Sample Size |
|---|---|---|---|---|
| Personal Digital Assistant (PDA) | Handheld | Palm | Z22 | 1 piece |
| Cell Phone | Pay-as-you-go Super thin flip superphonic ringtones full color screen | Virgin (Kyocera) | Marbl | 1 piece |
| Fax/Phone/ Copier Machine | Plain-paper fax and copier with 10-page auto document feeder and up to 50-sheet paper capacity. 512KB memory stores up to 25 pages for out-of-paper fax reception | Brother | Fax 575 | 1 piece |
| Data DVD | Standard 21331 DVD Video | Warner Brothers | DVDL-582270B1 | 1 piece |
| Data CD | Standard Audio CD | CURB Records | DIDP-101042 | 1 piece |

**Table 1-3. Post-Fumigation Testing Procedures for Category 3 Materials**

| Material | Description of Testing Procedure |
|---|---|
| PDAs | The import and export capabilities were tested, and the screen condition was noted. Keypad and screen conditions were noted. |
| Cell Phones | Incoming and outgoing call capabilities were tested by ring and audio functions. Keypad and screen conditions were noted. |
| Fax Machines | Incoming and outgoing fax capabilities were tested, as were incoming and outgoing call functions. |
| DVD | The audio and visual functions were tested. |
| CD | The audio functions were tested by playing the first 10 seconds of each song. |

### *1.3.3 Category 4 Equipment*

Category 4 equipment includes desktop computers and monitors. The objective of testing for this category of equipment (and materials) was to assess the impact of the fumigation conditions using a two-tiered approach: (1) visual inspection and functionality testing using a personal computer (PC) software diagnostic tool, and (2) detailed analysis for a sub-set of the tested equipment in conjunction with Alcatel-Lucent. This detailed analysis was performed through LGS Innovations, Inc., and was funded by EPA and the Department of Homeland Security's Directorate of Science & Technology (S&T) .

One computer system of each test set (chosen by Alcatel-Lucent as potentially the worst performing) was sent to LGS for the independent assessment and evaluation (IA&E). The other systems remained at the EPA facility and were put through a burn-in test (BIT) sequence five days a week, for eight hours a day, to simulate normal working conditions. All computer systems were evaluated using PC-Doctor® Service Center™ 7.5 (PC-Doctor, Inc.; Reno, NV) as the PC software diagnostic tool. The BIT sequence and PC-Doctor® Service Center™ 7.5 protocols were developed by Alcatel-Lucent specifically for this testing.

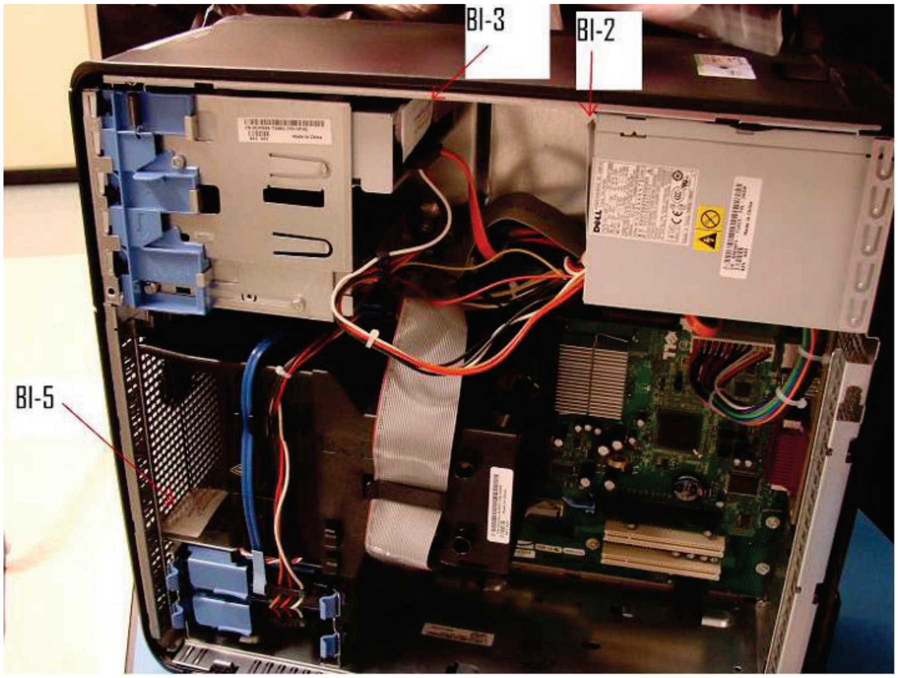
While the impact on computer systems was being assessed directly in this effort, the purpose of the testing was to consider the systems as surrogates for many of the components common to high-end equipment (e.g., medical devices, airport scanners). The objective was to identify components and specific parts of components that may be susceptible to corrosion because of the fumigation process. This information can then be used to make informed decisions about the compatibility of other equipment that may have similar components or materials and can reduce further testing or uncertainty in the field application. The Category 4 equipment and materials listed in Table 1-4 were selected by Alcatel-Lucent as appropriate test vehicle sets to meet the objectives of this study.

**Table 1-4. Category 4 Tested Materials**

| Computer Component | Description | Additional Details |
|---|---|---|
| Dell™ OptiPlex™ 760 | Desktop computer | See Appendix B for specifications. |
| Dell™ E1910H flat panel monitor | Desktop monitor | See Appendix B for specifications. |
| USB keyboard and mouse | Desktop keyboard and mouse | See Appendix B for specifications. |
| Super Video Graphics Array (SVGA) | Computer display standard. | See Appendix B for specifications. |
| Metal coupons for fumigations | Copper (Cu)<br>Aluminum (Al)<br>Silver (Ag)<br>Tin (Sn) | These metals are used extensively in fabricating desktop computers. Provided by Alcatel-Lucent |
| Cables | Computer power cord<br>Monitor power cord<br>Analog video cable | Standard cables |
| Industrial printed circuit board (IPC) | Circuit board | Provided by Alcatel-Lucent |

Further objectives in this study for Category 4 equipment and materials were to (1) provide an indication if localized conditions in an operating computer may be different from the bulk of the chamber and (2) obtain an indication of the potential impact the local conditions may have on the effectiveness of the 98-2 MeBr and $ClO_2$ fumigation processes to inactivate *B. anthracis* spores potentially located within the computer. For the first part of this objective, process parameter measurements in the bulk chamber and within the computers were compared. For the second part, biological indicators (BIs) were used to provide an indication of the effectiveness of the fumigation in the bulk chamber and within each computer.

BIs have been shown not to correlate directly with achieving target fumigation conditions for *B. anthracis* spores or inactivating *B. anthracis* spores on common building surfaces (LGS, 2009). While BIs do not necessary indicate achievement, they will sufficiently indicate a failure to achieve successful conditions. The locations of the NOMAD® RH monitor, metal coupons (on the FR4 Board provided by Alcatel-Lucent), IPC board, and BIs within each computer are shown in Figure 1-4(a) and (b). The NOMAD® (OM-NOMAD-RH, Omega Engineering, Inc., Stamford, NC) is an RH and temperature monitor with a built-in data logger. The placement of these items within the computers was decided based upon the air flow within the chamber and the desire not to affect the operation of the computer. The items were affixed to the inside of the side panel of the computer case using self-adhesive hook-and-loop dots (P/Ns 9736K44 and 9736K45, McMaster-Carr, Atlanta, GA).

(a) 

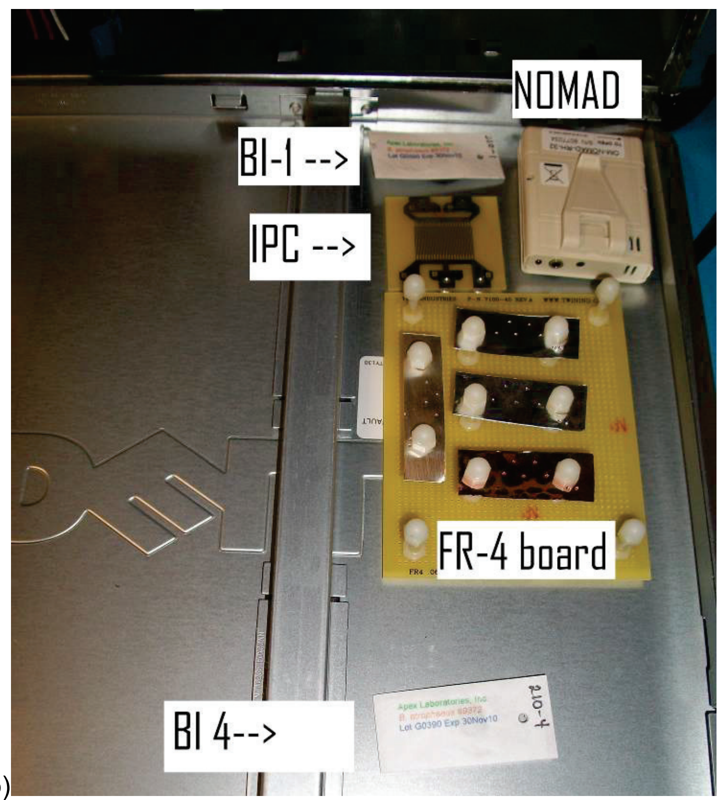

(b) 


**Figure 1-4. Location of NOMAD®, Metal Coupons, IPC Board, and BIs within the (a) CPU and (b) Panel**

# 2.0 Experimental Approach

## 2.1 DTRL MeBr Analytical Capabilities

Table 2-1 lists the analytical techniques used to quantify MeBr concentrations. These methods are discussed in Section 3.1.

**Table 2-1. DTRL MeBr Detection Methods**

| Manufacturer/ Organization | Method | Equipment |
|---|---|---|
| Key Instruments | Thermal conductivity detector | Fumiscope 5.0 |
| PureAire | Electrochemical detection | Air Check Advantage Methyl Bromide detector |
| MeBr in air | MeBr in air | Midget Fritted Glass Bubbler (MFGB) containing alcoholic potassium hydroxide |

## 2.2 DTRL $ClO_2$ Analytical Capabilities

The $ClO_2$ measurement capabilities used in this study include the four analytical techniques that were assessed separately or on a one-to-one basis depending on the type of measurement needed (continuous versus extractive). The techniques are listed in Table 2-2.

**Table 2-2. $ClO_2$ Analyses**

| Manufacturer/ Organization | Method | Equipment |
|---|---|---|
| ClorDiSys Solutions, Inc. | UV-VIS adsorption | MiniDox photometric monitor |
| ClorDiSys Solutions, Inc. | UV-VIS adsorption | EMS photometric monitor |
| AWWA | Standard Method 4500-$ClO_2$ B Modified | Collection in midget impingers filled with buffered potassium iodide (KI) solution |
| Dräger | Electrochemical Detection | Polytron 7000 transmitter |

UV-VIS Ultraviolet-visible

The ClorDiSys photometric monitors were used for real-time analysis and control. The modified Standard Method 4500-$ClO_2$ E was used to confirm the real-time analyses. The Dräger Polytron 7000 sensors were used only for safety (i.e., room monitor). Additional details on the photometric monitors and modified Standard Method 4500-$ClO_2$ E can be found in Sections 3.1.3 and 3.1.4.

## 2.3 General Approach

The impact of the fumigant on the material and electronic equipment was investigated under different fumigation conditions (concentration, temperature, RH, and exposure time). The sampling strategy for each fumigation approach (98-2 MeBr and $ClO_2$) is detailed in Section 2.4.

The effect of the fumigation process on materials and electronic equipment was investigated using visual inspection and an assessment of functionality. All visual inspections were documented in writing and with digital photographs. Functionality testing was documented in writing (and by digital photography, where appropriate). Additionally, a subset of Category 4 test sets was subjected to a detailed IA&E by Alcatel-Lucent and was detailed in their final report, “Assessment and Evaluation of the Impact of Fumigation with Methyl Bromide Technologies on Electronic Equipment,” (LGS, 2010). The results of the detailed IA&E on the original Category 4 test sets fumigated by $ClO_2$ are detailed, “Assessment and Evaluation of the Impact of Chlorine Dioxide Gas on Electronic Equipment,” (US EPA, 2010).

## 2.4 Sampling Strategy

### *2.4.1 MeBr Fumigation*

Figure 2-1 shows the general schematic for the 98-2 MeBr fumigation experimental setup. A pressurized gas cylinder containing 98 percent MeBr/2 percent chloropicrin (i.e., 98-2 MeBr) was connected to the MEC chamber. The chamber was heated to 37 °C using hot water radiators. A data acquisition and control system (Labview® platform) maintained the target RH (75%) by injecting humid air from a gas humidity bottle when the measured RH fell below the target RH. The control system also maintained a slight negative pressure inside the MEC chamber to prevent fumigant from leaking into the laboratory. Once RH and temperature target conditions had been met, the Fumiscope was zeroed on the humid chamber air and injection of the 98-2 MeBr began. The injection was automated by the control system until the target concentration (300 mg/L) was reached. Fine adjustments were made during the fumigation to maintain the target concentration. The pressure of the gas cylinder was monitored and logged in real time to determine the total amount injected into the chamber. The sorbent trap for 98-2 MeBr was 10 percent alcoholic potassium hydroxide. Two additional tests (computers OFF and ON) were used as a control with no fumigant added but exposed to the high temperature of 37 °C and 75 percent RH.

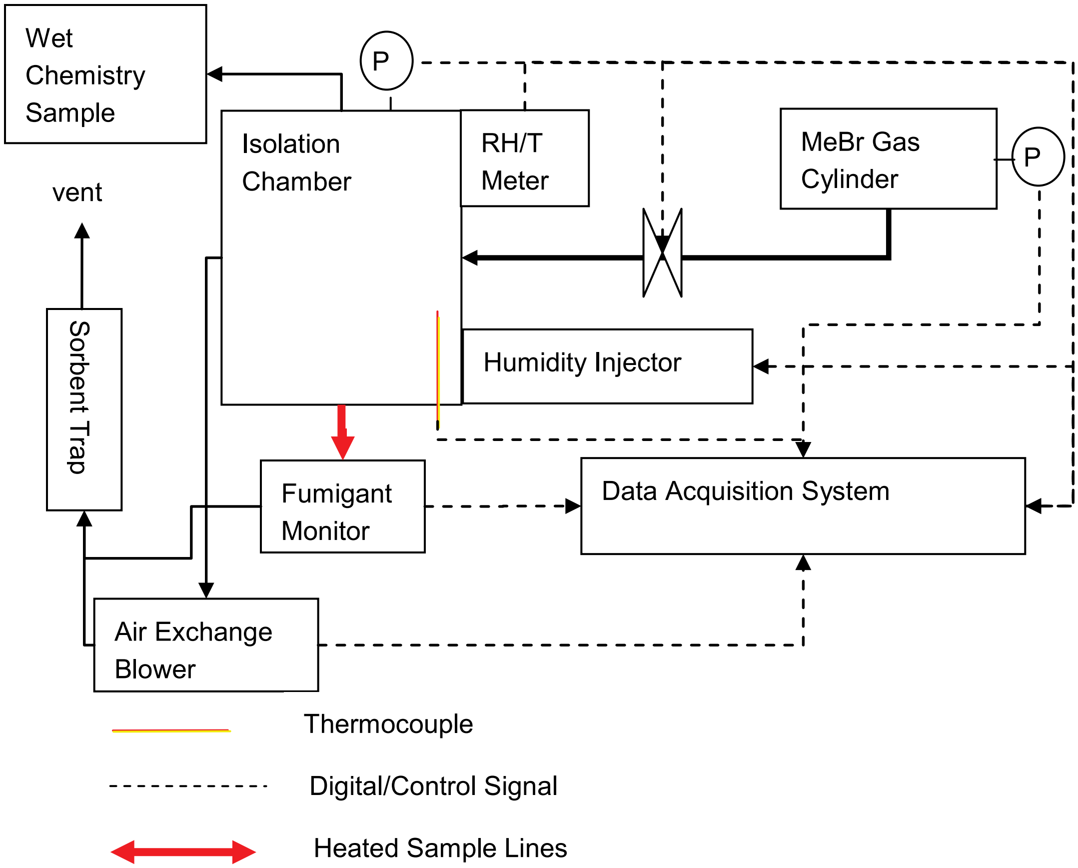



**Figure 2-1. Experimental Setup for the 98-2 MeBr Fumigations**

### *2.4.2 $ClO_2$ Fumigation*

The $ClO_2$ fumigations were performed at 3000 ppmv. Figure 2-2 shows the generic schematic for the fumigation experimental setup. The $ClO_2$ concentration in the test chamber was controlled directly with the MiniDox. The secondary fumigant monitor was the EMS. The wet chemistry samples, analyzed by modified Standard Method SM 4500-E, were taken every 30 minutes during the decontamination phase to confirm the concentration of $ClO_2$ in the MEC chamber. The RH of the MEC chamber was controlled by a feedback loop with LabView and a Vaisala temperature/RH (T/RH) sensor. When the RH reading fell below the desired setpoint, the DAS injected hot humid air into the MEC chamber.

Cooling was done by circulating cooling water just above the dew point (to prevent condensation) through small radiators equipped with fans. The temperature of the cooling water was raised or lowered to achieve the desired heat transfer. If necessary, the air exchange rate was also increased to aid in cooling: a blower removed the warm air from the chamber and replaced it with cooler air. The blower was also operated to prevent overpressurization of the isolation chamber.

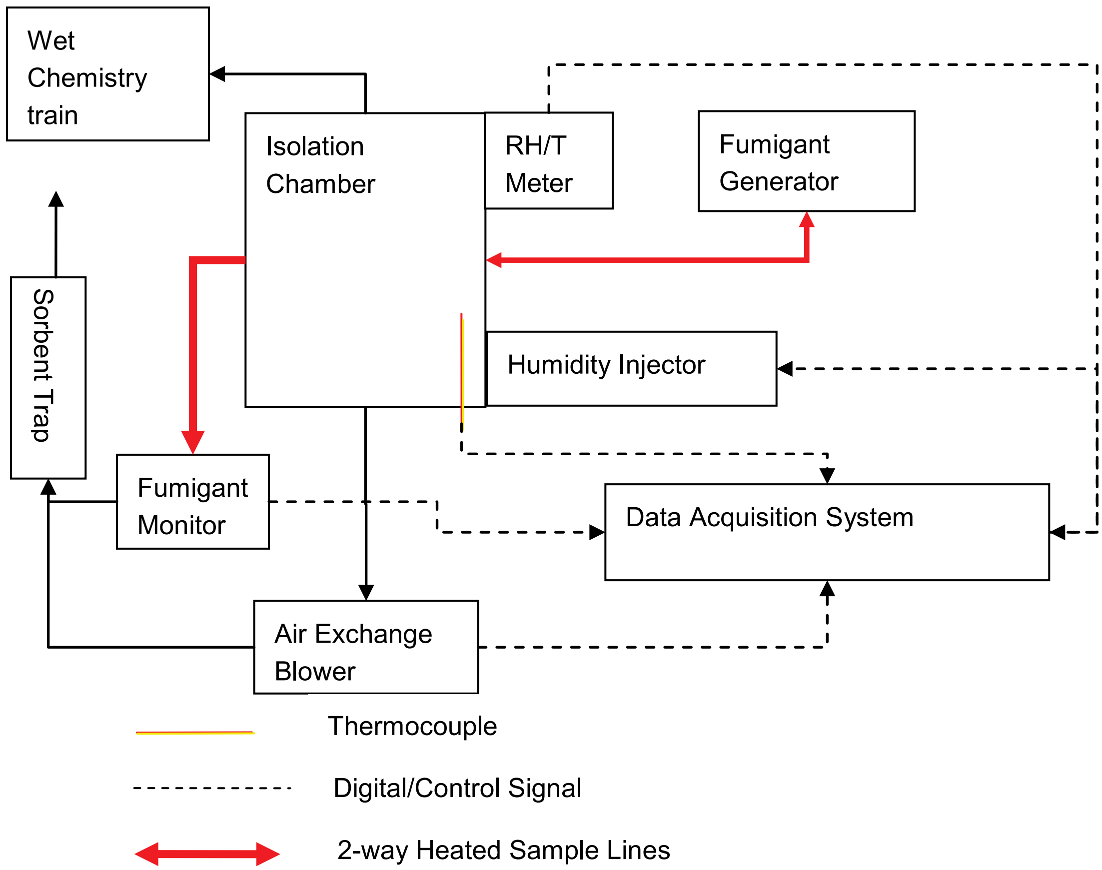



**Figure 2-2. Experimental Setup for $ClO_2$ Fumigations**

## 2.5 Sampling/Monitoring Points

Local variations in temperature were expected, especially due to the heat output of electronic devices while operating. This variation in temperature also affected RH. Because RH was a critical parameter in the effectiveness of the fumigant, the RH was checked by placing multiple NOMAD® T/RH sensors in and near fumigated equipment. The location of the sensor within the computers was shown in Figure 1-4. The monitor points within the computers allowed for determination of any temperature and RH gradients that might exist between the inside of the computers and the bulk chamber. The NOMAD® sensors logged RH and temperature in real time.

## 2.6 Frequency of Sampling/Monitoring Events

Table 2-3 provides information on the monitoring method, test locations, sampling flow rates, concentration ranges, and frequency/duration for the measurement techniques used.

**Table 2-3. Monitoring Methods**

| Monitoring Method | Test Location | Sampling Flow Rate | Range | Frequency and Duration |
|---|---|---|---|---|
| MiniDox $ClO_2$ Monitor | MEC test chamber | 5 L/min nominal | 50-10,000 ppmv $ClO_2$ | Real-time; 4 per minute |
| EMS Monitor | MEC test chamber | 5 L/min nominal | 50-10,000 ppmv $ClO_2$ | Real-time; 6 per minute |
| Modified Standard Method 4500-$ClO_2$ E | MEC test chamber | 0.5 L/min | 36 -10,000 ppmv $ClO_2$ | Every 60 minutes; 4 minutes each |
| Vaisala T/RH sensor | MEC test chamber; MiniDox Box | NA | 0-100 % RH<br>-40 to 60 °C | Real-time; 6 per minute |
| NOMAD® | MEC test chamber, Inside Category 4 chassis | NA | 5-95% RH<br>-20 to 70 °C | Real-time; 6 per minute |
| Key Chemical and Equipment Fumiscope 5.0 | MEC test chamber during fumigation | 1 L/min | 0-3000 $oz/ft^3$<br>0-22% at 37 °C | Real-time; 6 per minute |
| MeBr in air | MEC test chamber | 0.5 L/min | 1.5 -10,000 ppm MeBr | Every 2 hours, 4 minutes each |

NA – not applicable

## 2.7 Fumigation Event Sequence

For the fumigations, the decontamination cycle proceeds through three phases: Pre-conditioning phase, Exposure Phase, and Aeration Phase.

- *Pre-conditioning Phase.* During this phase, the MEC chamber was conditioned to maintain a constant, predetermined temperature and RH.

- *Exposure Phase.* The exposure phase in the test chamber is divided into two sequences:

    1) *Fumigant Charging Phase*. The fumigant charging phase corresponds to the time required to reach the target concentration of fumigant. The MiniDox or MeBr injection system directly feeds the test chamber to reach the desired fumigant concentration within the shortest time. The CT (ppmv-hours) of the charging phase was approximately one percent of the total CT accumulated in the overall exposure phase.

    2) *Exposure Phase*: The exposure phase corresponds to the set concentration time exposure (CT). Time zero was set as the time when the MEC test chamber reached the desired concentration (±10% standard deviation).

- *Aeration phase.* The aeration phase started when the exposure phase was completed (i.e., when the target CT had been achieved), proceeded overnight, and stopped when the concentration inside the chamber was below the OSHA Permissible Exposure Limit (PEL) of 20 ppm for MeBr and 0.1 ppm for $ClO_2$.

The phases of a fumigation event are graphically depicted in Figure 2-3. The times and demand rates for each phase shown are presented for illustration purposes only.

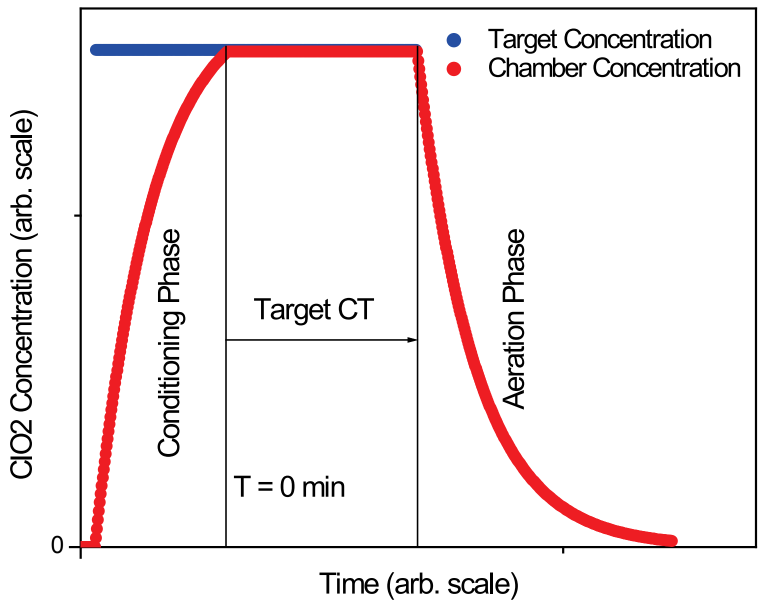



**Figure 2-3. Material and Equipment Exposure Time Sequence**

## 3.0 Testing and Measurement Protocols

Two separate isolation test chambers were used: the MeBr MEC chamber for the 98-2 MeBr exposure and the high temperature/RH control exposures, and the $ClO_2$ MEC chamber for the $ClO_2$ test conditions. No test chamber was used for the ambient control tests (no fumigant). Tested materials and equipment were photographed before and after exposure and any visual changes noted, including color, legibility, and contrast.

## 3.1 Methods

The MeBr concentration within the MEC chamber was measured using a Key Chemical and Equipment Fumiscope 5.0 thermal conductivity sensor as well as an MeBr in air wet chemistry method (see Table 2-1). The photometric monitors (MiniDox monitor and EMS) and the extractive modified Standard Method 4500-$ClO_2$ E were used for monitoring $ClO_2$ concentrations in the $ClO_2$ MEC chamber. Table 2-2 specifies where these methods were used within the experimental setups.

In addition to MeBr and $ClO_2$ measurements, other critical parameters measured were temperature and RH. Before each test, the Vaisala T/RH sensor used for control during testing was compared against a Vaisala T/RH sensor used as a reference (never exposed to fumigant). Secondary measurements in different locations within the chamber were measured by NOMAD® data loggers.

BIs were also included in the testing of Category 4 equipment. The use of BIs provided an indication of whether or not acceptable decontamination conditions were achieved due to variations in local conditions within the computers. The measurement equipment used in this project is described below.

### *3.1.1 Electrochemical Sensor for MeBr Concentration Measurement*

MeBr vapor concentration within the chamber was monitored using a Key Chemicals and Equipment Fumiscope 5.0. This instrument, while not specific for MeBr, was calibrated daily with a certified calibration gas of 7.97 percent (309 mg/L) from Scott Gas.

### *3.1.2 MeBr in Air Concentration Measurement*

The method used to verify the MeBr in air concentration was not a validated method, but was based on a paper published in *Analytical Chemistry* (Blinn, 1949). This paper describes the method as follows:

> A 2-liter sample of air containing methyl bromide was drawn by aspiration at controlled rates through two series-connected Fisher gas-absorbing scrubbers each containing 100 mL of 5% alcoholic potassium hydroxide. After the solutions from the absorbers were combined, they were allowed to stand for 2 hours at room temperature to complete hydrolysis. The resulting potassium bromide was completely dissolved by the addition of 300 ml. of water and 150 ml. of 10% acetic acid solution, then titrated with standard 0.1 N silver nitrate solution with sodium eosin as the indicator.

As performed for this study, modified Greenburg-Smith Method 5 impingers were used as the scrubbers, and a Method 5 meter box was used to quantify the amount of gas pulled through the sample train.

### *3.1.3 Photometric Monitors*

The ClorDiSys EMS monitor is identical to the photometric monitor built into the ClorDiSys generator (MiniDox), which was used to generate the $ClO_2$ in this study. Comparisons of the two instruments performed in a separate study indicated that the two instruments read within 3 percent of one another with an $R^2$ value of 0.99 (ClorDiSys, 2002)

The monitors are photometric systems operating in absorbance mode with a fixed path cell. An internal pump in the EMS and MiniDox provides flow of the test gas from the sample point to the analytical cell. The maxima and minima of an unspecified and proprietary $ClO_2$-specific absorbance band are monitored. These numbers are then used to calculate the absorbance at this analytical band. Before delivery, calibration was performed with National Institute for Standards and Technology (NIST)-traceable transmission band pass optical filters (385/0.9CU; optek-Danulat, Inc., Essen, Germany). The photometric systems include a photometer zero function to correct for detector aging and accumulated dirt on the lenses. Daily operation of the photometers includes moments when clean, $ClO_2$-free air is being cycled through the photometers. If the photometer reads above 0.1 milligrams per liter (mg/L) during these zero air purges, then the photometer is re-zeroed. Problems arising from condensation when sampling under high temperature or high RH conditions have been addressed by heating the sample lines and the photometer cell. Table 3-1 provides instrument specifications (ClorDiSys, 2002).

**Table 3-1. ClorDiSys EMS/MiniDoxs Photometric Monitor Characteristics**

| Parameter | Value | |
|---|---|---|
| | mg/L | ppm |
| Precision (SD) | ±0.1 | ±36 |
| Range | 0.1-30 | 50-10,900 |
| Accuracy (SD) | ±0.2 from 0.5-50 | ±72 from 181-18,100 |
| Resolution | 0.1 | 36 |

SD = Standard Deviation

### *3.1.4 Modified Standard Method 4500-$ClO_2$ E*

Standard Method 4500-$ClO_2$ E (Eaton, 2005) is an iodometric titration suitable for aqueous $ClO_2$ concentrations between 0.1 to 100 mg/L. This method does not address gas-phase sampling. The full method is quite complex in that a multi-titration scheme is used to differentiate several chlorine-containing analytes. A modification of this method to incorporate gas-phase sampling uses a buffered potassium iodide bubbler sample collection and restricts the official method to a single titration based upon Procedure Step 4.b (Eaton, 2005). This step analyzes the combined $Cl_2$, $ClO_2$, and chlorite as a single value and can be applied only where $Cl_2$ and chlorite are not present. Since the modified method (modified Standard Method 4500-$ClO_2$ E) described below is applied to gas-phase samples, the presumption of the absence of chlorite and chlorate is quite valid. Titration results higher than photometric methods indicate that $Cl_2$ may be present.

The modified Standard Method 4500-$ClO_2$ E is performed as described below.

1. Add 20 mL of phosphate buffer solution, pH 7.2 with KI (25 g KI/ 500 mL of buffer phosphate) (KIPB solution) to two impingers. A third impinger is left empty.
2. Route $ClO_2$ gas from the chamber into the KIPB solution in the impingers in series at a flow rate of 0.5 L/min for four minutes. Note if there is any liquid in the third impinger, or if the second impinger is yellow.
3. Combine the 20 mL of KIPB solution from each impinger into a 200 mL volumetric flask and rinse the impingers thoroughly with de-ionized water. Fill the flask to 150 -200 mL.
4. Add 1 mL of 6 N HCl to the solution.
5. Place solution in dark for five minutes.
6. Titrate the solution with 0.l N sodium thiosulfate (N = 0.1) to a clear endpoint.
7. Record the volume of sodium thiosulfate used in the titration. Conversion calculations from titrant volume to $ClO_2$ concentration are based on Standard Method 4500-$ClO_2$ B, where N = Normality:

   $ClO_2$ (mg/L) = Volume of sodium thiosulfate (mL) x N x 13.490 ÷ Volume of gas impinged (L)

This method removes many of the possible interferences listed in Standard Method 4500-$ClO_2$ E (Eaton, 2005). The initial presence of KI in excess prevents iodate formation, which can occur in the absence of KI and leads to a negative bias. The presence of the pH 7 buffer during impinging prevents oxidation of iodide by oxygen which occurs in strongly acidic solutions. Other interferences are unlikely to be a problem in this application, as the presence of manganese, copper, and nitrate is unlikely in a gaseous sample.

The second impinger filled with buffered KI solution is added in series to reduce the likelihood of breakthrough. The second impinger was not analyzed independently but was combined with the first impinger for analysis. System blanks were analyzed on a daily basis by titration of the KIPB sample. When titration yielded a volume of titrant greater than 0.5 percent of the expected value of the impinged sample, a new KIPB solution was mixed to provide a lower blank value.

### *3.1.5 Temperature and RH Measurement*

Temperature and RH measurements were performed with two types of sensors, the Vaisala HMP50 transmitter and the NOMAD® logger. The Vaisala transmitter was used for the real-time control of humidity and was placed at a point distant from the steam injector. The NOMAD® loggers were put in various places within the MEC chambers and within computers (Category 4) to provide a map of humidity and temperature conditions. The specifications of both instruments are shown in Table 3-2.

**Table 3-2. RH and Temperature Sensor Specifications**

| Instrument | Vaisala | NOMAD® |
|---|---|---|
| RH Range | 0 to 98% | 20 to 90% |
| RH Accuracy – 0 to 90% | ±3% | ±5% at 60% RH and 25 °C |
| RH Accuracy – 90 to 98% | ±5% | Unknown |
| RH Resolution | 0.001% [a] | Unknown |
| Temperature Range | -10 to 60 °C | 0 to 50 °C |
| Temperature Accuracy | ± 0.6 °C @ 20 °C | ± 1.8 °C |
| Temperature Resolution | 0.001 °C [a] | <1 °C |

[a] Vaisala resolution estimated from 22-bit resolution of personal data acquisition system (PDAQ).

Repeated exposure to fumigation conditions degrades both instruments. In the case of the Vaisala, the RH sensor becomes corroded and the higher resistance results in inaccurate RH readings. Corroded sensors were detected and replaced during the RH sensor comparisons before each test (see below). In the case of the NOMAD®, the fumigant probably corrodes the circuit board so that download of the logged data is sometimes impossible. To help prevent this reaction, the NOMAD® T/RH sensors were used only once.

A separate calibrated Vaisala HMP50, never exposed to fumigation, was used as an independent reference. Before each test, each Vaisala sensor was compared to the reference sensor at ambient (~40% RH) and at 75 % RH. If the Vaisala differed from the reference by more than 4 percent, then the removable RH sensors were replaced (independent of the rest of the transmitter).

### *3.1.6 Biological Indicators (BIs)*

Biological indicators are intended to mimic the response of difficult-to-kill spores such as *Bacillus anthracis*. Each fumigation method, therefore has a recommended or preferred BI. The following sections describe the BIs for the 98-2 MeBr and $ClO_2$ fumigations.

The BIs were *Bacillus atrophaeus* (*B. atrophaeus)* spores, nominally $1x10^6$ CFU, on stainless steel disks in Dupont™ Tyvek® envelopes. These BIs have been used extensively in NHSRC-related $ClO_2$ fumigation efficacy testing for *B. anthracis* spores deposited onto building materials. While it is easier for $ClO_2$ to inactivate the spores on the BIs than on most materials, BIs can provide a suitable indication of failure of the inactivation of *B. anthracis* on surfaces. Thus, failure of $ClO_2$ to inactivate the BIs suggests that conditions required to inactivate spores on environmental surfaces were not achieved (Rastogi, 2007). Further, the inactivation of *B. anthracis* spores on building materials and *B. atrophaeus* spores on the stainless steel BIs is highly sensitive to RH. For inactivation with $ClO_2$, spores typically require a minimum of 75 percent RH for effective kill conditions (Ryan, 2008). Inversely, *B. atrophaeus* is more resistant to MeBr fumigation than *B. anthracis* (Weinberg, 2003). Inactivation of these BIs by MeBr suggests conditions were far and above what would be necessary to inactivate anthrax spores; however, the exposure conditions (300 mg/l for 9 hours) were based on efficacy results obtained with *B. anthracis* spores (Ryan, 2010).

#### 3.1.6.1 BI Handling and Analysis Procedures

Within operational computers, the higher local temperatures expected would cause a localized area to have lower RH than the bulk of the chamber. BIs were, therefore, placed in the bulk chamber and within each computer in order to assess a difference in the failure to achieve the appropriate decontamination conditions. Five BIs were located in each computer (see Figure 1-4) and in the MEC test and control chambers. After removal from the chambers and computers following testing, the BIs were transferred to the on-site Biocontaminant Laboratory for analysis. The transfer was accompanied by a Chain of Custody (COC) form for each group of five BIs.

In the Biocontaminant Laboratory, the BIs were transferred aseptically from their envelopes to a sterile conical tube (Fisherbrand, Thermo Fisher Scientific, Inc., Waltham, MA) containing at least 25 mL of nutrient broth (NB) (BBL Dehydrated Nutrient Broth, BD Diagnostics Systems, East Rutherford, NJ). Each BI was placed in an individual sample tube; both positive and negative controls were analyzed in conjunction with each test group for quality assurance. The tubes were incubated for seven to nine days (at 32 °C for *Bacillus atrophaeus)*, then recorded as either “growth” or “no growth” based upon visual inspection. Tubes with growth turned the NB very cloudy and the consistency of the NB was changed. All tubes were plated on tryptic soy agar (TSA) (Remel Inc., Lenexa, KS) to confirm that any growth in the tube was indeed *B. atrophaeus* and not another organism that had contaminated the samples. Using aseptic techniques, the TSA plates were incubated overnight at 32 °C, depending on organism. A visual inspection of the plates was performed the following day to determine if the *B. atrophaeus* had grown; *B. atrophaeus* produces a reddish tint on the agar. Both positive and negative controls were used to confirm that *B. atrophaeus* growth on TSA was consistent.

### *3.1.7 Visual Inspection*

Visual inspection focused mainly on the expected effects of fumigation: any changes in color and any occurrence of corrosion. Color change could also affect legibility of printed paper materials. Digital photographs of each coupon or material were taken prior to fumigation. After fumigation, digital photographs were taken to document the condition of the materials/equipment. Category 4 equipment (computers) was photographed monthly to document changes over time. Smoke alarms were partially dismantled in order to take digital photographs of the equipment inside the casing. The cover of computer CPU casing was also removed so photographs of the internal parts could be taken. This dismantling was done at an approved electrostatic discharge (ESD) station. Changes in color or observed corrosion or corrosion products (i.e., powder inside a casing) were noted. Any changes in legibility or contrast of materials after fumigation were recorded as well.

### *3.1.8 Functionality Testing*

All electronic equipment in Categories 3 and 4 underwent functionality testing prior to and after fumigation, as did selected materials from Category 2, as appropriate. These tests were detailed in Tables 1-1 and 1-3 for the Category 2 and 3 materials, respectively. For the Category 4 equipment, the protocols for the computer setup and analysis were developed by Alcatel-Lucent for the specific equipment being tested (US EPA, 2010).

All Category 2 and 3 materials were analyzed before and immediately after fumigation, at six months, and at one year following fumigation. During the one year period, all equipment was stored in an indoor office/laboratory environment with logged temperature and RH.

Category 4 equipment was tested in triplicate. After the post-fumigation functionality test, one of the three computers fumigated with MeBr and one of the three computers fumigated with $ClO_2$ was sent to Alcatel-Lucent for in-depth failure analysis. The remaining computers remained at EPA for continued functionality testing for one year. During the one year period, the computers and monitors were stored in an indoor office/laboratory environment with logged temperature and RH. The post-fumigation analysis continued monthly for these pieces of Category 4 equipment, when possible.

The computer systems were maintained in the operational (ON) state and, if operational, were put through a BIT sequence five days a week, for eight hours a day, to simulate normal working conditions. Functionality testing was done by running a predefined routine specific to each of the items. These routines were documented for each item and maintained in the item's log book or on test report sheets. For the computer systems, PC-Doctor® Service Center™ 7.5 was run to complete a hardware and software diagnostic investigation. The results of the diagnostic protocol were maintained in the appropriate log book.

### *3.1.9 Detailed Functionality Analysis (Subset of Category 4)*

The assessment of the impact of fumigation on Category 4 equipment was performed in conjunction with Alcatel-Lucent through LGS Innovations, Inc. Four computers − one computer and monitor from each of the test conditions (control, and 98-2 MeBr and $ClO_2$ fumigations) − were sent to Alcatel-Lucent for detailed functionality testing. The worst-performing computer from each of the triplicate test sets was chosen for this in-depth testing. These computers and monitors, after undergoing the initial pre-/post-fumigation visual inspection and functionality screening, were preserved and shipped as detailed in Section 3.6. The order of increasing level of analysis was (1) aesthetic and functionality evaluation (energize, run diagnostic protocol), (2) visual inspection and more advanced diagnostics to identify affected components, (3) modular investigation, and (4) cross-section and failure mode analysis. The metal coupons and IPC boards were also analyzed by Alcatel-Lucent for weight gain, corrosion products, visual impacts and changes in conductivity (i.e., IPC boards).

## 3.2 Cross-Contamination

The two isolation chambers, MeBr MEC and $ClO_2$ MEC, were set up in two different laboratories at the EPA. There was no contact between the two chambers to eliminate any potential exposure of either MEC chamber to the other fumigant. Protocols provided by Alcatel-Lucent prohibited cross-contamination of corrosion particles by limiting the use of each test device to a single computer. BIs and wet chemistry samples are not expected to be affected by cross-contamination.

## 3.3 Representative Sample

Category 4 materials are as identical as possible to materials tested under a previous study using $ClO_2$ as the fumigant (US EPA, 2010). Materials and equipment were chosen as representative of, or as surrogates for, typical indoor construction materials or modern electronic devices. Each material or piece of equipment was tested in triplicate for representativeness. After initial inspection to confirm the representativeness of the Category 4 equipment post-treatment under the test conditions, the set that fared the worst from each test condition was sent for the detailed analysis performed by Alcatel-Lucent. The initial inspection was an assessment for visual changes and PC diagnostic using PC-Doctor® Service Center™ 7.5 (PC Doctor, 2011).

## 3.4 Sample Preservation Methods

Test samples (i.e., materials and equipment) were stored under temperature- and RH-controlled indoor ambient laboratory conditions until testing was performed. All samples, both test and control, were stored under the same conditions prior to and after the fumigation event.

The Category 4 items, specifically the computers and monitors, were treated differently from the items included in the other categories. The computers and monitors were removed from their original packaging, labeled with a designated sample number (see Section 3.5), and set up according to the protocol provided by Alcatel-Lucent. After the pre-test analysis, the computers were dismantled, placed into individual anti-static and anti-corrosion bags (Corrosion Intercept Technology; http://www.staticintercept.com/index.htm), sealed and stored until reassembly and preparation for the fumigation event. The computers were also dismantled and bagged during transport to and from the MEC chambers.

After exposure to the test conditions, the equipment underwent visual inspection and initial diagnostics with PC-Doctor® Service Center™ 7.5. The Category 4 items not shipped to Alcatel-Lucent for detailed analysis and all Category 2 and 3 items were transferred to an appropriate area (ESD work station, E-288, see below) 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 test conditions under which they were treated. The temperature and RH in the area were monitored and logged.

Before fumigation of the computers, the systems were opened to insert a T/RH monitor (NOMAD®) and BIs in each desktop case. The Category 4 metal coupons and IPC board were also placed in each computer case. The location and method of fastening the equipment inside the case were specified by Alcatel-Lucent. The insides of the desktop computers were digitally photographed. To maintain the integrity of the computer by avoiding static electricity, an ESD Station was established for work on the computers. An ESD station was set up in E-288 (EPA Facility, Research Triangle Park, NC) and a second sub-station (smaller) next to the MEC test chambers in H-224 and H-130 (EPA Facility, Research Triangle Park, NC). Training on this work station in E-288 was provided by Alcatel-Lucent on July 18, 2007, prior to the start of the original $ClO_2$ fumigation testing. In general, the station consisted of an electrostatic discharge work mat, an electrostatic monitor, and electrostatic discharge wrist bands. All computers were inspected and operated (i.e., diagnostic testing, long-term operation of computers for analysis of residual effects) on the ESD workstations. During operation of the computers, all computers were energized using surge protectors (BELKIN seven-outlet home/office surge protector with six-foot cord, Part # BE107200-06; Belkin International, Inc.; Compton, CA).

All BIs were maintained in their sterile Dupont™ Tyvek® envelopes, refrigerated, until ready for use. The BIs were allowed to come to the test temperature before being placed in the MEC test chamber. The BIs were maintained in their protective Dupont™ Tyvek® envelopes until transferred to the on-site Biocontaminant Laboratory for analysis.

## 3.5 Material/Equipment Identification

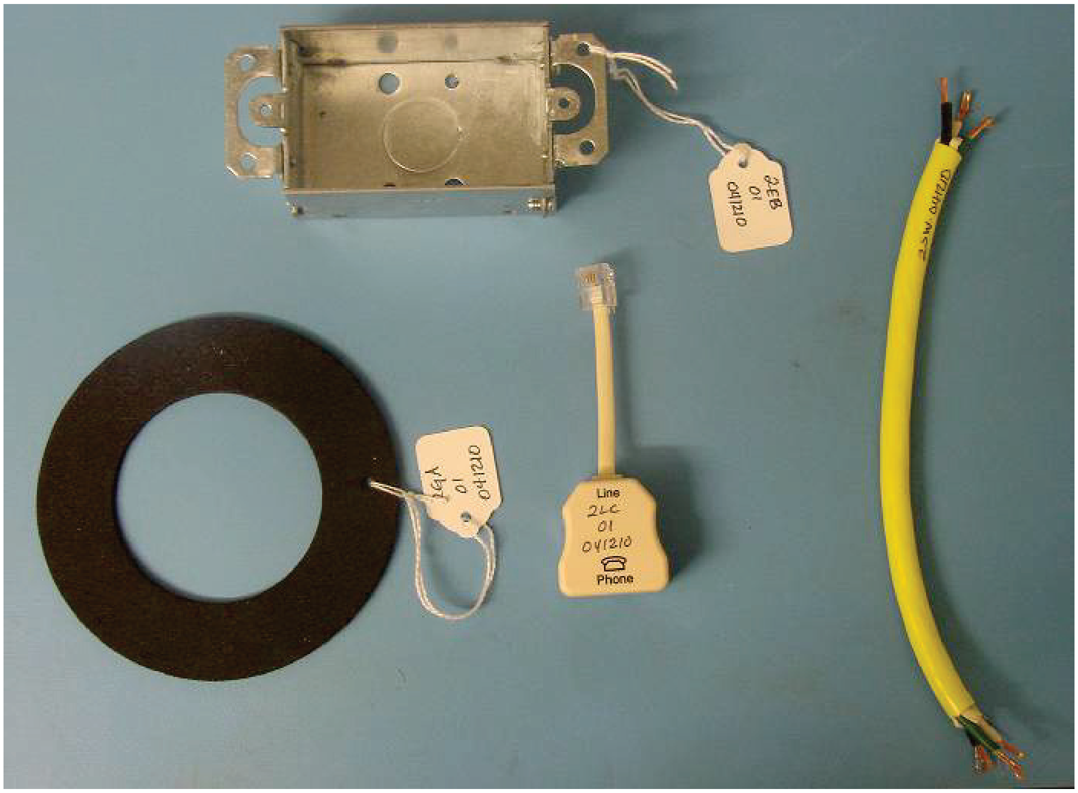
Each material and piece of equipment was given an identifying code number unique to that test sample material/equipment. The codes and code sequence were explained to the laboratory personnel to prevent sample mislabeling. Proper application of the code simplified sample tracking throughout the collection, handling, analysis, and reporting processes. All COC documentation for the test sample material/ equipment was labeled with the identifying code number. Table 3-3 shows the sample coding used in this study, with Figures 3-1 through 3-8 showing pictures of all of the materials that were tested. The Category 4 equipment was labeled as Decon###, where ### refers to a three-digit sequential number. A total of 21 computers and liquid crystal display (LCD) monitors were purchased for this project. The numbers, therefore, ranged from 202 to 222. However, 218 would not power on and was removed from the study; number 223 was added.

**Table 3-3. Sample Coding**

| AAA-NN-TXX-RXX | | | |
|---|---|---|---|
| | **Sample Code** | **Figure** | **Sample Type** |
| AAA | 2AL | 3-1a | 3003 Aluminum coupons |
| | 2CU | 3-1b | 101 Copper coupons |
| | 2CS | 3-1c | Low carbon steel coupons |
| | 2PC | 3-1d | Painted low carbon steel coupons |
| | 2S1 | 3-1e | 410 Stainless steel coupons |
| | 2S3 | 3-1f | 430 Stainless steel coupons |
| | 2S4 | 3-1g | 304 Stainless steel coupons |
| | 2S6 | 3-1h | 316 Stainless steel coupons |
| | 2S9 | 3-1i | 309 Stainless steel coupons |
| | 2HW/2SW | 3-2a | Housing wires (casing) and stranded wires |
| | 2LC | 3-2a | DSL conditioner |
| | 2EB | 3-2a | Steel outlet/Switch box |
| | 2SE | 3-2a | Sealants (caulk) |
| | 2GA | 3-2a | Gaskets |
| | 2DS | 3-2b | Drywall screw |
| | 2DN | 3-2b | Drywall nail |
| | 2CUS | 3-3a,d | Copper services * |
| | 2ALS | 3-3b,c | Aluminum services * |
| | 2CB | 3-3e | Circuit breaker |
| | 2SD | 3-4a,b | Smoke detector |
| | 2SW | 3-4c,d | Switches (lamps) |
| | 2LP | 3-5a | Laser printed colored papers (stack of 15 pages) |
| | 2IP | 3-5b | Ink jet printed colored papers (stack of 15 pages) |
| | 2PH | 3-5c | Photographs |
| | 3PD | 3-6a,b | PDAs |
| | 3CE | 3-6a,b | Cell phones |
| | 3FA | 3-6c | Fax machines (with telephones) |
| | 3DV | 3-7a | DVDs |
| | 3CD | 3-7b | CDs |
| | XXX | 3-9 | Biological Indicator (XXX=computer ID (if inside computer) or, XXX="MEC" for inside bulk chamber) |
| NN | 02, | | Replicate number (01, 02, 03, 04,05) |
| TXX | T01 or T02 | | Test Matrix (Category 2 and 3 = T01; Category 4 = T02) |
| RXX | R01 – R02 | | Run Number (R01-R02) for Category 2 and 3 materials |

* See Appendix C for parts list of Cu and Al service panels.


**Figure 3-1. Metal Coupons Used in the Compatibility Testing (photos prior to fumigation): (a) 3003 Aluminum; (b) 101 Copper; (c) Low Carbon Steel; (d) Painted Low Carbon Steel; (e) 410 Stainless Steel; (f) 430 Stainless Steel; (g) 304 Stainless Steel; (h) 316 Stainless Steel; and (i) 309 Stainless Steel.**




(a)

(b)

**Figure 3-2.** **(a) Stranded Wire, DSL Conditioner, Steel Outlet/Switch Box with Sealant (Caulk), Gasket and (b) Drywall Screws and Nails used in the Compatibility Testing**

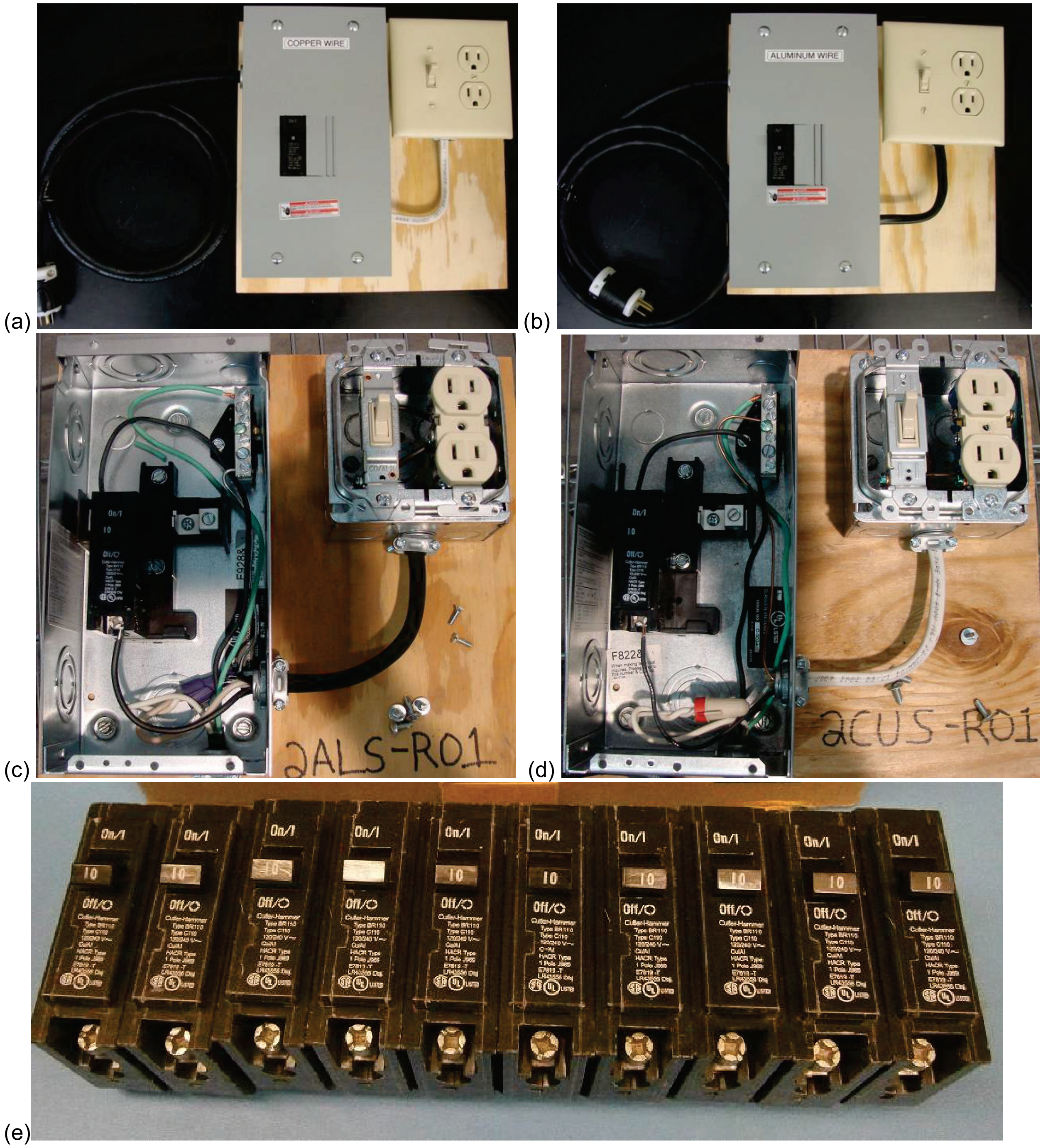
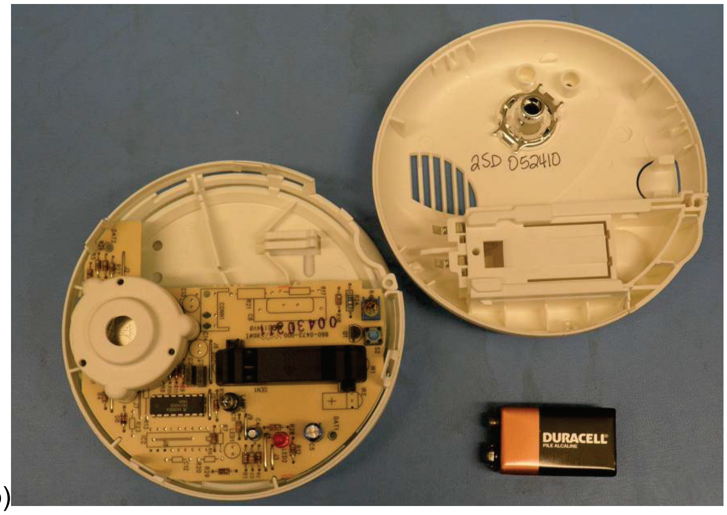



**Figure 3-3. (a, c) Copper Services, (b, d) Aluminum Services, and (e) Circuit Breakers used in the Compatibility Testing**

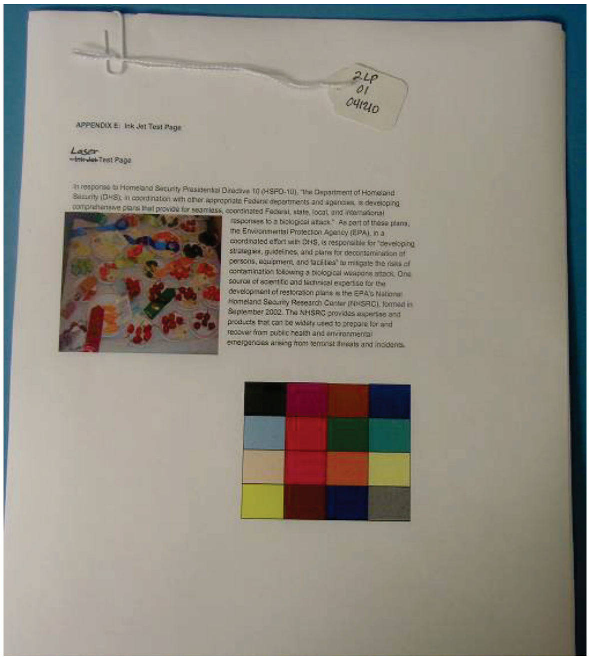
(a) 

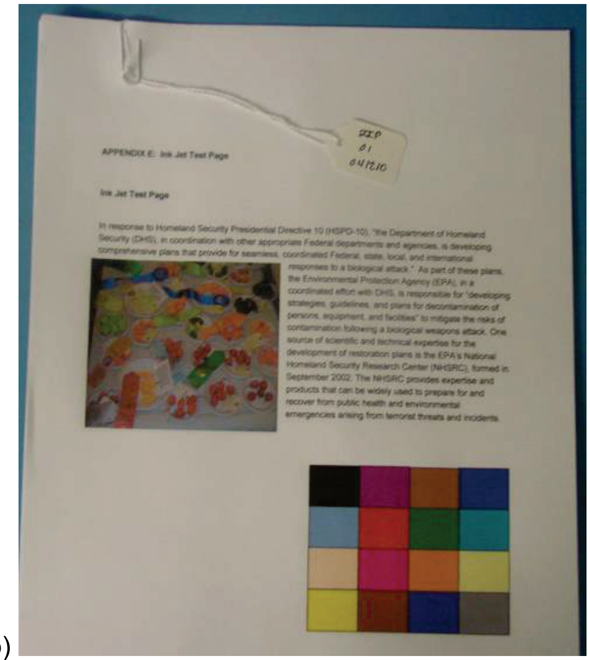
(b) 


(c) 


(d) 


**Figure 3-4. (a,b) Smoke Detector and (c,d) Lamp Switch used in the Compatibility Testing**

(a)



(b)



(c)



**Figure 3-5. (a) Laser and (b) Inkjet Printed Color Papers, and (c) Photograph used in the Compatibility Testing**

(a)
(b)
(c)

**Figure 3-6. (a,b) PDA and Cell Phone and (c) Fax Machine used in the Compatibility Testing**


**Figure 3-7.** **(a) Front of DVD (b) Back of DVD (c) Front of CD, and (d) Back of CD used in the Compatibility Testing**

**Figure 3-8. Desktop Computer and Monitor, Keyboard, Power Cord, and Mouse used in the Compatibility Testing**

## 3.6 Sample Shipping Procedures

The computer, monitor, and ancillary equipment shipped to Alcatel-Lucent were packaged inside Corrosion Intercept Technology bags (http://www.staticintercept.com/index.htm). The bagged equipment was shipped to Alcatel-Lucent using the original packaging (i.e., boxes and foam) after post-fumigation tests. The shipping and handling protocols were provided by Alcatel-Lucent.

## 3.7 Chain of Custody (COC)

Each material/piece of equipment sent to Alcatel-Lucent had a COC record describing the material/equipment and analysis to be performed. Similarly, all the BI samples sent for analysis by the Biocontaminant Laboratory had a COC.

## 3.8 Test Conditions

Two test matrices were used for the testing. Test Matrix T01 (Table 3-4) was used for Category 2 and 3 materials (combined), and Test Matrix T02 (Table 3-5) was used for Category 4 materials. The test matrices were built around the main objective of this project: to assess the damages, if any, to materials and electronic equipment functionality after remediation of a contaminated space using the 98-2 MeBr or

$ClO_2$ technology under various fumigation environment scenarios, and equipment state of operation. The list of parameters that were investigated is:

1. Effect of fumigation with 300 mg/L MeBr at 75% RH and 37 °C for 9 hours.
2. Effect of fumigation conditions without MeBr at 75% RH and 37 °C for 9 hours.
3. Effect of fumigation at high $ClO_2$ concentration (3000 ppmv) at standard conditions (75% RH, 75 °F) with a total CT of 9000 ppmv-hr. (***Category 4 only***).
4. Power state of Category 4 materials.

**Table 3-4. Test Conditions for Category 2 and 3 Materials**

| Run Name | Treatment Conditions[1] | Purpose of Test |
|---|---|---|
| **R01** | 300 mg/L MeBr, 75% RH, 37 °C for 9 hours | Determine the effect of MeBr on materials |
| **R02** | 0 mg/L MeBr, 75% RH, 37 °C for 9 hours | Determine the effect of RH on materials |

[1] Dwell phase parameters are listed for each run's Test Condition.

**Table 3-5. Test Conditions for Category 4 Equipment**

| Test Condition | Equipment Power State During Fumigation | Treatment Conditions[1] | Description |
|---|---|---|---|
| **Group 1** | | | |
| 1 | ON and Active | Ambient | Control test set |
| 2 | ON and Active | 75% RH, 37 °C for 9 hours | Control test set |
| 3 | OFF | 75% RH, 37 °C for 9 hours | Control test set |
| **Group 2** | | | |
| 4 | ON and Idle | Standard fumigation conditions (3000 ppmv $ClO_2$, 75 % RH, 75 °F, 3 hrs) | Tie in to past matrix with $ClO_2$ |
| **Group 3** | | | |
| 5 | ON and Active | 300 mg/L MeBr, 75% RH, 37 °C for 9 hours | Effect of power state |
| 6 | OFF | 300 mg/L MeBr, 75% RH, 37 °C for 9 hours | Effect of power state |

[1] 37 °C = 99 °F. 75 °F = 24 °C.

## 4.0 Visual Inspection

Photographs were taken as part of the scheduled functionality testing. The purpose of this physical documentation was to make comparisons over time, looking for changes such as discoloration of wire insulation, corrosion, residue, and decrease in the quality or readability of documents and photographs. Where changes were noted, all visual files and written documentation were reviewed to provide a detailed understanding of the effects of fumigation over time on that material/component. Functional effects are presented and discussed in Section 5.

### 4.1 Category 2 Materials

Category 2 materials had varying physical responses throughout the 12 month observation period following the 98-2 MeBr fumigation (Run R01 in Table 3-4) but seemed to maintain their pre-exposure functional characteristics with two exceptions as noted below. The low carbon steel and the steel outlet/switch box were affected by the fumigation; these effects are discussed below. The remaining Category 2 materials showed no signs of physical deterioration during the 12 month post-test observation period.

Figure 4-1(a) shows that, with the exception of low carbon steel, each set of metals remained tarnish free, with no signs of rust or corrosion. Figures 4-1(b) and (c), respectively, show the drastic transformation of the surface of the low carbon steel coupons from smooth and metallic to severely rusted following exposure. The effects of the 98-2 MeBr fumigation on low carbon steel were comparable to those observed with $ClO_2$ fumigations at high RH.

Figures 4-2(a) and (b), respectively, show the clean edges of the steel outlet/switch box before fumigation compared to the rusted edges observed after exposure. The exposed smoke detector remained fully operational throughout the year after exposure; the battery terminals, resistors, and other components showed no signs of physical damage as shown in Figure 4-1 (c). Figure 4-1 (d) shows that the exposed stranded wires remained tarnish free 12 months after exposure.

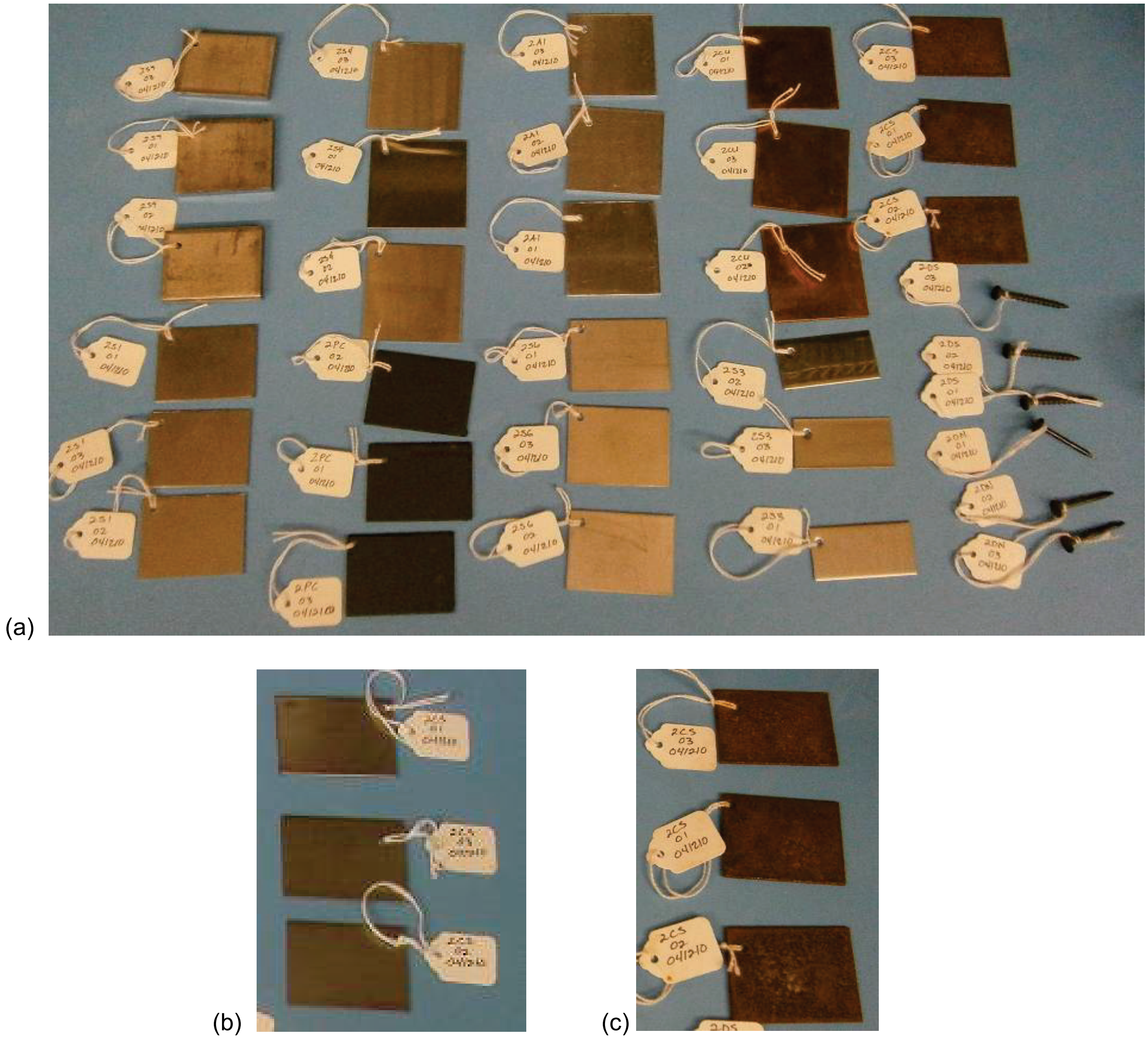



**Figure 4-1. (a) Category 2 Metals 12 Months after 98-2 MeBr Fumigation; (b) Low Carbon Steel before and (c) after Fumigation Showing Significant Corrosion.**

(a) (b) (c) (d)

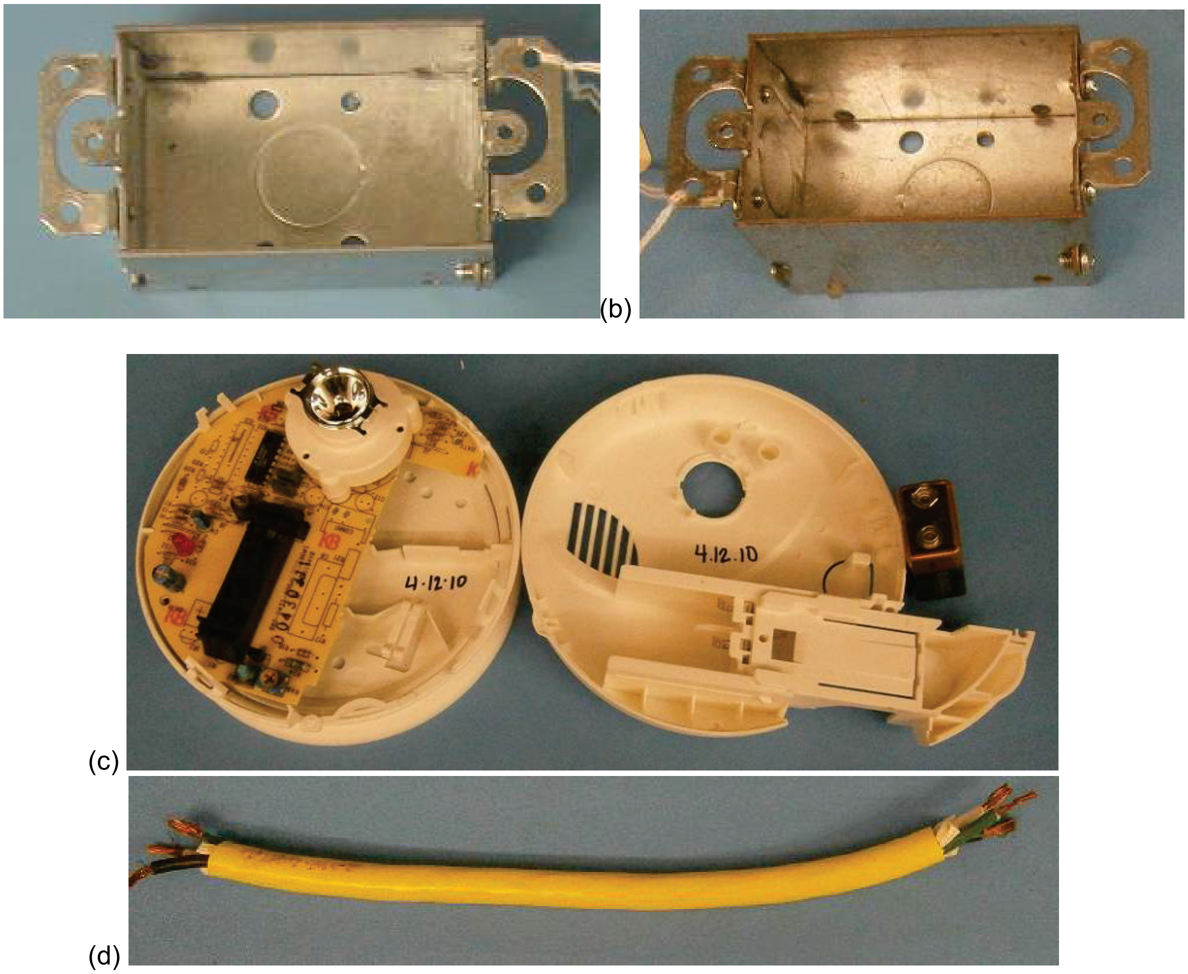



**Figure 4-2. (a) Steel Outlet/Switch Box before and (b) after Fumigation; and (c) Smoke Detector and (d) Exposed Stranded Wire after Fumigation.**

InkJet printed paper, laser printed paper, and color printed photographs remained visibly unchanged throughout the 12 month post-fumigation observation period. Color pigments do not appear to be adversely affected by exposure to MeBr with 2 percent chloropicrin, in marked contrast to the color pigment fading observed with $ClO_2$ fumigations.

The only Category 2 materials showing signs of physical effects following 98-2 MeBr exposure were low carbon steel and the steel outlet/switch box. There were no physical or functional effects to any of the other Category 2 materials tested.

## 4.2 Category 3 Materials

Category 3 Materials included small personal electronic equipment: fax machines, cell phones, PDAs, CDs, and DVDs. The physical appearance of these materials was observed and photo-documented before fumigation, then over a one-year observation period following the 98-2 MeBr fumigation.

The CDs and DVDs were all unaffected by the 98-2 MeBr fumigation. The disks maintained their pre-exposure appearance and showed no signs of damage during the 12 month observation period. Figure 4-3 shows the internal features of a representative fax machine. There were no signs of damage to any of the mechanical parts, and all exposed metal maintained pretest appearances and showed no signs of deterioration.

**Figure 4-3. Internal View of Fax Machine 12 Months after 98-2 MeBr Exposure**

Figure 4-4(a) shows the cell phone one year following the 98-2 MeBr fumigation. During the 12-month observation period, no visual changes were noted. The cell phone screen indicated no signs of dimming of the back light or detectable color alterations. The cell phone ring and voice transmitting and receiving ability maintained their initial quality throughout the one-year observation period. Figure 4-4(b) shows the PDA one year following the 98-2 MeBr fumigation. The screen maintained its pre-exposure physical appearance and the outer casing appeared unchanged. An internal physical evaluation of the PDA was not possible without damaging the device.

There was no visual impact seen in any of the Category 3 items following the 98-2 MeBr fumigation.


(a) (b)

**Figure 4-4. (a) Cell Phone and (b) PDA Powered On 12 Months after Exposure**

## 4.3 Category 4 Equipment

Category 4 equipment included desktop computers and monitors. Unlike the Category 2 and 3 materials that were fumigated only with 98-2 MeBr, additional sets of the Category 4 materials were fumigated with $ClO_2$. Table 4-1 summarizes the visual changes noted for both fumigants.

**Table 4-1. Documented Visual Changes in Category 4 Equipment**

| Equipment | Visual Changes Due to $ClO_2$ Exposure | Visual Changes Due to 98-2 MeBr Exposure |
|---|---|---|
| Desktop computer | Corrosion (inside and outside) and visible powder | Corrosion on metal edges, no visible powder |
| Computer monitor | None | None |
| Computer keyboard | None | None |
| Computer power cord | None | None |
| Computer mouse | None | None |

$ClO_2$ had some visually observed effects on the desktop computers, but no changes were noted for other equipment. These changes resulting from $ClO_2$ exposure agree with previous research conducted on this fumigant (US, EPA, 2010). Desktop computers exposed to 98-2 MeBr were slightly corroded on metal edges on the interior and exterior of the computer chassis. A summary of the noted visual changes as related to run conditions for both fumigants as well as control conditions is shown in Table 4-2. Any changes observed were present immediately after fumigation and did not appear to strengthen over the 12-month period of equipment observation and testing. The MeBr Fumigation C was aborted due to an electrical ground fault shutting down mixing fans inside the MEC chamber, it is believed the MeBr concentration exceeded 15% in the chamber.

**Table 4-2. Summary of Visual Changes Noted in Category 4 Equipment**

| | Ambient Controls | Conditioned Controls | Conditioned Controls | Conditioned Controls |
|---|---|---|---|---|
| **Temp, °C** | Lab conditions | 37.2 | 36.9 | 36.3 |
| **RH, %** | Lab conditions | 71.2 | 78.6 | 74.7 |
| **ppmv** | N/A | N/A | N/A | N/A |
| **ppmv- hours** | N/A | N/A | N/A | N/A |
| **Computer IDs** | 217,219,220 | 202,203 | 206,208 | 204,205 |
| **Computer Status** | On and Active | 202 – On and Active<br>203 – Off and open | 206 – Off and open<br>208 – On and Active | 204 – Off and closed<br>205- Off and open |
| **Visual Impacts** | No visual changes | No visual changes | No visual changes | No visual changes |

| **Fumigant** | **98-2 MeBr** | **98-2 MeBr** | **98-2 MeBr** | **$ClO_2$** |
|---|---|---|---|---|
| **Temp, °C** | 37.2 | 37.9 | 37.3 | 25.8 |
| **RH, %** | 76.1 | 75.4 | 67.3 | 75.2 |
| **ppmv** | ~74,000 (300 mg/L) | ~74,000 (300 mg/L) | ~74,000 [a]measured (300 mg/L) | ~3,300 |
| **Computer IDs** | 207,209 | 210,211 | 212,213 | 221-223 |
| **Computer Status** | 207 – On and Active<br>209 – Off and open | 210 – Off and open<br>211- On and Active | 212- Off and open<br>213- On and Active | On and idle |
| **Visual Impacts** | Minimal corrosion on back panel, some metal edges | Minimal corrosion on back panel, some metal edges | Heavy interior and exterior corrosion<br>Internal powder<br>Yellow liquid residue on motherboard and chassis | Light interior and exterior corrosion<br>Light internal powder |

N/A Not available.

[a] The third MeBr test was exposed to higher concentrations of 98-2 MeBr due to poor mixing caused by a Gound Fault Circuit Interrupter (GFCI) fault during fumigation. The exact concentration is unknown but is expected to be greater than 150,000 ppmv.

Corrosion of external metal parts was evident on the backs of some computers exposed to 98-2 MeBr and $ClO_2$. Figure 4-5(a) shows the absence of corrosion on the control PCs. Figure 4-5(b) shows corrosion on the same grid which occurred at 3000 ppmv $ClO_2$, and Figure 4-5(c) shows corrosion on the central grid which occurred at 74,000 ppmv 98-2 MeBr. Figure 4-5 (d) shows significant corrosion and a white powder on the central grid which occurred during 98-2 MeBr fumigation at an unknown, but suspected to be, much higher MeBr concentration. Rust-like powder was frequently seen on the lower peripheral component interconnect (PCI) slot covers on the lower rear of the $ClO_2$ and 98-2 MeBr exposed computers. This is evident in Figure 4-6.

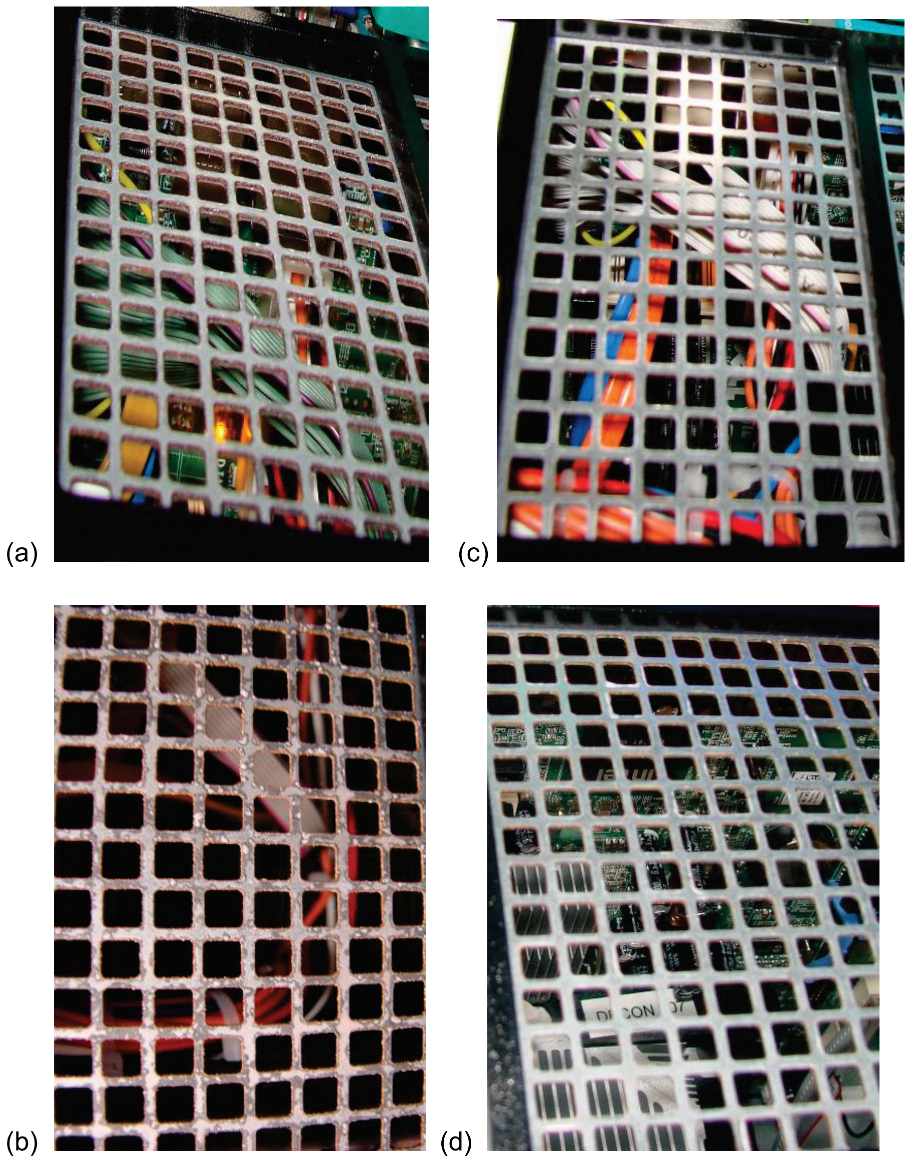



**Figure 4-5. Comparison of the metal grids on the back of tested computers: (a) control PC at test conditions, no exposure; (b) exposed to 3000 ppm $ClO_2$; (c) exposed to 74,000 ppm 98-2 MeBr; and (d) was likely exposed to a much higher concentration of 98-2 MeBr.**

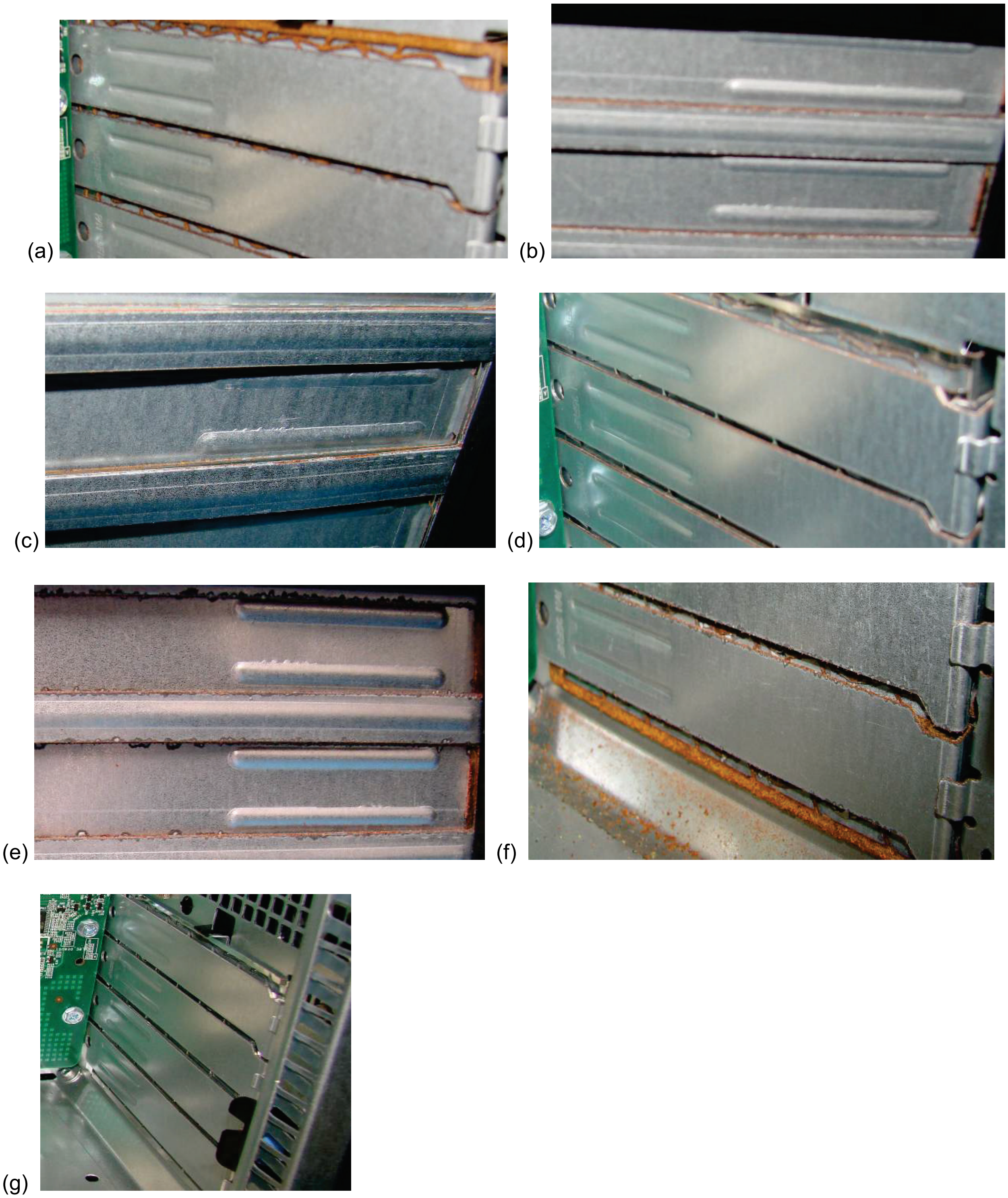



**Figure 4-6.** **Internal (a) and external (b) corrosion of PCI slots in $ClO_2$ exposed computers. Internal (c) and external (d) corrosion of PCI slots in 98-2 MeBr exposed computers. Internal (e) and external (f) corrosion of PCI slots in 98-2 MeBr computers likely exposed to much high concentrations. (g) Internal view of control PCI slots.**

Similar corrosion was observed on these computers internally and was found mostly on any cut metal edges. Figure 4-7 shows the difference between an unexposed (a) CD-ROM drive casing, corrosion on a $ClO_2$ casing at high RH (b), corrosion on a $ClO_2$ casing at lower RH (c), and corrosion on a 98-2 MeBr fumigated PC at suspected high concentration (d). For all visual corrosion effects, there is a notable difference between $ClO_2$ tests conducted at different RH setpoints. This comparison can clearly be seen between Figures 4-7 (b) and (c).


**Figure 4-7. An unexposed (a) CD-ROM drive casing, corrosion on a $ClO_2$ casing at high RH (b), corrosion on a $ClO_2$ casing at lower RH (c), and corrosion on the 98-2 MeBr fumigated PC at suspected high concentration (d).**

In the previous study with $ClO_2$ (US EPA, 2010) the CPU (aluminum alloy with a nickel-phosphorus coating) was thought to be the primary, if not sole, source of the corrosion products. The GPU heat sink remained unaffected (single aluminum alloy). In the current study, no corrosion was observed on either the CPU or the GPU heat sinks of the 98-2 MeBr or $ClO_2$ fumigated computers. Alactel-Lucent (US EPA, 2010) determined that, in this new generation of computers (higher heat producing CPUs), the heat sinks were made from a single aluminum alloy. Alactel-Lucent found no evidence of chlorine or bromine on the surface of the fins on either heat sink, which means that native aluminum oxide on the CPU surface is sufficiently robust to resist attack by both MeBr and chloropicrin . As no visible corrosion could be seen on the computers exposed to $ClO_2$, it appears that these surfaces are now sufficiently robust to also resist attack by $ClO_2$ under standard conditions.

In summary, visible changes occurred to computers that were exposed to both $ClO_2$ and 98-2 MeBr, including external and internal corrosion of metal parts for both test sets. The formation of powders inside the computer casing was observed primarily after $ClO_2$ fumigations but was also observed as an effect of the suspected high concentration exposure to 98-2 MeBr. Parts affected included external and internal stamped metal grids, external metal slot covers, and any internal cut metal edges. Higher RH conditions increased the severity of all $ClO_2$ effects.

## 5.0 Data Analysis/Functionality Tests

The results of functionality tests were reviewed for each material pre-exposure, immediately post-exposure, and then up to monthly thereafter for a period of one year looking for instances of intermittent or repeated failures. These tests ranged from simple stress tests performed on gaskets to the highly detailed PC-Doctor® Service Center™ 7.5 testing conducted on the Category 4 computers. Where changes were noted, all visual files and written documentation were reviewed to provide a detailed understanding of the effects of fumigation and the different run conditions on that material/component. For the Category 4 computers, failures are identified by the component parts themselves (such as CDs and DVDs) as well as the sub-component parts that are most likely to lead to failure of that component.

## 5.1 Category 2 Materials

Functionality tests were performed on Category 2 materials before and after 98-2 MeBr exposure, then periodically after exposure, and again at year's end. The breakers used in the Cu and Al services were the same 10 amp breakers that were tested alone. Because of the large number of breakers requiring testing, the breakers (10 per run condition) and services were tested at 20 amps (or 200 percent). The minimum to maximum time range to failure under these conditions is from 10 to 100 seconds. None of the beakers or services from any test fell outside the acceptable testing range. The resistance measurements over one year have an average standard deviation of 36 percent and range between 0 and 4.1 ohms. A resistance reading could not be obtained from the corroded low carbon steel coupons; contact could not be made between the coupon surface and the ohm meter terminals. There were no other functionality changes reported for any Category 2 materials exposed to 98-2 MeBr.

## 5.2 Category 3 Materials

Functionality tests were performed on Category 3 materials before and after 98-2 MeBr exposure, six months after, and then again at the one-year period. Category 3 materials consisted of PDAs, cell phones, fax machines, CDs, and DVDs. The results from these functionality tests show that no changes occurred during the one year observation period.

The PDA remained in the original working condition, able to synchronize with software installed on a desktop computer. The touch screen capability of the PDA was not compromised.

There was no evidence that 98-2 MeBr had any harmful effects on the operation of the cell phone. The cell phone was able to send and receive calls, provide clear audio on both ends of the call, and maintain the same clear ringtone for incoming calls as it had done prior to exposure. The keypad for the phone remained fully operational. The battery maintained its capability to charge fully and showed no physical signs of damage.

The fax machine maintained the same level of operation throughout the year. The quality of the sent and received facsimiles was comparable at year end to that before exposure. The telephone component of the fax machine also remained in good working condition.

The same computer was used to test the CD and DVD before and during the 12-month observation period following exposure. No problems were encountered reading the disks at any time. The sound quality of the CD after exposure was comparable to the quality before exposure. Similarly, the sound and picture quality of the DVD showed no signs of degradation.

## 5.3 Category 4 Equipment

PC-Doctor® Service Center™ 7.5 is commercially available software designed to diagnose and detect computer component failures. While the exact number and type of tests depends on the system being tested (see Appendix D), for the case of the Category 4 equipment, a total of 93 tests were run. A complete list of the PC-Doctor® Service Center™ 7.5 tests is shown in Appendix E.

The PC-Doctor® Service Center™ 7.5 protocol was developed and provided by Alcatel-Lucent for this effort. Alcatel-Lucent chose PC-Doctor® in order to have an industry-accepted standard method of determining pass versus failure of the computer subsystems. PC-Doctor® Service Center™ 7.5 functionality testing was conducted pre-fumigation, one day post-fumigation, then monthly on all functional computers for the next year with exceptions due to budget constraints. This testing provided valuable information about the extent and time dependence of the degradation of these computers following the various fumigation scenarios. All computers were kept under ambient laboratory conditions, in which humidity was not strictly controlled.

Standard protocol called for each test to be performed once. If any particular test failed the first time, the computer was tested a second time to correct for possible human error. A test that failed the second time was labeled “Fail”. If the test failed the first time but passed the second time, it was labeled “Pass2”. For tabulation, a score of 1,000 was assigned to each “Fail”, while a “Pass2” received a score of 1. During each pre- and post-fumigation testing period, a total PC-Doctor® score was assigned to each computer based upon the number of tests that failed on the first or second attempt.

Table 5-1 shows this score for each month for each computer, while Figure 5-1 is a graphical representation of the average score. For months and computers where tests received a “Fail”, the specific tests that failed are listed by test number for the month in adjacent columns.
The test numbers are described in Table 5-2, and a full listing is included in Appendix E. Numbers of DVD-ROM and DVD-RW drives, which are typically failing systems, have been color coded for ease of reference. Table 5-3 provides the average number of failures for each monthly test of PC-Doctor® Service Center™ 7.5 tests that received a “Fail” over the course of a year. For each test condition, the results are shown for each of the computers that underwent year-long testing. Three computers (Decon214, Decon215, and Decon216) were part of an aborted fumigation and are not included in this study. Computer Decon204 was sent to Alcatel Lucent for in-depth analysis. The power supply for Decon210 and Decon212 failed, and the computers could not be booted on replacement power supplies.

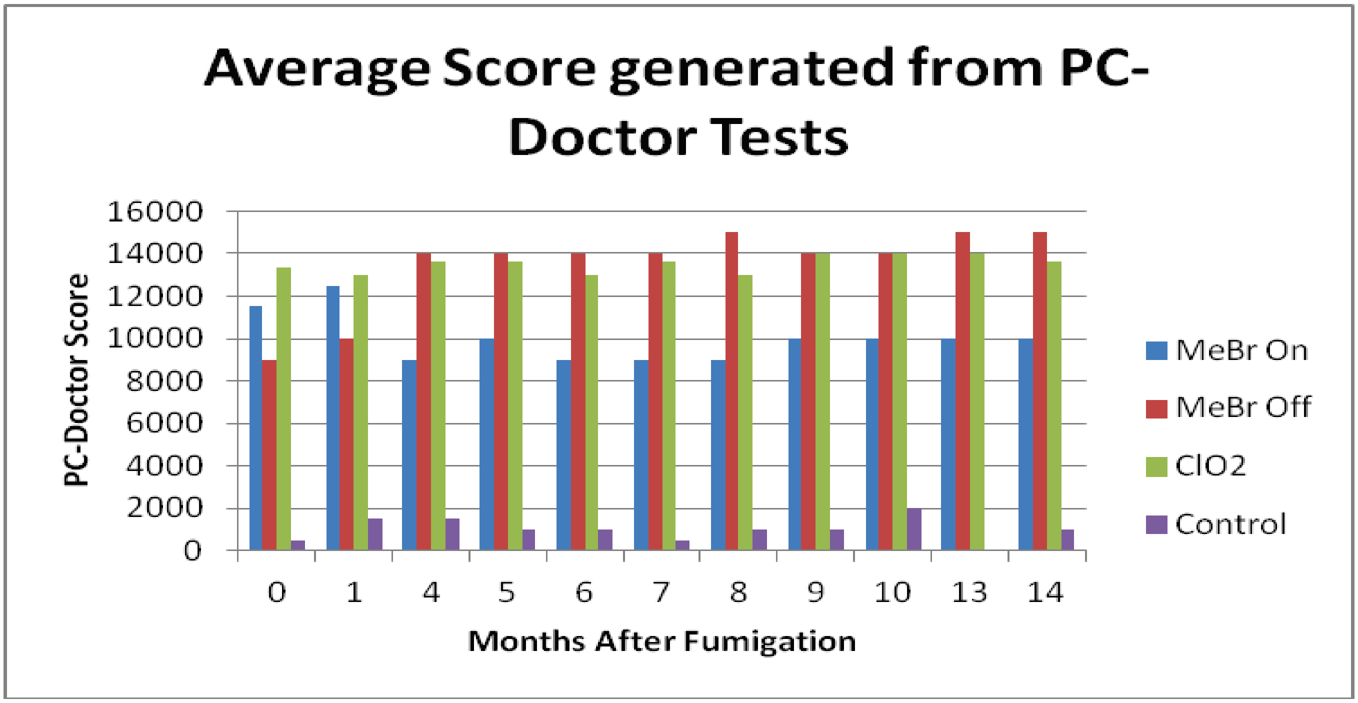



**Figure 5-1.** **Average PC-Doctor® Score per Exposure Type, score listed is based on a cumulative score of failures. A lower composite score means fewer component failures.**

**Table 5-1. PC-Doctor® Tests That Failed Twice for all Computer Fumigation Scenarios**
(Colored numbers are DVD-related components)

**Controls: On and Active**

| Computer ID | Day | Score | Failed Tests |
|---|---|---|---|
| Decon 202 | 0 | 1001 | 2 |
| | 1 | 1001 | 47, |
| | 38 | 2001 | 47,71, |
| | 65 | 2000 | 47,71, |
| | 101 | 1000 | 71, |
| | 135 | 1000 | 71, |
| | 169 | 1001 | 71, |
| | 199 | 0 | |
| | 231 | 1001 | 71, |
| | 263 | 0 | |
| | 295 | 0 | |
| Decon 208 | 0 | 1000 | 51, |
| | 1 | 0 | |
| | 42 | 1000 | 71, |
| | 69 | 1000 | 71, |
| | 134 | 1001 | 71, |
| | 166 | 1000 | 71, |
| | 203 | 0 | |
| | 235 | 2001 | 2,47, |
| | 267 | 1000 | 94, |
| | 299 | 4000 | 38,39,40,41, |
| | 329 | 0 | |
| | 361 | 1000 | 71, |
| | 405 | 1000 | 71, |

**Controls: Off**

| Computer ID | Day | Score | Failed Tests |
|---|---|---|---|
| Decon 203 | 0 | 0 | |
| | 1 | 0 | |
| | 37 | 1000 | 71, |
| | 65 | 0 | |
| | 101 | 0 | |
| | 135 | 1000 | 71, |
| | 164 | 1001 | 71, |
| | 190 | 2000 | |
| | 225 | 2000 | 46,47, |
| | 260 | 0 | |
| | 290 | 1000 | 71, |
| | 322 | 1000 | 71, |
| | 354 | 1 | |
| | 413 | 0 | |
| Decon 204 | 0 | 0 | |
| | 1 | 0 | |
| | 34 | 0 | |
| | 63 | 1000 | 71, |
| | 98 | 0 | |
| | 132 | 1000 | 71, |
| | 161 | 1000 | 71, |
| | 187 | 0 | |
| | 217 | 0 | |
| | 257 | 1000 | 71, |
| | 287 | 0 | |
| | 319 | 1000 | 71, |
| | 351 | 2000 | 59,71, |

| Computer ID | Day | Score | Failed Tests |
|---|---|---|---|
| Decon 205 | 0 | 0 | |
| | 1 | 0 | |
| | 34 | 1 | |
| | 63 | 0 | |
| | 98 | 1 | |
| | 133 | 1001 | 71, |
| | 161 | 1000 | 71, |
| | 187 | 0 | |
| | 217 | 2000 | 2,71, |
| | 257 | 1 | |
| | 287 | 1000 | 71, |
| | 319 | 1000 | 71, |
| | 351 | 0 | |
| | 404 | 22 | |
| Decon 206 | 0 | 0 | |
| | 1 | 0 | |
| | 41 | 1002 | 71, |
| | 70 | 1000 | 71, |
| | 134 | 1000 | 71, |
| | 166 | 1000 | 71, |
| | 194 | 0 | |
| | 224 | 1000 | 71, |
| | 264 | 1000 | 71, |
| | 299 | 0 | 0 |
| | 329 | 0 | 0 |
| | 361 | 1000 | 71, |
| | 405 | 0 | |

**98-2 MeBr, Computers On and Active**

| Computer ID | Day | Score | Failed Tests |
|---|---|---|---|
| Decon 207 | 0 | 0 | |
| | 7 | 14000 | 33,34,35,36,37,38,39,40,41,48,49,50,51,52, |
| | 36 | 15000 | 33,34,35,36,37,38,39,40,41,48,49,50,51,52,71, |
| Decon 211 | 0 | 0 | |
| | 2 | 9000 | 38,39,40,41,48,49,50,51,52, |
| | 40 | 10000 | 38,39,40,41,48,49,50,51,52,71, |
| | 118 | 9000 | 38,39,40,41,48,49,50,51,52, |
| | 152 | 10000 | 38,39,40,41,48,49,50,51,52,71, |
| | 182 | 9001 | 38,39,40,41,48,49,50,51,52, |
| | 212 | 9000 | 38,39,40,41,48,49,50,51,52, |
| | 245 | 9000 | 38,39,40,41,48,49,50,51,52, |
| | 278 | 10000 | 38,39,40,41,48,49,50,51,52,71, |
| | 308 | 10001 | 38,39,40,41,48,49,50,51,52,71, |
| | 377 | 10000 | 38,39,40,41,48,49,50,51,52,71, |
| | 405 | 10000 | 38,39,40,41,48,49,50,51,52,71, |
| Decon 213[a] | 0 | 0 | 0 |
| | 11 | 29001 | 7,12,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48, 49,50,51,52,53,54,55,56,57,58,59, |

[a] This computer was subjected to the aborted (suspected higher concentration) 98-2 MeBr fumigation.

**98-2 MeBr, Computers Off**

| Computer ID | Day | Score | Failed Tests |
|---|---|---|---|
| Decon 209 | 0 | 0 | 0 |
| | 6 | 9001 | 38,39,40,41,48,49,50,51,52, |
| | 35 | 10000 | 38,39,40,41,48,49,50,51,52,71, |
| | 106 | 14000 | 33,34,35,36,37,38,39,40,41,48,49,50,51,52, |
| | 153 | 14000 | 33,34,35,36,37,38,39,40,41,48,49,50,51,52, |
| | 183 | 14000 | 33,34,35,36,37,38,39,40,41,48,49,50,51,52, |
| | 201 | 14000 | 33,34,35,36,37,38,39,40,41,48,49,50,51,52, |
| | 233 | 15000 | 33,34,35,36,37,38,39,40,41,48,49,50,51,52,94, |
| | 265 | 14000 | 33,34,35,36,37,38,39,40,41,48,49,50,51,52, |
| | 295 | 14000 | 33,34,35,36,37,38,39,40,41,48,49,50,51,52, |
| | 327 | 15000 | 33,34,35,36,37,38,39,40,41,48,49,50,51,52,71, |
| | 383 | 15000 | 33,34,35,36,37,38,39,40,41,48,49,50,51,52,71, |
| Decon 210 | 0 | 1 | 0 |
| | 1 | 9002 | 38,39,40,41,48,49,50,51,52, |
| | 39 | 10000 | 38,39,40,41,48,49,50,51,52,71, |
| Decon 212[a] | 0 | 0 | 0 |
| | 11 | 115000 | Complete Failure |

[a] This computer was subjected to the aborted (suspected higher concentration) 98-2 MeBr fumigation

**$ClO_2$, Computers On and Idle**

| Computer ID | Day | Score | Failed Tests |
|---|---|---|---|
| Decon 221 | 0 | 0 | 0 |
| | 1 | 14004 | 34,42,43,44,45,46,47,53,54,55,56,57,58,59, |
| | 35 | 13001 | 42,43,44,45,46,47,53,54,55,56,57,58,59, |
| | 60 | 14001 | 42,43,44,45,46,47,53,54,55,56,57,58,59,71, |
| | 91 | 14000 | 42,43,44,45,46,47,53,54,55,56,57,58,59,71, |
| | 124 | 13000 | 42,43,44,45,46,47,53,54,55,56,57,58,59, |
| | 159 | 14000 | 42,43,44,45,46,47,53,54,55,56,57,58,59,71, |
| | 188 | 13000 | 42,43,44,45,46,47,53,54,55,56,57,58,59, |
| | 260 | 14000 | 42,43,44,45,46,47,53,54,55,56,57,58,59,71, |
| | 286 | 14000 | 42,43,44,45,46,47,53,54,55,56,57,58,59,71, |
| | 315 | 14000 | 42,43,44,45,46,47,53,54,55,56,57,58,59,71, |
| | 351 | 13000 | 42,43,44,45,46,47,53,54,55,56,57,58,59, |
| | 370 | 14000 | 42,43,44,45,46,47,53,54,55,56,57,58,59,71, |
| Decon 222 | 0 | 0 | 0 |
| | 1 | 13000 | 42,43,44,45,46,47,53,54,55,56,57,58,59, |
| | 36 | 13000 | 42,43,44,45,46,47,53,54,55,56,57,58,59, |
| | 60 | 14000 | 42,43,44,45,46,47,53,54,55,56,57,58,59,71, |
| | 91 | 13000 | 42,43,44,45,46,47,53,54,55,56,57,58,59, |
| | 124 | 13000 | 42,43,44,45,46,47,53,54,55,56,57,58,59, |
| | 159 | 14000 | 42,43,44,45,46,47,53,54,55,56,57,58,59,71, |
| | 188 | 13000 | 42,43,44,45,46,47,53,54,55,56,57,58,59, |
| | 260 | 14000 | 42,43,44,45,46,47,53,54,55,56,57,58,59,71, |
| | 286 | 14000 | 42,43,44,45,46,47,53,54,55,56,57,58,59,71, |
| | 315 | 14000 | 42,43,44,45,46,47,53,54,55,56,57,58,59,71, |
| | 351 | 14000 | 42,43,44,45,46,47,53,54,55,56,57,58,59,71, |
| | 370 | 13000 | 42,43,44,45,46,47,53,54,55,56,57,58,59, |
| Decon 223 | 0 | 1 | 0 |
| | 1 | 13000 | 42,43,44,45,46,47,53,54,55,56,57,58,59, |
| | 36 | 13000 | 42,43,44,45,46,47,53,54,55,56,57,58,59, |
| | 60 | 13000 | 42,43,44,45,46,47,53,54,55,56,57,58,59, |
| | 91 | 14000 | 42,43,44,45,46,47,53,54,55,56,57,58,59,71, |
| | 124 | 13000 | 42,43,44,45,46,47,53,54,55,56,57,58,59, |
| | 159 | 13000 | 42,43,44,45,46,47,53,54,55,56,57,58,59, |
| | 188 | 13000 | 42,43,44,45,46,47,53,54,55,56,57,58,59, |
| | 260 | 14000 | 42,43,44,45,46,47,53,54,55,56,57,58,59,71, |
| | 286 | 14000 | 42,43,44,45,46,47,53,54,55,56,57,58,59,71, |
| | 315 | 14000 | 42,43,44,45,46,47,53,54,55,56,57,58,59,71, |
| | 351 | 14000 | 42,43,44,45,46,47,53,54,55,56,57,58,59,71, |
| | 370 | 14000 | 42,43,44,45,46,47,53,54,55,56,57,58,59,71, |

**Ambient Controls, Computers On and Active**

| Computer ID | Day | Score | Failed Tests |
|---|---|---|---|
| Decon 217 | 0 | 0 | |
| | 1 | 0 | |
| | 63 | 1000 | 71, |
| | 92 | 1000 | 71, |
| | 133 | 2 | |
| | 152 | 3 | |
| | 186 | 1000 | 71, |
| | 216 | 1000 | 71, |
| | 246 | 0 | |
| | 281 | 1000 | 71, |
| | 355 | 1000 | 71, |
| | 365 | 0 | |
| Decon 219 | 0 | 0 | |
| | 1 | 0 | |
| | 63 | 1000 | 71, |
| | 92 | 0 | |
| | 133 | 1000 | 71, |
| | 153 | 1 | |
| | 186 | 1000 | 71, |
| | 216 | 1000 | 71, |
| | 246 | 0 | |
| | 281 | 2000 | 71,94, |
| | 355 | 0 | |
| | 365 | 1000 | 71, |
| Decon 220 | 0 | 0 | |
| | 1 | 0 | |
| | 55 | 0 | |
| | 89 | 0 | |
| | 119 | 0 | |
| | 151 | 0 | |
| | 186 | 1000 | 71, |
| | 216 | 10000 | 38,39,40,41,48,49,50,51,52,71, |
| | 246 | 9000 | 38,39,40,41,48,49,50,51,52, |
| | 281 | 11000 | 38,39,40,41,48,49,50,51,52,71,94, |
| | 355 | 9000 | 38,39,40,41,48,49,50,51,52, |
| | 365 | 10000 | 38,39,40,41,48,49,50,51,52,71, |

Table 5-2. PC-Doctor® Failed Test Correlation to PC Subsystem Components

| Failed PC-Doctor® Test | Subsystems | Test Description |
|---|---|---|
| 2 | **SoundMAX Integrated Digital High Definition Audio** | Rough Audio Test |
| 33 | **Floppy disk drive** | Linear Seek Test |
| 34 | | Random Seek Test |
| 35 | | Funnel Seek Test |
| 36 | | Surface Scan Test |
| 37 | | Pattern Test |
| 38 | **PLDS DVD-ROM DH-16D5S** | DVD Linear Seek Test |
| 39 | | DVD Random Seek Test |
| 40 | | DVD Funnel Seek Test |
| 41 | | DVD Linear Read Compare Test |
| 42 | **PLDS DVD+-RW DH-16AAS** | DVD Linear Seek Test |
| 43 | | DVD Random Seek Test |
| 44 | | DVD Funnel Seek Test |
| 45 | | DVD Linear Read Compare Test |
| 46 | | DVD-RW Read Write Test |
| 47 | | DVD+R Read Write Test |
| 48 | **PLDS DVD-ROM DH-16D5S** | CD Linear Seek Test |
| 49 | | CD Random Seek Test |
| 50 | | CD Funnel Seek Test |
| 51 | | CD Linear Read Compare Test |
| 52 | | CD Audio Test |
| 53 | **PLDS DVD+-RW DH-16AAS** | CD Linear Seek Test |
| 54 | | CD Random Seek Test |
| 55 | | CD Funnel Seek Test |
| 56 | | CD Linear Read Compare Test |
| 57 | | CD Audio Test |
| 58 | | CD-R Read Write Test |
| 59 | | CD-RW Read Write Test |
| 71 | **Intel(R) 82567LM-3 Gigabit Network Connection** | External loopback |
| 94 | **USB Port** | USB Port Test |

**Table 5-3. Average "Fail" Results Per Test over Year-Long Observation and Testing Period**

| **Fumigation Technology** | **None** | **3000 ppmv $ClO_2$, 3 hr.** | **Hot humid control (no fumigation)** | **Hot humid control (no fumigation)** | **74,000 ppmv 98-2 MeBr** | **74,000 ppmv 98-2 MeBr** |
|---|---|---|---|---|---|---|
| **Test Condition** | **Computer Off** | **Computer On and Idle** | **Computer On** | **Computer Off** | **Computer On** | **Computer Off** |
| Computer A | 0.5 | 13.6 | 1.1 | 0.6 | 14.5 [1] | 13.4 |
| Computer B | 0.6 | 13.5 | 0.9 | 0.7 | 9.5 | 9.5 [1] |
| Computer C | 4.5 | 13.5 | 0.6 [2] | 4.6 | Does not remain powered [3] | Does not boot [3] |

[1] These computers had only 2 post-test evaluations.

[2] This computer shut down early in the test and so was not "on" the entire duration.

[3] This computer was present during the uncontrolled high concentration of fumigant due to a loss in power.

As an example, Table 5-1 shows Decon202 with a score of 2,000 for Day 65 (after fumigation) and 2,001 for Day 38. These numbers mean that during Day 65 testing, two specific tests received a "Fail" during testing (2 x 1,000), while during Day 38, one test received a "Pass2" (1 x 1) and two tests received a "Fail" (2 x 1,000). The column to the right shows the ID of the test(s) that failed. By cross-referencing these *Failed Test* numbers (47 and 71) with Table 5-2, one can find that the failed tests were the DVD +R Read/Write test and the network loopback test. Because the DVD/CD drive is a frequent cause of failure, these subsystem failure codes have been color coded.

As the failed tests in Table 5-1 are examined, the vast majority (83.7%) were found to be related to the CD/DVD drive. A significant amount of the remaining failures were related to the floppy drive, and many were an intermittent network loopback failure which seems to be an issue with all computers, even controls. The intermittent "Pass 2" results also point to vulnerabilities in the same subsystems (DVD and floppy drives).

Analysis shows that the CD/DVD subsystem is not reliable, with one out of three failing in two of the control condition computer sets. Exposure to fumigants clearly reduced reliability of the CD/DVD systems. Table 5-1 shows that, with the exception of Decon209, failures of fumigated computers were immediately identified and did not develop over time. Decon209 did develop floppy drive failures at the two month mark. Analysis by Alcatel-Lucent (LGS, 2010) showed the presence of significant corrosion as a result of chlorine exposure, both in $ClO_2$ fumigations and from the chloropicrin component of the MeBr fumigations. This corrosion seems to have affected bearings and other moving parts of both the floppy drives and the CD/DVD drives.

The most significant compatibility finding is not a result of PC-Doctor® analysis. All computers exposed to 98-2 MeBr exhibited problems with the power supply, some catastrophically. The power supply to Decon213, for instance, began failing a few days after fumigation by tripping ground fault circuits and with burning smells. The same type of failure during the fumigation could have been the cause of the power failure inside the fumigation chamber. These same effects were eventually detected in all 98-2 MeBr fumigated computers, and all power supplies were replaced. Alcatel-Lucent (LGS, 2010) traced these failures to exposure to the chloropicrin component of the fumigant.

## 6.0 Fumigation Effectiveness and Fumigation Safety

### 6.1 Fumigation Effectiveness

BIs were used to obtain an indication of the potential impact of local conditions on the effectiveness of the fumigation process to inactivate spores potentially located within the computer. Specifically, the *B. atrophaeus* BIs were used to investigate $ClO_2$ and 98-2 MeBr sporicidal effectiveness, both in the bulk chamber and for localized hot spots inside the computers where the RH may be lower because of the heat generated by the computer electronics during operation. The BIs provided a qualitative result of growth or no growth after an incubation period of seven days. BIs have been shown not to correlate directly with achieving target fumigation conditions for *B. atrophaeus* spores or inactivation of *B. atrophaeus* spores on common building surfaces (Ryan, 2006). While BIs do not necessary indicate achievement, they provide a sufficient indication of a failure to achieve successful fumigation conditions (Ryan, 2006). *B. atrophaeus* BIs were used for historical reasons, even though *B. atrophaeus* has been shown to be more resistant to MeBr fumigation than other *Bacillus* species, including *anthracis* (Scheffrahn, 2003).

Figures 6-1 and 6-2 show the locations of the BIs within each computer. These locations were chosen based on the available mounting surfaces that afforded relatively unrestricted air flow. Two BIs were placed on the side cover (Figure 6-1) in areas of high air flow. Three more BIs (Figure 6-2) were placed inside the computer to capture both high and low air flow locations. BIs were also present in the MEC chamber, one on top of each Category 4 computer case and two between the keyboards and monitors on the top shelf of the MEC chamber.

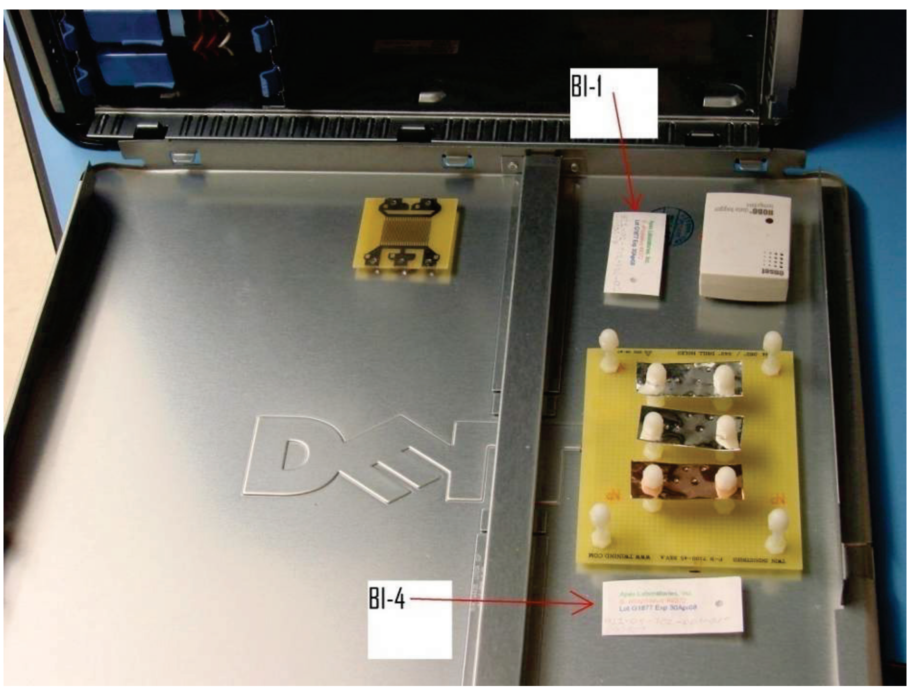



**Figure 6-1. Location of two of the five BIs inside the computer side cover**

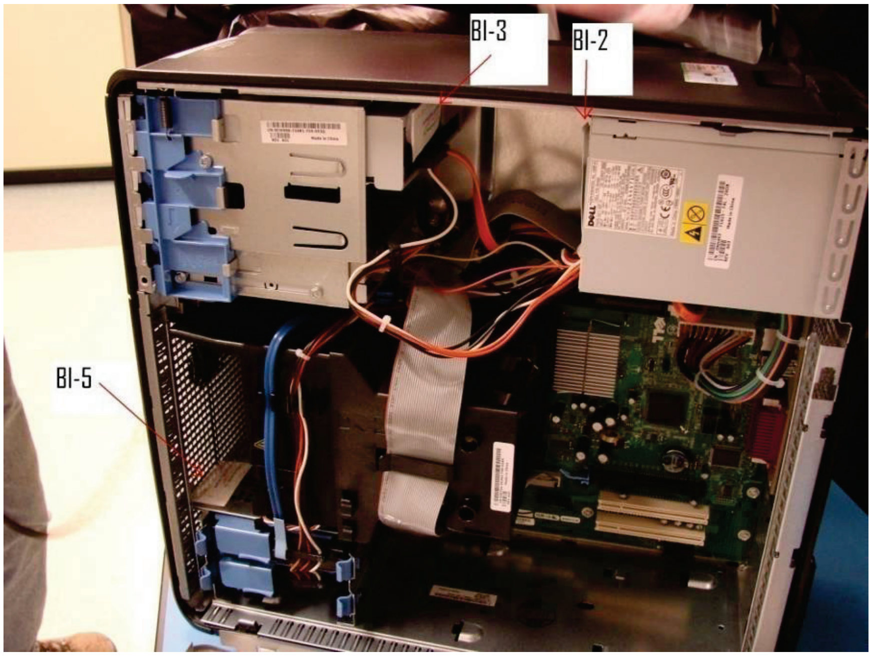



**Figure 6-2. Location of the remaining three BIs in both high and low air flow locations inside the computer**

Table 6-1 details the effect of each fumigation scenario on BI viability in both the fumigation chamber and inside the computers. BIs were not placed in the control runs that were conducted without fumigant.

**Table 6-1. BI Survival in the Chamber and Computers for each Fumigation Scenario**

| **Fumigation Technology** | **98-2 MeBr Fumigation 1** | | **98-2 MeBr Fumigation 2** | | **98-2 MeBr Fumigation 3**[a] | | **3000 ppmv $ClO_2$** |
|---|---|---|---|---|---|---|---|
| **Computer power** | **Off** | **On** | **Off** | **On** | **Off** | **On** | **On and idle** |
| BIs in Chamber | 100% | | 100% | | 40% | | 0% |
| BIs in Computer | 100% | 100% | 100% | 100% | 0% | 0% | 27% |

[a] This was the aborted 98-2 MeBr run, most likely at a much higher concentration.

The BI data support the hypothesis that the fumigant concentration was much higher during the third fumigation than the other two fumigations due to a power failure. The BIs inside the computers were the lowest in the MEC chamber, and may have been subject to higher concentrations due to gravimetric settling. The survival of the BIs following controlled 98-2 MeBr fumigation does not indicate that conditions would have been ineffective against *B. anthracis* spores. The exposure conditions (300 mg/l for 9 hours) were based on efficacy results obtained with *B. anthracis* spores (Ryan, 2010). The higher temperature (and lower humidity) inside the computers may have provided some protection to the BIs during $ClO_2$ fumigation.

## 6.2 Health and Safety Effects of Fumigation

The following information was included in Alcatel-Lucent's IA&E report (LGS, 2010).

Part of the current material compatibility (DECON) project included a study to determine the level and duration of MeBr outgassing from the 98-2 MeBr-exposed computers after they were removed from the fumigation chamber. This determination was accomplished using specially designed chambers and the highly sensitive Trace Atmospheric Gas Analyzer (TAGA) Atmospheric Pressure Ionization Mass Spectrometer available at EPA's NHSRC laboratory. The experimental design, including measurement equipment used and sample chamber, are briefly described here.

One-day after fumigation, the computers were placed inside chambers made from 304 stainless steel. This material was chosen because it is a special nonporous, silica-coated stainless steel that is inert to many reactive gases. Use of 304 stainless steel use eliminated any chamber adsorption artifacts. The chambers are shown in Figure 6-3. One chamber was dedicated to measuring MeBr outgassing from a test computer that was fumigated with 98-2 MeBr one day prior to the off-gassing measurements. The second chamber was used as a control for measuring the background outgassing from a control computer that had been subjected to the elevated temperature and humidity test condition 30 days prior to the off-gassing measurements.

**Figure 6-3. MeBr Outgassing Chambers**

The chambers were sealed with a Teflon gasket between the flanges of the front panel. Electrical power for the computers was supplied through a leak-tight bulkhead fitting. The computers could be turned on by inserting a piece of stainless steel rod through a bulkhead fitting and pressing the power button. The computer power state could be verified by peering through a ½" acrylic rod mounted through a different bulkhead facing the monitor. To sample the air inside the chambers, each chamber was equipped with a ¼" OD stainless steel tube that was connected into the inlet of the mass spectrometer. The mass spectrometer had an atmospheric pressure ionization source with a triple quadrupole mass spectrometer for mass selection. The mass spectrometer was calibrated for MeBr with standard methods. The MeBr calibration was linear to 2 ppmv and was anticipated to be linear to 20 ppmv. Values over that limit were outside the calibrated range and subject to significant error and instrumental non-linearity. This calibration range is important to note because, in this outgassing study, MeBr concentrations up to 650 ppmv were measured. Further research should be done to characterize the actual MeBr concentration from desorption.

The MeBr concentration in the chamber (see dashed line in Figure 6-4) was found to increase to 610 ppmv (0.061 v-%) during the course of the experiment (8.5 hours). Some material in the computer was clearly able to adsorb MeBr during fumigation and release the MeBr shortly thereafter. Since the Threshold Limit Value (TLV) is 1 ppm and the ceiling exposure limit is 20 ppm according to the Material Safety Data Sheet (MSDS), these measured values represent hazardous levels. Naturally, these levels would be attained only in a small sealed enclosure, but the quantity of MeBr that is contained in the computer is surprising. The differential change in MeBr is shown on the secondary axis of Figure 6-4. It appears that the desorption rate peaked at 4.5 hours and began to decline after that.

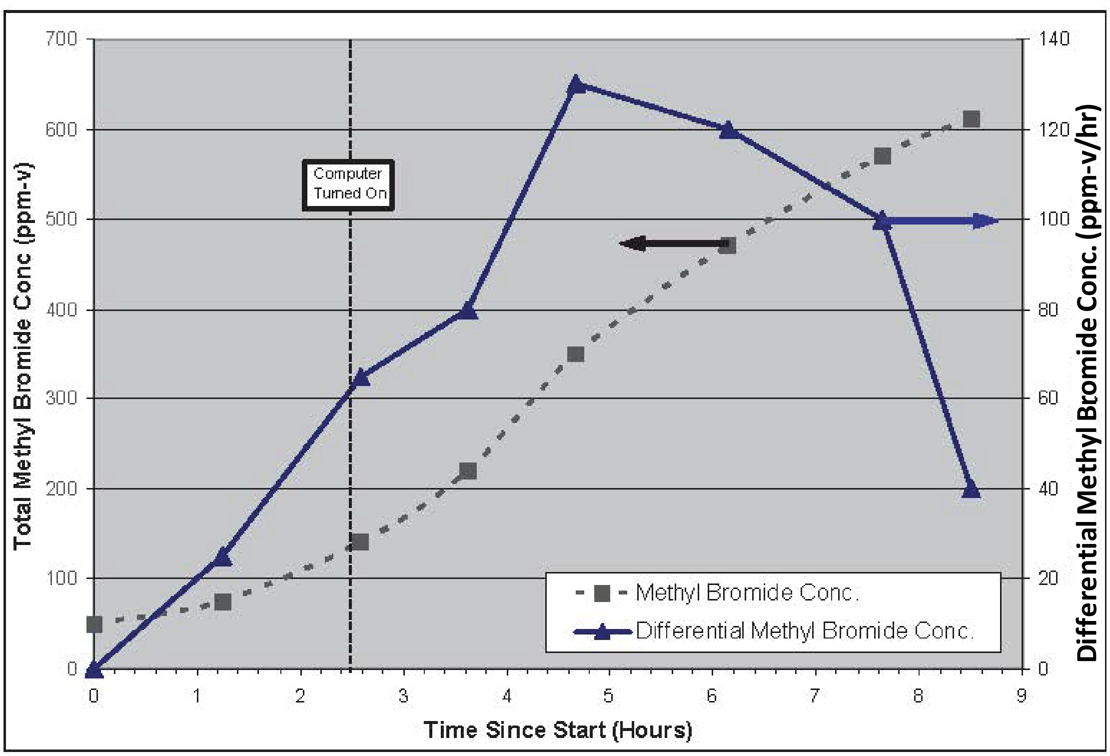



**Figure 6-4. Outgassing MeBr Concentration over Time from decon209 Computer Fumigated with 98-2 MeBr.**

A rough estimate is that the computer physically occupies 25 percent of the chamber space. That 25 percent translates into an average concentration of four times 0.061 or 0.25 vol-% MeBr in the computer. MeBr will behave similarly to an organic solvent and adsorb into organic materials, especially less dense materials. Likely candidates for such adsorbing materials in the computer test vehicles are the chip packages, cable coatings, connector bodies, printed circuit board laminates, optical elements and optical benches in the DVD drives, and epoxies that were used for various purposes in many subassemblies, (see Figure 6-5). In these absorbent materials, the MeBr concentration must be locally much greater than 0.25 vol-%.

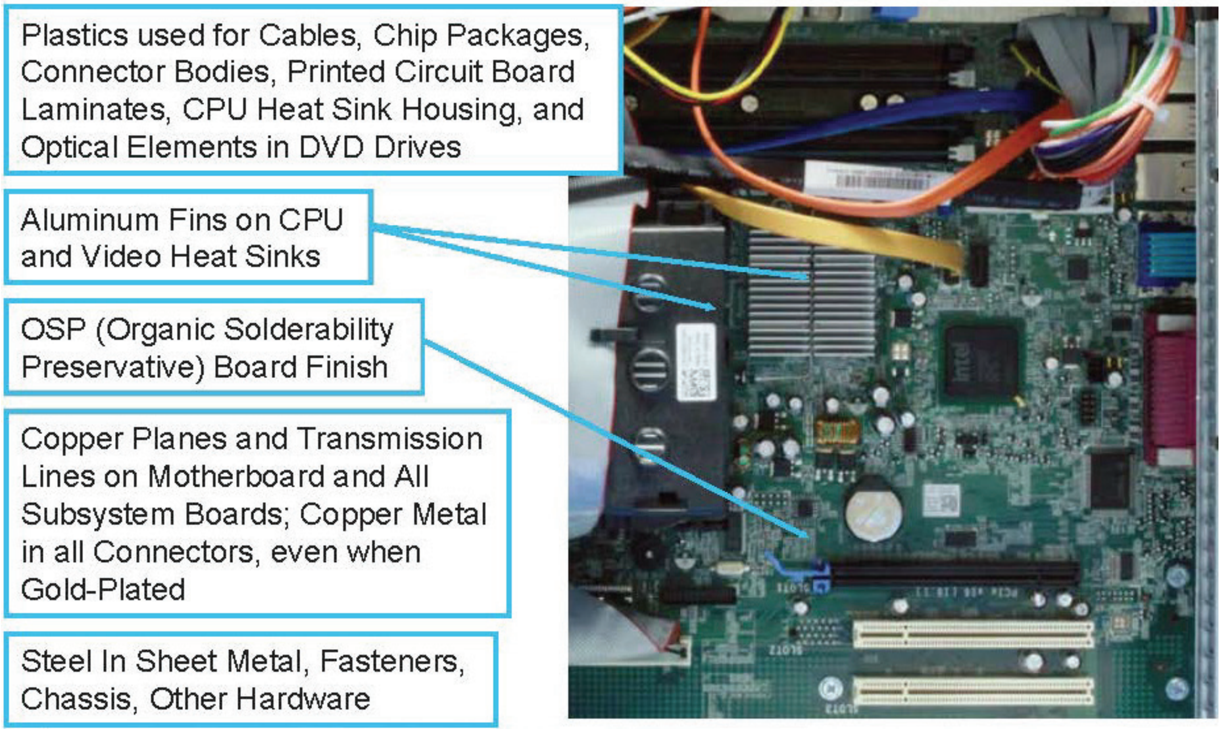



**Figure 6-5. Possible Corrosion-Susceptible Materials Inside the Dell Optiplex 760 Mini Tower Computers.**

There are obvious implications when fumigating larger equipment. The relative rate for MeBr outgassing is shown as a solid line in Figure 6-4. The out gassing rate appears to peak at roughly 4½ hours and decreases rapidly after 8 hours. Note that outgassing still occurs 8½ hours after the experiment started, illustrating the need for careful handling of fumigated samples post-exposure since the human health hazards, including fatal incidents, posed by exposure to MeBr are known (Thompson, 1966).

The MeBr outgassing rate will be limited by the diffusion out of the computer. However, high air flow rates past the computer can be used to dilute the MeBr to safe levels. This dilution process should be considered for enclosed fumigation systems. When it was placed in the sampling chamber, the outgassing computer, Decon209, was in an OFF state for 2½ hours after the start of the experiment. Decon209 was then turned on remotely and left turned on for the remaining 7½ hours of the experiment. The solid line in Figure 6-4 shows an outgassing rate which appears to peak near 4.5 hours then slowly decreased thereafter. Remembering the actual MeBr concentrations are not calibrated in this range, we must be careful about overly analyzing this trend. However, the characteristics of the detector are such that it would tend to saturate at some concentration level, and at lower levels than this “saturation concentration” the detector would under-represent the concentration. So the reduction in the rate of increase of outgassing (that is, the slight drop near 4 hours relative to a line drawn between the prior and following points seen in Figure 6-4) appears to be real. Turning on the computer apparently causes a very slow heating of those materials that had adsorbed MeBr. Over an hour is needed for those materials to increase appreciably in temperature, but once they did heat, the rate of outgassing increased. No powder was produced following fumigation with MeBr, nor were any other by-products of fumigation detected.

## 7.0 Quality Assurance

The objective of this study was to assess the impact of 98-2 MeBr on materials and electronic equipment due to fumigation under conditions known to be effective against biological threats. The Data Quality Objectives (DQOs) address this impact using visual inspection (both externally and internally) to assess the loss in value or use of the tested material/equipment, as well as functionality of the material/electronic equipment. The following measurements were considered critical to accomplishing part or all of the project objectives:

- Real-time fumigant concentrations
- Temperature
- RH
- Fumigation time sequence
- Material inspection and electronic equipment functionality time sequence
- Growth/no growth of the Bis.

## 7.1 Data Quality

The Quality Assurance Project Plan (QAPP) in place for this testing was followed with few deviations, many of which were documented in the text above. Deviations included:

- Use of the Fumiscope alone for determination of real-time MeBr concentration. The development of the method using the photoacoustic analyzer threatened to delay the testing past contractual deadlines.

- The MeBr Fumigation C was aborted due to an electrical ground fault shutting down mixing fans inside the MEC chamber. The risk of explosion was deemed too high to continue testing.

### *7.1.1 Data Quality Indicator Goals for Critical Measurements*

The Data Quality Indicators (DQIs) listed in Table 7-1 are specific criteria used to quantify how well the collected data meet the DQOs.

**Table 7-1. DQIs for Critical Measurements**

| Measurement Parameter | Analysis Method | Accuracy | Detection Limit | Completeness[1] % |
|---|---|---|---|---|
| Real-time $ClO_2$ concentration at the exit of the MEC test Chamber | ClorDiSys EMS monitor (0.1 – 30 mg/L) | 15% of SM-4500-EMiniDox | 0.1 mg/L 36 ppm | 95 |
| Real-time $ClO_2$ concentration inside the MEC test Chamber | ClorDiSys MiniDox monitor (0.1 – 30 mg/L) | 15% of SM-4500-E | 0.1 mg/L 36 ppm | 95 |
| Extracted $ClO_2$, high concentration | Modified SM 4500-$ClO_2$ E | 5% of Standard | 0.1 mg/L (solution) | 100 |
| Real-time MeBr concentration inside the MEC test Chamber | Fumiscope 5.0 | NA | NA | 95 |
| Relative humidity | RH probes (0-100 %) | ± 5 % full scale from factory | NA | 95 |
| Differential time | Computer clock | 1 % of reading | 0.5 sec | 95 |
| Temperature inside the isolation chamber | Thermocouple | $\pm$ 2 $^{o}$F | NA | 95 |

[1] Completeness goals of 100% are used for those parameters that are performed manually and infrequently: A completeness goal of 95% is used for those data streams that are automatically logged.

The DQIs listed in Table 7-1 are specific criteria used to quantify how well the collected data meet the DQOs. The accuracy of the real-time $ClO_2$ monitors was assessed with respect to the Modified SM 4500-$ClO_2$ E Method. Corrections to the real time concentration set-point were made such that the target concentration was attained according to the titration measurement. Precision of the real-time $ClO_2$ and MeBr monitors cannot be accessed due to unavailability of a constant-concentration source and the feedback nature of their operation in this specific testing setup. The accuracy of the extractive titration was assessed with respect to a standard solution.

The QAPP originally stated that the target accuracy for the RH probes would be 3.5 percent full scale from the factory; however, the factory specification is actually 5 percent full scale from factory. The accuracy goal for the RH probe was subsequently modified to reflect the factory specification.

### *7.1.2 Data Quality Indicators Results*

The accuracy of the real-time $ClO_2$ monitors was assessed with respect to the Modified SM 4500-$ClO_2$ E Method. Corrections to the real time $ClO_2$ concentration set-point were made such that the target concentration was attained according to the titration measurement. Accuracy of the real-time MeBr monitor is unknown because the Fumiscope is not specific to MeBr. The Fumiscope reading was used only for real-time control. The accuracy of the extractive titration was assessed with respect to a standard solution.

#### 7.1.2.1 98-2 MeBr Fumigations

Table 7-2 shows the actual DQIs for the MeBr fumigations.

**Table 7-2. DQIs for Critical Measurements for 98-2 MeBr Fumigations**

| | *Fumigation A* | | *Fumigation B* | | *Fumigation C* | |
|---|---|---|---|---|---|---|
| **Measurement Parameter** | **Accuracy (%)** | **Completeness (%)** | **Accuracy (%)** | **Completeness (%)** | **Accuracy (%)** | **Completeness (%)** |
| Fumiscope 5.0 | NA | 85.9 | NA | 95.8 | NA | 89 * |
| RH probes (0-100 %) | 4.4 | 70.1 | 1.7 | 98.5 | 9.5 | 21.2 |
| Thermocouple | ± 0.3 °C | 27.5 | ± 0.3 °C | 3.7 | ± 0.3 °C | 78.4 |

* While accuracy and completeness values have been listed for the aborted Fumigation C, there is strong evidence to suggest that the measured values were not representative of the bulk chamber conditions due to settling of the heavier gases in the unmixed chamber.

The Fumiscope was zeroed on hot humid air and spanned with calibration gas before each fumigation. Because the Fumiscope is not specific to MeBr, the accuracy of the measurement cannot be assessed. Accuracy may also be reduced if interferences are present in the experimental gas that were not present in the calibration gas. The accuracy of the differential time was not assessed, but is expected to be negligible through the use of a computer clock. The accuracy of the thermocouple was determined though the measurement of the uncertainty following calibration.

#### 7.1.2.2 $ClO_2$ Fumigations

Table 7-3 shows how the DQI parameters met the goals for the $ClO_2$ fumigation during exposure.

**Table 7-3. DQIs for Critical Measurements for $ClO_2$ Fumigations**

| | *Fumigation A* | |
|---|---|---|
| **Measurement Parameter** | **Accuracy (%)** | **Completeness (%)** |
| ClorDiSys EMS monitor (0.1 – 30 mg/L) | 11 | 100 |
| ClorDiSys MiniDox monitor (0.1 – 30 mg/L) | 12 | 100 |
| Modified SM 4500-$ClO_2$ E | 1.4 | 100 |
| RH probes (0-100 %) | -3.1 | 98.9 |
| Differential Time | NA | 74 |
| Thermocouple | ± 0.3 °C | 0 |

The accuracy of the differential time was not accessed but is expected to be negligible through the use of a computer clock. The accuracy of the thermocouple was determined though the measurement of the uncertainty following calibration.

## 7.2 Quantitative Acceptance Criteria

The quantitative acceptance criteria were associated with targeted setting conditions in the MEC test chambers or system control accuracy (SCA) and completeness. The other quantitative acceptance criteria are associated with the precision of the instruments during the entire exposure time.
The SCA is defined as the deviation from the set parameter over the duration of the test, as calculated by Equation 7-1:

$$SCA = \frac{\sqrt{\sum_{i=1}^{n}(Y_i - Yt)^2}}{\sqrt{n-1}\,Yt} \qquad (7\text{-}1)$$

where *Yt* is the target parameter.

Completeness is defined as the ratio of the total number of data points that satisfy the acceptance criteria to the total number of data points measured. All measured data are recorded electronically or on data sheets or project notebooks. The system accuracies and test completeness are presented in Table 7-4.

**Table 7-4. System Control Accuracy Results for Critical Measurements**

| Measurement Parameter | Analysis Method | System Control Accuracy (%) (Completeness, %) | | | | |
|---|---|---|---|---|---|---|
| | | Target | MeBr A | MeBr B | MeBr C | $ClO_2$ |
| Real-time $ClO_2$ concentration inside the MEC test chamber | ClorDiSys MiniDox monitor (0.1 – 30 mg/L | 10 (95) | | | | 3.1 (100) |
| Extracted $ClO_2$ inside the MEC test chamber | Modified SM 4500-$ClO_2$E | + 15 (100) | | | | 10.6 (100) |
| Real-time MeBr concentration inside the MEC test chamber | Fumiscope 5.0 | + 10 (95) | 11 (85.9) | 4.1 95.8 | 7.5* (89) | |
| Relative humidity inside both the MEC test and control chambers | RH probes (0-100 %) | + 5 (95) | 5.7 (70.1) | 2.1 (98.5) | 11.4* (21.2) | 0.3 (98.9) |
| Temperature inside both the MEC test and control chambers | Thermistor | + 5 (95) | 4.5 (27.5) | 6.7 (3.7) | 2.2* (78.4) | 9.9 (0) |

* Conditions reported during Run C are not fully representative of actual conditions due to poor mixing. The MeBr test (Run C) was exposed to higher concentrations of 98-2 MeBr due to poor mixing caused by a Gound Fault Circuit Interrupter (GFCI) fault during fumigation. The exact concentration is unknown but is expected to be greater than 150,000 ppmv.

To measure the instrument precision and stability, it is necessary to make replicate measurements of a relatively unchanging parameter. The ability to measure precision is dependent upon the type of data that is being measured. For this specific test program, precision is defined as the deviation from the average measured values over the duration of the test. The best way to represent all of the replicate responses to average values is with a relative standard deviation (RSD) for multiple measurements per run.

$$RSD = \frac{\sqrt{\sum_{i=1}^{n}(Y_i - \overline{Y})^2}}{\sqrt{n-1}\,\overline{Y}} \qquad (7\text{-}2)$$

The precision for each instrument used for each test sequence is presented in Table 7-5 and 7-6 for the MeBr and $ClO_2$ fumigations, respectively.

**Table 7-5. Precision Criteria for 98-2 MeBr Fumigations**

| | **98-2 MeBr Fumigation RSD (%)** | | |
|---|---|---|---|
| **Measurement Parameter** | **A** | **B** | **C*** |
| Fumiscope | 6.6 | 1.1 | 6.2 |
| KOH wet chemistry | 18 | 4.8 | 13 |
| RH probes (0-100 %) | 4.0 | 1.9 | 6.9 |
| Thermistor | 2.2 | 2.1 | 1.3 |

* Fumigation C data is not representative of the entire chamber due to poor mixing.

One useful metric may be the total amount of fumigant injected. The required amount of MeBr to reach setpoint and maintain conditions for Fumigation A was 1.6 kg, for Fumigation B was 2.3 kg, and for Fumigation C was 2.0 kg.

**Table 7-6. Precision (RSD %) Criteria for $ClO_2$ Fumigation**

| **Measurement Parameter** | **Fumigation A RSD (%)** |
|---|---|
| ClorDiSys MiniDox monitor (0.1 – 30 mg/L), | 1.9 |
| Modified SM 4500-$ClO_2$ E | 3.0 |
| RH probes (0-100 %) | 0.3 |
| Thermistor | 1.2 |

All data from this $ClO_2$ fumigation satisfied the precision requirements.

## 7.3 Audits

This project was assigned Quality Assurance (QA) Category III and did not require technical systems or performance evaluation audits.

## 8.0 Conclusions

In this study, all Category 2 and 3 materials proved to be resilient to 98-2 MeBr exposure, with the exception of the steel outlet/switch box (rusted edges) and the low carbon steel coupons (severe corrosion on the surface). Exposure to 98-2 MeBr resulted in far fewer damaging effects than the $ClO_2$ gas, and those effects were apparently caused by the chlorine (choropicrin) component. MeBr alone may prove to be the more compatible fumigant of the two. It is recommended that future work with MeBr be tested to examine the effects of just MeBr without chloropicrin.

Alactel-Lucent (LGS, 2010) determined that in this new generation of computers, the heat sinks were made from a single aluminum alloy that is resistant to MeBr and chloropicrin, as well as to $ClO_2$. The power system failures, eventually detected in all 98-2 MeBr exposed computers, were also traced by Alactel-Lucent to the chloropicrin component of the fumigant (LGS, 2010).

The vast majority (83.7%) of failed tests with 98-2 MeBr were found to be related to the CD/DVD drive. However, this subsystem is not reliable, with one out of three failing in two of the control condition computer sets. Exposure to fumigants clearly further reduced reliability of the CD/DVD systems.

Off gassing from plastics, rubber and other materials should be considered when fumigating with 98-2 MeBr. Tests showed that off-gassing is still occuring 8½ hours after the experiment started, illustrating the need for careful handling of fumigated samples post-exposure due to the human health hazards.

# 9.0 Recommendations

This section provides recommendations resulting from the experiments. The recommendations relate to functional failures of various tested materials and electronic components that were subjected to a decontamination scenario using 98-2 MeBr. These recommendations are presented below.

## 9.1 Corrective Actions

Corrective actions can be implemented immediately after the fumigation event to reduce/prevent further degradation of sensitive materials and components. These corrective actions include evaluation of the power supplies, which were vulnerable to the 98-2 MeBr. In addition, all personnel should be aware of the potential off-gassing of MeBr following fumigation which poses a health risk.

## 9.2 Listing of "At Risk" Material and Electronic Components

During the planning stages of a remediation, inventory at-risk components, including power supplies and metal bearings, and those that contain affected subsystems, such as DVDs and floppy drives. These components could be candidates for alternative decontamination techniques or immediate replacement after fumigation.

## 9.3 Further Research

An unexpected result of this study was that MeBr itself did not cause the observed corrosion.The observed corrosion was caused by the 2 percent chloropicrin (tear gas) which is added to warn users of exposure (LGS, 2010). This study should be repeated using MeBr alone.

A research plan should be developed to investigate additional materials/electronic component compatibilities that are vital to other high-end electronic equipment but not covered under these experiments. The list may include the compatibility of lubricated metals, aluminum alloys, and other types of plastic used in the electronics industry. As more information becomes available on the effectiveness of additional fumigation conditions, investigation of these additional fumigation conditions is important. In planning activities for remediation, the inventory of at-risk items and components can be prepared so that these items and components can be identified for special alternative decontamination procedures or immediate replacement.

The safety aspect of off-gassing should also be considered for future research. MeBr concentrations from the desorption from the computers exceeded expectations of the research team.

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## Appendix A: Category 2 & 3 Materials

| Material Description | Part Number | Vendor |
|---|---|---|
| PALM Z22 Handheld Organizer | | WALMART |
| Virgin Mobile Prepaid Marble Cell Phone - Black | | WALMART |
| First Alert 9-Volt Smoke Detector | 010921401 | WALMART |
| Brother Fax-575 Fax/Copier | | Walmart |
| CD: Today's #1 Hits (DIGI-PAK) | | Walmart |
| DVD: Sleepwalking | | Walmart |
| Spring-Clamp Incadescent Light | 1627K48 | McMaster Carr |
| DSL Line Conditioner | 1522T23 | McMaster Carr |
| Smoke Alarm Tester | 6638T21 | McMaster Carr |
| Textured Alloy Aluminum Sheet, 0.063" thick, 12"x12" | 88685K12 | McMaster Carr |
| Alloy 101 Oxygen-Free Copper Sheet, 0.064" Thick, 6"X6" | 3350K19 | McMaster Carr |
| Type 316 Stainless Steel Strip W/2B Finish, 12"X12" | 9090k11 | McMaster Carr |
| Type 309 Stainless Steel Rectangular Bar, 2"X12" | 9205K151 | McMaster Carr |
| Miniature Stainless Steel Shape Type 430 Strip, 1"X12" | 8457K49 | McMaster Carr |
| Type 410 SS Flat Stock Precision Ground, 12"X24" | 9524K62 | McMaster Carr |
| Low Carbon Steel Round Edge Rectangular Bar, 1.5"X6' | 6511k29 | McMaster Carr |
| Type E 304 Stainless Steel Strip W/#3 Finish, 2"X12" | 9085K11 | McMaster Carr |
| Yellow SJTO 300 Vac Service Cord, 15FT | 8169K32 | McMaster Carr |
| Steel Outlet/Switch Box | 71695K81 | McMaster Carr |
| 4X6 Standard Collor Print Glossy Finish | | Walgreens |
| Gasket, round | 14002 | Sigma Electric |
| Dry wall nail, coated, 1-3/8", Grip Rite Fas'ners | 138CTDDW1 | Lowe’s |
| Drywall screw, coarse thread, 1-5/8", Grip Rite Fas'ners | 158CDWS1 | Lowe’s |

## Appendix B:  Computer Specifications for Category 4 Testing

| | |
|---|---|
| **Base Unit:** | OptiPlex 760 Minitower Quad Base Standard Power Supply (224-5180) |
| **Processor:** | Core2 Quad, 9400/ 2.66GHz, 6M 1333FSB (317-0592) |
| **Memory:** | 3GB, Non-ECC, 800MHz DDR2, 3X1GB OptiPlex (311-9528) |
| **Keyboard:** | Dell USB Keyboard, No Hot Keys English, Black, Optiplex (330-1987) |
| **Monitor:** | Dell 18.5 inch Flat Panel Display, E1910, OptiPlex, Precision, Latitude and Enterprise (320-8151) |
| **Video Card:** | Integrated Video, GMA 4500, DellOptiPlex 760 and 960 (320-7407) |
| **Hard Drive:** | 80GB SATA 3.0Gb/s and 8MB DataBurst Cache, Dell OptiPlex (341-8006) |
| **Floppy Disk Drive:** | 3.5 inch, 1.44MB, Floppy Drive Dell OptiPlex Desktop or Minitower (341-3840) |
| **Floppy Disk Drive:** | Cable for 3.5IN, 1.44MB Floppy Drive, Dell OptiPlex Minitower (330-0474) |
| **Operating System:** | Windows XP PRO SP3 with Windows Vista Business LicenseEnglish, Dell Optiplex (420-9570) |
| **Mouse:** | Dell USB 2 Button Optical Mouse with Scroll, Black OptiPlex (330-2733) |
| **NIC:** | Intel Standard Manageability Hardware Enabled Systems Management, Dell OptiPlex (330-2902) |
| **CD-ROM or DVD-ROM Drive:** | 16X DVD+/-RW and 16X DVD, Data Only, Dell OptiPlex Minitower Black (313-7064) |
| **CD-ROM or DVD-ROM Drive:** | Cyberlink Power DVD 8.2, with Media, Dell Relationship LOB (421-0536) |
| **CD-ROM or DVD-ROM Drive:** | OPEN MARKET - Roxio Creator Dell Edition 10.3, Media, Dell RLOB (421-1189) |
| **Sound Card:** | Performance Core2Quad Dell OptiPlex 760 Minitower (317-0595) |
| **Speakers:** | Internal Chassis Speaker Option, Dell OptiPlex Minitower (313-3350) |
| **Cable:** | OptiPlex 760 Minitower Quad Standard Power Supply (330-3676) |
| **Documentation Diskette:** | Documentation, English, Dell OptiPlex (330-1710) |
| **Documentation Diskette:** | Power Cord, 125V, 2M, C13, Dell OptiPlex (330-1711) |
| **Factory Installed Software:** | No Dell Energy Smart Power Management Settings, OptiPlex (467-3564) |
| **Feature** | No Resource DVD for Dell Optiplex, Latitude, Precision (313-3673) |
| **Service:** | Basic Support: Next Business Day Parts and Labor Onsite Response 2 Year Extended (991-3622) |
| **Service:** | Basic Support: Next Business Day Parts and Labor Onsite Response Initial Year (991-6350) |
| **Service:** | Dell Hardware Limited Warranty Plus Onsite Service Extended Year(s) (992-6508) |
| **Service:** | Dell Hardware Limited Warranty Plus Onsite Service Initial Year (992-6507) |
| **Installation:** | Standard On-Site Installation Declined (900-9987) |
| **Installation:** | Standard On-Site Installation Declined (900-9987) |
| **Service One:** | Keep Your Hard Drive, 3 Year (984-0102) |
| **Misc:** | Shipping Material for System Smith Minitower, Dell OptiPlex (330-1186) |
| | Vista Premium Downgrade Relationship Desktop (310-9161) |

## Appendix C:  Parts List of Copper and Aluminum Service Panels

C.E.S. (Garner)
214-A Garner Business Court,
Garner NC, 27529.

Phone: 919-661-1155
Fax: 919-661-8866
Email: Garner0015@ces-us.net

PACKING SLIP

GAR/031103

Date: 01 Oct 2008

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Entered by: Robert Carr

ARCADIS US INC
4915 PROSPECTUS DR
SUITE F
DURHAM NC
27713

Account: 00150396001

Order Number: EPA

| Qty | Item | Description | $ Price Per | $ Goods |
|---|---|---|---|---|
| 84 | BR110 | SP 10A BR BREAKER | 5.27 E | 442.68 * |
| 1 | SHIPPING & HANDLING | SHIPPING & HANDLING | 82.15 E | 82.15 * |
| 14 | P&S PS5266-X | 15A 125V PLUG | 6.86 E | 96.04 |
| 100 | SO-14/3 | SO-14/3 | 936.02 M | 93.60 |
| 14 | MADISON MCG-50A560 | 1/2 CORD CONN | 449.00 C | 62.86 |
| 14 | C-H BR24L70FGP | 70A MLO FL LD CTR | 26.00 E | 364.00 |
| 100 | MADISON L-51 | 3/8 2SCR NMC CONN | 25.30 C | 25.30 |
| 30 | NM-B-14/2 ALUM | 14/2 ALUM ROMEX | 500.00 M | 15.00 |
| 250 | NM-B-14/2-CU-250C | NM-B-14/2-CU-WG-250CL | 215.00 M | 53.75 |
| 14 | RACO 192 | 4SQ 1-1/2D BOX COMB KO | 94.50 C | 13.23 |
| 7 | P&S 3232-I | DPLX RCPT-NEMA5-15R | 55.00 C | 3.85 |
| 7 | P&S 660-IG | SP 15A120V GRD AC SW | 74.50 C | 5.22 |
| 14 | MADISON CPB-50 | 1/2 PLSTC INS BUSH | 12.86 C | 1.80 |
| 14 | P&S TPJ18-I | IV 2G TOG/DPLX PLT | 66.07 C | 9.25 |
| 14 | RACO 778 | 4-IN SQ 1/2D 2G SW RING | 183.74 C | 25.72 |

Goods Total: $1294.45
Tax Total: $87.38
Total: $1381.83

Signature: ____________________ Print Name: ____________________

THE RISK IN THE GOODS SHALL PASS TO THE BUYER ON DELIVERY, BUT THE GOODS REMAIN THE PROPERTY OF THE SELLER UNTIL PAID FOR.
GOODS ARE SOLD ACCORDING TO VENDORS AND OUR OWN CONDITIONS OF SALE, COPIES OF WHICH ARE AVAILABLE UPON REQUEST.

E&OE DM/01

## Appendix D: Subsystems of Category 4 Computers (Provided by Alcatel-Lucent)

| # | Major subsystem | Description | Chipsets involved | PC-Doctor® Tests this subsystem (yes/no) |
|---|---|---|---|---|
| 1 | Motherboard | Dual processor CPU chip | Intel® Core™ 2 Duo E6400 | y |
| 2 | Motherboard | Dual processor CPU heat sink | Intel® Core™ 2 Duo E6400 | y |
| 3 | Motherboard | IO Controller IC | Intel® 82801HB/82801HR ICH8 | y |
| 4 | Motherboard | CMOS (CMOS RAM with RTC & NVRAM) | Intel® 82801HB/82801HR ICH8 | y |
| 5 | Motherboard | SDRAM memory cards (DIMM) | Hyundai 512 MB DDRW-SDRAM | y |
| 6 | Mthbd card connector | SRAM DIMM module board mounted connector | | y |
| 7 | Motherboard | Graphics and Memory Controller Hub | Intel® 82Q965 | y |
| 8 | Motherboard | Intel 82Q965 heat sink | Intel® 82Q966 | y |
| 9 | Motherboard | SPI (Serial Peripheral Interface) Flash Device: ROM BIOS FWH (firmware hub) : contains BIOS Setup program POST, PCI auto-config and Plug&Play support | MXIC MX25L8005 | y |
| 10 | Motherboard | SuperIO Controller (contains floppy drive controller, serial port controller, parallel port controller, power management (fan) controller | SMSC SCH5514D-NS | y |
| 11 | Motherboard | LPC Interface TPM (Trusted Platform Module) protects signature keys and encryption | | n |
| 12 | Motherboard | Lan-On-Motherboard (NIC) with 10/100/GbE support | Broadcom BCM5754KM Ethernet NIC and ATMEL AT45DB001B Flash SPI memory device | y |
| 13 | Motherboard | Battery (3V Lithium) | Panasonic CR2032 3V | y |
| 14 | Motherboard | Audio CODEC (compression/decompression) | Analog Devices HO Audio SoundMAX CODEC AD1983 | y |
| 15 | Motherboard | Frequency timing generator/Real time clock | Intel® Core 2 Duo E6400, ICS9LP5052 and 32.768k crystal clock chip | y |
| 16 | Motherboard | battery -- mount and socket | | n |
| 17 | MthBd cable connector | SATA Drive0 (hard drive) | Intel® 82801HB/82801HR ICH8 | y |

| # | Major subsystem | Description | Chipsets involved | PC-Doctor® Tests this subsystem (yes/no) |
|---|---|---|---|---|
| 18 | MthBd cable connector | SATA Drive1 (DVD drive) | Intel® 82801HB/82801HR ICH8 | y |
| 19 | MthBd cable connector | SATA Drive4 (not connected) | Intel® 82801HB/82801HR ICH8 | n |
| 20 | MthBd cable connector | SATA Drive5 (not connected) | Intel®82801HB/82801HR ICH8 | n |
| 21 | MthBd cable connector | Front Panel Connector (ON/OFF switch, 2 USB ports, front audio in/out ports) | | y |
| 22 | MthBd card connector | PCI Expressx16 connector (SLOT1) (not connected) | | n |
| 23 | MthBd card connector | PCI Expressx16 connector (SLOT4) (not connected) | | n |
| 24 | MthBd card connector | PCI Connector (SLOT2) | | y |
| 25 | MthBd card connector | PCI Connector (SLOT3) | | y |
| 26 | MthBd cable connector | Floppy drive connector | | y |
| 27 | MthBd cable connector | Serial connector (not connected) | | n |
| 28 | MthBd cable connector | Fan connector | | n |
| 29 | MthBd cable connector | Internal Speaker connector (not connected) | | n |
| 30 | MthBd cable connector | Processor power connector (4 pin) | | y |
| 31 | MthBd cable connector | Main power connector (24 pin) | | y |
| 32 | MthBd component | Beep speaker | | n |
| 33 | MthBd component | Capacitor | | n |
| 34 | MthBd component | Resistor | | n |
| 35 | MthBd component | Transistor | | n |
| 36 | MthBd component | Choke | | n |
| 37 | MthBd component | Solder bond pad -- specify location | | n |
| 38 | MthBd component | screws and other mounting hardware | | n |
| 39 | Fan | Main chassis fan | | n |
| 40 | Power supply module | Electrical function | | y |
| 41 | Power supply module | Mains power plugs (110V) | | n |
| 42 | Power supply module | Chassis | | n |

| # | Major subsystem | Description | Chipsets involved | PC-Doctor® Tests this subsystem (yes/no) |
|---|---|---|---|---|
| 43 | Power supply cable to motherbrd 24 pin conn | Power cable | | y |
| 44 | Floppy disk drive | Chassis | | n |
| 45 | Floppy disk drive | Motor | | y |
| 46 | Floppy disk drive | Head | | y |
| 47 | Floppy disk drive | Power connector | | y |
| 48 | Floppy disk drive | Power cable | | y |
| 49 | Floppy disk drive | Data cable | | y |
| 50 | Hard drive | Chassis | | n |
| 51 | Hard drive | Motor | | y |
| 52 | Hard drive | Head | | y |
| 53 | Hard drive | Power connector | | y |
| 54 | Hard drive | Power cable | | y |
| 55 | Hard drive | Data cable | | y |
| 56 | DVD Drive | Chassis | | n |
| 57 | DVD Drive | Drive motor | | y |
| 58 | DVD Drive | Head | | y |
| 59 | DVD Drive | Power connector | | y |
| 60 | DVD Drive | Power cable | | y |
| 61 | DVD Drive | Data cable | | y |
| 62 | DVD Drive | Drawer open/close on chassis | | y |
| 63 | Monitor | Screen | | y |
| 64 | Monitor | Data Cable | | y |
| 65 | Monitor | Data Cable connector | | y |
| 66 | Monitor | Power Cable | | y |
| 67 | Monitor | Power Cable 110V plug | | y |
| 68 | Monitor | Video connector on chassis | | y |
| 69 | Monitor | Base of monitor stand | | n |
| 70 | Mouse | USB Data Cable | | y |
| 71 | Mouse | Mechanical operation | | y |
| 72 | Keyboard | USB Data Cable | | y |
| 73 | Keyboard | Mechanical operation | | y |
| 74 | Commun. Port COM1 | COM1 connector on chassis | | y |
| 75 | Printer Port LPT1 | LPT1 connector on chassis | | y |

| # | Major subsystem | Description | Chipsets involved | PC-Doctor® Tests this subsystem (yes/no) |
|---|---|---|---|---|
| 76 | USB Port 1 keyboard | USB connector on chassis | | y |
| 77 | USB Port 2 mouse | USB connector on chassis | | y |
| 78 | USB Port 1 | USB connector on chassis | | y |
| 79 | USB Port 2 | USB connector on chassis | | y |
| 80 | USB Port 3 | USB connector on chassis | | y |
| 81 | USB Port 4 | USB connector on chassis | | y |
| 82 | USB Port 5 | USB connector on chassis | | y |
| 83 | USB Port 6 | USB connector on chassis | | y |
| 84 | Network (LAN) Port | Network (LAN) adapter connector on chassis | | y |
| 85 | Audio out | Audio line out connector (green) on chassis | | y |
| 86 | Audio in | Audio line in connector (blue & pink) on chassis | | y |
| 87 | CASE | Removable side of case | | n |
| 88 | CASE | Case interior floor | | n |
| 89 | CASE | Case back panel screens | | n |
| 90 | CASE | Case front panel | | n |
| 91 | CASE | PCI Plates | | n |
| 92 | CASE | Release Latch | | n |
| 93 | CASE | Screws on exterior | | n |

## Appendix E: PC-Doctor® Service Center™ 7.5 Tests

| Test # | Test |
|---|---|
| **System Board** | |
| 1 | RTC Rollover Test |
| 2 | RTC Accuracy Test |
| **Intel® Core™ 2 CPU 6400 @ 2.13GHz CPU:0** | |
| 3 | Register Test |
| 4 | Level 2 Cache Test |
| 5 | Math Register Test |
| 6 | MMX Test |
| 7 | SSE Test |
| 8 | SSE2 Test |
| 9 | SSE3 Test |
| 10 | SSSE3 Test |
| 11 | Stress Test |
| 12 | Multicore Test |
| **Intel® Core™ 2 CPU 6400 @ 2.13GHz CPU:1** | |
| 13 | Register Test |
| 14 | Level 2 Cache Test |
| 15 | Math Register Test |
| 16 | MMX Test |
| 17 | SSE Test |
| 18 | SSE2 Test |
| 19 | SSE3 Test |
| 20 | SSSE3 Test |
| 21 | Stress Test |
| 22 | Multicore Test |
| **CMOS** | |
| 23 | Checksum Test |
| 24 | Pattern Test |
| **512 MB DDR2-SDRAM (666 MHz)** | |
| 25 | Pattern Test |
| 26 | Advanced Pattern Test |
| 27 | Bit Low Test |
| 28 | Bit High Test |
| 29 | Nibble Move Test |
| 30 | Checkerboard Test |
| 31 | Walking One Left Test |
| 32 | Walking One Right Test |
| 33 | Auxiliary Pattern Test |
| 34 | Address Test |
| 35 | Modulo20 Test |
| 36 | Moving Inversion Test |

| | |
|---|---|
| **C:** | |
| 37 | Linear Seek Test |
| 38 | Random Seek Test |
| 39 | Funnel Seek Test |
| 40 | Surface Scan Test |
| 41 | SMART Status Test |
| 42 | SMART Short Self Test |
| 43 | SMART Extended Self Test |
| 44 | SMART Conveyance Self Test |
| **HL-DT-ST DVD+-RW GSA-H31N** | |
| 45 | (DVD-RW Drive) Read Write Test |
| 46 | (DVD-R Drive) Read Write Test |
| 47 | (CD-R Drive) Read Write Test |
| 48 | (DVD Drive) Linear Seek Test |
| 49 | (DVD Drive) Random Seek Test |
| 50 | (DVD Drive) Funnel Seek Test |
| 51 | (DVD Drive) Linear Read Compare Test |
| 52 | (DVD+R DL Drive) Read Write Test |
| 53 | (DVD+RW Drive) Read Write Test |
| 54 | (DVD+R Drive) Read Write Test |
| 56 | (CD-RW Drive) Read Write Test |
| 57 | CD-ROM Drive) Linear Seek Test |
| 58 | (CD-ROM Drive) Random Seek Test |
| 59 | (CD-ROM Drive) Funnel Seek Test |
| 60 | (CD-ROM Drive) Linear Read Compare Test |
| 61 | (CD-ROM Drive) CD Audio Test |
| **Floppy disk drive** | |
| 62 | Linear Seek Test |
| 63 | Random Seek Test |
| 64 | Funnel Seek Test |
| 65 | Surface Scan Test |
| **PCDoctor® USB Test Key 2.0 USB Device** | |
| 66 | Scan Test Port 1 |
| 67 | Scan Test Port 2 |
| 68 | Scan Test Port 3 |
| 69 | Scan Test Port 4 |
| 70 | Scan Test Port 5 |
| 71 | Scan Test Port 6 |
| **Intel® Q965/Q963 Express Chipset Family** | |
| 72 | Primary Surface Test |
| 73 | Fixed Transformation and Lighting Test |
| 74 | Transformation and Lighting Stress Test |
| **Intel® Q965/Q963 Express Chipset Family** | |
| 75 | Primary Surface Test |

| | |
|---|---|
| 76 | Fixed Transformation and Lighting Test |
| 77 | Transformation and Lighting Stress Test |
| **Broadcom NetXtreme 57xx Gigabit Controller** | |
| 78 | Network Link Test |
| 79 | TCP/IP Internal Loopback Test |
| 80 | Network External Loopback Test |
| **HID Keyboard Device** | |
| 81 | Keyboard Interactive Test |
| **Dell™ USB Mouse** | |
| 82 | Mouse Interactive Test |
| **SoundMAX Integrated Digital HD Audio Driver** | |
| 83 | Playback Mixer State Test |
| 84 | Sound Interactive Test |
| **Intel® Q965/Q963 Express Chipset Family** | |
| **85** | Audio Visual Interleave (AVI) Interactive Test |
| **Dell ™ E157FP (Plug and Play Monitor)** | |
| 86 | Monitor Interactive Test |
| **Communications Port (COM1)** | |
| 87 | External Register Test |
| 88 | External Loopback Test |
| 89 | Internal Register Test |
| 90 | Internal Control Signals Test |
| 91 | Internal Send and Receive Test |
| **ECP Printer Port (LPT1)** | |
| 92 | Internal Read and Write Test |
| 93 | External Read and Write Test |
| **PCI Bus** | |
| 94 | Configuration Test |
| **PCDoctor® USB Test Key 2.0 USB Device** | |
| 95 | USB Status Test |
| **Dell™ USB Keyboard** | |
| 96 | USB Status Test |
| **Dell™ USB Mouse** | |
| 97 | USB Status Test |
| Intel® Q963/Q965 PCI Express Root Port – 2991 | |
| 98 | PCI Express Status Test |
| **Microsoft UAA Bus Driver for High Definition Audio** | |
| 99 | PCI Express Status Test |
| **Intel® ICH8 Family PCI Express Root Port 1 - 283F** | |
| 100 | PCI Express Status Test |
| **Intel® ICH8 Family PCI Express Root Port 5 - 2847** | |
| 101 | PCI Express Status Test |
| **Broadcom NetXtreme 57xx Gigabit Controller** | |
| 102 | PCI Express Status Test |

| SoundMAX Integrated Digital HD Audio Driver | |
|---|---|
| 103 | Rough Audio Test |
| **Batch 5** | |
| 104 | System Timer |
| 105 | BIOS Timer |
| 106 | IRQ Controller |
| 107 | DMA Channels |
| 108 | RAM Refresh |
| 109 | RTC Clock |
| 110 | CMOS RAM |
| 111 | Keyboard |
| 112 | PCI |
| 113 | USB Port |
| 114 | Video Memory |
| 115 | Video Pages |
| 116 | VGA Controller Registers |
| 117 | VGA Color-DAC Registers |
| 118 | VESA Full Video Memory Test |
| 119 | COM 1 Registers And Interrupts |
| 120 | COM 1 Internal Loopback |
| 121 | COM 1 FIFO Buffers (16550A) |
| 122 | LPT 1 Command And Data Port |
| 123 | SMBUS |
| **Batch 4** | |
| 124 | CPU 1 CPU Registers |
| 125 | CPU 1 CPU Arithmetics |
| 126 | CPU 1 CPU Logical Operations |
| 127 | CPU 1 CPU String Operations |
| 128 | CPU 1 CPU Misc Operations |
| 129 | CPU 1 CPU Interrupts/Exceptions |
| 130 | CPU 1 CPU Buffers/Cache |
| 131 | CPU 1 CoProc Registers |
| 132 | CPU 1 CoProc Commands |
| 133 | CPU 1 CoProc Arithmetics |
| 134 | CPU 1 CoProc Transcendental |
| 135 | CPU 1 CoProc Exceptions |
| 136 | CPU 1 MMX Test |
| 137 | CPU 2 CPU Registers |
| 138 | CPU 2 CPU Arithmetics |
| 139 | CPU 2 CPU Logical Operations |
| 140 | CPU 2 CPU String Operations |
| 141 | CPU 2 CPU Misc Operations |
| 142 | CPU 2 CPU Interrupts/Exceptions |
| 143 | CPU 2 CPU Buffers/Cache |

| | |
|---|---|
| 144 | CPU 2 CoProc Registers |
| 145 | CPU 2 CoProc Commands |
| 146 | CPU 2 CoProc Arithmetics |
| 147 | CPU 2 CoProc Transcendental |
| 148 | CPU 2 CoProc Exceptions |
| 149 | CPU 2 MMX Test |
| 150 | Base Fast Pattern |
| 151 | Base Fast Address |
| 152 | Base Medium Pattern |
| 153 | Base Medium Address |
| 154 | Base Heavy Pattern |
| 155 | Base Heavy Address |
| 156 | Base Bus Throughput |
| 157 | Extended Fast Pattern |
| 158 | Extended Fast Address |
| 159 | Extended Medium Pattern |
| 160 | Extended Medium Address |
| 161 | Extended Heavy Pattern |
| 162 | Extended Heavy Address |
| 163 | Extended Code Test |
| 164 | Extended Advanced Pattern |
| **PCI post Card Test** | |
| 165 | D1 |
| 166 | D2 |
| 167 | D3 |
| 168 | D4 |
| 169 | D5 |
| 170 | D6 |
| **Power Supply Tests** | |
| 171 | 20/24 |
| 172 | Motherboard |
| 173 | Hard drive |
| 174 | DVD drive |
| 175 | Floppy Drive |

SCIENCE

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Washington, DC 20460