EDGEWOOD

CHEMICAL BIOLOGICAL CENTER

U.S. ARMY RESEARCH, DEVELOPMENT AND ENGINEERING COMMAND

ECBC-TR-661

EFFECTS OF VAPORIZED DECONTAMINATION SYSTEMS ON SELECTED BUILDING INTERIOR MATERIALS: VAPORIZED HYDROGEN PEROXIDE

Mark D. Brickhouse
Teri Lalain
Philip W. Bartram
Monicia Hall
Zoe Hess
Louis Reiff
Brent Mantooth

RESEARCH AND TECHNOLOGY DIRECTORATE

Zach Zander
David Stark
Pamela Humphreys
Barry Williams

SCIENCE APPLICATIONS INTERNATIONAL CORPORATION
Gunpowder, MD 21010-0068

Shawn Ryan
Blair Martin

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
Research Triangle Park, NC 27711

Approved for public release; distribution is unlimited.

January 2009

20090409210

ABERDEEN PROVING GROUND, MD 21010-5424

Disclaimer

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorizing documents.

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
XX-01-2009	Final	Nov 2003 – Jun 2006

4. TITLE AND SUBTITLE
Effects of Vaporized Decontamination Systems on Selected Building Interior Materials: Vaporized Hydrogen Peroxide

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
EPA IAG DW 939917-01-0

6. AUTHOR(S)
Brickhouse, Mark D., Lalain, Teri, Bartram, Philip W., Hall, Monicia, Hess, Zoe, Reiff, Louis, Mantooth, Brent (ECBC); Zander, Zach, Stark, David, Humphreys, Pamela, Williams, Barry (SAIC); Ryan, Shawn, and Martin, Blair (EPA)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) AND ADDRESS(ES)
DIR, ECBC, ATTN: AMSRD-ECB-RT-PD//AMSRD-ECB-RT-BD, APG, MD 21010-5424
SAIC, P.O. Box 68, Gunpowder, MD 21010-0068
U.S. EPA Office of Research and Development National Homeland Security Research Center, 109 T. W. Alexander Dr., Research Triangle Park, NC 27711

8. PERFORMING ORGANIZATION REPORT NUMBER
ECBC-TR-661

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Environmental Protection Agency/National Homeland Security Research Center 109 T.W. Alexander Drive Research Triangle Park, NC 27711

10. SPONSOR/MONITOR'S ACRONYM(S)
EPA/NHSRC

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT:
To address Homeland Security needs for decontamination, the U.S. Environmental Protection Agency (EPA) established an Interagency Agreement with the U.S. Army Edgewood Chemical Biological Center (ECBC) to take advantage of ECBC's extensive expertise and specialized research facilities for the decontamination of surfaces contaminated with chemical and biological (CB) warfare agents. The National Homeland Security Research Center (NHSRC) formed collaboration with ECBC in a mutual leveraging of resources expanding upon ECBC's on-going programs in CB decontamination to more completely address the parameters of particular concern for decontamination of indoor surfaces in buildings following a terrorist attack using CB agents. Vaporized hydrogen peroxide (VHP) and ClO_2 are decontamination technologies that have been used to decontaminate indoor surfaces contaminated with anthrax and show potential for use in decontaminating indoor surfaces contaminated by chemical agents. This program is specifically focused on decontamination of the building environment for purposes of restoring a public building to a usable state after a terrorist contamination episode. Since building interiors may contain a large surface composed of concrete cinder block, wood, steel, carpet, ceiling suspension tile, and painted wallboard, the effort was designed to determine how building materials are affected by the decontaminant. The focus of this technical report is the evaluation of the building interior materials and the Steris VHP technology.

15. SUBJECT TERMS
Material Compatibility VHP vaporized hydrogen peroxide

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Sandra J. Johnson
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. TELEPHONE NUMBER** *(include area code)*
U	U	U	UL	55	(410) 436-2914

Blank

PREFACE

To address homeland security needs for decontamination, the U.S. Environmental Protection Agency (EPA) established an Interagency Agreement with the U.S. Army Edgewood Chemical Biological Center (ECBC) to take advantage of ECBC's extensive expertise and specialized research facilities for the decontamination of surfaces contaminated with chemical and biological (CB) warfare agents. This report was published through the Technical Releases Office; however, it was edited and prepared by the Decontamination Sciences Branch, Research and Technology Directorate, ECBC.

The National Homeland Security Research Center (NHSRC) formed a collaboration with ECBC to more completely address the impact of decontaminants on indoor surfaces in buildings. The work was completed under EPA IAG DW 939917-01-0. The work discussed in this report was started in November 2003 and completed in June 2006.

The use of either trade or manufacturers' names in this report does not constitute an official endorsement of any commercial products. Manufacturer names and model numbers are provided for completeness. This technical report may not be cited for purposes of advertisement.

This report has been approved for public release. Registered users should request additional copies from the Defense Technical Information Center; unregistered users should direct such requests to the National Technical Information Service.

Acknowledgements

A program cannot be successfully completed without the contributions of a good team. The authors thank the following individuals for their hard work and assistance with the execution of this technical program:

- David Sorrick (ECBC) for his assistance in acquiring the test equipment and design and construction of the circuit breaker test stations.
- Dr. David Cullinan (Science Applications International Corporation) for preparing many coupon run baskets, coupon measurements, and chain-of-custody forms during the time his assigned laboratory was closed.

Blank

CONTENTS

FIGURES

TABLES

Blank

EFFECTS OF VAPORIZED DECONTAMINATION SYSTEMS ON SELECTED BUILDING INTERIOR MATERIALS: VAPORIZED HYDROGEN PEROXIDE

1. INTRODUCTION

The material compatibility effort was designed to determine how the decontaminant vapors impact building materials within an enclosed building interior space. Since building interiors may contain large surfaces of complex material compositions and electrical components such as circuit breakers, data are needed to determine how such materials are affected by exposure to the vapor. Vaporized hydrogen peroxide (VHP) and ClO_2 were selected since these decontamination technologies have been used to decontaminate indoor surfaces contaminated by anthrax and/or show potential for use in decontaminating indoor surfaces contaminated by chemical agents. The representative building interior materials tested were unpainted concrete cinder block, standard stud lumber (wood 2 in. by 4 in., fir), latex-painted ½-in. gypsum wallboard, ceiling suspension tile, painted structural steel, and carpet. The physical properties of the building materials were measured using ASTM test methods. The material compatibility studies also investigated electrical breakers using Underwriters Laboratories (UL) test methods. Specialized chemical testing was conducted to determine if chemical changes occurred in select building materials. In addition, visual appearance was documented. This report contains the results for the VHP-exposed coupon material compatibility tests. The ClO_2 results are documented in a separate report.

2. SUMMARY OF CONCLUSIONS

In general, the VHP-exposed building materials showed no change in appearance or integrity compared to non-exposed samples. The samples were evaluated for outliers using the Dixon's Q-Test in accordance with (IAW) ASTM Method E 178 and for statistically demonstrated differences using the Welch's *t* test. The following list contains the summary of conclusions from this technical report:

- <u>Painted Structural Steel</u>: The fumigated structural steel coupons showed some minor changes (1–3%) in tensile strength when compared to the control coupons. All samples were above the specified tensile strength requirements of the ASTM test (20% or more). There is no obvious change in the potential for failure of the steel after a fumigation using VHP.
- <u>Gypsum Wallboard</u>: Exposure to VHP makes gypsum wallboard more resistant to penetration by a nail.
- <u>Ceiling Tile</u>: Exposure to VHP causes a small increase in the breaking force of the ceiling tile coupons.
- <u>Carpet</u>: Exposure to VHP appears to slightly increase the force required to pull the carpet tuft bind.
- <u>Concrete Cinder Block</u>: The fumigated concrete cinder blocks did not exhibit any changes from the control samples. There is no evidence to indicate that fumigation with VHP has any effect on the cinder blocks.
- <u>Wood</u>: The fumigated pine furring strips exhibited no statistically detectible changes from the control samples; however, a very minor trend of increasing maximum force and increasing time to break were observed.
- <u>Circuit Breaker</u>: Exposure to VHP presented a conflicting picture of the effects on circuit breakers. Under the 60 amp challenge, exposed circuit breakers trip more rapidly than the controls. Under the 30 amp challenge, the circuit breakers trip more slowly than the controls. Either situation could present a problem to the user. Failure

criteria must be established to determine if the changes observed in this test present an acceptable response.

- Visual Inspection: No differences were observed for any of the coupons after VHP exposure and aging compared to before VHP exposure.

3. BACKGROUND

To address homeland security needs for decontamination, the U.S. Environmental Protection Agency (EPA) established an Interagency Agreement with the U.S. Army Edgewood Chemical Biological Center (ECBC) to take advantage of ECBC's extensive expertise and specialized research facilities for the decontamination of surfaces contaminated with chemical and biological (CB) warfare agents. The National Homeland Security Research Center (NHSRC) formed a collaboration with ECBC in a mutual leveraging of resources, expanding upon ECBC's on-going programs in CB decontamination to more completely address the parameters of particular concern for decontamination of indoor surfaces in buildings following a terrorist attack using CB agents, toxic industrial chemicals (TICs), or toxic industrial materials. In the context of decontamination, the contaminants of interest are those that can persist on indoor surfaces leading to continuing chance of exposure long after the contamination occurs. The VHP and ClO_2 are decontamination technologies that have been used to decontaminate indoor surfaces contaminated with anthrax spores and show potential for use in decontaminating indoor surfaces contaminated by some chemical agents. This program is specifically focused on decontamination of the building environment for purposes of restoring a public building to a usable state after a terrorist contamination episode. Systematic testing of decontamination technologies generates objective performance data, so building and facility managers, first responders, groups responsible for building decontamination, and other technology buyers and users can make informed purchase and application decisions.

Since building interiors may contain a large surface composed of complex materials, the material compatibility effort was designed to determine how the decontaminant vapors impact building materials within an enclosed building interior space. The objective of this study was to conduct laboratory test procedures to determine to what degree building materials were affected by decontamination using VHP and ClO_2. The building interior materials used for testing were a subset of the variety of structural, decorative, and functional materials common to commercial office buildings, regardless of architectural style and age. The building materials encompassed a variety of material compositions and porosities; the materials studied included unpainted concrete cinder block, standard stud lumber (wood 2 in. by 4 in., fir, type II), latex-painted ½-in. gypsum wallboard, acoustical ceiling suspension tile, primer-painted structural steel, and carpet. The material compatibility studies also investigated material(s) related to electrical breaker connections. The physical appearance was documented by visual inspection of the test material. The physical properties of the building materials were measured using standardized ASTM and UL test methods.

The process for exposing the building material samples to VHP and results for the material demand study are documented in a separate report titled, *Material Demand Studies: Materials Sorption of Vaporous Hydrogen Peroxide*, by Lawrence Procell, et. al. This testing followed the operating procedures specific to the Steris technology.

The VHP technology developed by STERIS (EPA registration #58779-4) has been in use for more than a decade. The VHP fumigant was initially used to sterilize pharmaceutical processing equipment and clean rooms.[1,2] In response to the anthrax attacks of October 2001, STERIS adapted its VHP technology to perform the decontamination of two U.S. government facilities: (1) General Services Administration Building 410, Anacostia Naval Base, Washington, DC, and (2) U.S. Department of State SA-32, Sterling, VA, mail center.

Decontamination of an interior space using VHP is a four-phase process involving preparation of the building interior air (dehumidification), achieving a steady state decontaminant level (conditioning), performing the decontamination, and then aerating for safe reentry (Figure 1).[3]

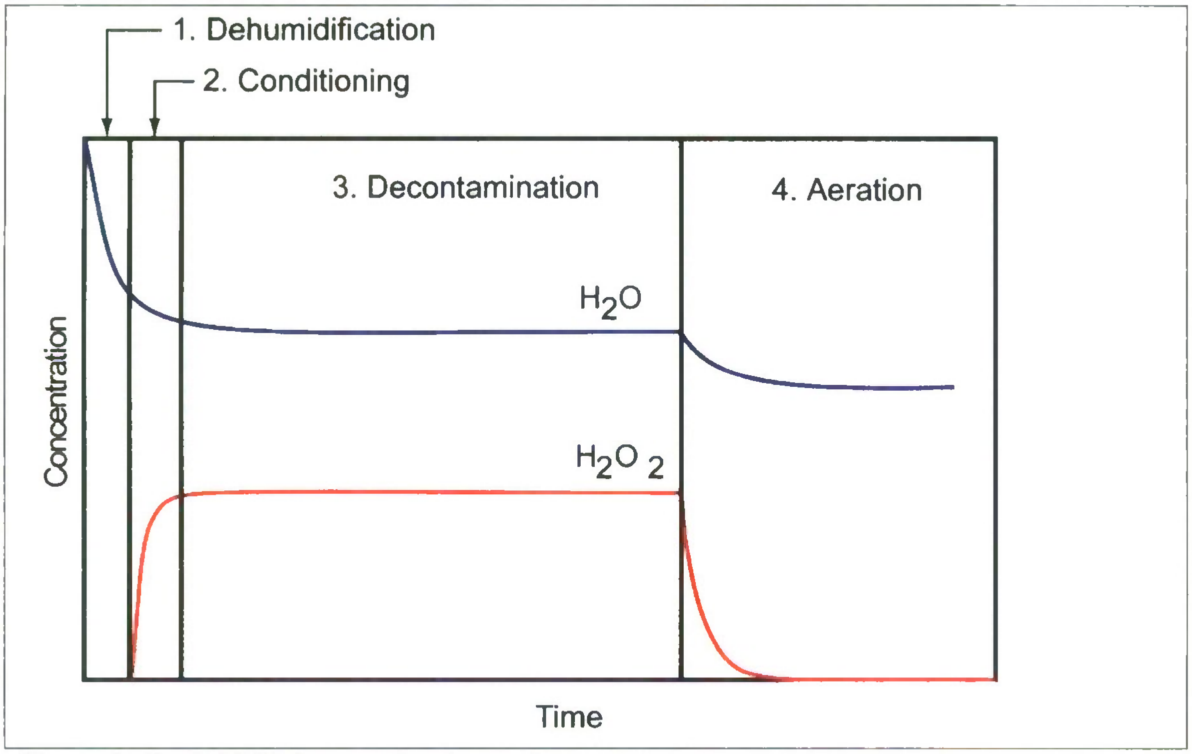


Figure 1. Steris VHP decontamination cycle.

(1) Dehumidification: Hydrogen peroxide vapor can co-condense with water vapor, producing an undesired condensate high in hydrogen peroxide. If ambient conditions are likely to permit condensation—high humidity and/or cold temperatures—this can be prevented by circulating dry, heated air through the interior prior to injection of the hydrogen peroxide vapor. The target humidity level is determined by the concentration of vapor to be injected and desired steady state concentration for the decontamination. The lower relative humidity (RH) permits a higher concentration of hydrogen peroxide without reaching a saturation point. For this study, the maximum RH at start-of-run (prior to introducing decontaminant) was 30%.

(2) Conditioning: During the conditioning phase, the injection of hydrogen peroxide vapor is initiated at a rapid rate to achieve the desired chamber concentration set point without condensation. Once the target concentration is achieved, the injection rate was lowered to maintain the set point concentration.

(3) Decontamination: Decontamination is a timed phase dependent on the hydrogen peroxide vapor concentration. In actual building applications, a decontamination timer counts down from the preset decontamination time. If the concentrations or temperature values fall below the set point, the timer stops. This ensures that, during the decontamination phase, the building interior is exposed to at least the minimum decontamination conditions for the desired exposure time. For this laboratory-scale study, the enclosure VHP concentration was maintained within the target concentration range.

(4) Aeration: After completion of the decontamination phase, the hydrogen peroxide injection is terminated. Air is introduced into the chamber. The air displaces the hydrogen peroxide. The system is monitored until the hydrogen peroxide concentrations falls to a safe level for coupon removal.

4. EXPERIMENTATION

The material compatibility testing was conducted in compliance with the Quality Assurance Project and Work Plan[4] developed under the Quality Management Plans[5,6] and EPA E4 quality system requirements.[7-10]

4.1 Coupon Preparation

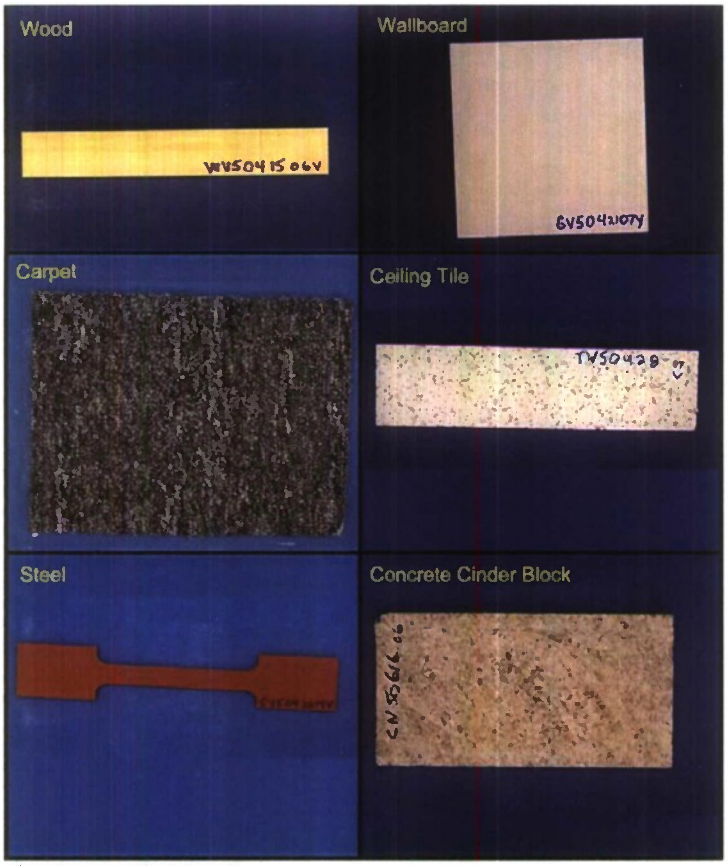
Test coupons were prepared IAW the ASTM testing requirements for the material compatibility testing. The coupons were cut from stock material IAW the procedure in Appendix B of the Quality Assurance Project Plan (QAPP),[11] which has been reproduced as Appendix B of this report. Coupons were prepared by obtaining a large enough quantity of material that multiple test samples could be obtained with uniform characteristics (e.g., test coupons were all cut from the interior rather than the edge of a large piece of material). The building materials studied, including supplier and coupon dimensions, are provided in Table 1 and Figure 2.

Table 1. Representative building interior material list.

Material	Code	Supplier	Length (in.)	Width (in.)	Thickness (in.)
Structural Wood, fir, type-II	W	Home Depot	10 ± 0.062	1.5 ± 0.062	0.5 ± 0.03125
Latex-Painted Gypsum Wallboard	G	Home Depot	6 ± 0.062	6 ± 0.062	0.5 ± 0.062
Concrete	C	York Supply	4 ± 0.5	8 ± 0.5	1.5 ± 0.1875
Carpet	R	Home Depot	6 ± 0.5	8 ± 0.125	N/A
Painted Structural Steel	S	Specialized Metals	12 ± 0.062	2 ± 0.0625 0.75 ± 0.062	0.25 ± 0.00781
Ceiling Suspension Tile, Acoustical	T	Home Depot	12. ± 0.125	3 ± 0.062	0.56 ± 0.062
Circuit Breakers	B	Home Depot	N/A	N/A	N/A

Chain-of-custody (CoC) cards were used to ensure that the test coupons were traccable throughout all phases of testing. The test coupons were measured and visually inspected prior to testing. Coupons were measured to ensure that the test coupon was within the acceptable tolerances (Appendix A). Coupons were visually inspected for defects and/or damage. Coupon mcasurements and visual inspection were recorded on the CoC card. Coupons that werc not within the allowable size tolerances and/or damaged were discarded. Each coupon was assigned a unique identifier code that matches thc coupon with the sample, test parameters, and sampling scheme (Appendix B). The unique identifier code was recorded on the CoC form. The CoC cards followed each sample from exposure testing through material compatibility testing to disposal.

The material compatibility studies also investigated materials related to electrical breaker connections such as intact circuit breakers. The circuit breakers were one-pole circuit breakers (HOM120, 2400 watts, 120/240 V, 20 amp).



*Coupons are not shown to scale

Figure 2. Representative photograph of the test coupons.

4.2 Coupon Exposure: Wood, Wallboard, Ceiling Tile, Steel, Carpet, and Concrete Cinder Block

The process for exposing the building material samples to VHP and results for the material demand study are documented in a separate report titled "*Material Demand Studies: Materials Sorption of Vaporous Hydrogen Peroxide*", by Lawrence Procell, et. al. This testing followed the operating procedures specific to the Steris technology. A brief overview of the exposure process is provided in this section; the material demand report contains the detailed test information and results.

The coupons were placed in the exposure chamber. The humidity inside the glovebox was regulated below 30% RH during the dehumidification phase with dry air added as necessary. The temperature during the decontamination phase was kept above the minimum requirement of 30 °C. The vapor generator was operated to maintain the chamber concentration within specified ranges. The target concentration was 250 ppm VHP for 4 hr for a total concentration time (CT) value of 1000 ppm-hr. The half-target concentration was 125 ppm VHP for 8 hr for a total CT value of 1000 ppm-hr. Air exchange conditions selected were chosen to maximize the residence time of the vapor in the chambers, while concurrently minimizing the background vapor decomposition under baseline conditions in the absence of materials. The VHP tests were conducted with a turnover rate of approximately 16 exchanges/hr to compensate for the higher spontaneous decomposition of VHP. Aeration of the chamber was conducted following the decontamination phase (exposure period). Aeration of the chamber continued until the vapor concentration fell to/below the levels required by the ECBC Risk Reduction Office to assure safe operation for personnel. The coupons remained in the chamber until aeration was complete. The standard measuring range of the VHP monitor is 0–10.0 ppm H_2O_2 with a display resolution of 0.1 ppm. Control samples were prepared using the same procedure as the test runs except with only air (no fumigant) through the chamber. Three replicate runs were done for each sample at each condition. The samples were removed from the chamber and marked with unique sample identifier codes and visually examined.

4.3 Coupon Exposure: Circuit Breakers

The circuit breakers (Hom220, Home Depot) were placed in the exposure chamber and exposed to the same fumigant as the other building materials discussed in Section 4.2. After exposure to the decontaminant, the circuit breakers were stored in a fume hood for 2 days then placed in storage under load for 3 months. Each set of circuit breakers was inserted into an electrical box (8 spaces, 16 circuits, 100 amp max from square D, Home Depot # 577-340). The circuit breaker box was wired with 12 gauge, 20 amp wire into the 120 V outlet. Each circuit breaker was wired in series with an electrical lamp (s513e) with an outlet box (s110e) manufactured by Thomas & Bretts (Home Depot # c214477 and b214426, respectively). The load in each lamp was a Phillips 40 watt light bulb (Philips and Sylvania, Home Depot). Current was applied to the circuits and monitored. At the end of 90 days, the circuit breakers were tested to determine the effect of VHP.

4.4 Visual Inspection

The coupons were visually inspected and digitally photographed upon removal from the chamber. Visual inspection of the coupon surfaces was conducted through side-by-side comparison of the decontaminated test surface and fresh coupons of the same test material. The testing staff looked for changes such as discoloration, blistering, warping, and peeling on the test coupon compared to the fresh coupon. After the visual inspection was completed, the coupon custody was transferred to the Material Compatibility Technical Leader for the 3 month aging period and material compatibility testing. The coupons were examined again at the time of the material testing, and the visual appearance was recorded on the data test forms. If the coupon had dramatic changes compared to a fresh coupon, then the coupon was photographed, and the photograph was included in the report. Representative photographs of each material type are provided in this report.

4.5 Coupon Aging

The material compatibility studies were conducted using the coupons from the material demand study. The coupons were aged for a minimum of 90 days following exposure to decontaminant prior to material compatibility testing. The coupons were placed in open containers and stored under ambient conditions. The open container arrangement allowed aging of the coupons in conditions mimicking real-world aging.

4.6 Data Review and Technical Systems Audits

The approved Material Compatibility QAPP specified procedures for the review of data and independent technical system audits. All data were peer reviewed within 2 weeks of collection. The project quality manager (or designee) was required to audit at least 10% of the data collected. The project quality manager (or designee) performed four technical system audits over the course of testing. A technical system audit is a thorough, systematic, on-site qualitative audit of the facilities, equipment, personnel, training, procedures, record keeping, data validation, data management, and reporting aspects of the system.

4.7 Physical Testing

An Instron model 5582 was used for the physical property testing. The Instron is a universal testing machine capable of performing tensile, compression, shear, peel, and flexural tests on most materials and components. Each material subsection contains a photograph of the coupon loaded into the test apparatus. Table 2 lists the Instron model 5582 specifications.

Table 2. Instron model 5582 specifications.

Feature	Units	Value
Load Capacity	kN	100
	kgf	10,000
Maximum Speed	mm/min	500
Minimum Speed	mm/min	0.001
Maximum Force at Full Speed	kN	75
Maximum Speed at Full Load	mm/min	250
Return Speed	mm/min	600
Position Control Resolution	mm	0.06
Total Crosshead Travel	mm	1235
Total Vertical Test Space	mm	1309
Height	mm	2092
Width	mm	1300
Depth	mm	756
Weight	kg	862

4.8 Statistical Analyses

The data from the material compatibility testing phase of the systematic decontamination program was subjected to a statistical analysis to determine if the differences observed between the various test sets were merely the result of random variations in test data or represented actual differences in the performance of the materials as a result of exposure to fumigation chemicals.

Methods used were from the statistical analysis functions embedded within the Microsoft® Excel software and *Practical Statistics for Analytical Chemists*, Robert L. Anderson, 1987, Van Nostrand Reinhold Company.

First, the individual coupon test sets were tested to see if there were statistical outliers that could be eliminated from the data. The Dixon's Q-Test for outliers was first used to identify potential outliers within a test group of coupons that had undergone similar treatment (controls and half-target or full-target exposures). If an outlier was identified in the test group analysis, it was eliminated, and the statistics (averages and standard deviations) recalculated.

Once statistical outliers had been eliminated, the test groups were analyzed to determine if they were statistically significantly different, that is, to determine if the treatment with the chosen fumigant had a detectable effect on the sample.

Welch's *t* test values were calculated to compare the test groups, and results are reported for the 95% level of confidence. The percent level of confidence reported indicates the confidence that the two sample groups being compared are, in fact, different and represent truly different samples. A 95% level of confidence indicates that there is a 5% chance (1 chance in 20) that the two samples are, in fact, subparts of the same population. If a comparison determines that a sample is significantly different at the X% level of confidence, it is also significantly different at any lower level of confidence.

Detection that a control and exposed sample are statistically different implies that the treatment likely had some detectable effect on the material. Statistically different results do not imply that the material will fail as a result of treatment, unless the material no longer meets specifications. In some cases, measured values may vary by several percent; however, there is no statistically detectible difference. It cannot be assumed that this difference is real unless the difference is statistically detected (e.g., Welch's *t* test).

4.9 Chemical Testing by Fourier Transform Infrared Spectroscopy (FTIR)

The effects of decontaminant vapor on the cellulose and other polymers in wood at the molecular level were studied using a diffuse reflectance Fourier Transform Infrared (DRFTI) technique. Chemical reactions between the decontaminant vapor and wood (i.e., oxidation and cleaving of the polymer chains) can be evidenced by significant changes in the IR spectra of the wood. The FTIR test was performed on 12 wood coupons to examine the substructural oxidation effect of VHP and liquid hydrogen peroxide. Results of these tests are provided in Section 12 herein.

4.10 Post Fumigation Inspection

The coupons were visually inspected prior to fumigation, immediately after fumigant, and after storage at time of material testing. Carpet coupons were inspected for any frayed tufts, pulled loops, and other noticeable defects. Concrete coupons were inspected for cracks, chips (particularly at the corners), any raised ridge sections, and other noticeable defects. Steel coupons were inspected for any ridged sections on the small I-beam cross section, rust, peeling paint, and any other noticeable defects. Tile coupons were inspected for crushed corners and edges and any other noticeable defects. Wallboard coupons were inspected for any damage to the paper section, as well as any other noticeable defects. Wood coupons were inspected for any knots, missing knots, splitting, and other noticeable defects. The inspections were compared to the initial inspections. No differences were observed for any of the coupons after VHP exposure and aging compared to before VHP exposure.

5. EVALUATION OF STRUCTURAL STEEL

5.1 Introduction

The effects of VHP on the physical integrity of steel were investigated using the tension test described in ASTM test method A370-03a, *Standard Test Methods and Definitions for Mechanical Testing of Steel Products*, Sections 5-13. The tension test was used to determine the integrity of steel coupons exposed to vaporous decontaminant compared to unexposed (control) steel coupons.

5.2 Sample Preparation and Testing

The steel samples were removed from storage, visually inspected, and measured. The coupons from chamber positions 1, 4, 7, 10, and 16 were selected for testing; the coupons were selected to obtain representation throughout the test chamber. The samples were used "as is" without any additional preparation. The testing was conducted IAW the ASTM test method A370-03a. The Instron fixture for the steel test was installed prior to testing. The Instron universal testing machine operation and calibration verification was conducted by suspending a certified weight from the fixture and recording the weight. Three sets of five coupons were tested for each concentration (target and half target), and four sets were tested for the controls (0 ppm). The load required to rupture the steel coupons was measured in Newtons (N). The tensile strength is the maximum tensile stress that a material is capable of sustaining and is calculated by dividing amount of force required to rupture a specimen by the specimen cross-sectional area. The cross-sectional area for the steel dog bone shaped coupon is the center width of the coupon multiplied by the center thickness. No precision or bias requirements have been established for this test method. The results of control coupons were compared against decontaminant exposed samples. A statistical analysis of the data was conducted to determine if the decontaminant exposed steel coupon results were statistically different compared to the control steel coupons. A photograph of a representative steel sample before and after testing is provided in Figure 3.

5.3 Results

The coupons were stored for at least 90 days after fumigation. The actual number of storage days was based on the arrival of the Instron fixtures for testing. The coupons for a particular fumigation were studied after a similar number of days in storage. The load required to rupture the steel coupons, tensile strength results, and number of days in storage before testing values are provided in Table 3.

Figure 3. Photograph of the steel coupon test.

5.4 Discussion

The steel studied was an A572 Grade 50 high-strength structural steel. The minimum tensile strength requirement is 450 N/mm^2. The control coupons and VHP-exposed coupons met this minimum specification.

A statistical analysis of the test group results was conducted to detect potential statistical outliers (Q test) and determine if there are any differences between the control and exposed samples (Welch's *t* test). Two test coupons were flagged for having tensile strength values that were outliers within their test sets at the Q equals 0.99 confidence level. However, within test groups (control samples, half-target concentration samples, and full-target concentration samples), statistical analysis showed that none of the coupons could be eliminated as statistical outliers. Therefore, all values were retained for the statistical analysis.

Table 3. VHP steel test results.

Maximum Load	**0 ppm Control Samples Tension Test Results (N)**				**Half-Target Concentration Results (N)**			**Target Concentration Results (N)**		
	Test 1	**Test 2**	**Test 3**	**Test 4**	**Test 1**	**Test 2**	**Test 3**	**Test 1**	**Test 2**	**Test 3**
Coupon ID	SN50310	SSN50622	SN50228	SSN50623	SV50420	SV50603	SV50606	SV50405	SV50517	SV50518
Coupon 1	60,975	65,766	61,284	60,627	61,175	62,453	60,493	60,393	60,430	61,121
Coupon 2	60,402	61,079	60,997	62,074	61,559	59,570	62,283	60,655	61,194	61,034
Coupon 3	60,577	62,921	60,848	64,483	60,806	61,380	62,932	61,793	61,180	61,321
Coupon 4	59,711	64,075	61,109	61,238	60,731	64,594	62,046	60,245	60,959	61,202
Coupon 5	60,725	61,732	60,600	63,661	60,900	63,982	62,257	61,148	61,401	61,524
Test Avg	60,478	63,115	60,968	62,417	61,034	62,396	62,002	60,847	61,033	61,240
Std Dev	477	1874	260	1622	338	2023	907	631	371	191
Test Set Avg ± Std Dev	61,744 ± 1597				61,811 ± 1337			61,040 ± 437		
Tensile Strength	**Control Samples Tensile Strength Results (N/mm²)**				**Half-Target Concentration Results (N/mm²)**			**Target Concentration Results (N/mm²)**		
Coupon ID	SN50310	SSN50622	SN50228	SSN50623	SV50420	SV50603	SV50606	SV50405	SV50517	SV50518
Coupon 1	565	577	538	532	537	548	531	559	530	566
Coupon 2	559	509	565	545	570	523	577	562	537	565
Coupon 3	561	552	563	566	563	511	552	572	537	538
Coupon 4	524	562	566	567	562	567	544	558	535	537
Coupon 5	562	542	561	589	534	561	494	566	539	540
Test Avg	554	548	559	560	553	542	540	563	535	549
Std Dev	17	26	12	22	17	24	30	6	3	15
Test Set Avg ± Std Dev	555 ± 19				545 ± 23			549 ± 15		
Number of Days in Storage	**Control Samples (Days)**				**Half-Target Concentration (Days)**			**Target Concentration (Days)**		
Coupon ID	SN50310	SSN50622	SN50228	SSN50623	SV50420	SV50603	SV50606	SV50405	SV50517	SV50518
Days	95	98	98	97	107	96	93	92	104	103
Test Set Avg ± Std Dev	97 ± 1				99 ± 6			100 ± 6		

Note: The cells highlighted in orange indicate that the data points were statistically identified as outliers within their test sets, but not within the test group (four control groups); therefore, the values were retained.

The average values for the maximum load for the test groups are: 61,744 ± 1597 N for the control coupons; 61,811 ± 1337 N for the half-target coupons; and 61,040 ± 437 N for the full-target coupons. The average values for the tensile strength of the steel coupons are as follows: 555 ± 19 N/mm^2 for the control coupons; 545 ± 23 N/mm^2 for the half-target coupons; and 549 ± 15 N/mm^2 for the full-target coupons.

For the half-concentration and full-concentration samples, the average tensile strengths are slightly lower than the control samples; but, all are well over the minimum acceptable value from the ASTM standard of 450 N/mm^2. The differences are statistically insignificant at the 95% level of confidence.

6. EVALUATION OF GYPSUM WALLBOARD

6.1 Introduction

The effects of VHP on the physical integrity of gypsum wallboard were investigated using the nail pull resistance test method B as described in ASTM Test C473-03, *Standard Test Methods for Physical Testing of Gypsum Panel Products*, Section 13. The test measures the ability of the wallboard to resist nail-pull through by determining the load required to push a standard nail through the wallboard. The ASTM test was used to determine the integrity of the gypsum wallboard coupons exposed to vaporous decontaminant compared to unexposed (control) gypsum wallboard coupons.

6.2 Sample Preparation and Testing

The gypsum wallboard samples were removed from storage, visually inspected, and measured. The coupons from chamber positions 1, 2, 4, 5, and 7 were selected for testing; the coupons were selected to obtain representation throughout the test chamber. The samples were brought to moisture equilibrium such that the weight of the sample did not change by more than 0.2% on successive weighings at a minimum interval of 2 hr. The sample preparation was conducted within a temperature range of 15–25 °C and an RH of 48–75%. The testing was conducted IAW the ASTM test method C473-03. The Instron fixture for the gypsum wallboard test was installed prior to testing. The Instron universal testing machine operation was verified by suspending a certified weight from the fixture and recording the weight. Three coupons were tested for each concentration (target and half target), and four sets were tested for the controls (0 ppm). The force required to drive a nail shank through the wallboard coupons was measured in N with five replicate measurements made for each coupon (i.e., each coupon was punctured five times). The ASTM method indicates that any coupon measurement in the series that varies 15% more than the average needs to be discarded. If 15% of the coupons deviate from the average, the method states that the test will be repeated. No additional precision or bias requirements have been determined for this test by ASTM. The results of control coupons are compared against decontaminant exposed samples. A statistical analysis of the data was conducted to determine if the decontaminant exposed coupon results were statistically different compared to the control coupons. A photograph of a representative gypsum wallboard sample before and after testing (i.e., holes) is provided in Figure 4.

6.3 Results

The coupons were stored for at least 90 days after fumigation. The actual number of storage days was based on the arrival of the Instron fixture for testing. The coupons for a particular fumigation were studied at the same number of days. The load required to push the nail through the wallboard coupons is provided in Table 4.

6.4 Discussion

A statistical analysis of the test group results was conducted to detect potential statistical outliers (Q test) and determine if there are any differences between the control and exposed samples (Welch's *t* test). Although there was a great deal of scatter in the data (The standard deviations of the results are between 14–22% of the mean value within the various test groups.), none of the individual coupons were determined to be outliers at the Q equals 0.99 confidence level.

The average tension test results are 48.6 $\pm$ 7.0 N for the control group, 56.6 $\pm$ 12.8 N for the half-target group, and 63.3 $\pm$ 9.5 N for the full-target group. The Welch's *t* test was used to determine if there were statistically significant differences among the test groups (control, half target, and full target). The control test groups were significantly different from the full-target and half-target coupons at the 95% confidence level. The half-target and full-target coupons were not significantly different at the 95% level of confidence.

These test methods show that exposure to VHP has statistically significant effects on the maximum load of wallboard coupons as determined by the ASTM test method. Exposure to VHP fumigation resulted in an increase in the ability of the wallboard to resist nail pull-through. However, this test does not indicate whether this decrease in maximum load would result in failure of installed wallboard after fumigation.

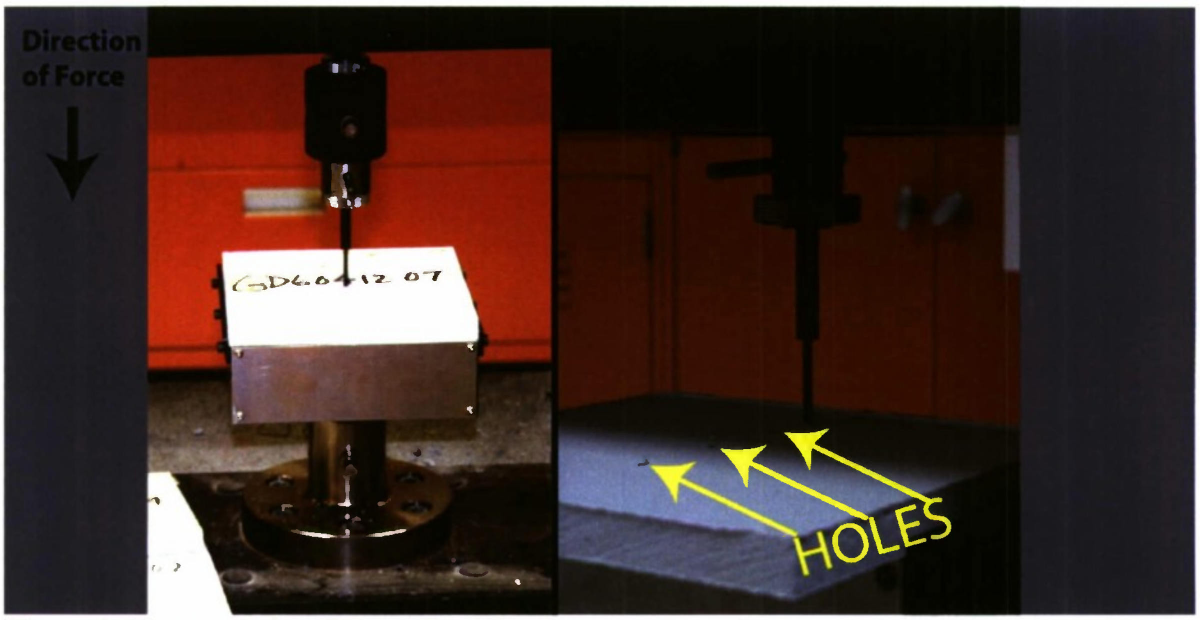


Figure 4. Representative photograph of the gypsum wallboard coupon test.

Table 4. Gypsum wallboard coupon test results for maximum load.

Force	0 ppm Control Samples Tension Test Results (N)				125–150 ppm Half-Target Concentration Results (N)			250–300 ppm Target Concentration Results (N)		
	Test 1	Test 2	Test 3	Test 4	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
Coupon Set ID	GN50303	GN50401	GN50620	GN50621	GV50407	GV50505	GV50506	GV50421	GV50526	GV50531
Hole 1	47.2	40.2	59.1	48.1	60.7	65.6	46.5	71.8	70.2	56.3
Hole 2	53.8	42.5	45.3	47.5	61.6	64.4	37.1	72.7	62.4	51.0
Hole 3	64.1	41.3	55.3	46.0	75.3	54.5	43.5	67.5	72.8	53.5
Hole 4	56.6	36.5	47.2	52.7	78.7	65.9	48.8	60.2	83.2	54.0
Hole 5		45.6	45.0	54.4	71.4	52.3	40.9	58.8	70.7	53.3
Test Avg	55.4	41.2	50.4	49.7	69.5	60.5	43.3	66.2	71.8	53.6
Std Dev	7.0	3.3	6.4	3.6	8.1	6.6	4.6	6.4	7.5	1.9
Test Set Avg ± Std Dev	48.6 ± 7.0				56.6 ± 12.8			63.3 ± 9.5		

7. EVALUATION OF ACOUSTICAL CEILING TILE

7.1 Introduction

The effects of VHP on the physical integrity of ceiling tile were investigated using the transverse strength test as described in ASTM Test C367-99, *Standard Test Methods for Strength Properties of Prefabricated Architectural Acoustical Tile or Lay-In Ceiling Panels*, Sections 1, 3–5, and 21–29. The test measures the force required to cause the tile to break. The ASTM test was used to determine the integrity of the ceiling tile coupons exposed to vaporous decontaminant compared to unexposed (control) ceiling tile coupons.

7.2 Sample Preparation and Testing

The acoustical ceiling tile samples were removed from storage, visually inspected, and measured. The samples were brought to moisture equilibrium such that the weight of the sample did not change by more than 1% on successive weighings at a minimum interval of 2 hr. The sample preparation was conducted within a temperature range of 18–24 °C and an RH of 48–75%. The testing was conducted IAW the ASTM test method C367-99. The Instron fixture for the ceiling tile test was installed prior to testing. The Instron universal testing machine operation was verified by suspending a certified weight from the fixture and recording the weight. For each test, the coupons from chamber positions 1–8 were selected for testing; this selection consisted of all coupon placed in the chamber during a single fumigation trial. Three sets of four machine-direction coupons and four cross-machine-direction coupons were tested for each concentration (0 ppm, target, and half target). The load required to break the ceiling tile coupons was measured in N. Figure 5 shows a photograph of a coupon loaded into the Instron for the machine and cross-machine direction tests. No precision or bias requirements have been established for this test method. The results of control coupons have been compared to decontaminant exposed tiles. A statistical analysis of the data was conducted to determine if the decontaminant exposed coupon results were statistically different compared to the control coupons.

Figure 5. Representative photograph of the acoustical ceiling tile coupon test.

The Modulus of Rupture (MOR) was calculated according to the test method using the following equation:

$$MOR\ units\ N/mm^2\ (lb/in.^2) = \frac{3 \times P \times L}{2 \times b \times d^2}$$

where

P	=	maximum load, N (lbf)
L	=	length of span, mm (in.)
b	=	specimen width, mm
d	=	specimen thickness, mm

7.3 Results

The coupons were stored for at least 90 days after fumigation. The actual number of storage days was based on the arrival of the Instron fixture for testing. The coupons for a particular fumigation were studied at the same number of days. A photograph of a representative ceiling tile sample before and after testing is provided in Figure 6. The load required to rupture the ceiling tile coupons, ceiling tile coupon MOR results, and number of days in storage are provided in Table 5.

7.4 Discussion

A statistical analysis of the individual test results was conducted to detect potential statistical outliers (Q test) and determine if there are any differences between the control and exposed samples (Welch's *t* test). None of the coupons could be eliminated as statistical outliers from within their individual test sets or test groups (control, half-target concentration, or target concentration samples) at the Q equals 0.99 level of confidence.

For the machine-direction tests, the maximum load values are as follows: 35.23 $\pm$ 4.92 N for the controls, 40.76 $\pm$ 5.20 N for the half-target coupons, and 36.63 $\pm$ 4.07 N for the full-target coupons. The MORs are: 0.82 $\pm$ 0.11 N/mm^2 for the controls, 0.97 $\pm$ 0.15 N/mm^2 for the half-target, and 0.82 $\pm$ 0.11 N/mm^2 for the full-target coupons.

For the cross-machine tests, the maximum load values are as follows: 28.83 ± 5.02 N for the controls, 32.18 ± 3.22 N for the half-target coupons, and 27.23 ± 3.69 N for the full-target coupons. The MORs are 0.67 ± 0.12 N/mm^2 for the controls, 0.76 ± 0.07 N/mm^2 for the half-target coupons, and 0.62 ± 0.08 N/mm^2 for the full-target coupons.

Figure 6. Photograph showing acoustical ceiling tile end of test configuration.

Table 5. VHP Coupon test results for tile.

Maximum Load – Machine Direction	**0 ppm Control Samples Tension Test Results (N)**			**125–150 ppm Half-Target Concentration Results (N)**			**250–300 ppm Target Concentration Results (N)**		
	Test 1	**Test 2**	**Test 3**	**Test 1**	**Test 2**	**Test 3**	**Test 1**	**Test 2**	**Test 3**
Coupon Set ID	TN50307	TN50610	TN50613	TV50418	TV50511	TV50601	TV50316	TV50427	TV50428
Coupon 1	36.00	37.11	28.74	45.12	48.61	45.00	33.27	39.54	41.34
Coupon 2	30.28	41.46	40.05	44.01	37.78	43.26	30.40	33.40	40.98
Coupon 3	32.16	41.72	35.61	39.09	36.73	31.50	40.17	35.46	33.96
Coupon 4	33.62	27.11	38.88	45.36	34.38	38.22	33.52	42.76	34.73
Test Avg	33.02	36.85	35.82	43.40	39.38	39.50	34.34	37.79	37.75
Std Dev	2.41	6.83	5.08	2.93	6.32	6.06	4.14	4.18	3.95
Test Set Avg ± SD	35.23 ± 4.92			40.76 ± 5.20			36.63 ± 4.07		
Modulus of Rupture – Machine Direction	**Control Samples Tensile Strength Results (N/mm²)**			**Half-Target Concentration Results (N/mm²)**			**Target Concentration Results (N/mm²)**		
Coupon Set ID	TN50307	TN50610	TN50613	TV50418	TV50511	TV50601	TV50316	TV50427	TV50428
Coupon 1	0.83	0.86	0.67	1.05	1.31	1.04	0.77	0.92	0.96
Coupon 2	0.69	0.96	0.93	1.02	0.88	1.00	0.70	0.77	0.83
Coupon 3	0.74	0.97	0.82	0.89	1.00	0.73	0.93	0.82	0.69
Coupon 4	0.78	0.63	0.90	1.05	0.80	0.89	0.78	0.99	0.69
Test Avg	0.76	0.85	0.83	1.00	0.99	0.91	0.80	0.88	0.79
Std Dev	0.06	0.16	0.12	0.07	0.22	0.14	0.10	0.10	0.13
Test Set Avg ± SD	0.82 ± 0.11			0.97 ± 0.15			0.82 ± 0.11		
Maximum Load – Cross Machine	**Control Samples Tension Test Results (N)**			**Half-Target Concentration Results (N)**			**Target Concentration Results (N)**		
	Test 1	**Test 2**	**Test 3**	**Test 1**	**Test 2**	**Test 3**	**Test 1**	**Test 2**	**Test 3**
Coupon Set ID	TN50307	TN50610	TN50613	TV50418	TV50511	TV50601	TV50316	TV50427	TV50428
Coupon 1	20.08	29.97	30.85	40.17	34.79	31.47	25.19	23.80	24.86
Coupon 2	25.63	30.15	34.15	30.74	28.86	31.06	23.17	22.55	26.93
Coupon 3	23.33	26.17	30.07	30.98	33.82	33.10	27.38	34.69	26.67
Coupon 4	24.38	37.15	34.00	28.69	33.40	29.08	31.54	30.17	29.84
Test Avg	23.36	30.86	32.27	32.65	32.72	31.18	26.82	27.80	27.08
Std Dev	2.38	4.58	2.11	5.12	2.64	1.65	3.59	5.68	2.06
Test Set Avg ± SD	28.83 ± 5.02			32.18 ± 3.22			27.23 ± 3.69		

Table 5. VHP Coupon test results for tile (continued).

MOR – Cross Machine	Control Samples Tensile Strength Results (N/mm²)			Half-Target Concentration Results (N/mm²)			Target Concentration Results (N/mm²)		
Coupon Set ID	TN50307	TN50610	TN50613	TV50418	TV50511	TV50601	TV50316	TV50427	TV50428
Coupon 1	0.47	0.69	0.71	0.93	0.81	0.73	0.58	0.55	0.58
Coupon 2	0.59	0.70	0.79	0.71	0.78	0.72	0.54	0.52	0.62
Coupon 3	0.54	0.61	0.70	0.72	0.78	0.77	0.63	0.80	0.62
Coupon 4	0.56	0.86	0.79	0.66	0.78	0.67	0.73	0.70	0.60
Test Avg	0.54	0.71	0.75	0.76	0.79	0.72	0.62	0.64	0.60
Std Dev	0.05	0.11	0.05	0.12	0.01	0.04	0.08	0.13	0.02
Test Set Avg ± SD	0.67 ± 0.12			0.76 ± 0.07			0.62 ± 0.08		
Number of Days in Storage	**Control Samples Days**			**Half-Target Concentration Days**			**Target Concentration Days**		
Coupon Set ID	TN50307	TN50610	TN50613	TV50418	TV50511	TV50601	TV50316	TV50427	TV50428
Days in Storage	191	284	281	184	183	299	189	189	188
Test Set Avg ± SD	252 ± 53			222 ± 67			189 ± 1		

In all cases, the cross-machine test results were lower than those in the machine-direction orientation. When examining the individual coupon sets tested, there are obvious variations among the test groups (control, half-target exposure, or full-target exposure). In the machine-direction and cross-machine tests, the half-concentration coupons had higher maximum loads and MORs. For the machine-direction tests, the half-concentration results are significantly different from the control test groups and full-target coupons at a 95% confidence level. The control coupons and full-target coupons were not, however, significantly different at the 95% confidence level.

For the cross-machine tests, the control coupons were not significantly different from either the half- or full-target coupons at the 95% confidence level. From these test methods, it is not clear that the VHP fumigation process has, overall, a statistically significant effect on the maximum load and MOR of acoustic ceiling tile. The maximum load and MOR did increase due to long exposure (8 hr) at lower concentration (150 ppm); however, the effect was only significant in the machine direction tests.

8. EVALUATION OF CARPET

8.1 Introduction

The effects of VHP on the physical integrity of loop pile carpet fibers were investigated using ASTM Test C1335-03, *Standard Test Method for Tuft Bind of Pile Yarn Floor Coverings*. The method determines the force required to pull out a tuft of a pile yarn from a floor-covering sample. The ASTM test was used to determine the integrity of the loop pile carpet fibers exposed to vaporous decontaminant compared to unexposed (control) loop pile carpet fibers.

8.2 Sample Preparation

The carpet samples were removed from storage, visually inspected, and measured. The coupons from chamber positions 1, 3, 4, 5, and 7 were selected for testing; the coupons were selected to obtain representation throughout the test chamber. The samples were brought to moisture equilibrium such that the weight of the sample did not change by more than 0.2% on successive weighings at a minimum interval of 2 hr. The sample preparation was conducted within a temperature range of 15–24 °C and RH of 48–75%. The testing was conducted IAW the ASTM test method D1335-03, *Standard Test Method for Tuft Bind of Pile Yarn Floor Coverings*. The Instron fixture for the carpet test was installed prior to testing. The Instron universal testing machine operation and calibration verification was conducted by suspending a certified weight from the fixture and recording the weight. Three sets of five coupons were tested for each concentration (target and half target), and four sets were tested for the controls (0 ppm). The load required to pull a carpet loop from the binding was measured in N, and five replicate measurements were made for each coupon. No bias requirements have been established for this test method. The results of control coupons were compared to decontaminant exposed samples. A statistical analysis of the data was conducted to determine if the decontaminant exposed coupon results were statistically different compared to the control coupons. A photograph of a representative carpet sample before and after testing is provided in Figure 7.

8.3 Results

The coupons were stored for at least 90 days after fumigation. The actual number of storage days was based on the arrival of the Instron fixture for testing. The coupons for a particular fumigation were studied at the same number of days. The carpet tuft bind results and number of days in storage are provided in Table 6.

8.4 Discussion

A statistical analysis of the individual test results was conducted to detect potential statistical outliers (Q test) and determine if there are any differences between the control and exposed samples (Welch's *t* test). Although there was a great deal of scatter in the data (the standard deviations of the results are 25% of the mean value within the various test groups), none of the coupons were determined to be outliers at the Q equals 0.99 confidence level.

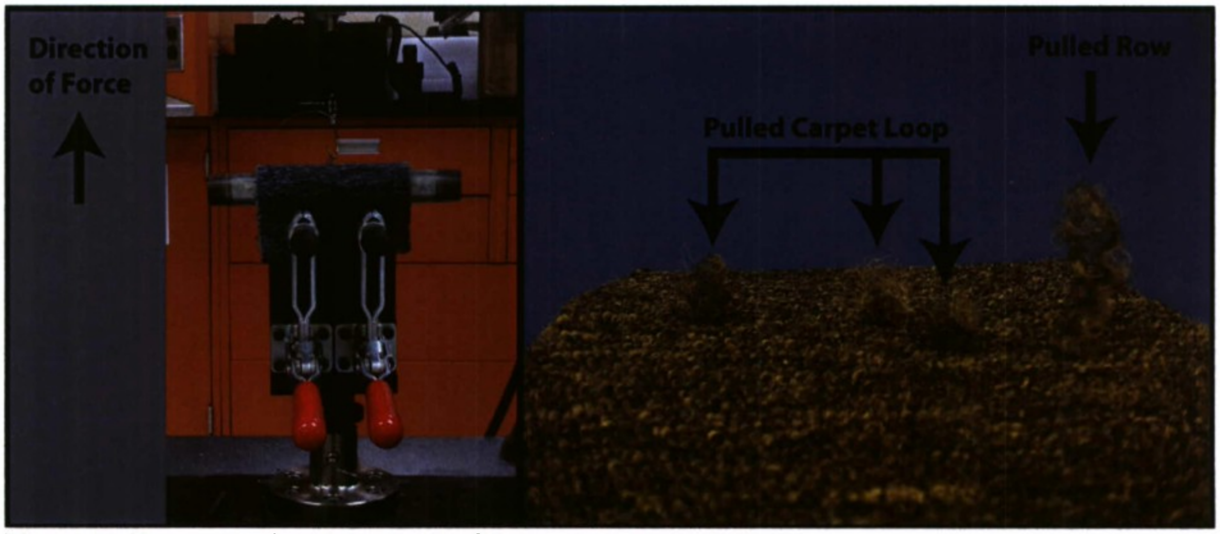


Figure 7. Representative photograph of the carpet coupon test.

Table 6. Carpet coupon test results for average tuft bind.

Tuft Bind Force	0 ppm Control Sample Results (N)														
	RN50309					RN50614					RN50615				
Coupon	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Loop 1	12.5	15.9	14.7	11.0	9.5	21.9	23.1	24.4	12.2	9.6	11.9	17.1	13.4	19.0	18.2
Loop 2	14.9	13.1	8.0	15.9	16.2	13.7	21.6	18.9	8.4	18.0	18.7	10.9	15.4	13.6	14.1
Loop 3	10.8	13.7	14.1	9.2	12.5	19.0	20.2	16.5	14.3	13.8	10.0	10.6	16.6	13.0	10.5
Loop 4			8.9	14.3	14.1	15.3	18.3	14.1		13.1	19.2	17.6		16.2	11.9
Loop 5			19.2			16.9		15.0		18.6	14.9	10.7		15.5	16.1
Test Avg	12.7	14.3	13.0	12.6	13.1	17.3	20.8	17.8	11.6	14.6	14.9	13.4	15.2	15.5	14.1
SD	2.0	1.5	4.6	3.0	2.9	3.2	2.0	4.1	3.0	3.7	4.1	3.6	1.6	2.4	3.1
Days	147					148					147				
Test Set Avg ± SD	14.8 ± 3.7														
Tuft Bind Force	1000–1250 ppm Half-Target Concentration Results (N)														
	RV50321					RV50429					RV50502				
Coupon	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Loop 1	X	12.0	14.7	16.5	12.2	15.3	16.8	12.7	25.6	15.1	17.7	11.0	13.0	13.2	15.9
Loop 2	X	20.7	20.7	16.2	19.1	18.8	23.7	13.0	16.3	21.2	19.4	18.2	10.6	13.5	14.8
Loop 3	X	12.2	10.9	19.4	14.5	12.3	15.8	19.0	18.3	19.2	13.1	7.7	19.0	15.9	13.8
Loop 4	X	15.1	16.0		18.2	22.4	26.2	20.7	14.6	15.7	14.0	18.5	15.7		
Loop 5	X	19.9	23.6		15.0	16.9	25.5	20.3	21.7			18.5	11.7		
Test Avg	X	16.0	17.2	17.4	15.8	17.1	21.6	17.1	19.3	17.8	16.0	14.8	14.0	14.2	14.8
Std Dev	X	4.2	5.0	1.8	2.8	3.8	4.9	4.0	4.4	2.9	3.0	5.1	3.4	1.5	1.1
Days	161					152					149				
Test Set Avg ± SD	16.8 ± 4.0														
Tuft Bind Force	2000–2500 ppm Target Concentration Results (N)														
	RV50419					RV50519					RV50520				
Coupon	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Loop 1	11.2	12.5	15.3	19.8	10.4	10.5	15.1	11.5	18.0	21.3	16.8	16.5	16.6	10.0	13.1
Loop 2	18.0	12.9	10.0	13.0	14.2	19.1	21.8	8.3	12.2	15.8	12.5	17.3	11.9	21.7	11.2
Loop 3	16.0	11.0	15.6	19.8	16.5	20.7	15.5	11.6	14.0	14.1	18.0	14.1	10.3	17.6	14.6
Loop 4	19.2		11.6	20.7	18.4	23.5	12.8			16.8			10.2	11.3	
Loop 5	16.2			17.7	16.6	12.5	21.3			16.2				18.4	
Test Avg	16.1	12.1	13.1	18.2	15.2	17.2	17.3	10.5	14.7	16.8	15.7	16.0	12.2	15.8	13.0
Std Dev	3.0	1.0	2.8	3.1	3.1	5.6	4.0	1.8	2.9	2.7	2.8	1.6	3.0	5.0	1.7
Days	147					148					147				
Test Set Avg ± SD	15.3 ± 3.7														

Notes: The cells highlighted in gray are samples that were not required to be analyzed, due to meeting the test method sampling criteria of ±15%. X denotes data lost electronically and not available for calculation.

The values for the average tuft bind for the groups of coupons are as follows: 14.8 ± 3.7 N for the control coupons, 16.8 ± 4.0 N for the half-target coupons, and 15.3 ± 3.7 N for the full-target coupons. There are variations among the test groups (control, half-target exposure, or full-target exposure) at the 95% confidence level. While the differences between the control and full-target groups are statistically insignificant, the half-target values are determined to be statistically different from the controls and full-target groups. The results suggest that VHP fumigation at the half-target concentration for long exposure times (8 hr) used in this study may have an effect on the tuft bind tests of carpet coupons as determined by our test methods. The fumigation made it more difficult, i.e., greater bind force, to pull a tuft out of the test carpet used in this study.

9. EVALUATION OF CONCRETE CINDER BLOCK

9.1 Introduction

The effects of VHP on the physical integrity of concrete cinder block coupons were investigated using the compression test described in ASTM Test C140-03, *Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units*. The ASTM test was used to determine the integrity of the concrete cinder block coupons exposed to vaporous decontaminant compared to unexposed (control) concrete cinder block coupons.

9.2 Sample Preparation and Testing

The concrete cinder block samples were removed from storage, visually inspected, and measured. The coupons from chamber positions 1, 4, and 7 were selected for testing; the coupons were selected to obtain representation throughout the test chamber. The samples were placed in an environmental range of 16–32 °C and <80% RH for 48 hr prior to testing. The testing was conducted IAW the ASTM test method C140-03, *Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units*. The Instron fixture for the concrete cinder block test was installed prior to testing. A photograph of a concrete cinder block coupon loaded into the Instron test apparatus is shown in Figure 8. The Instron universal testing machine operation and calibration verification was conducted by suspending a certified weight from the fixture and recording the weight. Three sets of three coupons were tested for each concentration (0 ppm, target, and half target). The load required to rupture the coupons was measured in kilogram-force per square millimeter and can be found in Table 7. No precision or bias requirements have been established for this test method. The results of control coupons were compared to decontaminant exposed samples. A statistical analysis of the data was conducted to determine if the decontaminant exposed coupon results were statistically different compared to the control coupons.

9.3 Results

The coupons were stored for at least 90 days after fumigation. The actual number of storage days was based on the arrival of the Instron fixture for testing. The coupons for a particular fumigation were studied at the same number of days. A photograph of a representative concrete cinder block samples before and after testing is provided in Figure 9. The coloring difference between the samples in the picture is a result of the room lighting and is not real. Both samples were taken on the same blue color mat. The load required to crush the concrete cinder block coupons, coupon gross area compressive strength results, and number of days in storage values are provided in Table 7. The concrete cinder block is a heterogeneous material sample to sample. The break patterns varied from sample to sample; a photograph of each sample is provided in Appendix D.

9.4 Discussion

A statistical analysis of the individual test results was conducted to detect potential statistical outliers (Q test) and determine if there are any differences between the control and exposed samples (Welch's *t* test). None of the coupons could be eliminated as statistical outliers from within their individual test sets or test groups (control, half-target concentration, or target concentration samples) at the Q equals 0.99 level of confidence. A Welch's *t* test evaluation of the data for maximum load and gross area compressive strength indicates that there are no statistically significant differences among the means of the exposed and control samples at the 95% confidence level. These test methods indicate that exposure to VHP has no significant effect on the maximum load or gross area compressive strength of cinder blocks.

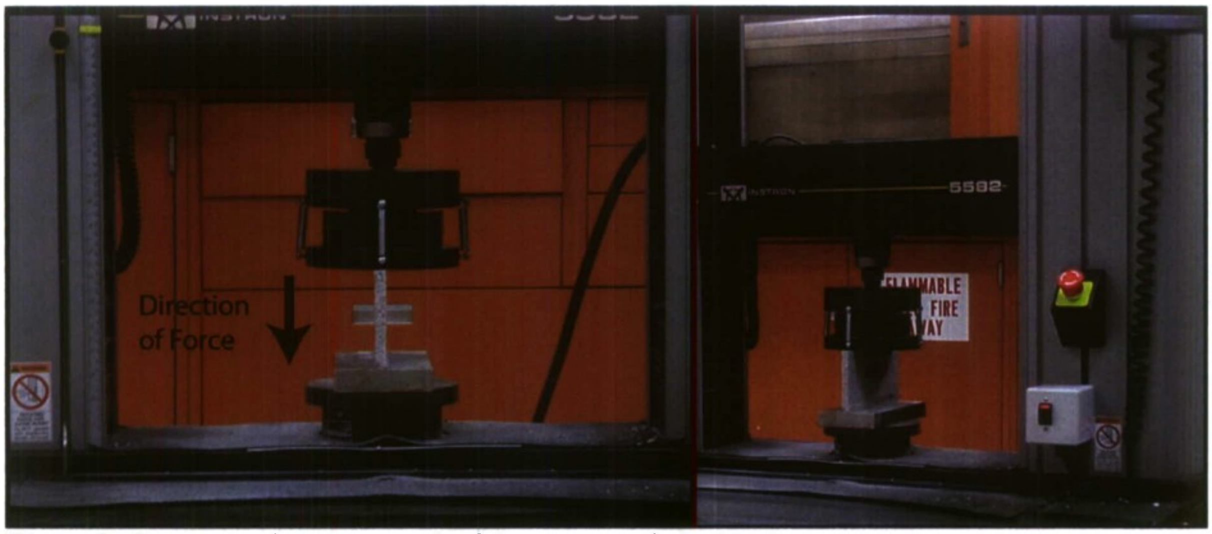


Figure 8. Representative photograph of the concrete cinder block coupon test.

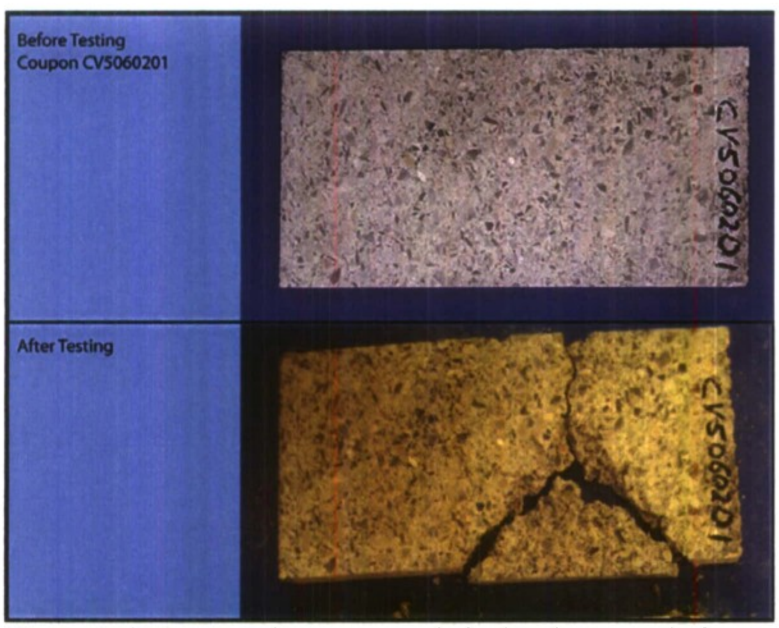


Figure 9. Representative concrete cinder block coupon before and after testing.

Table 7. Concrete cinder block coupon test results.

Maximum Load	0 ppm Control Samples Results (kgf)			1000–1250 ppm Half-Target Concentration Results (kgf)			2000–2500 ppm Target Concentration Results (kgf)		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
Coupon Set	CN50510	CN50524	CN51027	CD51129	CD51201	CD51205	CD51011	CD51012	CD51013
Coupon 1	3760	3252	4880	4243	3619	3091	5372	2959	3558
Coupon 2	3112	2711	3011	3001	4458	4107	2871	2376	3839
Coupon 3	2554	2557	3310	3074	2366	4596	3818	2790	4027
Test Avg	3142	2840	3734	3439	3481	3931	4020	2708	3808
Std Dev	603	365	1004	697	1053	768	1262	300	236
Test Set Avg ± Std Dev	3239 ± 729			3617 ± 776			3512 ± 898		
Gross Area Compressive Strength	**Control Samples Results (kgf/mm²)**			**Half-Target Concentration Results (kgf/mm²)**			**Target Concentration Results (kgf/mm²)**		
	Test 1	**Test 2**	**Test 3**	**Test 1**	**Test 2**	**Test 3**	**Test 1**	**Test 2**	**Test 3**
Coupon Set	CN50510	CN50524	CN51027	CD51129	CD51201	CD51205	CD51011	CD51012	CD51013
Coupon 1	1.9	1.5	2.3	2.2	1.7	1.6	2.8	1.4	1.8
Coupon 2	1.5	1.4	1.6	1.3	2.1	1.8	1.4	1.1	2.1
Coupon 3	1.1	1.2	1.7	1.5	1.2	2.2	2.0	1.3	1.8
Test Avg	1.5	1.4	1.9	1.7	1.7	1.9	2.0	1.3	1.9
Std Dev	0.4	0.2	0.4	0.5	0.5	0.3	0.7	0.1	0.2
Test Set Avg ± Std Dev	1.6 ± 0.4			1.7 ± 0.4			1.7 ± 0.5		
Number of Days in Storage	**Control Samples (Days)**			**Half-Target Concentration (Days)**			**Target Concentration (Days)**		
	Test 1	**Test 2**	**Test 3**	**Test 1**	**Test 2**	**Test 3**	**Test 1**	**Test 2**	**Test 3**
Coupon Set	CN50510	CN50524	CN51027	CD51129	CD51201	CD51205	CD51011	CD51012	CD51013
Coupon 1	126	127	219	128	126	211	162	211	160
Coupon 2	126	127	219	128	126	211	162	211	160
Coupon 3	126	127	219	128	126	211	162	211	160
Test Set Avg ± Std Dev	157 ± 46			155 ± 42			178 ± 25		

10. EVALUATION OF WOOD

10.1 Introduction

The effects of VHP on the physical integrity of wood were investigated using the bending edge-wise test described in ASTM Test D4761-02a, *Standard Test Methods for Mechanical Properties of Lumber and Wood-Base Structural Material*, Sections 6–11. The ASTM test was used to determine the integrity of the wood coupons exposed to vaporous decontaminant compared to unexposed (control) wood coupons.

10.2 Sample Preparation

The wood samples were removed from storage, visually inspected, and measured. The coupons from chamber positions 1, 4, 7, 10, and 14 were selected for testing; the coupons were selected to obtain representation throughout the test chamber. The samples were brought to moisture equilibrium such that the weight of the sample did not change by more than 0.2% on successive weighings at a minimum interval of 2 hr. The sample preparation was conducted within a temperature range of 15–25 °C and an RH of 48–75%. The testing was conducted IAW the ASTM test method D4761-02a, *Standard Test Methods for Mechanical Properties of Lumber and Wood-Base Structural Material*, Sections 6–11. The Instron fixture for the wood test was installed prior to testing. The Instron universal testing machine operation and calibration verification was conducted by suspending a certified weight from the fixture and recording the weight. Three sets of five coupons were tested for each concentration (0 ppm, target, and half target). The load required to rupture the wood coupons was measured in Newtons. The setup of the Instron for testing the wood furring strips can be seen in Figure 10. No precision or bias requirements have been established for this test method. The results of control coupons were compared to decontaminant exposed samples. A statistical analysis of the data was conducted to determine if the decontaminant exposed coupon results were statistically different compared to the control coupons.

10.3 Results

The coupons were stored for at least 90 days after fumigation. The actual number of storage days was based on the arrival of the Instron fixtures for testing. The coupons for a particular fumigation were studied after storage for the same number of days. A photograph of a representative wood sample before and after testing is provided in Figure 11. The wood coupon results for the required load and time to break, moisture content, and number of days in storage are provided in Table 8. The wood samples vary slightly in knot and grain pattern from sample to sample. The break patterns varied from sample to sample; a photograph of each sample is provided in Appendix C.

10.4 Discussion

A statistical analysis of the individual test results was conducted to detect potential statistical outliers (Q test) and determine if there is a difference between the control and exposed samples (Welch's t test). Within the target concentration test group, two coupons were outliers within their test sets with respect to both maximum force required to break and time-to-break values at the Q equals 0.99 confidence level. Of these two outliers, only Coupon 5 of Test 2 was an outlier within the entire test group of 15 coupons. This value was removed from the data sets before statistical analysis was performed. The moisture content of Coupon 4 of Test Set 2 for the half-target concentration test group was also noted as an outlier; however, it was not an outlier when considering the entire test group. Therefore, this value was retained.

When considering the data from the test groups of coupons, the average maximum load values for the VHP-exposed coupons increases by 11–18% over the value for the control sets for half- and full-concentration sets. The time-to-break values for the exposed coupons are also higher (3–18%), but the moisture content values show no trend.

The average maximum force value for the control samples was determined to be 4006 $\pm$ 861 N. The half-concentration samples were determined to have an average maximum force value of 4431 $\pm$ 929 N (an increase of 10.6%) while the target-concentration samples have an average maximum force value of 4725 $\pm$ 732 N (an increase of 17.9%).

The average time-to-break value for the control coupons is 3.9 $\pm$ 0.9 s. The half-concentration coupons have an average time-to-break of 4.0 $\pm$ 0.9 s, and the target-concentration coupons have an average time-to-break of 4.6 $\pm$ 0.7 s.

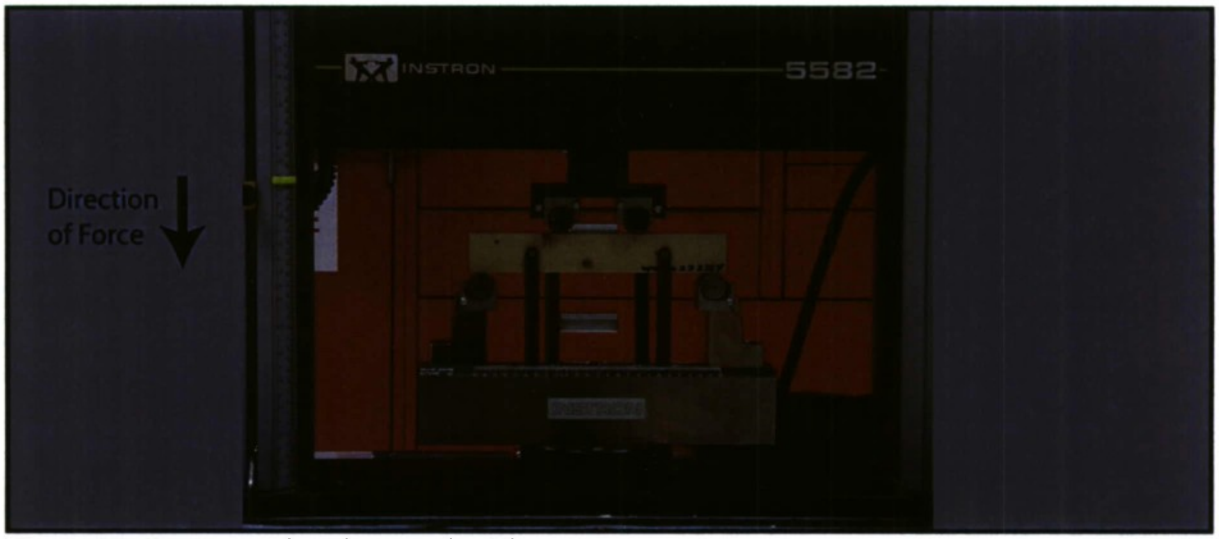


Figure 10. Representative photograph of the wood coupon test.

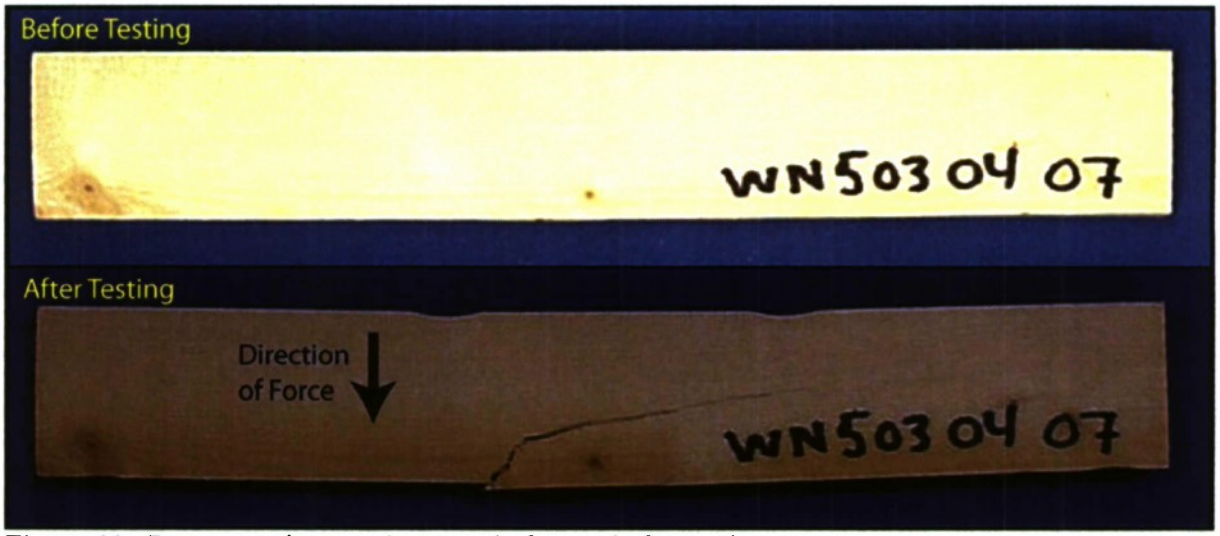


Figure 11. Representative wood coupon before and after testing.

Table 8. Wood coupon test results.

Maximum Force	0 ppm Control Samples Results (N)			1000–1250 ppm Half-Target Concentration Results (N)			2000–2500 ppm Target Concentration Results (N)		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
Coupon Set	WN50304	WN50608	WN50609	WV50415	WV50509	WV50510	WV50406	WV50425	WV50426
Coupon 1	4562	4766	2475	3038	2873	6306	4730	4400	4202
Coupon 2	3782	4739	2888	4014	4389	4542	4951	5153	3023
Coupon 3	4539	3560	3038	3977	4877	4174	5045	4919	4715
Coupon 4	3858	4177	5312	5752	3717	3938	4862	4287	4394
Coupon 5	4076	3136	5175	4696	4842	5323	6428	1305	5040
Test Avg	4163	4076	3777	4295	4140	4857	5203	4013	4275
Std Dev	369	721	1355	1006	849	965	695	1556	769
Test Set Avg ± Std Dev	4006 ± 861			4431 ± 929			4725 ± 732		
Time to Break	**Control Samples Results (min)**			**Half-Target Concentration Results (min)**			**Target Concentration Results (min)**		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
Coupon Set	WN50304	WN50608	WN50609	WV50415	WV50509	WV50510	WV50406	WV50425	WV50426
Coupon 1	4.6	4.6	2.4	3.0	2.9	5.5	4.7	4.1	4.1
Coupon 2	3.8	4.5	2.7	4.0	3.5	3.6	5.0	4.9	3.0
Coupon 3	4.5	3.3	2.9	4.0	3.8	3.4	5.0	4.6	4.7
Coupon 4	3.9	3.9	5.3	5.8	3.6	3.3	4.9	4.2	4.3
Coupon 5	4.1	2.7	5.2	4.7	4.5	4.9	6.4	1.3	4.8
Test Avg	4.2	3.8	3.7	4.3	3.7	4.1	5.2	3.8	4.2
Std Dev	0.4	0.8	1.4	1.0	0.6	1.0	0.7	1.4	0.7
Test Set Avg ± Std Dev	3.9 ± 0.9			4.0 ± 0.9			4.6 ± 0.7		
Moisture content	**Control Samples (%)**			**Half-Target Concentration (%)**			**Target Concentration (%)**		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
Coupon Set	WN50304	WN50608	WN50609	WV50415	WV50509	WV50510	WV50406	WV50425	WV50426
Coupon 1	0.15	-0.12	-0.12	-0.10	1.04	0.83	0.12	-0.05	-0.22
Coupon 2	0.09	-0.07	-0.10	-0.16	0.96	0.88	-0.02	-0.19	-0.15
Coupon 3	0.20	-0.18	-0.19	-0.17	0.91	0.83	0.14	-0.15	-0.13
Coupon 4	0.12	-0.12	-0.06	-0.05	-0.13	0.75	0.08	-0.15	-0.02
Coupon 5	0.18	-0.10	0.02	-0.15	0.93	0.84	0.16	-0.19	-0.11
Test Avg	0.15	-0.12	-0.09	-0.13	0.74	0.83	0.10	-0.15	-0.12
Std Dev	0.04	0.04	0.08	0.05	0.49	0.05	0.07	0.06	0.07
Test Set Avg ± Std Dev	-0.02 ± 0.13			0.48 ± 0.52			-0.06 ± 0.13		
Number of Days in Storage	**Control Samples Days**			**Half-Target Concentration Days**			**Target Concentration Days**		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
Coupon Set	WN50304	WN50608	WN50609	WV50415	WV50509	WV50510	WV50406	WV50425	WV50426
Days	138	145	144	136	143	142	145	189	188
Test Set Avg ± Std Dev	142 ± 3			142 ± 10			176 ± 21		

Note: The values highlighted in orange were determined to be outliers within their individual test sets, but not within their individual test groups at the Q equals 0.99 confidence level. The values highlighted in red were determined to be outliers within the test set and test group and were removed from the data set prior to statistical analysis.

The average change in moisture content for the control samples after storage was -0.02 $\pm$ 0.13%. For the half-concentration coupons, the average change in moisture content was 0.48 $\pm$ 0.52, and for the full-concentration coupons, the average change in moisture was -0.06 $\pm$ 0.13%.

The differences between the controls and target concentration samples with respect to the maximum force and time-to-break were statistically significant at the 95% confidence level. The half-target concentration samples were not statistically different from the controls.

The results do suggest that VHP fumigation at the full target conditions may impact the wood used for this study according to the ASTM test method. Fumigation appeared to increase the force and time required to break the wood.

11. EVALUATION OF ELECTRICAL CIRCUIT BREAKERS

11.1 Introduction

The impact of fumigant and humidity on the performance of electrical circuit breakers post treatment was also investigated in this study. This investigation involved circuit breakers prepared as baseline, test, and control. Baseline circuit breakers are the as-purchased circuit breakers. The test circuit breakers were prepared in the exposure chambers using fumigant. The control circuit breakers were prepared in the exposure chambers using a temperature and RH profile similar to that of the test breakers.

11.2 Sample Preparation

The single pole, 20 amp rated circuit breakers were purchased from Home Depot (model HOM120). All of the circuit breakers were installed in the testing stations to confirm they were operational before exposure testing. All of the circuit breakers were removed from the stations, numbered, and CoC initiated. The baseline circuit breakers were put aside until needed. The test and control exposure testing was discussed in Section 4. Each run used seven circuit breakers. After a test or control circuit breaker set was prepared in the exposure chamber, the breakers were removed from the exposure chamber and visually inspected.

11.3 Circuit Breaker Testing Stations

After visual inspection, the breakers were installed in the testing station and observed for 90 days under load (Figure 12). The testing station is an electrical box containing 8 spaces, 16 circuits, 100 amp max from square D (Home Depot No. 577-340). The circuit breaker box was wired with 12 gauge, 20 amp wire into the 120 V outlet. Each circuit breaker was wired in series with an electrical lamp (s513e) with an outlet box (s110e) manufactured by Thomas & Bretts (Home Depot Nos. c214477 and b214426, respectively). Each lamp contained a Phillips 40 watt light bulb (Home Depot No. a356140). The test or control circuit breakers were installed into slots 1–7, and the baseline circuit breaker was installed in slot 8 (Figure 12, upper left corner).

11.4 Results and Discussion

The circuit breakers were exposed to fumigant and visually inspected after removal from the exposure chamber. No visual damage was observed on any of the circuit breakers used in this program following fumigation. The circuit breakers were then installed into the testing stations for 90 days. The stations were observed on each workday, and light bulbs were replaced as needed. No breakers failed during the 90 day storage under load. Following the 90 day storage, the breakers were tested using current-time measurements done at 150 and 300% (30 and 60 amp) of the breakers rated value. Tests were done using an AVO/multi-amp MS-2, available from Advanced Test Equipment

Rentals. The test results are provided in Table 9. The circuit breaker data were statistically analyzed to determine if the breaker was compromised after exposure to decontaminant by comparing the test results obtained with fumigant-exposed circuit breakers to those obtained with control coupons (not exposed to fumigant). Each breaker station contained one control breaker that had not been exposed in the chamber.

The measurement for the analysis was the time for the circuit breaker to open (Time-to-Open) when experiencing a current above its rated value. A circuit breaker that trips too quickly will protect personnel and equipment but can represent a significant loss of time and productivity for the users. A circuit breaker that takes too long to trip could result in a heat buildup, and possibly a fire, and might fail to protect equipment, users, and property.

A statistical analysis of the individual test results was conducted to detect potential statistical outliers (Q test) and determine if there are any differences (Welch's *t* test) between the control circuit breakers and samples exposed to VHP. No statistical outliers were found in any of the data at the Q equals 0.99 level of confidence.

Table 10 summarizes the data for the average and standard deviation for the various test groups. The Welch's *t* test was used with a 95% confidence level to determine if the changes in the Time-to-Open between the groups were statistically significant. At the 30 amp challenge level, the slight increases in the Time-to-Open from the control to the VHP-exposed circuit breakers were not determined to be statistically significant. Additionally, no difference existed at the 30 amp challenge between the 4 and 8 hr controls.

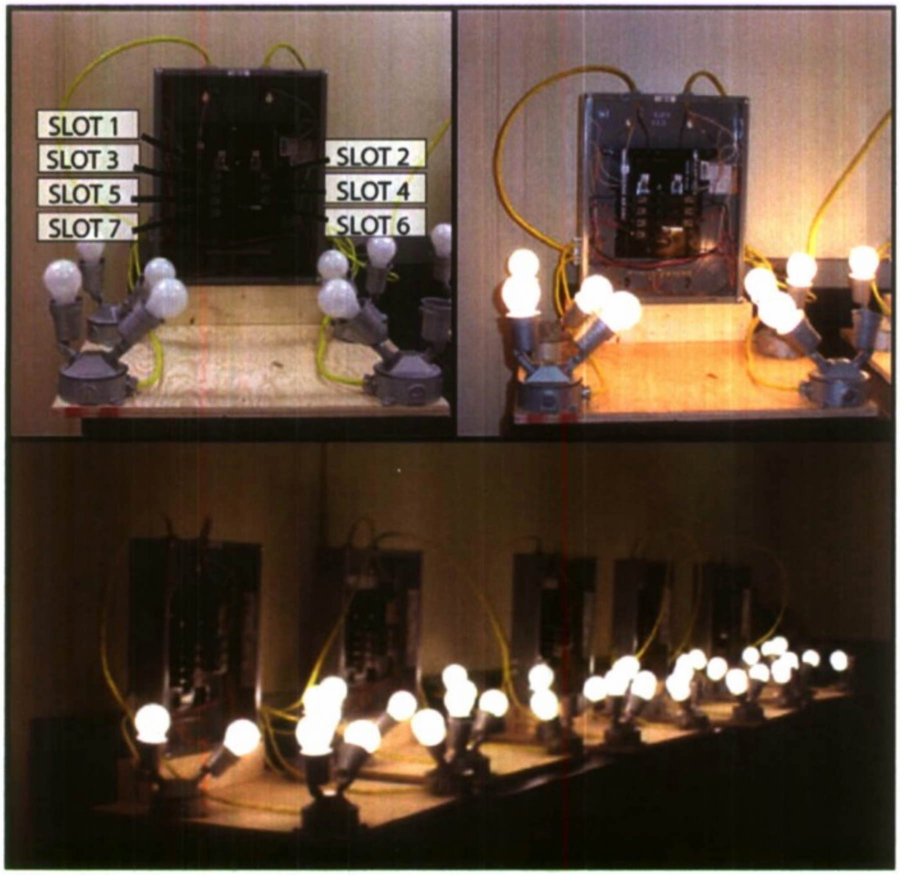


Figure 12. Circuit breaker test station photograph.

Table 9. VHP-exposed circuit breaker results.

4 hr VHP Box Test	60 Amp Test Time (s)	30 Amp Test Time (s)	4 hr Control	60 Amp Test Time (s)	30 Amp Test Time (s)
BV5051301	5.23	60.13	BN5022401	5.57	65.16
BV5051302	4.23	82.72	BN5022402	5.70	62.53
BV5051303	5.94	118.05	BN5022403	6.31	59.24
BV5051304	5.60	65.52	BN5022404	4.08	44.76
BV5051305	4.51	91.55	BN5022405	4.90	48.26
BV5051306	2.95	50.50	BN5022406	6.52	62.51
BV5051307	5.93	59.19	BN5022407	2.60	53.92
Control	5.01	91.06	BN50224NA*	4.96	40.94
Test Average	4.91	75.38	Test Average	5.10	56.63
Standard Deviation	1.09	23.62	Standard Deviation	1.38	7.82
8 hr Box Test	**60 Amp Test Time (s)**	**30 Amp Test Time (s)**	**8 hr Control**	**60 Amp Test Time (s)**	**30 Amp Test Time (s)**
BV5051201	2.44	64.80	BN5030801	5.75	67.61
BV5051202	4.28	79.00	BN5030802	5.92	43.72
BV5051203	4.60	57.23	BN5030803	5.14	49.62
BV5051204	3.62	55.94	BN5030804	6.39	70.91
BV5051205	3.30	84.22	BN5030805	5.90	56.40
BV5051206	4.66	60.63	BN5030806	5.69	69.43
BV5051207	2.51	58.90	BN5030807	5.06	57.39
Control	3.03	49.96	BN50308NA*	6.12	66.65
Test Average	3.63	65.82	Test Average	5.69	59.30
Standard Deviation	0.93	11.25	Standard Deviation	0.46	10.45

Table 10. Average and standard deviation by group.

Exposure	30 Amp Challenge Time-to-Open (s)	60 Amp Challenge Time-to-Open (s)
4 hr Control	56.63 ± 7.82	5.10 ± 1.38
4 hr at 250 ppm VHP	75.38 ± 23.62	4.91 ± 1.09
8 hr Control	59.30 ± 10.45	5.69 ± 0.46
8 hr at 125 ppm VHP	65.82 ± 11.25	3.63 ± 0.93

However, under the 300% challenge (60 amp), a statistically significant decrease in the Time-to-Open due to the 8 hr VHP exposure was observed. No difference was determined to exist between the control set and 4 hr VHP-exposed test group. While no difference was determined to exist between the 4 and 8 hr control groups, the Time-to-Open for the 8 hr VHP-exposed group was statistically significantly different than the 4 hr VHP-exposed group.

These results do suggest that the longer exposure to the fumigant, even at lower concentration levels, did result in a statistically significant effect on the circuit breakers that became apparent at the higher (300% of rated value) test challenge. No specification was found to determine if this effect was within the device failure criteria.

12. FTIR ANALYSIS OF SELECT WOOD SAMPLES

Using a Thermo-Nicolet Model 670 with Compact Parabolic Concentrator (CPC) Diffuse Reflectance Accessory and Mercury-Cadmium-Telluride (HgCdTe) Detector, 12 wood coupons were tested for substructural oxidation. Samples were tested in the 5000–650 cm^{-1} range with 4 cm^{-1} resolution.

12.1 Sample Preparation

In August 2005, eight wood coupons were collected from the Sample Storage Room. Coupons were prepared to show the cellular effects of exposure to VHP as compared to unexposed wood coupons and compared to unexposed coupons treated with liquid hydrogen peroxide. Coupons WV5042509, WV5042609, WV5050909, and WV5051010 were exposed in the VHP chamber and allowed to age prior to FTIR testing. Coupons WN5030409 and WN5060809 were not exposed to any hydrogen peroxide and allowed to age prior to FTIR testing. Coupons WN5030417 and WN5060817 were not exposed to VHP, but spiked with 0.5 mL of liquid hydrogen peroxide on one end of the coupon. During a 30 min evaporation period, the liquid hydrogen peroxide was periodically stirred. After 30 min, the coupons were blotted dry with Kimwipe cloths. These coupons were subsequently transferred to the FTIR for analysis.

12.2 FTIR

Twelve wood coupons were tested for substructural oxidation using a Thermo-Nicolet Model 670 with a CPC Diffuse Reflectance Accessory and HgCdTe Detector. Instrument parameters were 4000–650 cm^{-1} spectral range, 4 cm^{-1} resolution, 64 scans, Happ-Genzel apodization, Mertz phase correction, 2X zero fill, and 2 cm^{-1} final data spacing.

Following preparation of the coupons, they were further prepared for analysis on the FTIR. Using 400 grit silicon carbide paper, the surface of the wood coupon was abraded. Sample sizes of <100 μg were collected. The sample was introduced to the Thermo-Nicolet Model 670 via the CPC Diffuse Reflectance Accessory.

12.3 Background and Analysis Method

The cellulose in wood is a linear polymer of β-(1,4)-D-glucopyranose (polysaccharide) units. This, as well as other polysaccharides with similar structures, provides the rigidity to wood. The effects of VHP on the polymer, if occurring, may be expected to result in cleavage of the chains at the C-O-C linkages, oxidation of the O-H functionalities to the respective carbonyl, and/or opening of the monomer rings. Expected effects in the infrared spectra of the wood will be shifts and/or reductions in bands related to O-H and C-O-C, as well as increases in intensities of bands in the region of the spectra arising from C equals O functional groups.

The effect of VHP on wood was investigated at the molecular level using DRFTI. DRFTI is a technique in which the material to be investigated is diluted, after grinding or powdering, with a nonabsorbing material (e.g, potassium bromide). A small quantity of the resulting mixture is placed in an accessory that allows the collimated infrared beam from the spectrometer to be focused on the surface of the material from above. Because the surfaces of the particles of analyte and diluent are oriented randomly, the infrared energy becomes decollimated, or diffused. The resulting spectrum is treated mathematically using the Kubelka-Munk transformation. The technique is used extensively in the pharmaceutical industry and analysis of agricultural products.

While a literature search has indicated that DRFTI may be expected to be useful to elucidate the effects of VHP on wood, it may be difficult to prove a negative response of the wood to VHP. For this reason, wood samples subjected to a more aggressive oxidation than would be expected during this test will also be analyzed. Wood specimens (positive controls) exposed to liquid hydrogen peroxide (35%) and negative controls (no treatment) were prepared and analyzed similarly as the test specimens.

The primary assumption of analysis was that the effects of exposure to hydrogen peroxide would oxidize the –OH in rings and ether linkages in the cellulose polymer of the wood. This would result in an increase in carbonyl bands noticeable in the 1700 cm^{-1} region. Normalization of samples would be performed by analyzing the region around 2900 cm^{-1}. The ratio of CH stretching in this region can be compared to carbonyl stretching regions.

12.4 Results and Discussion

Table 11 shows the integrated area responses for each sample in the 2900 cm^{-1} and 1700 cm^{-1} regions analyzed. The ratio of the two regions is also provided. Using the Welch's t test, no statistically significant differences existed between the analyses of the control, VHP-exposed, or liquid H_2O_2 exposed coupon sets. Analysis by this method did not reveal any changes to the structure of the wood due to oxidation by hydrogen peroxide (vapor or liquid).

Table 11. FTIR test results.

VHP-Exposed Coupon Set						
Sample ID	WV5042509	WV5042609	WV5050909	WV5051010	Average	SD
3025–2800	15.52	15.06	17.29	19.34	16.80	1.95
1824–1689	9.93	7.18	7.86	8.89	8.47	1.20
ratio	0.64	0.48	0.45	0.46	0.51	0.09
Control Coupon Set						
Sample ID	WN5030409	WN5060809	WN5030417	WN5060817	Average	SD
3025–2800	20.03	15.80	24.21	20.54	20.15	3.44
1824–1689	8.87	7.55	10.59	8.83	8.95	1.25
ratio	0.44	0.48	0.44	0.43	0.45	0.02

Table 11. FTIR test results (continued)

Liquid H_2O_2 Exposed Coupon Set						
Sample ID	WN5030417	WN5060817			Average	SD
3025–2800	16.06	29.44			22.75	9.46
1824–1689	7.31	12.13			9.72	3.41
ratio	0.46	0.41			0.43	0.03

13. QUALITY ASSURANCE FINDINGS

Two technical audits of the Instron destructive testing process on VHP-fumigated coupons were conducted over the course of the program. The first technical audit, conducted on 6 June 2005, covered steel coupons from a control run in the VHP chamber. All operations were IAW the SOPs and IOPs. A second technical audit, conducted on 19 October 2005, involved ceiling tile coupons. All operations were IAW the applicable SOPs and IOPs. Data quality audits were conducted on 7 of the 56 VHP material compatibility tests (13%). All were found to be acceptable IAW the QAPP.

Blank

LITERATURE CITED

1. Jahnke, M.; Lauth, G. Biodecontamination of a Large Volume Filling Room with Hydrogen Peroxide. *Pharm. Eng.*, 1997, 2-12.

2. McDonnell, G. G.; Gringol, G.; Antloga, K. Vapor Phase Hydrogen Peroxide Decontamination of Food Contact Surfaces. *Dairy, Food Environ. Sanit.*, 2002, 868-873.

3. Brickhouse, M. D.; Turetsky, A.; McVey, I. *Decontamination of CBW Agents by mVHP: Demonstration of the CBW Decontamination of a Building using mVHP*; ECBC-TR-470; U.S. Army Edgewood Chemical Biological Center: Aberdeen Proving Ground, MD, 2007; UNCLASSIFIED Report (AD-B333 526).

4. Brickhouse, M. D. Quality Assurance Project Plan and Work Plan for Deposition Velocity Studies: Materials Sorption of Vaporized Hydrogen Peroxide or Chlorine Dioxide, Doc. No. DSQAPP2004DV, 2004.

5. Quality Management Plan (QMP) for the National Homeland Security Research Center (NHSRC) Office of Research and Development (ORD); U.S. Environmental Protection Agency: Washington, DC, 2003.

6. Quality Management Plan for Environmental Programs; U.S. Army Edgewood Chemical Biological Center Research, Development and Engineering Command: Aberdeen Proving Ground, MD, 2003.

7. EPA Guidance for Data Quality Assessment, Practical Methods for Data Analysis. EPA QA/G-9; U.S. Environmental Protection Agency: Washington, DC, 2000.

8. EPA Requirements for Quality Assurance Project Plans; EPA QA/R-5; U.S. Environmental Protection Agency: Washington, DC, 2001.

9. EPA Guidance for Quality Assurance Project Plans; EPA QA/G-5; U.S. Environmental Protection Agency: Washington, DC, 2002.

10. EPA Guidance on Environmental Data Verification and Data Validation; EPA QA/G-8; U.S. Environmental Protection Agency: Washington, DC, 2002.

11. Brickhouse, M. D. Quality Assurance Project Plan and Work Plan for Effects of Vaporized Decontamination Systems on Selected Building Interior Materials; Doc. No. DSQAPP2004MC, 2004.

Blank

ACRONYMS

APG	Aberdeen Proving Ground
ASTM	American Society for Testing and Materials
CB	Chemical and Biological
CoC	Chain-of-Custody
CPC	Compact Parabolic Concentrator
CT	Concentration Time
DRFTI	Diffuse Reflectance Fourier Transform Infrared
ECBC	U.S. Army Edgewood Chemical Biological Center
EPA	U.S. Environmental Protection Agency
FTIR	Fourier Transform Infrared Spectroscopy
HgCdTe	Mercury-Cadmium-Telluride
IAW	In Accordance With
IR	Infrared
IOP	Internal Operating Procedure
MOR	Modulus of Rupture
NHSRC	National Homeland Security Research Center
QAPP	Quality Assurance Project Plan
QMP	Quality Management Plan
RH	Relative Humidity
SAIC	Science Applications International Corporation
SOP	Standing Operating Procedure
TIC	Toxic Industrial Chemicals
UL	Underwriters Laboratories
VHP	Vaporized Hydrogen Peroxide

Blank

APPENDIX A

DETAILED COUPON PREPARATION AND INSPECTION PROCEDURES

COUPON PREPARATION PROCEDURE: The coupon preparation, unless otherwise noted, was conducted at the U.S. Army Edgewood Chemical Biological Center (ECBC) Experimental Fabrication Shop.

Mechanically Graded Lumber (Bare Wood)

- Stock Item Description: 2 x 4 x 8 KD WW/SPF Stud
- Supplier/Source: Home Depot, Edgewood, MD
- Coupon Dimensions: 10 in. x 1 ½ in. x ½ in.
- Preparation of Coupon: The machined ends of the stock were discarded by removing greater than ¼ in. of the machined end. Coupons were cut from stock using a table saw equipped with an 80 tooth crosscut blade.

Latex-Painted Gypsum Wallboard

- Stock Item Description: ½ in. 4 ft. x 8 ft. Drywall
- Supplier/Source: Home Depot, Edgewood, MD
- Coupon Dimensions: 6 in. x 6 in. x ½ in.
- Preparation of Coupon:
  - The ASTM method requires that the samples be taken from the interior of material rather than from the edge (machined edge). The machined ends of the stock were discarded by cutting away > 4 in. from each side.
  - Coupons were cut from stock using a table saw equipped with an 80 tooth crosscut blade.
  - The 6 in. x 6 in. coupons were painted with 1 mil of Glidden PVA Primer and followed by 1–2-mils of Glidden latex topcoat. The primed coupons were allowed to stand for > 24 hr prior to the application of the topcoat.
  - All six sides of the 6 in. x 6 in. coupon were painted.

Concrete Cinder Block

- Stock Item Description: 8 in. x 16 in. x 1.5 in. concrete cinder block cap
- Supplier/Source: York Supply, Aberdeen MD
- Original Coupon Dimensions: 4 in. x 8 in. x 1.5 in.
- Modified Coupon Dimensions: 4 in. x 8 in. x 0.5 in.
- Preparation of Coupon:
  - Coupons were cut from stock using a water-jet.
  - Four coupons were cut from each stock piece.
  - Original dimensions too large for material testing.
    - Each coupon cut into three sections.
    - Two sections measured at modified coupon dimensions.
    - Third section discarded.

Carpet

- Stock Item Description: 12 ft. Powerhouse 20 Tradewind
- Supplier/Source: Home Depot, Edgewood, MD
- Coupon Dimensions: 6 in. x 8 in.
- Preparation of Coupon:
  - Coupons were cut from the stock using a utility knife.

- The longer direction (8 in.) was cut parallel to the machine edge.
- The machined edge was discarded by removing >½ in.

Painted Structural Steel

- Stock Item Description: A572 Grade 50, 4 ft. x 8 ft. x ¼ in.
- Supplier/Source: Specialized Metals, Coral Springs, FL
- Coupon Dimensions: 1/4 in. x 12 in. total, dog bone shaped with 2 in. wide at ends, 0.75 in. width at center
- Preparation of Coupon:
  - Coupons were cut from stock using a water-jet.
  - A visual observation was conducted on each coupon to determine if size and shape deviated from dimension, and the coupons were discarded if deviations were evident.
  - Coupons were cleaned and degreased following procedures outlined in TTC-490.
  - Coupons were prepared for painting with red oxide primer per TT-P-645.

  The ECBC Experimental Fabrication Shop prepared the materials in accordance with the standards used for preparing and painting steel. TTC-490 is a Federal Standard providing cleaning methods and pretreatment of iron surfaces for application of organic coatings. The pretreatment is the application of a zinc phosphate corrosion inhibitor. TT-P-645 is a Federal Standard for the application of alkyd paint. These standards were not obtained through this program but were purchased by the Experimental Fabrication Shop for their work.

Ceiling Suspension Tile

- Stock Item Description: Armstrong 954, Classic Fine Textured, 24 in. x 24 in. x 9/16 in.
- Supplier/Source: Home Depot, Edgewood, Maryland
- Coupon Dimensions: 12 in. x 3 in. x 9/16 in.
- Preparation of Coupon: Coupons were cut from stock using a table saw equipped with an 80 tooth crosscut blade. Sixteen samples were removed from each stock item.

COUPON INSPECTION PROCEDURE: All coupons were inspected prior to testing to ensure that the material being used was in suitable condition. Coupons were rejected if there were cracks, breaks, dents, or defects beyond those typical for the type of material. In addition, coupons were measured to verify the coupon dimensions. Coupons deviating from the following dimension ranges were discarded.

Mechanically Graded Lumber	10 in. ± 1/16 in. x 1.5 in. ± 1/16 in. x 0.5 in. ± 1/32 in.
Latex-Painted Gypsum Wallboard	6 in. ± 1/16 in. x 6 in. ± 1/16 in. x 0.5 in. ± 1/16 in.
Concrete Cinder Block	4 in. ± ½ in. x 8 in. ± ½ in. x 0.5 in. ± 1/16 in.
Carpet	6 in. ± 1/8 in. x 8 in. ± 1/8 in.
Painted Structural Steel	1/4 in. ± 1/128 in. x 12 in. ± 1/16 in. and 2 in. ± 1/16 in. wide at ends, ¾ in. ± 1/16 in. wide center
Ceiling Suspension Tile	12 in. ± 1/8 in. x 3 in. ± 1/16 in. x 9/16 in. ± 1/16 in.

APPENDIX B

COUPON IDENTIFIER CODE

All coupons were marked with an ID number that consisted of a nine character alphanumeric code. A description of the identifier pattern and example code is shown as follows:

Code Pattern

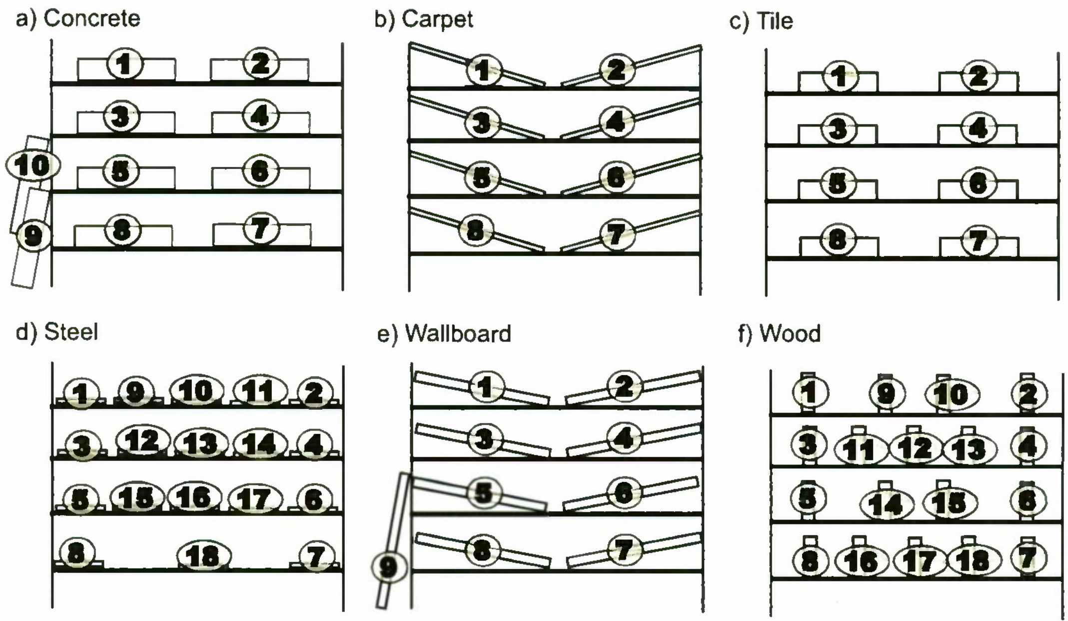
Character	*Explanation*		
1	Material		
	W	=	wood
	G	=	gypsum
	S	=	A572 steel
	T	=	acoustic ceiling tile
	C	=	concrete cinder block
	R	=	carpet
	B	=	circuit breakers
	A	=	Aluminum coupons
	F	=	Copper coupons
	E	=	Steel coupons
2	Fumigant		
	V	=	VHP
	D	=	chlorine dioxide
	N	=	no fumigant
	Test start date		
3	year		for example: 4 = 2004
4,5	month		for example: 06 = June
6,7	day		for example: 10 = the 10th of a month
8,9	Chamber position (see IOP DS04016 Figure 1)		

Example GV4101104

Gypsum wallboard with test start date of October 11, 2004 and is sample number four.

The coupon placement figure taken from the test plan is provided below.

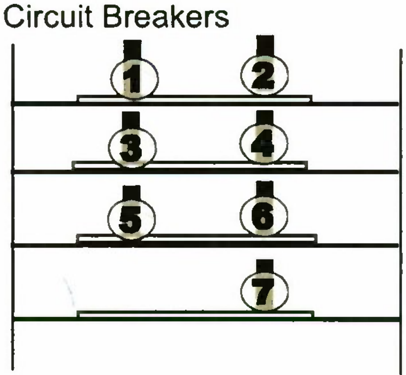
Figure B.1: IOP DS04016 Figure 1, "Coupon Placement in Chambers"



Coupons shown on rack shelves from direction of glove box transfer chamber. Pictoral coupon scaling for length and width is (0.75 * 2 *(cm / 10)).

Fiaure B.2: IOP DS04016 Fiaure. "Circuit Breaker Placement in Chambers

a) Circuit Breakers

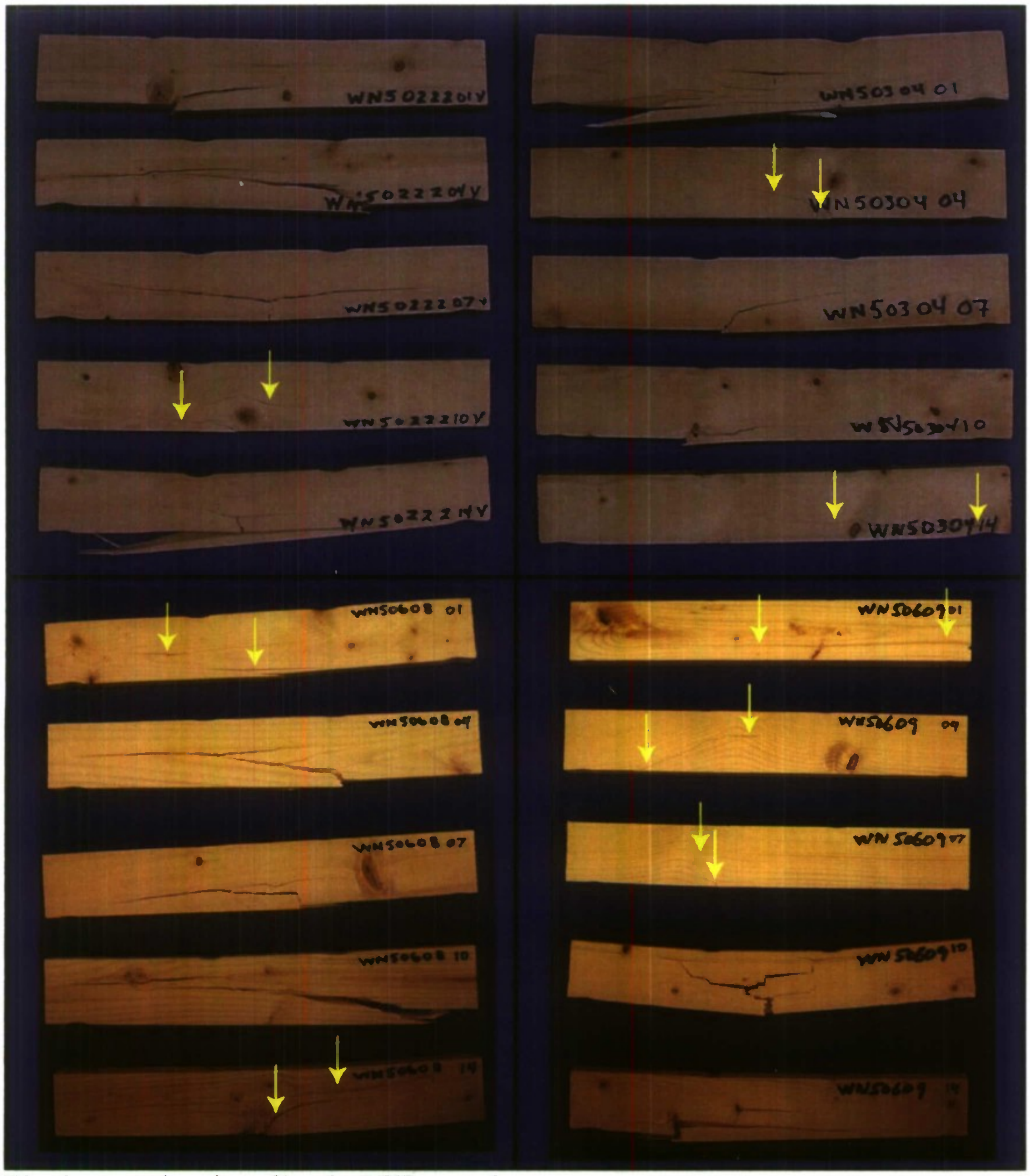


Coupons shown on rack shelves from direction of glove box transfer chamber.

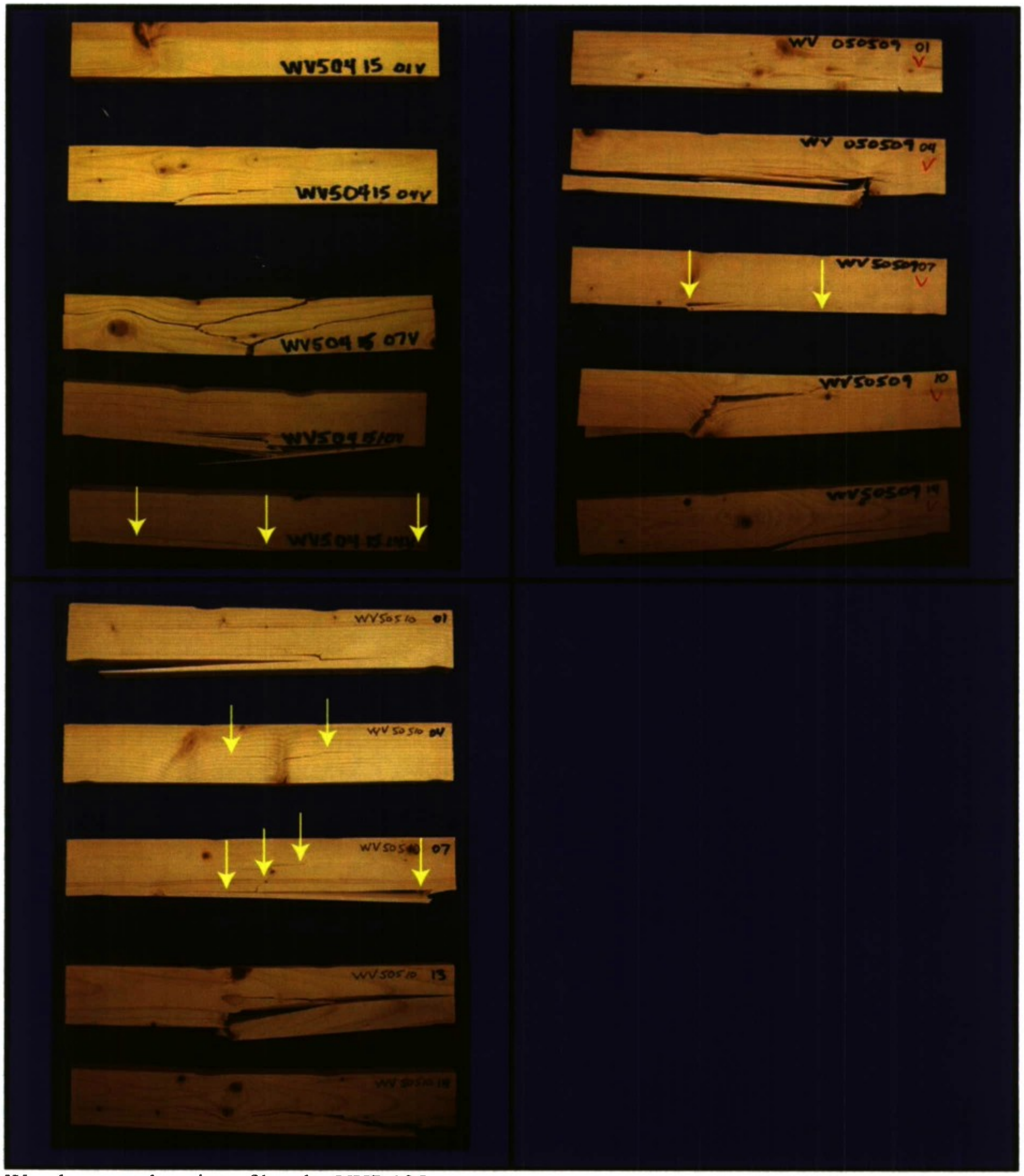
APPENDIX C

WOOD COUPON LOCATION OF BREAK

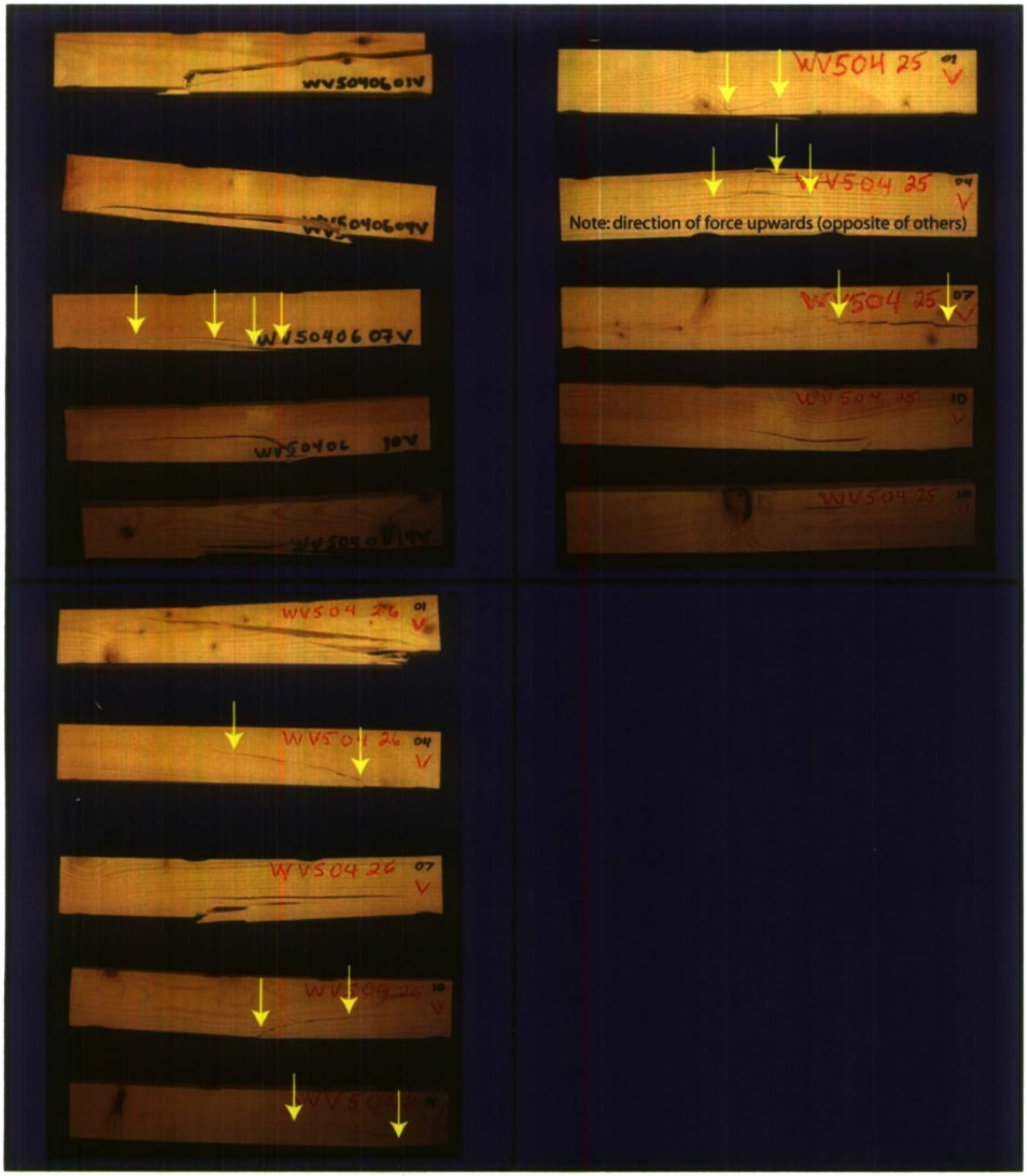
The ASTM test method requires reporting the location of the break for each wood sample. The purpose of this appendix is to provide this reporting information in pictorial form. Yellow arrows are used on samples where the photograph contract may not clearly show the location of the break.



Wood coupon location of break: VHP control set.



Wood coupon location of break: VHP 125 ppm set.



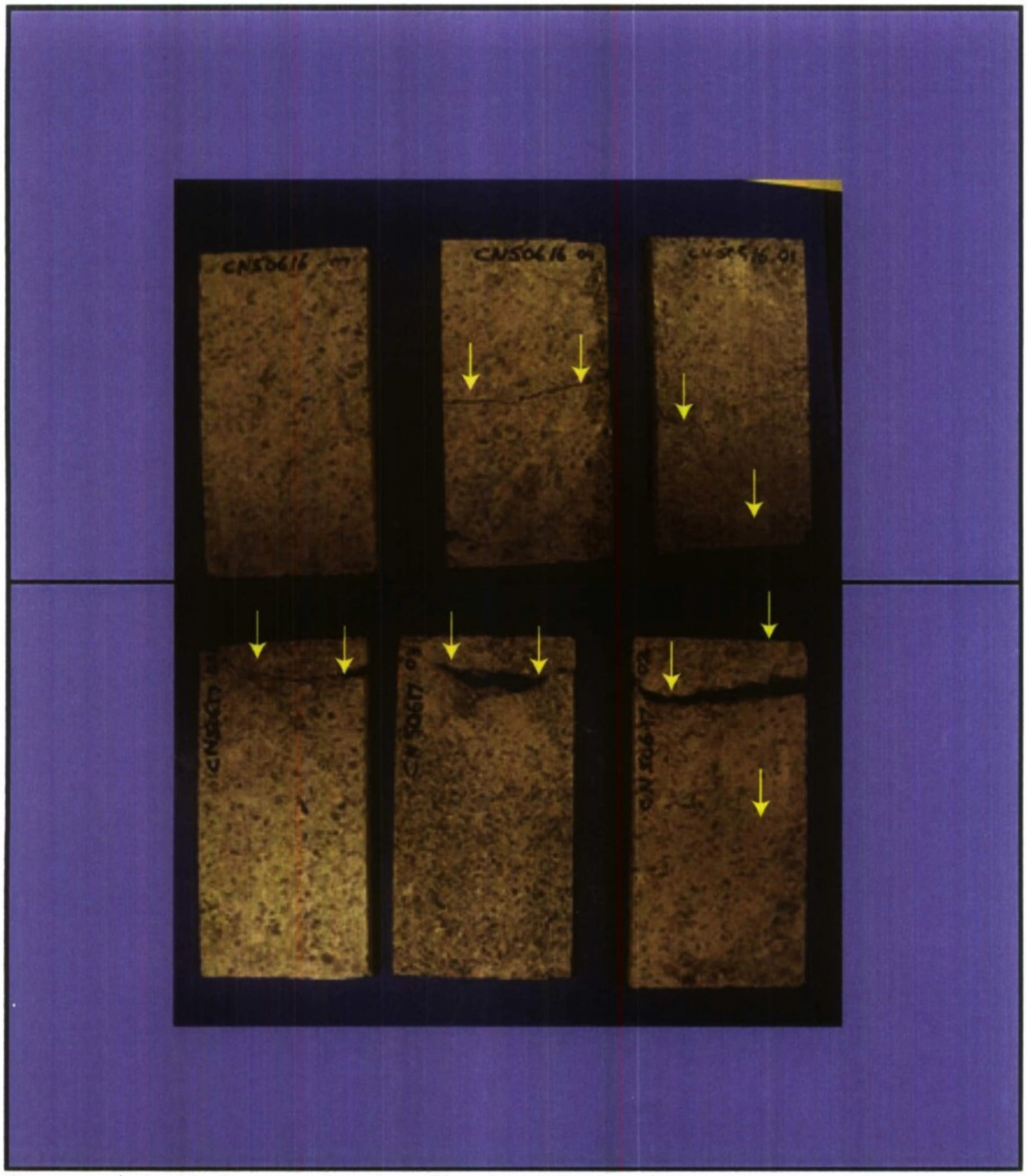
Wood coupon location of break: VHP 250 ppm set.

Blank

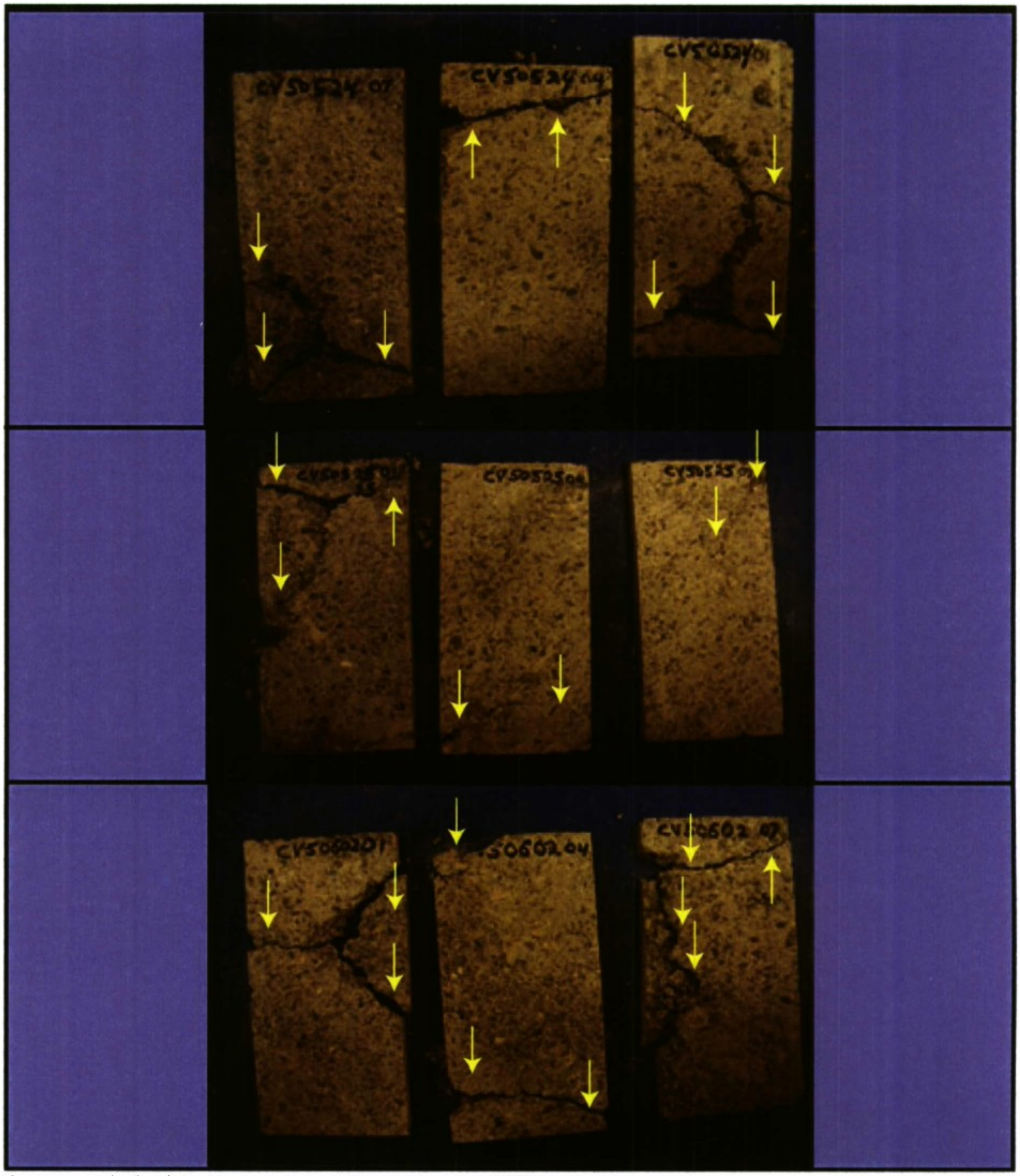
APPENDIX D

CONCRETE CINDER BLOCK COUPON BREAK LOCATION

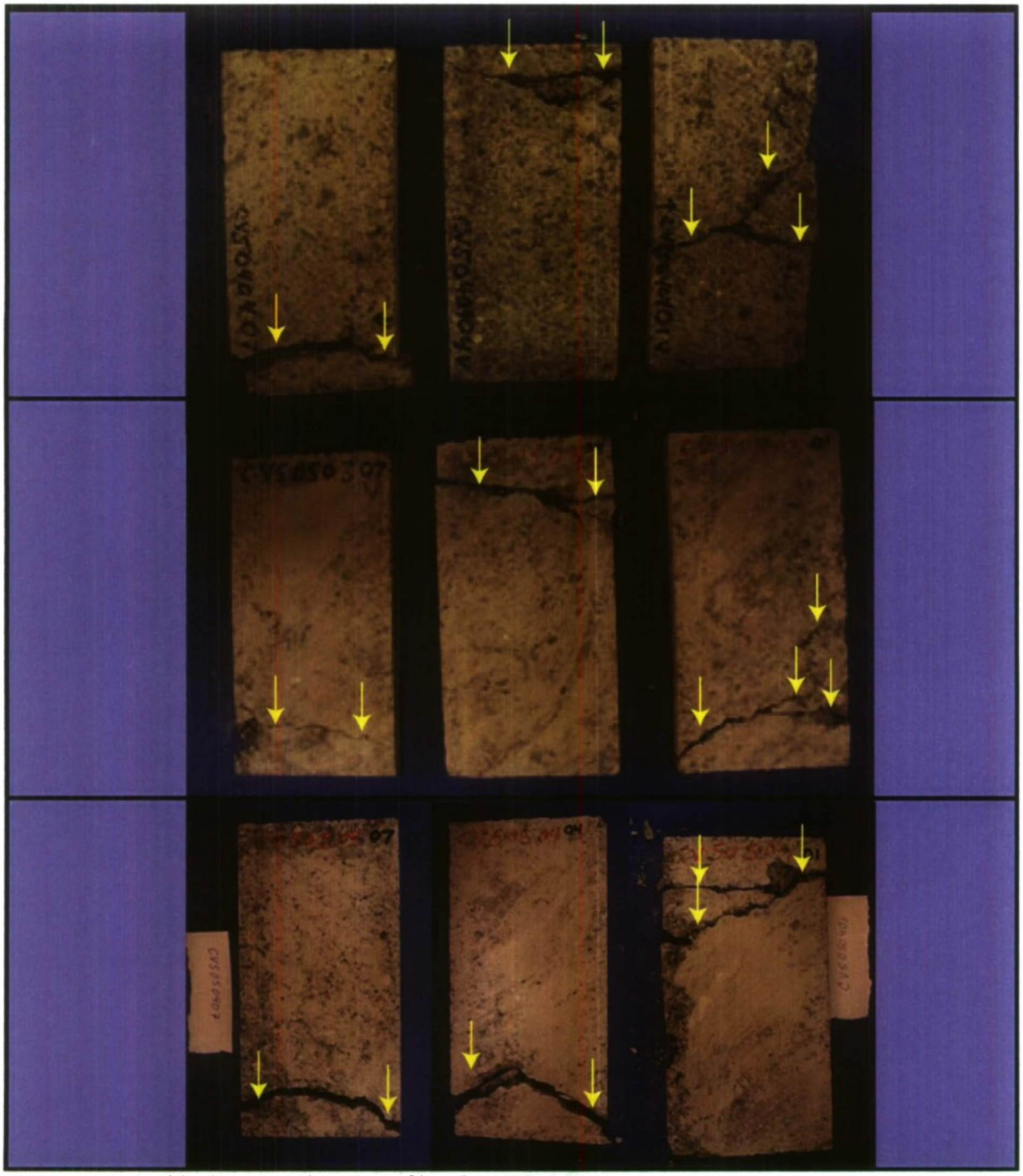
There is no requirement for reporting the location of the break; however, concrete block is a variable material and differences in location were observed. The purpose of this appendix is to provide additional information through test photographs. Yellow arrows are used on samples where the photograph contract may not clearly show the location of the break.



Concrete cinder block coupon location of break: VHP control set.



Concrete cinder block coupon location of break: VHP 125 ppm set.



Concrete cinder block coupon location of break: VHP 250 ppm set.