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Evaluion of the Effectiveness of Coatings in Reducing Dislodgeable Arsenic, Chromium, and Copper from CCA Treated Wood

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List of Acronyms

As	Arsenic
Av	Average
AWPA	American Wood Preservers' Association
BL	Baseline
CCA	Chromated Copper Arsenate
CD-Rom	Compact Disk – Read Only Memory
CL	Confidence Limits
CPSC	Consumer Product Safety Commission
DCCA	Dislodgeable CCA Wood Analytes
DAs	Dislodgeable Arsenic
DCr	Dislodgeable Chromium
DCu	Dislodgeable Copper
DI	Deionized Water
DPD	Dew Point Depression
DQI	Data Quality Indicator
EPA	United States Environmental Protection Agency
ERC	Environmental Research Center (old building)
FIFRA	Federal Insecticide Fungicide and Rodenticide Act
H&S	Health and Safety
HF	Hydrofluoric Acid
ICP	Inductively Coupled Plasma
ICP-MS	Inductively Coupled Plasma—Mass Spectrometry
ID	Identification
Ln	Natural Logarithm
Mph	Miles Per Hour
MS	Matrix Spikes
MS/MSD	Matrix Spikes and Matrix Spike Duplicates
MSD	Matrix Spike Duplicates
MSD	Mean of the Squared Difference
NCDC	National Climate Data Center
NE	Northeast
NFG	National Functional Guidelines
NOAA	National Oceanic and Atmospheric Administration
NOPW	Number of Previous Wipes
NW	Northwest

NWS	National Weather Station
OLS	On-Site Laboratory Support
OPP	Office of Pesticide Programs
pcf	Pounds per Cubic Foot
PEA	Performance Evaluation Audit
PFA	Perfluoroalkoxy
PM	Project Manager
PSA	Primary Sampling Area
PTFE	Polytetrafluoroethylene
QA/QC	Quality Assurance and Quality Control
QAM	QA Manager
QAO	Quality Assurance and Quality Control (QA/QC) Officer
QAPP	Quality Assurance Project Plan
RDU	Raleigh—Durham International Airport
RPD	Relative Percent Difference
RSD	Relative Standard Deviation
RSD/RPD	Relative Standard Deviation or Relative Percent Deviation
RTP	Research Triangle Park
SAP	Scientific Advisory Panel
Std. Dev.	Standard Deviation
STL	Severn Trent Laboratory
SYP	Southern Yellow Pine
TFE	Tetrafluoroethylene
TSPW	Time (Months) Since the Previous Wipe
U.S.	United States
WA	Work Assignment
WAL	Work Assignment Leader
WAM	Work Assignment Manager
UV	Ultraviolet

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Executive Summary

EPA conducted a study to evaluate the effect of coatings on dislodgeable arsenic, chromium, and copper residues on the surfaces of chromated copper arsenate (CCA) treated wood. Dislodgeable CCA (DCCA), determined by wipe sampling the wood surfaces, was the primary evaluation criterion for the coatings tested in this study, due to the potential for ingestion of CCA chemicals by hand-to-mouth activities of young children that contact CCA treated wood. The study was conducted by EPA's Office of Research and Development in Research Triangle Park, North Carolina, in support of the Office of Pesticide Programs (OPP) and in collaboration with the staff of the Consumer Product Safety Commission (CPSC), who used a similar protocol to evaluate several of the same products at a site in Gaithersburg, Maryland.

EPA risk assessors, the coatings and wood treating industries, and citizens who may be concerned about contact with CCA treated wood need sound information regarding the impact of coatings on dislodgeable arsenic residues. Although no longer produced or available for most consumer residential uses, CCA treated wood has been used extensively for construction of decks and play structures that may have a long service life and therefore, may pose a potential exposure route for CCA residues for many years to come.

Locally purchased deck treatment products suitable for application by homeowners were applied per manufacturers' instructions to purpose-built test decks. Application of the coatings to CCA-treated decking initially reduced the amount of dislodgeable arsenic, chromium, and copper residues, and the effectiveness decreased for all products tested over the two-year period of the study. The significance of the results reported in this study must be viewed in light of the limitations of the study design; most notably that the study evaluated the effectiveness of a relatively small convenience sample of the deck-coating products available for consumers at the time the study was initiated and the study was conducted on small test decks in the relatively mild climate of central North Carolina. Since the test decks were not subjected to the normal wear and tear stresses that full-scale, in-use decks experience, the results of this study may be indicative of the maximum period of effectiveness expected from the products that were tested.

Two sources of weathered CCA-treated southern yellow pine (SYP) were harvested from in-service decks and used to construct a series of miniature decks ("minidecks"), onto which one of twelve coatings was applied per manufacturer's instructions. Products included oil- and water-based sealants and stains, two porch and deck paints, and two products that were advertised to encapsulate CCA treated wood. Instructions for ten of the products recommended surface preparation with a cleaning agent followed by a rinse prior to application of the coating, instructions for one product recommended only a water rinse, and instructions for one product recommended

neither cleaning nor rinsing prior to application. Instructions for six of the products recommended two applications of the product.

Each minideck contained four CCA-treated specimens: two from a source deck which had been in service for two years prior to the study and two from a source deck in service for seven years. Each coating was applied to three minidecks. There were also three positive control (CCA treated, uncoated) minidecks and one negative control (untreated, uncoated) minideck for a total of 40 minidecks. After coating, the minidecks were subjected to outdoor weathering at a controlled site in North Carolina where climate measurements were recorded on a near-continuous basis (Figure E-1).

Figure E-1. Minideck Test Site at EPA's Research Triangle Park, North Carolina, Campus

Dislodgeable arsenic (DAs), chromium (DCr), and copper (DCu) were determined at specified intervals: baseline (pre-coat and pre-rinse or wash), and after 1, 3, 7, 11, 15, 20 and 24 months. The DCCA residues were determined by wiping deck surfaces with a polyester wipe attached to a 1.1 kg weight that slides between rails of a wipe apparatus, as developed by the staff of the CPSC (Figure E-2). The arsenic, chromium and copper were extracted from the wipe in a nitric acid solution and the total amount of each metal in the extract was determined by inductively coupled plasma-mass spectrometry (ICP-MS). Baseline samples on uncoated control minidecks were taken

before rinsing the minideck surfaces using a mild pressure wash. Thus, the baseline DCCA results provide insight into the impact of rinsing CCA-treated decking.

Figure E-2. Sampling to Determine Dislodgeable Arsenic (DAs) Residues on CCA-Treated Wood Using the CPSC Wipe Sampling Apparatus

The statistical analyses used to evaluate coating performance compare dislodgeable CCA residues determined on the uncoated CCA controls with CCA residues determined for the coated minidecks at each time period. For completeness and to establish the robustness of the study's major conclusions, the data were analyzed using a variety of alternative statistical models.

The amount of DAs versus time for each specimen on each minideck exhibited some immediately recognizable trends. Each coating, as well as the positive controls (uncoated CCA-treated minidecks), showed a significant decrease in DAs between baseline (prerinse and precoat) and samples taken 1 month after coating. The rinsing preparation step for the uncoated CCA controls initially reduced the DAs by about 71 percent. Thus, the rinse step provides some reduction in DAs; however, the reduction is relatively small compared to the reduction attributable to most of the coatings. The results indicate that coating (using any of the coatings tested) mitigates DAs to some degree in excess of the reduction associated with rinsing alone, although not always at

a statistically significant level. Over time, DAs increased as specimens weathered after they were coated. However, the time trend is generally uneven, because the amount determined at any wipe sampling event is an imprecise snapshot in time of the effects of processes that decrease and processes that increase the amount of dislodgeable residues - wipe sampling, and presumably, precipitation remove residues, whereas weathering and time are expected to adversely affect coating performance and result in increased residues.

Example log-scale plots, Figures E-3 and E-4 below, illustrate changes in DAs with time for two minidecks: deck 8C, coated with a water-based stain, and Deck 13A, an uncoated CCA-treated positive control deck. Lines above the data in each plot indicate the baseline DAs determined prior to rinsing and coating. The colors are keyed to individual specimens, source deck, A (older) or C (newer), and end grain orientation, up or down. The difference between the lines at the top of the graph and the first data point at time = 1 month in Figure E-3 demonstrates the impact, after one month of weathering, of rinsing and coating, whereas the difference in Figure E-4 is attributable to the impact of rinsing the uncoated CCA-treated control deck.

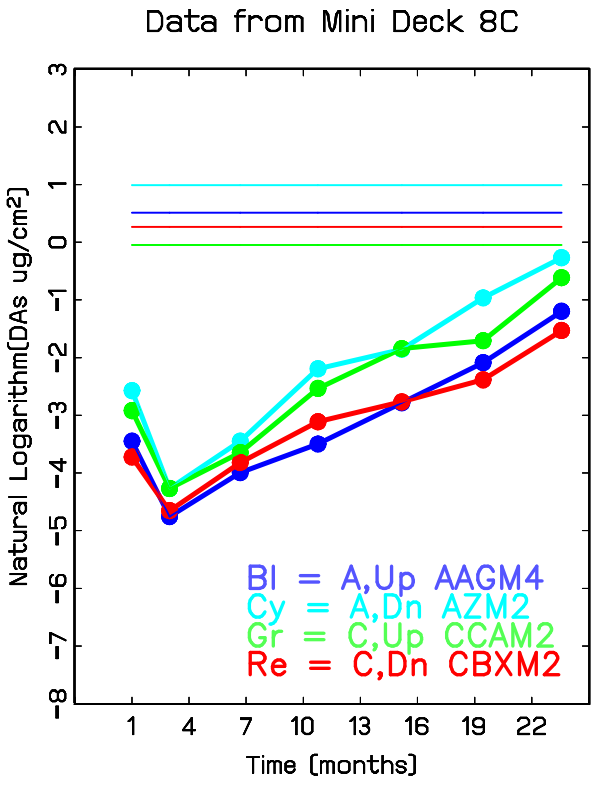

Figure E-3. DAs vs. Time Determined on Four Specimens of Minideck 8C, Coated with a Water-Based Stain

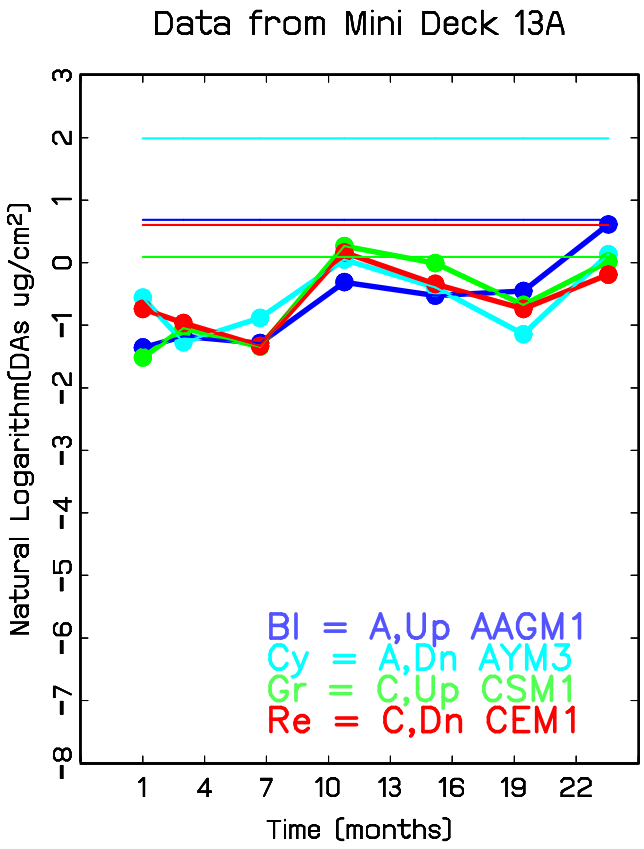

Figure E-4. **DAs vs. Time Determined on Four Specimens of One of the Positive Control Minidecks (no coating applied)**

The key findings of the study are captured in the pair-wise analyses of differences between each coating and the uncoated CCA-treated minidecks at each of the seven sampling events over the two-year study. The pair-wise analyses demonstrate that (1) all of the coatings tested reduced DCCA. However, the efficacy of each product decreased over the period of the study and by 24 months only two of the products, the paints, had DAs levels sufficiently low enough that their differences from the positive control were found to be statistically significant (p-value[1] < 0.05); and (2) the reductions of DAs for one product, a water-based sealant, were not statistically different from the positive control over the entire course of the study (p-value ranged from 0.0885 to 0.9635).

The results of these tests were consistent with the results of parallel tests conducted by CPSC staff in Gaithersburg, MD, despite differences in the wood substrate tested (CPSC staff used new CCA-treated wood) and some of the methods employed. Several coatings were common to both the EPA and CPSC staff studies and the ordering of performance of these coatings was similar between studies.

Additional research is needed to address key questions, including:

- What is the effect of periodic (e.g., monthly, quarterly) rinsing or cleaning as compared to coating over time?
- What is the effect of application of multiple coats and periodic re-coating?
- What products perform best in specific climates?
- What products perform best on boards of different ages and conditions?
- How do abrasion and wear and tear effect mitigation of DAs?
- What are the potential hazards and risks associated with preparation steps, e.g., sanding and scraping previously coated CCA-treated wood? Elevated levels of

[1] A p-value is a measure of the amount of statistical evidence supporting an alternative hypothesis relative to a particular null hypothesis, with smaller p-values corresponding to greater evidence. The null hypothesis is usually the hypothesis of "no difference" or "no effect," for example, no difference in mean DAs between Coating 1 and the Coating 13 at time period 1. Whereas the alternative hypothesis asserts that a difference (or effect) exists, for example, Coating 1 and Coating 13 have different mean DAs at time period 1. P-values always lie between 0 and 1 and thus are probabilities. In fact, the p-value is the probability of finding a difference (or an effect) as large as the one observed in the data, when the null hypothesis is true. A p-value less than 0.05 is generally considered to be "statistically significant" although the choice of 0.05 is somewhat arbitrary and sometimes other cutoff values - 0.1 or 0.01, are used to classify findings as statistically significant or not.

arsenic were measured in peeling paint chips (and possibly attached wood fibers) recovered from the weathered painted test decks.

The results of this study provide a reasonable indication of the maximum ability of typical existing deck coating products to reduce dislodgeable CCA residues and suggest that there is an opportunity for development of products specifically targeted to not only enhance the appearance of CCA-treated wood, but also to maximize the ability of the treatments to reduce dislodgeable CCA residues. Ideally, products would be formulated to maximize the period of time between treatments and minimize preparation steps that may create the potential for human exposure and movement of the CCA residues to the environment.

In support of such efforts to develop coatings and other potential mitigation measures, it may be useful to develop and utilize testing methods that help gain insight into other characteristics of CCA residues. For example, greater insight into the nature and behavior of the soluble and insoluble fractions of the CCA residues obtained by wipe sampling may suggest that certain coating ingredients (e.g., water repellant) are appropriate. Likewise an improved understanding of the relationships between CCA residues and exposure routes may suggest other appropriate mitigative measures.

This report supersedes the previously issued “Interim Data Report.” In addition to covering the complete dataset through 24 months of testing, this final report also utilizes more sophisticated data analysis models. The draft quality assurance project plan (QAPP) was posted for public and stakeholder comment and the QAPP as well as the Interim Data Report were the subjects of letter peer review. An open peer review of the draft final report by OPPTS’s Scientific Advisory Panel took place in November of 2006. Records of the letter peer reviews and the supporting documents, and minutes of the peer review meeting (SAP Minutes No. 2007-02) can be found in EPA’s Science Inventory (www.epa.gov/si/) at Record 150970.

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1. Project Description

1.1 Background

CCA is a wood preservative that is impregnated under pressure into wood to protect it from decay and insect damage. CCA is registered under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) by EPA's Office of Pesticide Programs (OPP). In October 2001, EPA-OPP prepared a preliminary deterministic exposure assessment for selective internal and external peer review comments as an interim report intended to address child residential "playground" exposures. In addition, EPA requested guidance from the FIFRA Scientific Advisory Panel (SAP) for risk mitigation measures such as sealants and coating processes. The SAP Panel made "recommendations regarding the need for additional studies in this area..." because the weight-of-evidence from available studies indicates that certain coatings can substantially reduce dislodgeable and leachable CCA chemicals." The Panel also recommended that "EPA inform the public of the ability of certain coatings to substantially reduce leachable and dislodgeable CCA chemicals…"

In March 2003, the registrants of CCA wood preservatives signed an agreement with EPA for voluntary cancellation of CCA-treated wood for residential uses (such as playsets and decks) effective beginning January 1, 2004. However, existing decks and playsets made of CCA-treated wood will still be in use. Therefore, the potential remains for dermal contact with arsenic, chromium, and copper residues on treated surfaces, and this may be a concern for infants and small children, due to their close contact with surfaces and hand-to-mouth activities (Kwon et al., 2004; Ursitti et al., 2004; Zartarian et al., 2006).

In support of OPP's need for information for risk assessment development, the Office of Research and Development (ORD) conducted a study that evaluated the ability of selected coatings to reduce the amount of dislodgeable CCA (DCCA) chemicals on the surfaces of CCA-treated wood. The Consumer Product Safety Commission (CPSC) was a collaborator on this project via an interagency agreement (CPSC-I-03-1235) between EPA and CPSC. The test data support EPA and CPSC efforts to inform the public regarding the use and maintenance of existing CCA-treated wood products, such as decks and playground equipment.

In previous studies, CPSC staff determined the relationship between the amount of arsenic transferred to a hand by contact with CCA-treated wood and the amount determined by the CPSC wipe technique (Thomas et al., 2004; Levenson et al., 2004; Hatlelid et al., 2004). EPA modified the CPSC wipe technique in an effort to increase sensitivity. Appendix A reports experiments conducted by EPA and CPSC staff to determine the relationship between dislodged CCA residues determined using each approach. Although calculation of human exposure is considered beyond the scope

this coatings study, the wipe comparison experiments established a relationship between the two surrogate wipe methods. However, further analysis or experimentation may be needed to reduce uncertainty and/or estimate potential intake due to contact based upon the data presented in this report.

This report supersedes the previously issued "Interim Data Report." In addition to covering the complete dataset through 24 months of testing, this final report also utilizes a more sophisticated data analysis model. The draft quality assurance project plan (QAPP) was posted for public and stakeholder comment and the QAPP as well as the Interim Data Report were the subjects of letter peer review. An open peer review of the draft final report by OPPTS's Scientific Advisory Panel took place in November of 2006. Records of the letter peer reviews and the supporting documents, and minutes of the peer review meeting (SAP Minutes No. 2007-02) can be found in EPA's Science Inventory (www.epa.gov/si/) at Record 150970.

1.2 Project Objectives

The objective of this project was to evaluate the ability of typical deck coating products to reduce dislodgeable CCA chemicals (DCCA) on pressure treated wood. Environmental variables that impact coating performance include ultraviolet (UV) radiation, condensation, precipitation, and thermal shock. Efficacy of coatings may also be impacted by the level and fixation of CCA treatment, age and condition of the wood at the time of coating, and type and dimensions of the treated wood, among other variables (Lewbow et al., 2003). Due to the large number of variables, and EPA's desire to provide guidance quickly for in-service wood, the scope of this evaluation was limited to selected coatings applied to aged CCA-treated southern yellow pine (SYP) wood exposed to natural outdoor weathering at a site in North Carolina.

Due to the large number of variables that potentially impact coating performance and the lack of a standardized protocol for evaluation of the efficacy of coatings to reduce DCCA, secondary objectives were to gain insight into the usefulness of the CPSC wipe sampling approach for evaluation of coating performance and identification of future research needs.

1.3 Experimental Design

Two sources of weathered CCA-treated SYP were harvested from in-service decks and used to construct a series of miniature decks (minidecks), onto which selected coatings were applied. Dislodgeable arsenic (DAs), chromium (DCr), and copper (DCu) were measured at specified intervals. Weathering tests were conducted by exposing minidecks to natural outdoor conditions at a site in Research Triangle Park, North Carolina. The ability of the coatings to reduce DCCA as the wood and coatings

weather was evaluated by periodically determining the amount of DCCA removed from the surface of the wood specimens using a specific wipe technique.

For the purposes of this study, DCCA was defined as the amount of CCA analyte removed from the surface of the test specimen using a method based on a dermal wipe procedure initially developed and demonstrated by the staff of the CPSC. The CPSC staff method was slightly modified for the EPA study. The different wipe sampling methods and all modifications implemented by EPA at each stage of the project are fully described in Section 2.8.3 of this report. A side study was conducted to determine the comparability of the two methods and the results of that study are presented in Appendix A.

Wood nomenclature used in this report is defined in Figure 1-1. A “board” is defined as the unit of wood removed from an existing structure (the “source”), while “specimen” refers to the pieces of each board cut for this project (specimens are sometimes called coupons in weathering testing jargon). Furthermore, areas on specimens that were wipe-sampled during each sampling interval are termed “primary sampling areas” (PSA), in contrast to adjacent areas which were not sampled at each interval. Each specimen used in this project contained one PSA and one adjacent area. The PSAs were wipe-sampled during each sampling event (i.e., at 1, 3, 7, 11, 15, 20 and 24 months after coating). Areas on the minidecks adjacent to the PSAs were termed “baseline areas” (BL) because they were used to calculate specimen-specific baseline DCCA values (refer to Section 2.8.2.1 for further explanation).

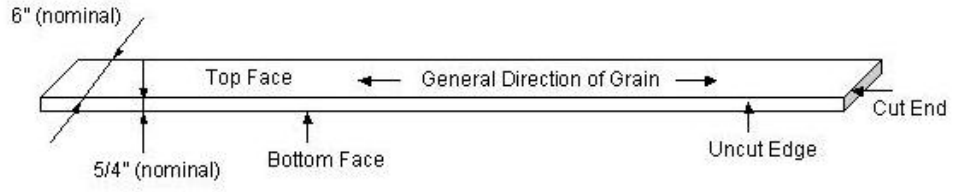

Figure 1-1. Wood Nomenclature

All sampling was done on the top faces of the boards (those facing up on the original source structure from which the boards were harvested). A “grain-up” or “bark side up” board is defined as one where the tree growth rings, evident on the cut end of the board, form a convex pattern (a “hill”) when observed with the face of the board that was exposed on the source deck facing up. Likewise, a “grain-down” or “bark side down” board is defined as one where these rings form a concave (a “valley”) pattern when the exposed face is facing up. Because wood tends to deform along these ring

lines, grain orientation may be an important variable in the measurement and mitigation of DCCA on surfaces of CCA-treated wood. Grain-down boards tend to deform in a manner which “cups” and holds water and moisture while compressing the wood fibers on the sampling surface, while grain-up boards tend to deform in a manner which sheds water from the surface of the board but also creates tension in the wood fibers which may exacerbate splitting and cracking on the sampling surface.

Each minideck had nine decking specimens: two specimens from each of the aged wood sources (one specimen with bark side up grain orientation and one with bark side down orientation), separated by specimens of new untreated wood (all positioned bark side up) to prevent cross-contamination and to serve as blank controls to assess cross-contamination potential as a result of splash-over of rain water, for example. The minidecks were constructed with each of the aged wood specimens having the same top face as the specimen had during its exposure on its source structure. Prior to coating the minidecks, baseline DCCA concentrations were determined by averaging the results of wipe samples from the two areas adjacent to the PSAs. A total of twelve different coatings were applied to three minidecks each. Additionally, three identical, but uncoated minidecks and one untreated, uncoated minideck were included as controls. The minidecks were prepared for coating according to the specific coating manufacturer’s recommendations. Coating was then applied to each minideck per coating manufacturer’s instructions. After allowing the coatings to dry and cure, the minidecks were subjected to natural weathering for a period of two years. During the two-year weathering period, at specified intervals (1 month, 3 months, 7 months, 11 months, 15 months, 20 months and 24 months after coating application) each specimen was wipe-sampled for DCCA and the results from each sampling event were statistically compared with corresponding DCCA results from uncoated control minidecks. Supporting samples included wood core samples, liquid samples of the coatings applied and paint chip samples.

The experimental design is a split plot with repeated measurements. In the language of split-plot designs, each minideck is a whole plot, and the whole-plot treatment is coating. The split-plot treatment is defined by the two-by-two factorial arrangement of the combinations of source decks (A, C) and grain orientation (up, down), each board corresponding to a split-plot. Repeated measurements were taken on each board over the seven time periods.

The coatings were randomized to minidecks with the only restriction being that neighboring minidecks were not assigned the same coatings. In particular, the replication was not blocked, and this is a difference between the experiment and a typical split-plot design. Models for the analysis of the data include fixed effects for coating, source deck, grain, and time; and random effects for minideck, boards, and experimental error.

Potential statistical models for the data all have the same fixed effect structure (main effects and all interactions), but differ according to the assumed covariance structure of the random effects, the scale of the response (e.g., log-transformed or not), and the method of baseline adjustment (direct, covariate, none). In Section 3.2.5, the results from a number of model variations are reported in order to establish the robustness of the major findings to modeling assumptions.

1.4 Data Quality Objectives

The critical measurements for the natural weathering tests are total arsenic, and to a lesser extent, total chromium, and total copper concentrations, which are subsequently converted to dislodgeable arsenic, chromium, and copper, reported as mass per unit area ($\mu g/cm^2$), based on the area of the wiped surface. Data quality indicator (DQI) goals for concentration in terms of accuracy, precision, and completeness, as established in the QAPP for this project, are shown in Table 1-1. The method detection limit (MDL) for the analytical method is also shown. The 0.1 µg/L MDL corresponds to 0.000032 $\mu g/cm^2$ DAs. An assessment of accuracy, precision and completeness goals is presented in Section 5.

Table 1-1. Data Quality Indicator Goals for Critical Measurements

Analyte	Method	Accuracy (Percent Recovery)	Precision (Percent RSD/RPD)	Completeness (Percent)	Method Detection Limit (ug/L)
Arsenic (total)	SW-846 Method 6020 (modified)	90-110	10	90	0.1
Chromium (total)	SW-846 Method 6020 (modified)	90-110	10	90	0.1
Copper (total)	SW-846 Method 6020 (modified)	90-110	10	90	0.1

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2. Sampling and Analysis Protocol

Many elements of the experimental protocol were considered in detail because, at the time of the tests, no standardized protocol existed to evaluate the ability of coatings to reduce DCCA from CCA-treated wood. The discussion below is primarily limited to what was actually done. Methodological alternatives that were considered and side experiments to assess various aspects of the experimental procedures are described in more detail in Section 4.

2.1 Selection of Wood Sources

Criteria established to select from candidate aged wood source structures included the age and condition of the deck and the availability of sufficient amounts of grain up and grain down boards treated to 0.40 pound per cubic foot (pcf) with Ground Contact CCA-C to meet project needs. Additionally, sources needed to be of the SYP species, as it is the most widely-used CCA treated wood species in the U.S. According to the Southern Pine Council (SPC), SYP is preferred "because of its ease of treatability. The unique cellular structure of Southern pine permits deep, uniform penetration of preservatives, rendering the wood useless as a food source for fungi, termites and micro-organisms. Some 85 percent of all pressure-treated wood is Southern pine" (SPC, 2006). In 2004, the SPC estimated that 76 percent of all CCA treated lumber and timbers were SYP with the next most common species group being the Hemlock-Fir group at 9 percent (Lebow, 2006). Regional differences are likely, with SYP overwhelmingly predominant in the Southeast U.S., a greater percentage of hemlock-fir, Douglas-fir and spruce-pine-fir on the west coast, and red pine and ponderosa pine also being used in the north and mid-west (Lebow, 2006).

Age, general condition and coating/treatment history were additional source deck selection criteria as it was recognized that these variables might impact coating performance. Given the almost infinite combinations of age, treatment history, and condition, and the need for a relatively large amount of material, two locally available in-service decks were selected for testing from approximately a dozen candidate decks that were offered for use in the project. Details of the selected decks are provided below.

Environmental Research Center (ERC) Deck: This structure was located outside at EPA's original (leased) Research Triangle Park laboratory facility. It was a stand-alone deck with generally full weather exposure and only moderate shading by adjacent buildings during low sun positions. Given its open, stand-alone nature, abrasion patterns appeared very consistent and the boards were visually similar to one another. The deck was constructed of SYP, treated to 0.40 pound per cubic foot (pcf) with Ground Contact CCA-C. This source was approximately 7 years old and was reported to have received one application of a deck sealant near the beginning of its use (over 5

years ago). The overall condition of the wood was considered fair: the coloration was gray and there was slight-to-moderate splintering. Specific locations and orientations of individual boards were documented during dismantling of the source structure; a map of the structure showing the location of each specimen tested was prepared. This map is shown in Figure 2-1. Photos are provided in Figure 2-2. This deck is referenced as the "A" source.

New Hill Deck: This source was an outdoor deck on a private residence. It represents a source of relatively new, good-condition, aged CCA-treated wood. The coloration of the wood was light brown and relatively bright and there was minimal splintering. The New Hill Deck was an exposed, attached structure. There was no noticeable biological growth or other dampness-related defects. The deck was constructed of SYP, treated to 0.40 pcf with Ground Contact CCA-C, had been in service for just over one year, and had never been chemically cleaned or treated. Specific locations and orientations of individual boards were documented during dismantling of the source structure; a map of the structure showing the location of each specimen tested is shown in Figure 2-3. Photos are provided in Figure 2-4. This deck is referenced as the "C" source.

2.2 Preparation and Characterization of Wood Sources

2.2.1 Source Wood Harvesting and Preliminary Characterization

Wood specimens were prepared from boards with nominal 5/4" x 6" cross-sectional dimensions, taken from the source structures described in Section 2.1. Care was taken to minimize handling and abrasion of the primary (i.e., 6" width) faces of the treated source boards, with the short edges of the board preferentially held during transport and cutting. New 5/4" x 6" SYP that was not CCA treated was used for the blank control specimens and the cross-contamination control specimens that were located at the ends of each minideck and between each of the four CCA-treated boards on each minideck.

For each aged CCA-treated board, the total board length was recorded along with visually-observable source wood characteristics; the most important being predominant grain orientation (up versus down). Each board was also characterized as to predominant grain type (percent flat versus percent edge grain), predominant ring spacing (tight, medium, wide), predominant wood season (percent early versus percent late wood), and predominant wood type (percent heartwood versus percent sapwood). The percentages of the various grain characteristics defined above were visually observed, estimated and documented.

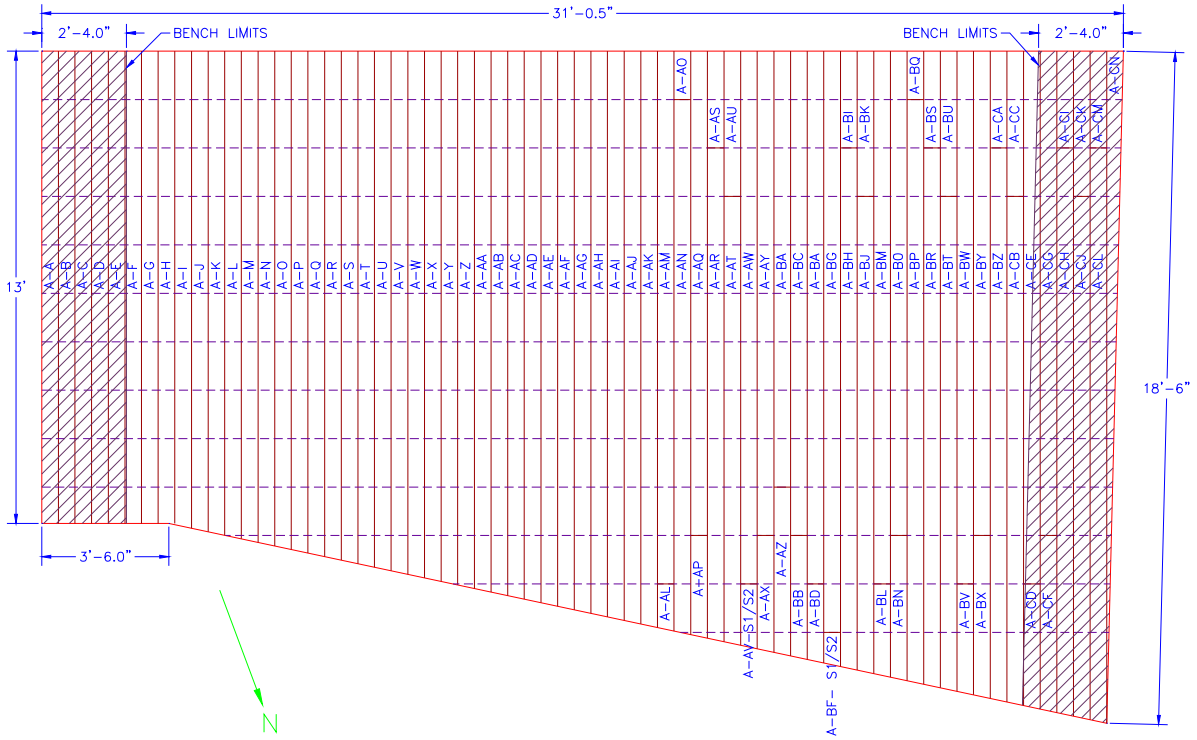


Figure 2-1. ERC Deck Map (Source A)

Figure 2-2. Views of ERC Deck

Note that moisture stains were temporary and that boards under benches were not used to construct minidecks.

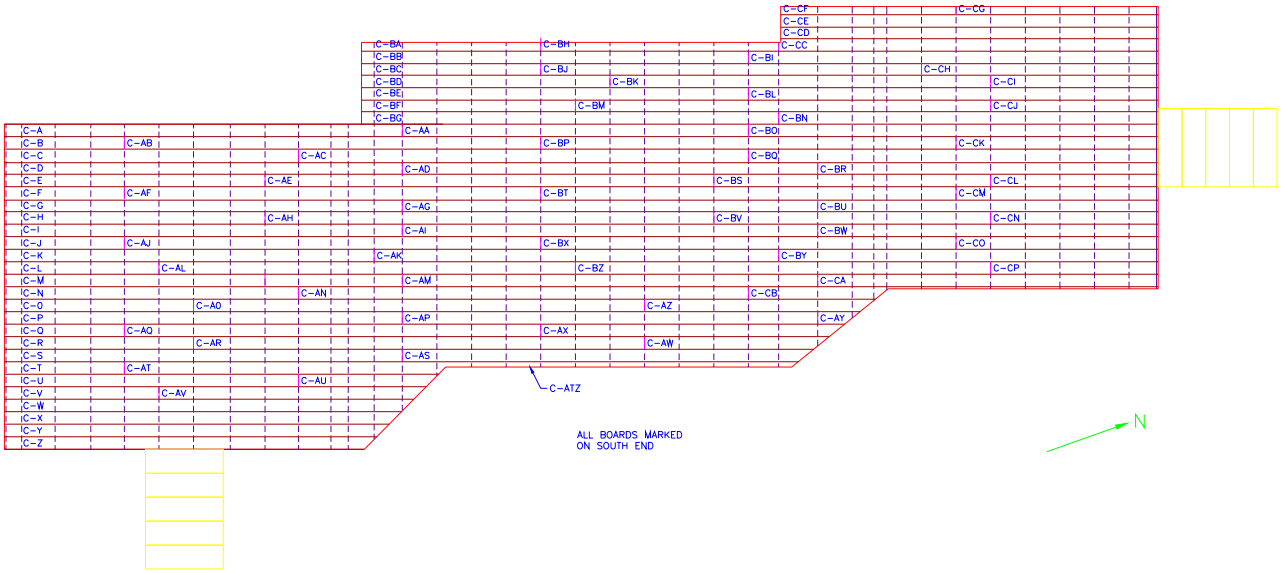


Figure 2-3. New Hill Deck Map (Source C)

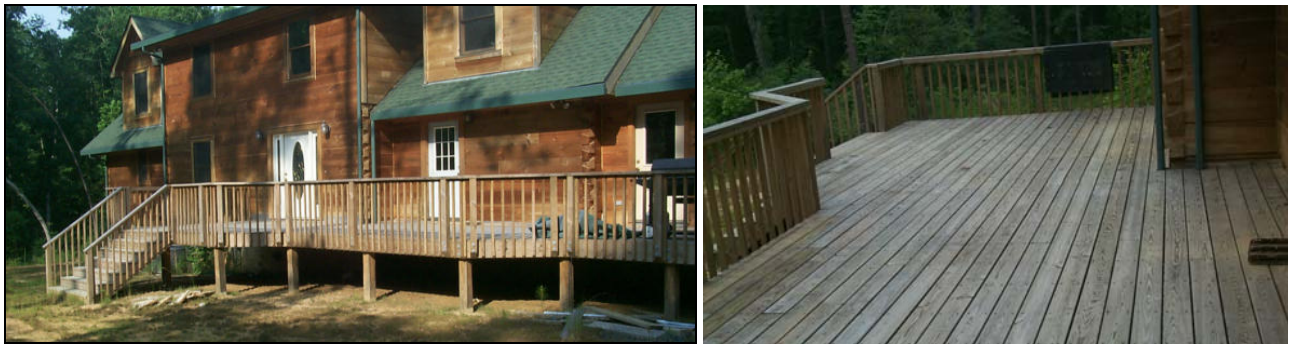


Figure 2-4. Views of New Hill Deck

Aged boards were cut into specimens of approximately 86 cm (34") lengths using a circular table saw. These lengths were cut in such a manner as to capture three sets of existing nail holes on each aged wood specimen, and required that the nail holes were spaced on 16-inch centers as typical. Of utmost concern was that the PSAs were segments of the specimen with a 38-cm (15-in) or more clear distance between adjacent nail holes, to allow for the full wipe length without crossing nail holes. Nail holes were not wiped during either the baseline or routine wipe sampling events. To prevent cross-contamination of samples, the saw was decontaminated between cutting the different types of wood and the untreated wood was cut separately (after installation of a new blade). Decontamination of the saw was done by wiping the blade with a cloth moistened using deionized water.

Where possible, the ends of each board were removed and archived and segments between each 86-cm test specimen were removed and archived. Some of these interior segments were used to characterize the source wood via moisture content measurement and wood core sampling for total arsenic, chromium, and copper analyses. The 86-cm wood specimens were visually inspected to ensure that they did not have excessive amounts of deformities, presence of heartwood, knots, resin pockets, or other defects (no specimens were disqualified). Each segment was identified with a unique alphanumeric code as follows:

- Aged board codes were prefixed by the letter "A" for source A, the ERC Deck, and "C" for source C, the New Hill Deck.

- Each aged board from the two sources was identified with a unique letter (A, B, C, and so forth).

- Each space between adjacent nail holes was identified with an alphanumeric code, where the prefix "BL" refers to segments used for establishing baseline characteristics, while the prefix "M" refers to segments that were to be regularly wiped; that is, the PSAs. These codes were suffixed with sequential numbering (1, 2, 3, etc.) along the length of each source board.

- Unused, unwiped segments were designated with the prefix "X."

The specimen identification criteria presented above is illustrated by the example schematic in Figure 2-5. In this example, BL1, BL2, BL3, BL4, and BL5 would be wipe-sampled before cutting the board. These results would be used to establish baseline DCCA values for the PSAs identified as M1, M2, and M3. After cutting the boards to harvest 86-cm specimens (illustrated in the figure by the dashed boxes) for minideck construction, BL2 and BL5 would be subsequently used for taking one core sample each for total arsenic, chromium, and copper analyses, as well as moisture content. M1, M2, and M3 would be wipe-sampled during routine sampling events to determine

coating efficacy. BL1, BL3, and BL4 would be wipe-sampled only periodically in an effort to determine the effects of abrasion and rewiping on coating efficacy and DCCA. For example, if Figure 2-5 was Board A from Source C and cut as shown by the dashed boxes, this board would generate wipe sampling areas C-A-BL1, C-A-BL3, C-A-BL4, C-A-M1, C-A-M2 and C-A-M3.

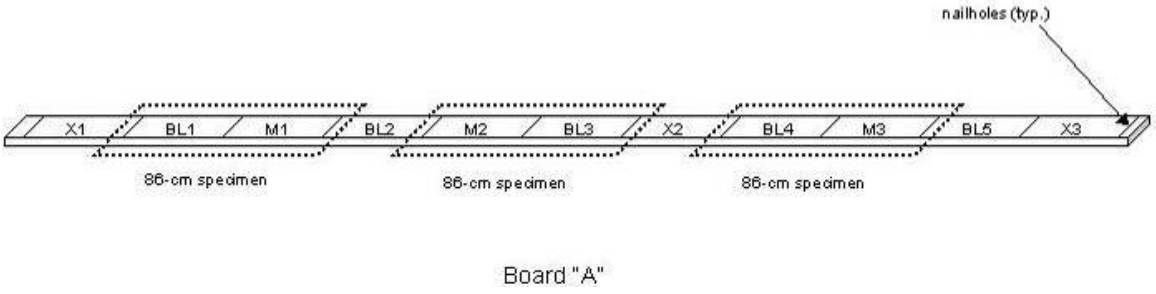


Figure 2-5. Specimen Identification and Baseline Sampling Scheme Example

All cut specimens were identified on one cut end or uncut edge with its identification code, as well as with its “top” side using permanent marker. All numbered specimens were qualitatively and semi-quantitatively characterized for visually-observable wood condition characteristics, with data recorded on a standardized wood characterization data sheet. The characteristics recorded included number of knots for that specimen , splintering, cracking, and rotting (for these last three, a rating of 1 to 5, with 5 being like new wood and 1 being complete failure, was assigned). All of this source characterization data is included in full in Appendix B (a summary table can be found in Appendix C, Table C-1). Additionally a photo record was made of all specimens which includes photographs taken at the beginning of the test (i.e., precoating), as well as at each sampling event after coating (Appendix D). Remaining segments of wood were retained and archived.

2.2.2 Baseline Sampling

Each source board used in the construction of the minidecks had at least two time = 0, baseline wipe samples taken from it prior to coating. The wipe method used to collect these samples is described in Section 2.8.3.1. Samples were then digested and analyzed for CCA content. The baseline wipe sample results were used to establish baseline DCCA concentrations for the PSAs on the minidecks. Furthermore, the baseline data were used to assess the variability of DCCA across each board (intraboard) and between boards (interboard) and source decks. The results of this sampling are presented in Section 3.1.1. The full dataset showing tables with summarized data and the individual specimen baseline values is provided in Appendix E. Summary tables are included in Appendix C, Tables C-2 and C-3. Data

summaries include averages, standard deviations, and RSD for each board and include summary statistics at the end of each table for each source (A and C). The RSDs are indicators of variability within and between boards.

The baseline measurements were made using acid-washed sampling wipes in a method termed the “A2” sampling method, as described in Section 2.8.3.1. The “2X” sampling method utilized unwashed wipes and was the method used for subsequent sampling events; it is described in Section 2.8.3.2. A side study was conducted to develop calibration equations to convert between results obtained using wipes prepared by the baseline method (A2) and the main-study method (2X), taking the form cX, as indicated below. However, these factors had no impact on the analysis of variance because ln(cX) = ln(c) + ln(X) and thus only the intercept in the ANOVA model is affected by the use of the calibrated measurements; not comparisons among coatings. The full wipe comparison report is included as Appendix D.

Additional variables that were considered in the aforementioned wipe comparison study included: grain orientation (up, down), source deck (A, C), rinse (rinsed, unrinsed), and sample preparation lab (EPA, CPSC). “Unrinsed” boards in this context refers to boards that were taken directly from storage and wipe-sampled, while “rinsed” boards were thoroughly hosed down with tap water and allowed to dry for several days before wipe sampling. “Prep lab” refers to which laboratory digested or extracted the wipes and subsequently either analyzed the samples in-house (CPSC) or sent them out to an analytical laboratory for analysis (EPA).

Statistical model selection was used to identify calibration equations for predicting method 2X DCCA measurements from method A2 DCCA measurements and the other factors, including grain orientation (up, down), source deck (A, C), rinse (rinsed, unrinsed), and prep lab (EPA, CPSC). Based on these analyses, separate calibration equations are suggested for rinsed and unrinsed boards, but not for any of the other factors. In other words, when models for predicting DCCA using 2X wipes from DCCA using A2 wipes, grain, source deck, rinse, and prep lab were considered, the identified prediction model depends only on DCCA using A2 wipes and rinse.

The wipe method correction factors are summarized as follows:

- For arsenic:

  Rinsed Specimens: As-2X = 1.44 (As-A2), 95 percent Confidence Interval: (1.21, 1.66)
  Unrinsed Specimens: As-2X = 0.81 (As-A2), 95 percent Confidence Interval: (0.72, 0.91)
  The R-square value for the combined models is 0.75

- For chromium:

Rinsed Specimens: Cr-2X = 1.32 (Cr-A2), 95 percent Confidence Interval: (1.08, 1.56)
Unrinsed Specimens: Cr-2X = 0.82 (Cr-A2), 95 percent Confidence Interval: (0.73, 0.92)
The R-square value for the combined models is 0.58

- For copper:

Rinsed Specimens: Cu-2X = 1.20 (Cu-A2), 95 percent Confidence Interval: (0.99, 1.42)
Unrinsed Specimens: Cu-2X = 0.83 (Cu-A2), 95 percent Confidence Interval: (0.74, 0.91)
The R-square value for the combined models is 0.76

Because the baseline analyses for this study were done on unrinsed boards, the unrinsed specimen equations were used to adjust the baseline results. In this report, raw (uncorrected) baseline data are reported in the appendices, but only "corrected" baseline DCCA data are presented in the body of the report. Likewise, reported values which are calculated using baseline DCCA in the calculation (e.g., the percent reduction values) always use the corrected baseline values. DCCA from all subsequent sampling events are reported uncorrected, as they were conducted using the 2X wipe method.

2.2.3 Wood Core Sampling and Analysis

Up to four wood core samples were taken from each CCA treated board used to construct minidecks for this study. Professional judgment was used to select areas from which to take core samples to ensure that their average would be representative of the board in question. Individual core samples were taken by advancing a ¼-inch diameter drill bit through the entire 1-inch (5/4" nominal) thickness of the board and collecting the wood shavings.

The wood shavings were then dried to constant weight in a drying oven at approximately 105°C. The dry weight of the sample was recorded. The wood shavings were subsequently digested in concentrated nitric acid using a similar protocol to that defined in Section 2.8.4 for the wipe samples. This procedure is consistent with American Wood Preservers Association (AWPA) Standard A7-93 (microwave assisted nitric acid digestion). Digestates were analyzed by inductively coupled plasma - mass spectrometry (ICP-MS), consistent with AWPA Standard A21-00.

AWPA standards allow the actives composition of CCA-C – the formulation used to treat the wood used in this study – to vary between 44.5 – 50.5 percent for CrO_3, 17.0 – 21.0 percent for CuO, and 30.0 – 38.0 percent for As_2O_5 in a specific assay zone, the outer 0.6 in (15 mm) (Lebow, 1996). Knowing that the source wood for this project was treated to target retentions of 0.40 pounds per cubic foot (pcf), hypothetical, ideal actives composition (analyte concentrations) can be calculated for each CCA analyte: 0.190 pcf (86.1 g/cf) CrO_3, 0.074 pcf (33.6 g/cf) CuO, and 0.136 pcf (61.7 g/cf) As_2O_5.

Furthermore, the average dry, pretreatment density of SYP is 32 pcf, or 14.5 kg/cf. Using these values, predicted levels of CCA analytes in the study wood core samples can be approximated as:

CrO_3	(86.1 g/cf) / (14.5 kg/cf) x (1000 mg/g) = **5,938 mg/kg**
CuO	(33.6 g/cf) / (14.5 kg/cf) x (1000 mg/g) = **2,317 mg/kg**
As_2O_5	(61.7 g/cf) / (14.5 kg/cf) x (1000 mg/g) = **4,255 mg/kg**

For comparison, wood core sample data is presented in Section 3.1.2.

2.3 Minideck Construction

After cutting and marking specimens with their identification codes, source wood specimens were transported to the minideck host site. The minidecks were constructed on site in accordance with Figure 2-6. The minideck surfaces were initially constructed without leaving spaces between the boards. When this mistake was discovered, the three internal untreated boards per deck were removed and planed sufficiently on either edge enough to be spaced approximately $1/8^{th}$ inch (the thickness of a 16p nail spacer) from adjacent boards. The untreated boards were then reattached to the tops of the minidecks and the deck tops were rinsed with tap water and allowed to dry for at least 48 hours before coating. Following construction, the minideck surfaces were prepared (e.g., washed, rinsed, etc.) in strict accordance with the particular coating manufacturer's recommendations for coating aged wood as described in Section 2.5.

Three minidecks were constructed for each of the 12 selected coatings and an uncoated positive control. Minidecks were identified as 1-A, 1-B, 1-C (for coating #1), 2-A, 2-B, 2-C (for coating #2), and so on. Each minideck contained two 86-cm aged source "A" specimens, two 86-cm aged source "C" specimens, and five 86-cm untreated wood specimens. In addition to these 13 minideck series, an additional uncoated minideck was constructed using 5 boards all of untreated SYP. The three inside boards of this deck were wipe-sampled at the prespecified regular sampling event intervals as negative control blanks.

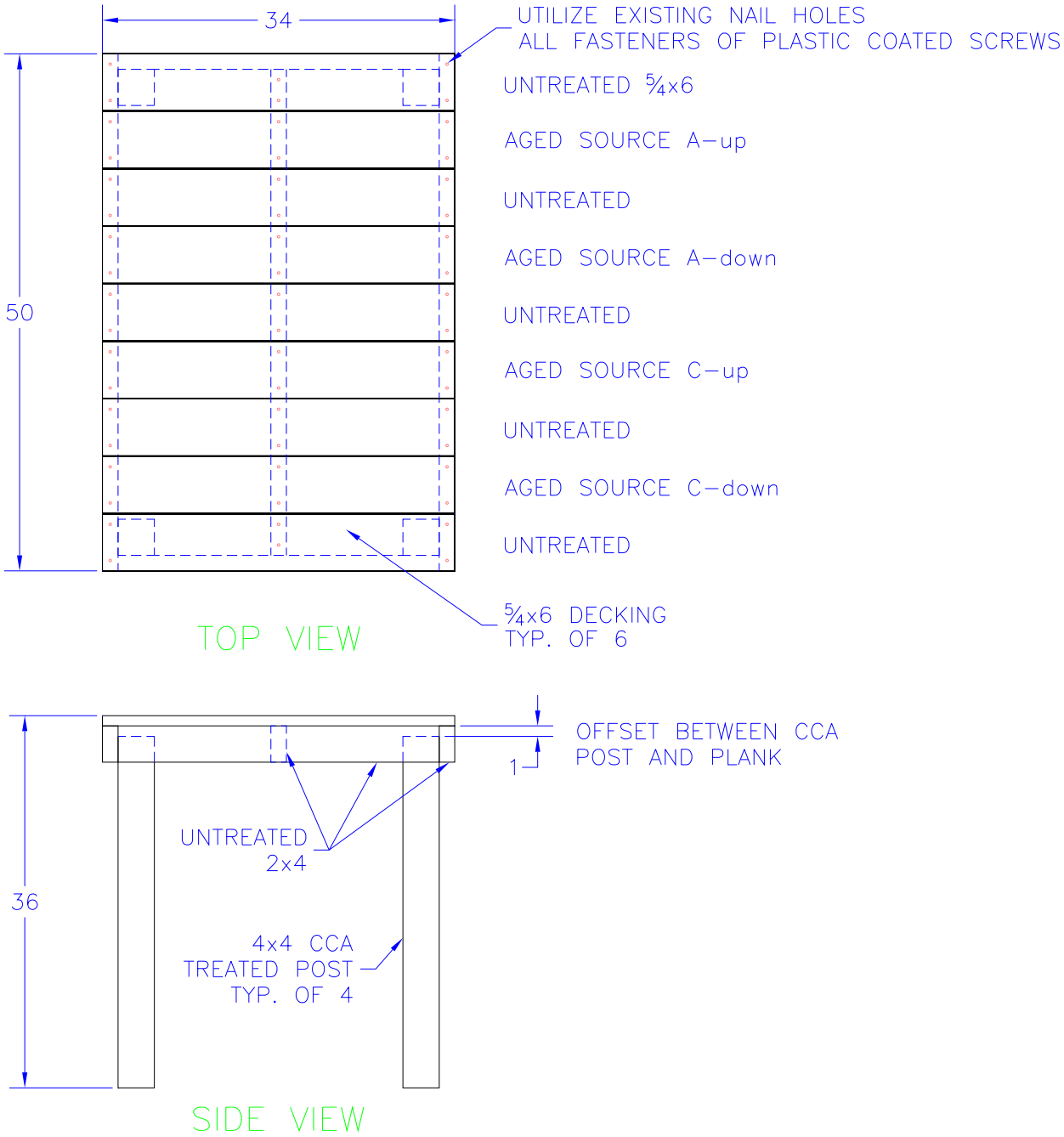


Figure 2-6. Schematic of Minideck Construction

Note that untreated 34" specimens were planed so that 1/8" of space was provided between each pair of specimens

New 4” x 4” CCA-C treated wood posts were used in the construction of the minidecks. Specimens were screwed directly into a grid of 2” x 4” untreated SYP supports. To avoid contamination, these supports were slightly offset above the tops of the posts to ensure that the treated posts did not have the opportunity to directly contact the wood test specimens. Plastic-coated screws were advanced through existing nail holes on the treated specimens to secure decking specimens to the minideck frames. The same type of coated screws was used to attach the new, untreated specimens to the support frames. The minidecks were free-standing (i.e., posts are not set into the ground) and were leveled after setting them on the test site. A photograph of a typical minideck is provided as Figure 2-7. A list of the treated wood specimen IDs that were used on each minideck is shown in Table 2-1. Specimens were matched with minidecks randomly, with the only qualifier being that the three replicate minidecks per coating utilize boards cut from different source boards. In other words, for each set of three minidecks, a total of 12 (4 boards x 3 minidecks) different source boards are represented.

Figure 2-7. Photograph of Typical Minideck

Note that white plastic containment system underneath minideck was for a separate bioavailability study, otherwise not related to this project

Table 2-1. Wood Specimens Used to Construct Minidecks

		Source – Grain Orientation			
Coating #	**Deck ID**	**A – up**	**A – down**	**C – up**	**C–down**
1	1-A	A-AE-M1	A-Z-M1	C-N-M1	C-BO-M2
	1-B	A-V-M3	A-AT-M3	C-BE-M2	C-CC-M1
	1-C	A-AJ-M1	A-BW-M4	C-S-M2	C-AA-M2
2	2-A	A-O-M3	A-BY-M2	C-BZ-M3	C-E-M3
	2-B	A-BC-M2	A-AH-M4	C-BI-M1	C-AN-M1
	2-C	A-AR-M1	A-P-M1	C-BY-M2	C-BX-M3
3	3-A	A-T-M1	A-L-M3	C-N-M3	C-CE-M2
	3-B	A-AG-M3	A-AF-M1	C-BJ-M2	C-AN-M3
	3-C	A-AD-M2	A-BW-M2	C-CD-M1	C-AA-M1
4	4-A	A-T-M2	A-BG-M4	C-CD-M2	C-AD-M2
	4-B	A-BC-M1	A-AH-M1	C-BM-M2	C-AM-M2
	4-C	A-I-M3	A-Q-M2	C-AC-M1	C-BT-M4
5	5-A	A-U-M2	A-L-M2	C-AC-M2	C-CE-M1
	5-B	A-AD-M1	A-Z-M3	C-BM-M3	C-BO-M1
	5-C	A-AR-M3	A-BG-M3	C-CA-M1	C-AD-M3
6	6-A	A-U-M1	A-BY-M1	C-BZ-M2	C-AA-M3
	6-B	A-AC-M2	A-AN-M3	C-AJ-M1	C-AI-M1
	6-C	A-BC-M3	A-P-M2	C-S-M3	C-CC-M2
7	7-A	A-O-M2	A-Y-M2	C-N-M2	C-AM-M3
	7-B	A-V-M1	A-AH-M3	C-BY-M1	C-BX-M1
	7-C	A-AJ-M3	A-BW-M1	C-BZ-M4	C-E-M2
8	8-A	A-AR-M2	A-BY-M3	C-BE-M1	C-AE-M3
	8-B	A-I-M1	A-AT-M1	C-AC-M3	C-AM-M1
	8-C	A-AG-M4	A-Z-M2	C-CA-M2	C-BX-M2
9	9-A	A-T-M3	A-P-M3	C-AP-M1	C-BW-M1
	9-B	A-AC-M1	A-AE-M2	C-BI-M2	C-AN-M2
	9-C	A-AG-M2	A-AN-M1	C-BZ-M1	C-AE-M2
10	10-A	A-AD-M3	A-BG-M2	C-AP-M3	C-AD-M1
	10-B	A-X-M1	A-Y-M1	C-BJ-M1	C-AK-M4
	10-C	A-AJ-M2	A-Q-M3	C-BU-M2	C-BT-M2
11	11-A	A-U-M3	A-Q-M1	C-AP-M2	C-AI-M3
	11-B	A-X-M2	A-AH-M2	C-BE-M3	C-BW-M2
	11-C	A-AJ-M4	A-BW-M3	C-BJ-M3	C-AE-M1
12	12-A	A-O-M1	A-AN-M2	C-AJ-M2	C-AM-M4
	12-B	A-AC-M3	A-AE-M3	C-BI-M3	C-AD-M4
	12-C	A-V-M2	A-L-M1	C-BM-M1	C-BT-M1
13 (uncoated)	13-A	A-AG-M1	A-Y-M3	C-S-M1	C-E-M1
	13-B	A-I-M2	A-AT-M2	C-AJ-M3	C-AI-M2
	13-C	A-X-M3	A-BG-M1	C-BU-M1	C-BT-M3

2.4 Selection of Coatings

Basic formulation and application information for a large number of products was obtained primarily by using Internet searches and visits to local retail hardware and home improvement stores and compiled into a master list of 125 products. Products ultimately selected for testing are listed generically in Table 2-2. The list includes two paints, two products specifically marketed to prevent DCCA exposure, and eight products marketed as stains and sealants (four oil-based products and four water-based products, one of which was marketed as alkyd-based, one acrylic, one both alkyd and acrylic, and one specifying neither).

For preserving the appearance of CCA-treated decks, experts generally recommend the use of penetrating finishes such as oil and water-based sealants rather than film-forming products such as paints due to the tendency of film-forming products to crack and peel as the substrate shrinks and swells with uptake and release of moisture (Williams and Feist, 1993). For this reason, eight of the twelve products selected were oil or water-based sealants and stains that fall into the category of penetrating finishes. The oil and water-based paints were selected because porch and deck paints are widely available to consumers and may be applied to CCA decking. The two products that were marketed to encapsulate CCA treated wood were selected because they were marketed as products that would reduce exposure to CCA residues and could be readily applied by consumers.

Products were classified by base (oil vs. water), cover (clear, semi-transparent, opaque), and product type. Product type was broken out into the following: paints, primers, sealants, stains, and other. Additional classification descriptors included ingredients (primarily alkyd or acrylic), surface (penetrating vs. film-forming) and color. Note that the classifications are derived from information provided on the product label and from information provided on product MSDS sheets. In that regard, the classifications are arbitrary and are not necessarily exclusive of one another. For this reason, and due to the limited number of products tested that were attributed to each category, analyses of the coatings by category are presented and discussed in Section 4, “Study Limitations, Exploratory Analyses, and Future Directions”.

Table 2-2. Selected Products for Evaluation

#	Product Type	Base	Cover	Main Ingredients	Comments
1	Sealant	Oil	Semi	Aliphatics, Napthalene	"Cedar" with UV blocker
2	Sealant	Oil	Clear	Acrylic, alkyd, urethane	"Clear"
3	Stain	Oil	Clear	Acrylic	"Deep tone base"
4	Stain	Oil	Clear	Alkyd	"Clear stain"
5	Sealant	Water	Clear	Unknown[1]	"Clear"
6	Sealant	Water	Clear	Acrylic, alkyd	"Clear"
7	Stain	Water	Semi	Alkyd	"Cedar" with UV blocker
8	Stain	Water	Clear	Acrylic	"Tint base, solid" with no tint added[2]
9	Paint	Water	Opaque	Acrylic	"Gray". Latex, designed for porches and floors
10	Paint	Oil	Opaque	Alkyd, polyurethane	"Gray". Designed for porches and floors
11	Other	Water	Clear	Elastic vinyl	Designed for CCA encapsulation
12	Other	Water	Clear	Polymer	Designed for CCA encapsulation
13	No coating	N/A	N/A	N/A	Uncoated control minidecks

[1] MSDS for coating listed no ingredients >1 percent.

[2] Note that the labeling for product #8 specifically states that it must be tinted before use.

2.5 Coating Application

After baseline characterization of source wood, construction of the minidecks, and preparation of the minidecks for coating, all exposed surfaces of the decks were coated in accordance with coating manufacturers' recommendations. Coatings were applied to fully cover the top faces, exposed uncut edges, and cut ends of CCA-treated wood specimens. For the paints, products #9 and 10, a common latex primer was first applied in accordance with the paint and primer manufacturers' instructions. For all coatings, top faces were coated first, followed by the exposed edges and the cut ends. Because the coatings' manufacturers generally recommended that application not be done during periods of direct sunlight, an open air shelter (canopy) was temporarily set up on site to allow for coating minidecks in the shade. After 24-hours of initial coating drying in the shade, minidecks were manually relocated to allow for additional drying in exposed conditions.

Flow sheets generically detailing the wood preparation procedures employed for each coating are provided as Appendix F. The surfaces of the minidecks for each coating (except coating #7, which did not call for a rinse prior to coating) were rinsed with a pressure washer at a 1,000-3,000 psi setting. Ten of the coatings also had a deck cleaning product applied, as specified in their instructions. Note that specific products

used to prepare the minidecks for coating are not mentioned in order to maintain coating confidentiality. The surfaces of the positive (#13, uncoated) and negative control minidecks were rinsed with a pressure washer at a 1,000-3,000 psi setting.

Two types of 2" chip brushes were used to apply coatings to the minidecks: one brush with natural bristles and the other with polyolefin bristles (to apply coatings whose manufacturer recommended a synthetic bristled brush). Prior to coating application, both brush types were analyzed in order to ensure that they did not contribute significant amounts of arsenic, chromium, or copper to the wood surfaces. Each type of brush used was prequalified for use per a set of control samples whereby two brushes of each type were agitated in a 250 mL vessel containing 40 mL of deionized water for 30 seconds. The liquid samples were than transferred to Digitubes for digestion. Four milliliters of nitric acid were added to each tube and the samples were then digested at 95°C for two hours. Digested samples were sent to the analytical laboratory used for this project, for analysis. Arsenic levels were found to be below the reporting limit of 0.1 µg/L, chromium levels were <1 µg/L and copper levels were lower than levels seen on blank, untreated boards. A summary of the data is tabulated in Appendix C, Table C-4.

Three new brushes were used for each minideck: a brush for coating each of the two aged wood sources and a brush for the new untreated wood surfaces. Untreated surfaces were coated first, followed by the aged CCA surfaces. Brushes were prepared for initial coating application in accordance with brush manufacturer's recommendations. After a particular coating was applied to a given group of triplicate minidecks, used brushes were sealed individually in plastic bags and archived.

Separate aliquots of coating were used for each minideck in order to prevent cross-contamination of coating by re-dipping the brush applicator. Three aliquots of coating were used for each minideck: one for the "A" specimens, one for the "C" specimens, and one for the untreated (identified for sampling as "N") specimens. Separate aliquots of coating were poured into disposable plastic graduated volumetric beakers. The disposable beakers were acid-washed using a procedure similar to that specified in Section 2.8.4 prior to use. Poured but unused coating for each replicate minideck was composited so that one sample was retained for each coating and wood type (new/untreated and the two, aged, CCA-treated sources). These leftover coating samples were stored in sealed, unused paint containers and archived for possible future analyses. Application procedures and any notable observations were documented for each coating using a coating application data form (a sample form is provided as Appendix G).

The amount of coating, measured as both volume and mass, applied to each substrate on each minideck was determined by transferring 200 to 300-mL of coating directly

from the original coating container into a 400-mL graduated beaker, from which the substrates were coated. The starting volume of coating in the beaker and the final volume (after squeezing out excess coating from the brush used) were recorded and, from these, a calculation of the volume of coating applied was made. Additionally, the container of unused coating and the brush to be used for application was preweighed. After the coating was applied, the final weight of the beaker and brush was measured and recorded. The weight applied was calculated as the difference between the initial and the final weights.

Unused aliquots of each coating tested were sampled directly from the coating container in duplicate and prepared and analyzed in accordance with methods specified in Section 2.9.

2.6 Outdoor Weather Site Setup

Minidecks were subjected to outdoor weathering at a field on EPA's RTP research campus. Prior to placement of the minidecks, the site was cleared, tilled, leveled and, except for the area directly underneath each minideck, covered with landscape fabric and gravel to retard growth of vegetation. Minidecks were randomly assigned to gridded blocks, with the qualifier that minidecks featuring the same coating were not allowed in the same row, column, or diagonally immediately adjacent to one another. The site layout showing sequentially numbered minideck locations is provided as Appendix H. The location of each minideck is summarized in Table 2-3 – the blocks listed in Table 2-3 correspond to those shown on the site plan in Appendix H. Each minideck was leveled after placement at the test site.

Table 2-3. Minideck Block Assignments (blocks correspond to those identified in Appendix H)

Minideck	Block
1-A	6
1-B	29
1-C	22
2-A	39
2-B	7
2-C	33
3-A	36
3-B	10
3-C	14
4-A	37
4-B	23
4-C	5
5-A	25
5-B	43
5-C	9
6-A	13
6-B	28
6-C	45
7-A	2
7-B	41
7-C	34
8-A	18
8-B	32
8-C	48

Minideck	Block
9-A	46
9-B	3
9-C	26
10-A	42
10-B	27
10-C	24
11-A	30
11-B	4
11-C	20
12-A	1
12-B	35
12-C	21
13-A	19
13-B	40
13-C	12
BC	8
NC	47
LH	15
SC1	31
SC2	38
SC3	16
LC1	44
LC2	11
LC3	17

- BC = the blank, negative control, minideck
- NC = 1 minideck with no CCA wood used (for a related bioavailability study being conducted)
- LH = 1 uncoated CCA minideck for leachate collection (for a related bioavailability study being conducted)
- SC1, SC2, SC3 = 3 soil controls (for a related bioavailability study, no minidecks are located in these blocks)
- LC1, LC2, LC3 = 3 leachate controls (for a related bioavailability study, no minidecks are located in these blocks)

2.7 Weather Data Collection

Weather data were collected using a Davis Instruments Vantage Pro Plus™ weather monitoring station located as shown in Figure 2-8. The weather data was compiled with WeatherLink® for Vantage Pro™ software, and downloaded to a Microsoft Excel file, although there were several periods during the second year of operation when the data logger malfunctioned and on-site data was missing. Data that was routinely collected via the Vantage Pro Plus™ are listed in Table 2-4.

Figure 2-8. Photograph of Minideck Site

Note weather monitoring station on the right.

Table 2-4. Vantage Pro Plus™ Weather Station Data

	Units			
Barometric Pressure	in Hg	Mm Hg	hPa (Tor)	Mb
Inside Humidity	percent			
Outside Humidity	percent			
Dew Point	°F	°C		
Rainfall	In	Mm		
Rate of Rainfall	in/hr	Mm/hr		
Solar Radiation	W/m2			
UV Index & Dose	index	Meds		
Inside Temperature	°F	°C		
Outside Temperature	°F	°C		
Apparent Temperature	°F	°C		
Wind Speed	Mph	m/s	km/h	
Predominant Wind Direction	N, NNE, NE, ENE, E, ESE, SE, SSE, S, SSW, SW, WSW, W, WNW, NW, NNW			
Wind Chill	°F	°C		

The data can be archived at 1 min, 5 min, 10 min, 15 min, 30 min, 1 h, or 2 h (data were archived at 30-minute intervals).

All data points are discrete except for Rate of Rainfall and UV Dose.

The National Oceanic and Atmospheric Administration (NOAA) in RTP, North Carolina, collected data on wind speed and direction, temperature, precipitation amount, direct solar radiation, and total solar radiation at the site used for minideck weathering through the first year of this testing. Weather data measurements collected by NOAA at the site are summarized in Table 2-5.

Table 2-5. NOAA-Generated Weather Data

Parameter	Unit	Remarks
Required		
Irradiance (UV)	W/m^2	Direct and total radiation is available.
Temperature	°F	
Precipitation, Duration	hours	Can be determined from strip chart, although certain losses may occur due to evaporation.
Precipitation, Amount	inches	Automated rain gage.
Dew Point (Measure of dew formation)	°F	Dew point could be used to calculate dew point depression (diff. with temp.) If DPD is small, there is likely to be dew overnight.
Wind direction + speed		

NOAA's test site metrology instrumentation was calibrated against working standards traceable to standards at Eppley Laboratory (for solar radiation). This calibration was conducted periodically based on the stability of the instrument and the judgment of the instrument operators. The temperature system was checked against certified data from NOAA's Raleigh-Durham International Airport (RDU) weather station on stable days and relative humidity measurements were calibrated using a sling psychrometer. The weighing rain gage was calibrated with weights and also against a manual rain gage with each precipitation event. The Aerovane wind system recorded wind speed in miles per hour (mph) and only begins to register at 3 mph. It was also checked against RDU on stable windy days.

These and other parameters are additionally collected by the NOAA's National Climate Data Center (NCDC), at their RDU weather station, and are available in monthly summaries, detailing specified conditions on a daily and, for some parameters, an hourly basis. The RDU station does not monitor solar radiation. Supplemental solar radiation measurements were obtained from the State Climate Office of North Carolina for their Reedy Creek Field Laboratory monitoring site, also in close proximity to the EPA test site.

NOAA-generated data from the test site were compared to data from the Vantage Pro Plus™ weather monitoring station dedicated for use during this project. Spot checks of all parameters common to both the NOAA and Vantage Pro Plus™ unit were conducted and determined to be well within reasonable tolerances (± 5-10 percent depending on parameter). Because the on-site NOAA weather data became unavailable several months into the study, certified data from NOAA's RDU station was also used to confirm the on-site weather monitoring station data. Details of these spot check results are provided in Appendix I. Finally, the solar radiation data from the

Reedy Creek site was compared with data from the weather station at the test site and showed agreement within 1 percent on a monthly average basis. All sets of comparisons were in agreement.

During the second year of the study, the performance of the on-site weather station's data logger became unstable and for several periods, data was not properly logged, so the weather data was supplemented by NOAA-RDU data and State Climate Office of North Carolina, Reedy Creek Station data.

2.8 DCCA Measurement Methods

2.8.1 Sampling and Extraction Methods

Prior to beginning DCCA measurements for use in the study, pre-testing was performed to determine characteristics of the wipes and their ability to retain levels of target analytes. These tests were fully described in the Interim Report and are summarized here.

2.8.1.1 Wipe Blank Study

A number of blank evaluations were performed to evaluate the amounts of target compounds inherent in the extraction process and the wipes themselves. Initially, unwashed wipes directly out of the bag were acid extracted. Blank results for arsenic and chromium are shown in Table 2-6. This initial wipe blank analysis did not include an analysis for copper.

Table 2-6. Wipe Blank Analyses

Sample Number	As (µg/L)	Cr (µg/L)
AQS-54	1.2	0.8
AQS-55	1.3	1.1

To investigate the potential to reduce the background levels of As and Cr measured in the wipe blanks, nine wipes were pretreated using an acid-wash, rinsing thoroughly with de-ionized water, and allowing them to dry in a clean environment. Results comparing the acid-washed wipe to the out-of-the-bag wipe blanks are shown in Table 2-7. Measurements from a control sample consisting only of nitric acid that had been through the extraction process (with no wipe added) are also presented.

Table 2-7. Results from September 2003 Wipe Comparison Study

Average	As (µg/L)	Cr (µg/L)	Cu (µg/L)
Wipe Blank (Out-of-Bag)	0.41	0.93	2.1
Digested Nitric Blank	<0.10	<0.50	0.3
Acid-Washed Wipe Blank	0.2	<0.50	1.3

It should be noted that the results for the initial out-of-bag wipe blanks experiments (Table 2-6) were based on testing a whole 12" x 12" wipe while the data collected from the September 2003 Wipe Comparison Study (Table 2-7) were based on using half of a wipe.

2.8.1.2 Spiking Study

A number of spike studies were done to ensure that the analytes of interest could be effectively captured by the wipes, extracted and analyzed. Initially, three samples were prepared by spiking known amounts of stock solutions of arsenic and chromium standards onto a clean glass plate and allowing the liquid to evaporate. Each glass plate was then wiped using the CPSC technique and the wipes were extracted and analyzed. Recovery results are shown in Table 2-8.

Table 2-8. Results of Spiking onto Glass

	As	Cr	Units
Spiked Amount	50	49.75	µg
Sample AQS-56	33	38	µg
Sample AQS-57	41	46	µg
Sample AQS-58	41	46	µg
Average	38.3	43.3	µg
SD	4.6	4.6	µg
Percent recovery (avg)	77 percent	87 percent	
Percent RSD	12 percent	11 percent	

A small amount of residue was observed on the glass after sampling with the wiping apparatus. This residue could be removed with further cleaning which indicated that the stain was metal salts and not etching.

In a subsequent methods development experiment, pretreated wipes were directly spiked with 1 µg/L, 50 µg/L and 1000 µg/L of arsenic, chromium and copper standard, extracted, and analyzed. Results are shown in Table 2-9. The higher recoveries (as

compared with the results in Table 2-8) indicate that extraction and analysis techniques may be more robust than the efficacy of the wipe sampling method in picking up materials from the surfaces of the test substrates. However, the fairly low RSDs in Table 2-8 indicate that the sampling method results in reproducible measurements under the conditions of the glass spiking experiment.

Table 2-9. Results of Spiking Wipes Directly

Sample ID	Arsenic (µg/L)	Recovery (Percent)	Chromium (µg/L)	Recovery (Percent)	Copper (µg/L)	Recovery (Percent)
SS-562	1.0	100	1.0	100	1.2	120
SS-563	47	94	51	102	47	94
SS-564	1100	110	1000	100	970	97

In addition to liquid standards, CPSC also provided EPA with CCA dust material that contained a known amount of arsenic. A pre-measured weight of this material was placed directly into extraction vessels containing the acid-rinsed wipes and the samples were extracted and analyzed. This spiking was done in duplicate and recoveries for arsenic were 98 percent and 102 percent. As a result of these spike studies, it was determined that arsenic, chromium and copper could be adequately recovered from wipe samples.

2.8.2 Wipe Sampling Events

Wipe samples were taken directly from the top faces of the specimens on the minidecks. Each specimen had three sets of nail holes and two possible sampling areas: a BL area and a PSA area, as previously defined. The length of all wipe samples was 15 inches to avoid contact with nail holes which were typically spaced on 16-inch centers.

The wipe sampling device (see Figure 2-9) used for the tests was designed and constructed by CPSC staff, (CPSC staff 2003b). The wipe sampling device utilizes a 1.1 kg disc that is approximately 8.65 cm in diameter as the wiping block (note that the actual width of 5/4" x 6" decking is approximately 5.5" or 14 cm). The sampling device allows for the use of variable wipe lengths; for this study, 38 cm was used, yielding a sampling area of approximately 314 cm^2. The EPA- wipe method incorporated relatively minor modifications from the CPSC method, as described in Section 2.8.5.

Figure 2-9. CPSC Wipe Sampling Apparatus

2.8.2.1 Baseline Sampling of Boards and Minidecks

The baseline (BL) areas were wipe-sampled prior to coating using wipes that had been pre-washed in nitric acid in an effort to reduce trace contaminants from the wipes. Prior to beginning collecting routine wipe samples 1 month post-coating, it was determined that DI water rinsing steps were not sufficient in removing the nitric acid from the wipe and the nitric acid pre-wash was discontinued due to concerns about the unnatural and potentially detrimental effect of the residual acid on the coating. Accordingly, the routine wipe samples taken on the PSAs at 1, 3, 7, 11, 15, 20 and 24 months after coating utilized wipes that had not been acid-washed.

Individual baseline DCCA values were determined for each PSA on each specimen to be coated and tested. The baseline DCCA of a PSA was determined by averaging the precoating baseline DCCA from the two adjacent BL specimens on either side of the PSA.

The PSA itself was not directly wipe-sampled prior to coating to avoid artificially removing DCCA from the PSAs before coating them. These areas were wipe-sampled at specified intervals using wipes that were straight out of the bag and wetted, as described in Section 2.8.3.2.

2.8.2.2 Subsequent Wipe Sampling Events

Subsequent sampling was done with "out of the bag" wipes, simply wetted with DI water. The wipe methods employed are described in Section 2.8.3.3. Several more qualitative measures were taken to qualify and document wipe-sampling events:

- Wipe sampling events were only conducted when specimens appeared dry and when weather forecasts indicated that consistent, dry weather would prevail for the entire sampling event. Actual climatic conditions were recorded and well-documented throughout the entire study, including sampling events.

- During each sampling event, each minideck was digitally photographed prior to sampling, with BL and PSA areas identified in a running photo log.

Routine control samples that were taken included:

- Three negative control wipe samples taken; one from each of the three interior untreated, uncoated specimens on the control minideck that contained no treated boards. These control measurements provided an indication of whether there was significant atmospheric deposition of CCA analytes at the site.

- One untreated (but coated, for minidecks prefixed 1 through 12) specimen from each minideck was wipe-sampled during each regular sampling event. Because there are five untreated specimens on each minideck, there are a total of 10 such potential sampling areas. The specific areas sampled during each routine sampling event were randomly selected for each minideck and were different for each sampling event.

2.8.3 Wipe Sampling Methods

2.8.3.1 EPA Acid-Wash, Rinse, and Saturate with DI Water Wipe Preparation Technique (A2 Method)

For the precoat and baseline sampling events, TexWipes TX1009 clean room wipes (100 percent continuous filament polyester), were cut in half using a new razor blade that had been cleaned using acetone and a lint-free wipe on an acetone-cleaned lab bench. After cutting, the half-wipes were placed in a wide-mouth glass bottle and soaked in a 10 percent solution of Trace Metals Grade Nitric Acid. The bottle was

placed in an oven at 85°C overnight. When the bottle was removed from the oven, the nitric acid solution was decanted and wipes were rinsed in the bottle five times with deionized H_2O. After the final rinse, each wipe was removed and squeezed by hand so that they were damp but no more water could be removed. The damp wipes were placed into individual Digitubes until used for wipe sampling. This technique was determined to consistently yield moisture contents of 2.1 ± 0.1 (1 standard deviation) times the dry wipe weight.

2.8.3.2 EPA 2X DI Water Wipe Preparation Technique (2X Method)

For subsequent sampling events (samples taken 1, 3, 7, 11, 15, 20 and 24 months after coating), TexWipe TX1009 clean room wipes were cut in half using a new razor blade or scissors cleaned using acetone and a lint-free wipe on an acetone-cleaned lab bench. After cutting, the half-wipes were inserted into PTFE tubes, into which two times the wipe weight in DI water was added to be soaked up by the wipe. Therefore the wet wipe was three times its dry weight. Wetted wipes were stored in their sealed PTFE tubes until use. Sampling staff, while cutting, transferring, and wetting the wipes, wore nitrile or latex gloves.

2.8.3.3 Standard EPA Wipe Method (Adaptation of CPSC Staff Method)

The adaptation of the CPSC staff wipe method employed by EPA for all sampling events is described below. The differences between this method and the CPSC staff method are listed in Section 2.8.5.

Prior to starting a new wipe sample, the sampling staff donned a new pair of disposable nitrile or latex gloves over a second pair of gloves that were not changed between wipes (i.e., double gloved). The rubber-coated side of the steel rubbing disk was covered with plastic wrap. The wetted wipe was then removed from the PTFE tube, folded in half, and placed over the plastic wrap and secured with a plastic tie-wrap strap. The disk was lowered so that it was in contact with the wood and slid along the tracks of the sampling apparatus forward and backward for five 38-cm (15-inch) strokes, where each stroke consisted of one forward and back movement. The speed of sampling was variable depending on the quality of the area being wiped, with rougher wipe areas sometimes requiring longer sampling times (slower average speeds). Splinters and sampling area imperfections could “hold up” the sampler requiring adjustment of the horizontal force (the only vertical force was the weight of the disk) exerted on the weight to continue moving it forward. However, the poly wipe material is very resilient and no losses of wipe material due to snagging were observed. The wipe was rotated 90° on the rubbing disk, which was then slid forward and back for five more strokes, for a total of 10 front-and-back strokes. Sampling staff then removed the wipe from the disk and placed it back into its PTFE extraction tube.

Wood splinters larger than a grain of rice were removed from the wipe prior to placing it in the extraction vessel.

After the sample was taken, the plastic wrap was discarded and the wiping apparatus was decontaminated by wiping the rails of the apparatus with lint-free wipes wetted with DI water.

2.8.4 Wipe Extraction and Analysis Techniques

Wipe samples were prepared for analysis using techniques employed by CPSC staff (2003b) and Stilwell, et al. (2003), with adaptations for use with laboratory equipment available for this project. As such, a microwave- or heat-assisted extraction and digestion procedure was employed comparable to that used in prior studies, and similar to SW-846 Methods 3051 and 3052.

Precleaned disposable digestion vessels were used for sample collection and digestion. All volumetric glassware was prepared by acid cleaning by leaching with hot 1:1 nitric acid for a minimum of two hours, then rinsed with deionized water and dried in a clean environment. 30 ± 0.1 mL 10 percent nitric acid (trace metal grade HNO_3, DI H_2O) was added slowly to the digestion vessel containing the wipe sample to allow for preextraction. Once any initial reaction had ceased, the sample was capped and introduced into an Environmental Express HotBlock metals digestion system. The vessels were placed into the digestion system and heated for 1 hour at 95°C. After digestion system extraction, sample vessels were allowed to cool for a minimum of 5 minutes prior to removing them from the system. The liquid was poured off into a 100 mL volumetric flask. In addition, as much extraction liquid as possible was squeezed by hand from each wipe. The gloves, funnels, and flask necks were rinsed with DI H_2O. The extracted wipe was then placed back into the extraction flask with an additional 30 mL of 10 percent HNO_3.

Again, the vessels were placed into the digestion system and heated for 1 hour at 95 °C. After extraction, the liquid was poured off into the aforementioned 100 mL volumetric flask. As much extraction liquid as possible was squeezed by hand from each wipe and the gloves, funnels, and flask necks were rinsed with DI H_2O. The wipe was placed back into the extraction vessel and 20 mL of 10 percent HNO_3 was added to each extraction vessel before the digestion system cycle was repeated. The extract was then poured into the 100 mL volumetric flask. Deionized water was used to rinse the extraction vessel; rinsate was added to the 100mL volumetric flask. If necessary, deionized water was added to take the contents to the 100 mL level. The contents of the 100 mL flasks were then transferred to and stored in two plastic tubes (duplicate or split samples) with caps, manufactured by SCP Science of virgin polypropylene and certified contaminant-free. One split sample was sent to an analytical laboratory for analysis, while the other was archived, under refrigeration or freezer storage.

Analyses for total arsenic, chromium, and copper were conducted by STL in Savannah, Georgia, using a modification of SW-846 Method 6020 (ICP-MS). STL utilizes ICP-MS for arsenic analysis, modifying the technique to utilize hydrogen plasma, rather than argon as classically performed. This modification eliminates concerns over the formation of $Ar^{40}Cl^{35}$, which can create a positive bias when measuring As. STL-Savannah's analytical method has reporting limits of 0.10 µg/L for all three CCA analytes (this corresponds to a DAs of 0.000032 µg/cm^2). Per the specified analytical method, the hold time for all metals other than mercury is 6 months.

Each set of samples submitted included blind blanks and spiked samples for continued monitoring of laboratory performance during the project.

2.8.5 Differences between EPA and CPSC Procedures

Differences between the CPSC staff and EPA 2X methods for collection and analysis of surrogate wipes on CCA-treated wood include:

- EPA used plastic wrap to cover the rubber-coated side of the rubbing disk rather than Parafilm.

- C-clamps were not used by EPA to secure the horizontal wiper (because the boards being wiped are part of a deck structure). An assistant held the wiper in place.

- In the EPA method, poly wipes were immediately placed directly into the vessels in which extraction will take place.

- A three-step extraction and digestion procedure was used by EPA rather than the CPSC staff one-step water bath extraction and digestion.

- EPA used a half of a polyester wipe folder over itself once before being affixed to the block, while CPSC used a quarter wipe which did not need to be folder over. As such, EPA's wipe pattern was slightly wider than CPSC's.

- EPA used a 2X DI water spike (wetted wipe weight is three times the dry wipe weight) to prewet the wipes while CPSC staff used a 1x, 0.9-percent saline solution spike (wetted wipe weight is two times the dry wipe weight).

- EPA used a 38-cm (15-in) wipe length (nominal 314 cm^2 sampling area) while CPSC staff used a 50-cm (19.7-in) wipe length (nominal 405 cm^2 sampling area).

2.8.6 Calculation of DCCA from Extraction Fluid Concentrations

Raw data from the analytical laboratory were reported in units of µg/L and represent the mass of analyte per unit volume of extraction solution sent to the laboratory. For standard wipe sampling results, data were converted to units of mass of analyte per unit surface area wipe-sampled (i.e., DCCA), in units of µg/cm^2, using the following equation:

$$C_{DCCA} = \frac{C_{DF} \times \frac{V}{1000}}{A}, \qquad \text{(Equation 2-1)}$$

where

C_{DCCA} = DCCA of a sample (µg/cm^2),
C_{DF} = Concentration of analyte in extraction fluid (µg/L),
V = Total volume of extraction fluid (mL) = 100 mL (typically),
A = Area of wiped surface (cm^2) = 314 cm^2.

Using the reporting limits of 0.1 µg/L from the analytical laboratory, this correlates to a sampling detection limit of 0.000032 µg/cm^2.

2.9 Preparation and Analysis of Coating Samples

Total arsenic, chromium, and copper in the bulk coatings were determined in a manner similar to that used to analyze the wipe samples (acid digestion and extraction followed by ICP-MS). The coating was thoroughly shaken to ensure homogeneity and then an aliquot was transferred to a tared PTFE digestion vessel and allowed to dry. Following loss of volatiles through drying, the residue was digested using concentrated nitric acid as described in EPA SW-846 Method 3052. Additionally, hydrofluoric acid (HF) was added as necessary to ensure complete digestion in accordance with the method. Specifically, 9 ml of concentrated nitric acid and 3 ml of concentrated hydrofluoric acid were added and the samples were microwaved for 25 minutes at 50 psi followed by 45 minutes at 80 psi. The HF was neutralized before analysis by addition of 30 ml of a 4-percent boric acid solution prior to a second microwave digestion for 30 minutes at 50 psi. This process converts the HF to BF_3, which is a gas that leaves the sample. The digestate was quantitatively transferred to a volumetric flask and brought to 100 ml with 10 percent nitric acid before submission to the analytical laboratory for ICP-MS analysis (SW-846 Method 6020).

These results are presented in Section 4.4.

2.10 Archiving of ICP-MS Samples

Analysis of the samples by ICP-MS consumed only a fraction of the submitted sample. ARCADIS/EPA archived an aliquot of each digestate, to be held until the completion of the project. Samples were archived by storing them in TFE or PFA containers under refrigeration. Additionally, any remaining sample volume at the analytical laboratory was archived until the analytical results were confirmed.

2.11 Moisture Analysis of Wood Specimens

Initial precoat wood moisture content was measured using a hand-held meter, after the technique had been qualified via side-by-side testing with the drying oven technique, ASTM D4442 (Primary Oven Drying). Per ASTM D4442, a small representative wood sample was weighed prior to drying overnight at 103° C in a forced air oven. After 24 hours, the sample was cooled in a desiccator, weighed and returned to the oven. The process was repeated until weight changes between weighings were within ± 5 percent.

The results of the moisture analyses are included in the Specimen Characterization Data contained in Appendix B.

2.12 Miscellaneous Samples

Other samples that were collected during the study and archived or analyzed are summarized in Table 2-10.

Table 2-10. Miscellaneous Samples Collected

Sample Description	# Samples Analyzed	# Samples to be Archived
Unaltered coating	2 for each coating	Leftover coating was stored
Leftover brush-applied coating	N/A	1 for each coating and wood type
Brush wash water	2 for each brush type	Brushes were retained
Wood	Up to 4 cores per board	Leftover wood was stored

2.13 Quality Control Samples

The following types of quality control samples were included: (1) positive (CCA-treated, uncoated) controls, (2) negative (untreated, uncoated) controls, (3) cross-contamination controls, (4) wipe frequency (rewipe, abrasion) controls. Each is discussed briefly below.

2.13.1 Positive (CCA-Treated, Uncoated) Controls

The three minidecks prefixed by the number 13 were constructed in exactly the same way as the minidecks for coatings #1 through #12, except that they were not coated. The results from these minidecks were used to determine how the DCCA values vary over time without considering the effect of coating. As such, control deck DCCA values could be determined at each sampling event for comparison with DCCA from the coated decks. These positive control results were used to assess coating performance in the statistical data analysis.

The advantage to using the positive control minidecks for this purpose was that other potentially important factors were captured in the minideck 13 (uncoated) results and thus factored into the statistical analyses. These included: the effect of rinsing the boards prior to coating (assessed via comparison of precoat and samples taken 1 month after coating for the positive control minidecks), the effect of weathering between subsequent sampling events, and the effect of climatic conditions during the sampling itself. The use of the positive control minideck DCCA results thus allowed for these and other potential sources of bias to be considered in the data analysis.

These results are represented by the data presented for Deck #13 (uncoated).

2.13.2 Negative (Untreated, Uncoated) Controls

The single uncoated minideck, labeled BC (for “blank control”), consisting of five untreated specimens, was used to routinely take blank samples to measure the background levels or atmospheric deposition of CCA analytes. Wipe samples were taken from the same areas of the middle three boards on this deck during each monitoring event, similar to samples taken from the other minidecks.

These results are presented in Section 4.7.

2.13.3 Wipe Frequency (Rewipe, Abrasion) Controls

Each CCA-treated test specimen on each minideck included two sampling areas: a PSA (suffixed “M”) and an adjacent baseline sampled area (suffixed “BL”). BL areas were those that were initially wiped prior to coating to establish baseline DCCA. A subset of the BL areas were resampled during each of sampling events 1 through 5. All of the BL areas on one of the three minidecks per coating (as well as the positive control minidecks) were sampled during each of the five sampling events. Because there were three minidecks per coating, a given BL area was resampled every third sampling event. As such, the coatings on these sections of lumber were not abraded by wiping to the same extent as the coatings on the PSAs, so the effect that wiping has on coating efficacy could be investigated.

These results are presented in Section 4.6.

2.13.4 Analytical Laboratory Control Samples

A series of laboratory control samples were sent with each batch of samples tested by the analytical laboratory. Each set of digested wipe samples submitted to the analytical laboratory typically included five percent additional blind field blanks (extracted unused wet wipes), one blind blank (extraction fluid only), one set of three different concentration-spiked samples, and duplicates (split samples) for five percent of the wipe sample digestates that were analyzed to assess laboratory performance. Control samples were not identified as such to the analytical laboratory performing the analyses. For example, assuming that a total of 200 wipe samples were collected and shipped to the analytical laboratory in a single batch, the following additional samples were to be included:

- Ten (10) field blank samples prepared by taking unused wetted wipes and extracting them in accordance with the procedures previously specified
- One (1) blank consisting of extraction fluid only
- One (1) digestion fluid sample spiked to 1.0 µg/L (0.015 µg in 15 mL digestion fluid) with As, Cr, and Cu (depending on the range of DCCA in the particular batch of test samples being collected, this spike could instead be 10,000 ug/l to more appropriately capture a higher range)
- One (1) digestion fluid samples spiked to 50 µg/L (0.75 µg in 15 mL digestion fluid) with As, Cr, and Cu
- One (1) digestion fluid samples spiked to 1000 µg/L (15 µg in 15 mL digestion fluid) with As, Cr, and Cu
- Ten (10) duplicates (selected split samples of digested wipes from actual samples generated)

Furthermore, the analytical laboratory analyzed project-specific post-digestion spiked samples for each analyte, as well as equipment blanks run on each batch of samples. Results of the laboratory control samples are discussed in Section 5.

2.14 Paint Chip Sampling

Fragments of cracked and peeling paint were collected from the painted minidecks at the end of the study period and analyzed to determine if elevated CCA analyte

concentrations were associated with paint chips. Testing involved collecting samples of chipping/peeling paint from the minidecks coated with paint using cleaned tweezers. These decks were identified with the prefixes 9- and 10-, as they correspond to coatings #9, a water-based (latex) paint, and #10, an oil-based (enamel) paint. For both paints, the wood surfaces were coated with a commonly-available primer prior to coating with the paints themselves. Samples were taken from each of the CCA-treated boards of each of the three minidecks coated with the given paint and composited into a single sample, homogenized, subsampled, weighed, digested and analyzed. The same general procedure was used for the untreated boards from the three minidecks coated with the given paint. For each composite sample, the extraction fluid was split so that duplicate analyses for total arsenic, total chromium, and total copper could be run by the analytical laboratory. Table 2-11 lists the samples that were analyzed.

Table 2-11. Composite Samples Taken for Paint Chip Sampling/Analysis

Coating #	Boards to Sample	# of Minidecks	# of Boards (total)	Type of Sample	Number of Samples
9	CCA-Treated	3	12	Composite	Duplicate
9	Untreated	3	15	Composite	Duplicate
10	CCA-Treated	3	12	Composite	Duplicate
10	Untreated	3	15	Composite	Duplicate

Plastic tweezers were decontaminated prior to sampling and in between each of the four samples. Approximately equal amounts of paint fragments were removed from each of the five untreated wood boards on each of the three coating #9 minidecks. Individual paint fragment samples were taken from various places on each board to ensure a representative sample. All paint fragments for a given sample were added to a single digitube which had been preweighed in the laboratory prior to sampling. A total paint mass of 1.5 grams was targeted for collection. Sampling was repeated accordingly for the five untreated wood boards on each of the three coating #10 minidecks, then the four CCA-treated wood boards on each of the three coating #9 minidecks and lastly, the four CCA-treated wood boards on each of the three coating #10 minidecks. From each digitube, a representative 0.5-gram subsample of paint fragments was removed and placed in another digitube. The balance of the paint fragments (~1.0 gram) was left in each of the original digitubes. The Digitubes were weighed and reweighed to determine the mass of paint in each sample. The contents of each of the eight digitubes were then digested in their entirety, in accordance with the procedures specified in Section 2.9. Each of the 1.0-gram composite sample digestates were split into two equal duplicate samples and shipped to the analytical laboratory for determination of total arsenic, chromium, and copper in accordance with the procedures in Section 2.9.

Comparison of the 0.5 and 1.0 gram paint fragment digestate analysis results were used to help determine if there was any impact on analysis by the paint matrix itself.

These results are presented in Section 4.4.

3. Study Results

The discussion of results focuses on DAs, rather than the other DCCA measurements, because it is considered the analyte with the most critical exposure risks. However, DCr results may become important if cleaning products change the chromium speciation from (III) to (VI), for example. In general the trends for DCr and DCu are similar to those presented for DAs. Additionally, all of the raw and reduced DCCA is provided in appropriate sections of the appendix.

3.1 Source Characterization and Sampling Events

3.1.1 Distribution of Baseline Data

Source deck specific random effects analysis of the log-transformed, pre-averaging baseline measurements resulted in the summary statistics presented in Table 3-1, which shows that although the mean measured DAs on the newer source deck C boards is considerably lower than on the older source deck A boards, the within- and between-board variations associated with each source are comparable.

Table 3-1. Summary Statistics for Source Deck Specific Random Effects Analysis

Statistic	Source A	Source C
Mean ln(DAs)	0.68	0.11
Within Parent Board Variance	0.095	0,070
Between Parent Board Variance	0.169	0.156

Figures 3-1 through 3-6 provide simple box plots of the distribution of baseline data. These figures are grouped by analyte and source, and plot coating on the x-axis versus baseline DCCA on the y-axis. Appendix J includes similar plots grouped by board instead of by coating.

In each of the box plots presented, the box stretches from the lower hinge (defined as the 25th percentile) to the upper hinge (defined as the 75th percentile) and therefore contains the middle half of the scores in the distribution. The median is shown as a line across the box. Therefore, ¼ of the distribution is between this line and the top of the box and ¼ of the distribution is between this line and the bottom of the box. The plus symbol (+) shows the mean. In these plots, the bars on either side of the box define the minimum and maximum.

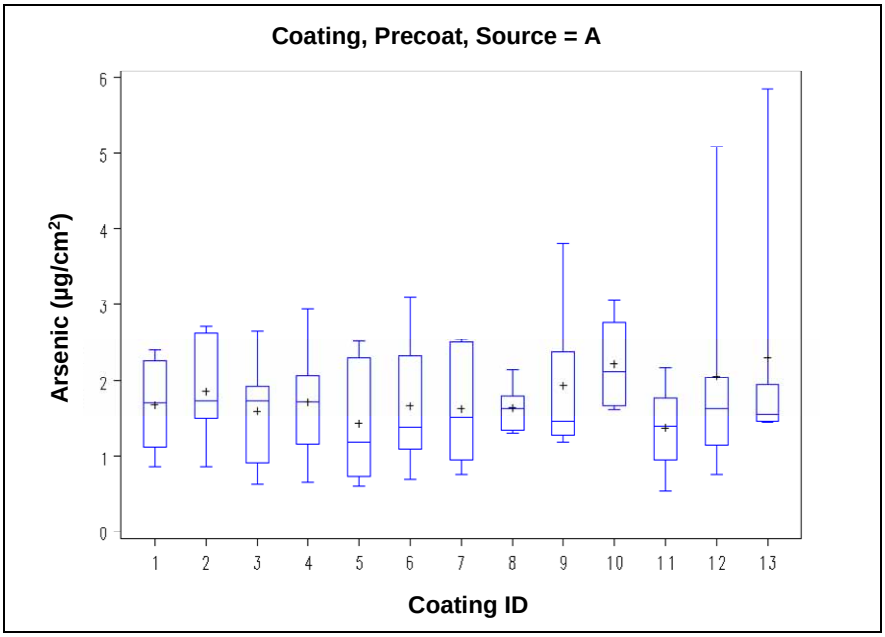


Figure 3-1. Box Plot, Baseline DAs, by Coating, Source A

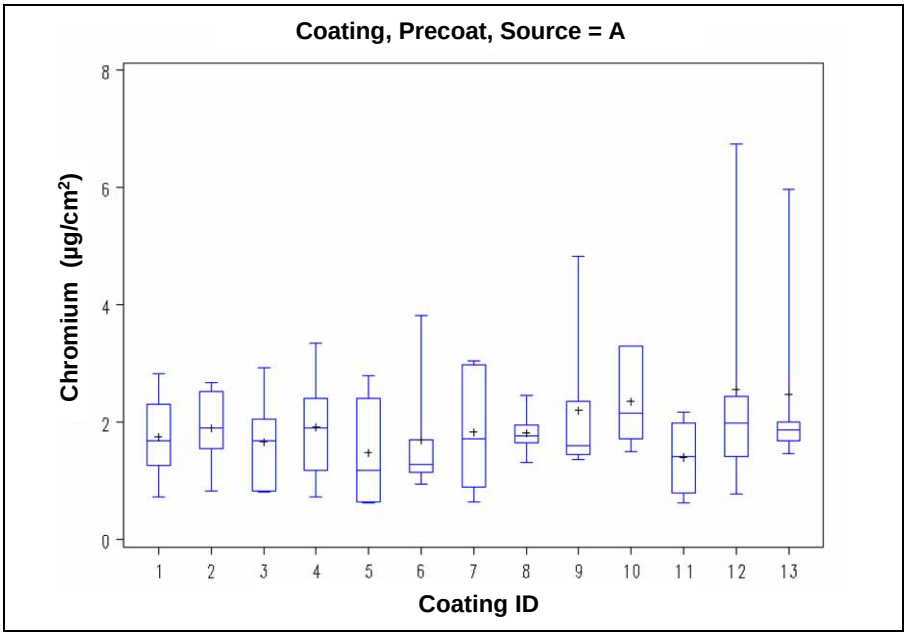


Figure 3-2. Box Plot, Baseline DCr, by Coating, Source A

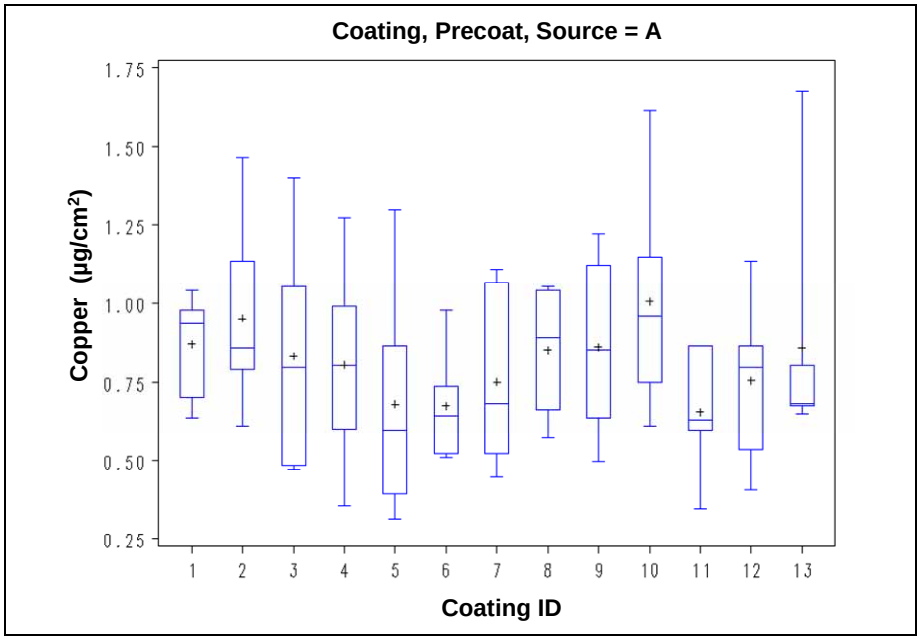


Figure 3-3. Box Plot, Baseline DCu, by Coating, Source A

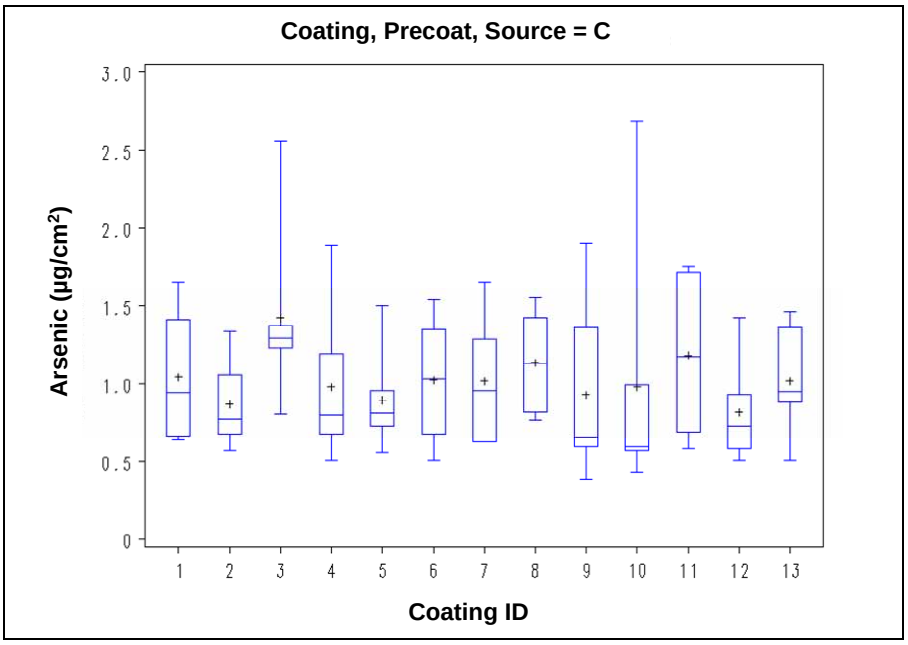


Figure 3-4. Box Plot, Baseline DAs, by Coating, Source C

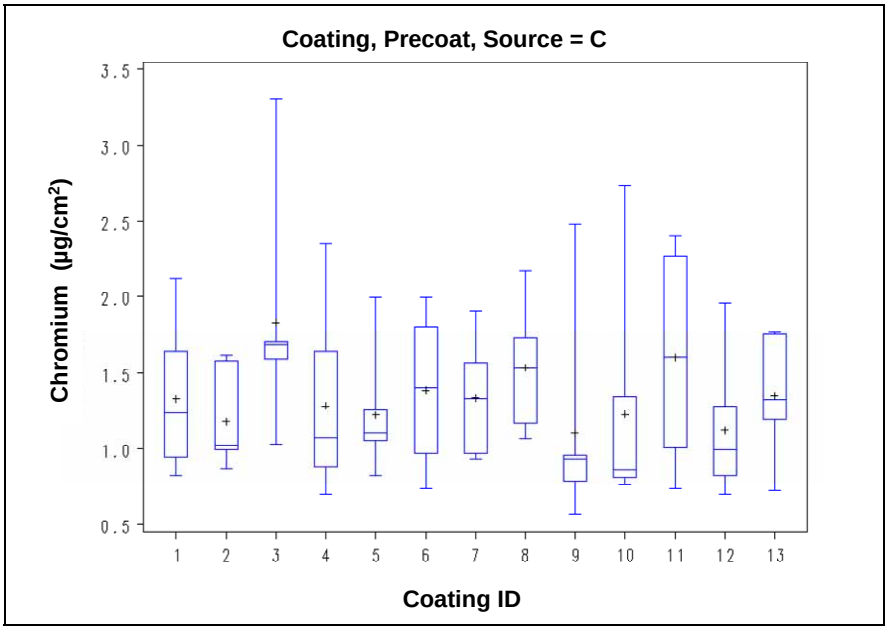


Figure 3-5. Box Plot, Baseline DCr, by Coating, Source C

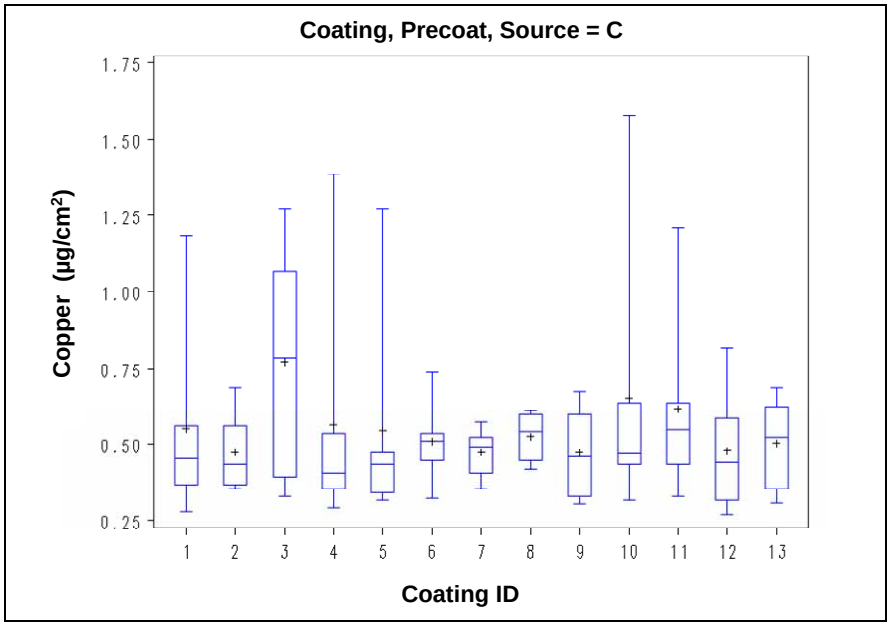


Figure 3-6. Box Plot, Baseline DCu, by Coating, Source C

3.1.2 Wood Core Sample Data

The wood core data for source A and source C are summarized in Tables C-5 and C-6 in Appendix C. The tables show averages, standard deviations, and RSDs for each board and include summary statistics at the end of each table for each source (A and C). RSDs should not be interpreted as indicators of data quality, but rather as indicators of natural variability in CCA retention within and between boards. Note that some of the boards listed in these tables were not actually used in the construction of the minidecks; however, they are included here for completeness. Complete data showing the results of each individual wood core sample measurement are provided in Appendix K.

The overall average results, reported as solid-phase concentrations in Table 3-2, generally compare favorably with the expected concentrations and ratios of concentrations of CCA analytes calculated in Section 2.2.3. There are some wood core sample data points that are clear outliers and overall variability is relatively high at about 50 percent RSD. Additionally, because of the way that boards are cut from the tree, taking core samples from the wide face – as done in this study – increased the likelihood that heartwood (which does not accept and retain CCA as readily as sapwood) was sampled. If the narrow faces had been sampled, sapwood would have more consistently been sampled and the values would have likely been more consistently high and less variable (Lebow, 2006).

Table 3-2. Comparison of Nominal, Source A, and Source C CCA Actives Composition

	Nominal CCA	Source A	Source C
As (mg/kg)		1,645	2,075
As as As_2O_5 (mg/kg)	4,255	2,522	3,182
As_2O_5 (percent)	34.0 (30.0 – 38.0)	31.7	35.2
Cr (mg/kg)		2,045	2,095
Cr as CrO_3 (mg/kg)	5,938	3,933	4,029
CrO_3 (percent)	47.5 (44.5–50.5)	49.4	44.5
Cu (mg/kg)		1,203	1,465
Cu as CuO (mg/kg)	2,317	1,506	1,834
CuO (percent)	18.5 (17.0–21.0)	18.9	20.3

3.1.3 Coating Application

The total volume and mass of coating applied to the A, C, and N boards (the untreated boards) on each minideck were determined as illustrated in Figure 3-7. No coating

mass data were recorded for coating #1, because the decision to measure mass was made after the coating #1 decks were coated. Measured volumes were rounded to the nearest increment of 5 mL. Mass measurements are reported to the nearest 0.1 g.

A complete tabulated summary of the coating application data is included in Appendix C, Table C-8. The summary includes average, standard deviation, and RSD for each combination of board type and coating. RSDs should not be interpreted as indicators of data quality, but rather as indicators of the variability inherent in the coating methods utilized. Any variability in coating volume or mass among decks is part of the natural variability one would see in practice, on real decks being coated by homeowners. Film thickness proved to be quite difficult to measure on wood substrates and was not appropriate for non-film forming coatings; as such, film thicknesses were only measured on some minidecks and these data are not presented.

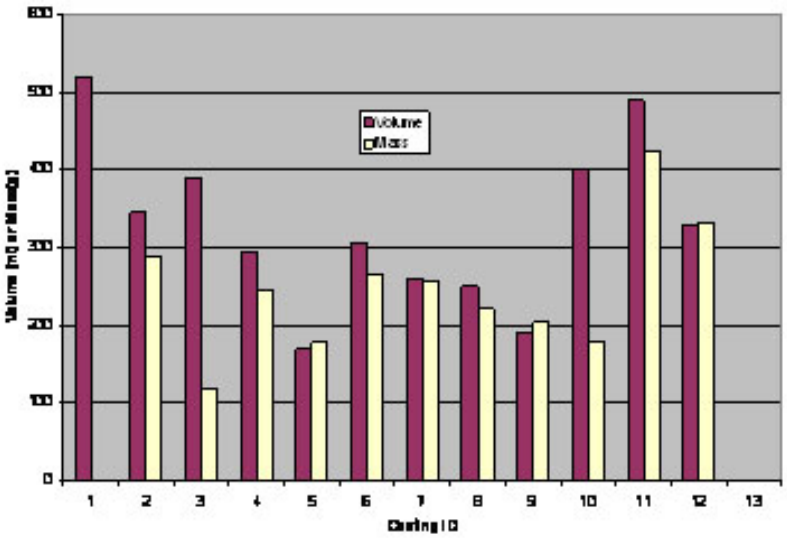


Figure 3-7. Coating Application (total of triplicate minidecks on both A and C sources)

3.2 Coating Performance Data

Tabulated summaries of the wipe sampling data for DAs, DCr and DCu is included in Appendix C (Tables C-9, C-10 and C-11, respectively). A complete set of wipe sampling data, including data for both the PSA (M) samples and baseline (BL) samples at each sampling event, is provided in Appendix N.

3.2.1 DCCA vs. Time

Baseline and time series DCCA values for each CCA analyte, sorted by coating, and averaged over the combined A and C sources are shown graphically using a natural log-transformed DCCA scale on the y-axis in Figures 3-8 through 3-10. The tabulated

data used to create these graphs is included Appendix C (Table C-9). Several generalized observations can be made from these data. First, each coating, as well as the positive controls (uncoated minidecks), generally show a significant decrease in DCCA between baseline (prewash, precoat) and samples taken 1 month after coating. This suggests an impact on DCCA from rinsing or washing the minidecks. Second, the coated minidecks all have lower DCCA than the positive controls, which indicates that coating (using any of the coatings tested) initially mitigates DCCA to some degree. Third, over the course of this study, DCCA increases with time after coating, most likely due to the effects of weathering and possibly abrasion on the coating, although it should be noted that the uncoated positive controls show similar, though generally less pronounced, trends.

Note that confidence intervals are not shown on Figures 3-8 through 3-10 to avoid obscuring the general trends. Refer to Figures 3-28 and 3-29 for graphical representations that show statistically significant differences between coatings by time and also Tables 3-11 and 3-12 that present p-values for differences between means at each time point and present estimated 95% confidence intervals for estimated percent reductions between coatings and the positive controls at each time period.

3.2.2 Graphical Data Analysis

The experimental design and associated statistical methods used in this section were introduced in Section 1.3.

The total number of valid DCCA observations in the dataset is 1,090. The effects of interest are coating, grain orientation, source deck, and time, and thus there are up to four-way interactions that need to be considered.

The analysis of variance models are very useful for identifying significant factor effects, but are less informative with regard to understanding the nature of the factor effects, especially those involving higher-order interactions. Therefore, graphical displays are extensively used to supplement the standard statistical analyses presented in the following sections. The intent is to provide a graphical representation of the patterns and trends in the data that are indicated by the numerical analysis of variance results.

The statistical analysis begins with a comprehensive graphical presentation and summary of the data, in order to provide an objective and transparent “look” at the experimental data unadulterated by any statistical model imposed on the data, and to aid the interpretation of the formal statistical analysis of variance results presented later in this discussion.

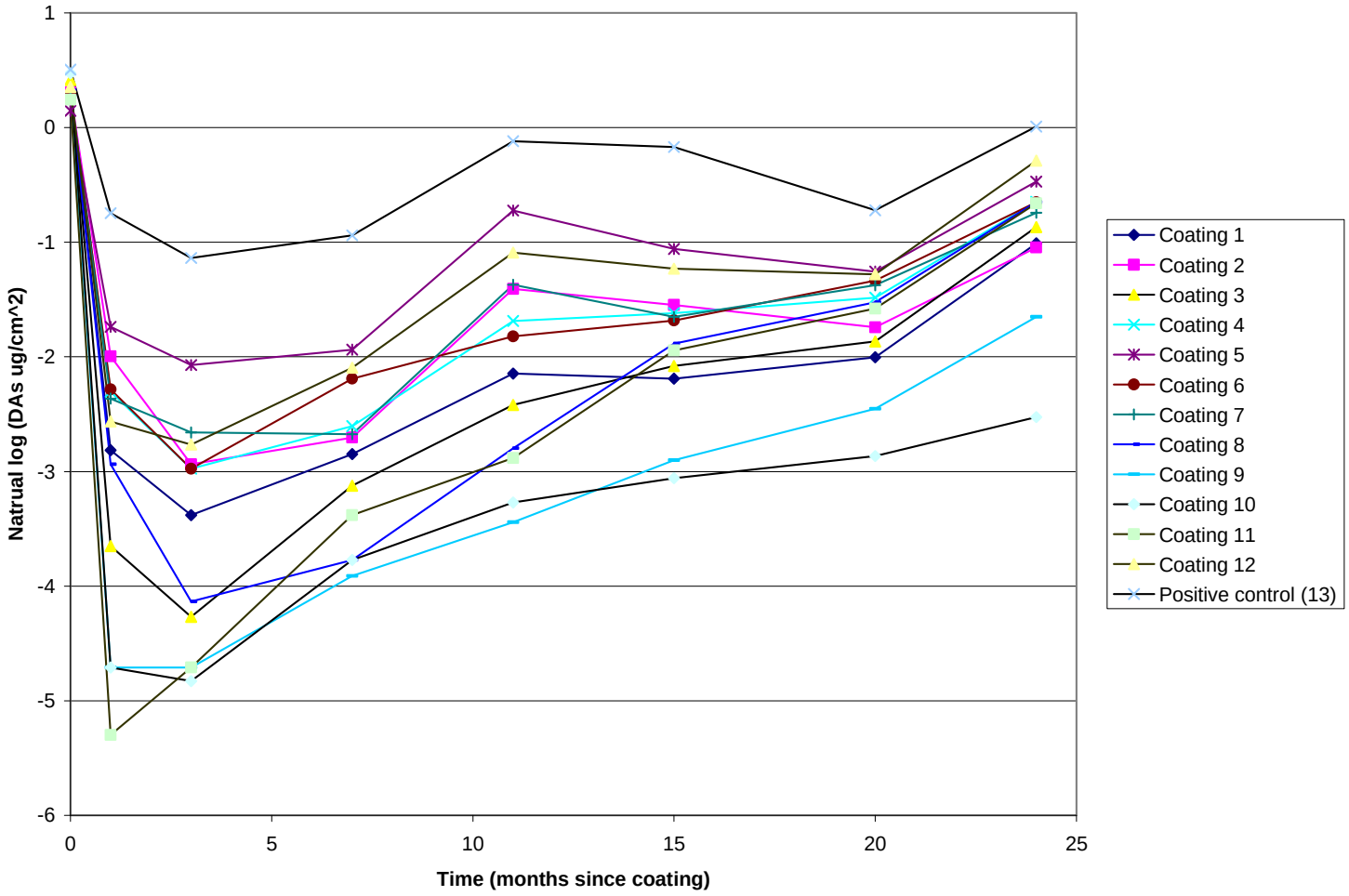


Figure 3-8. Average DAs vs. Time for All Coatings

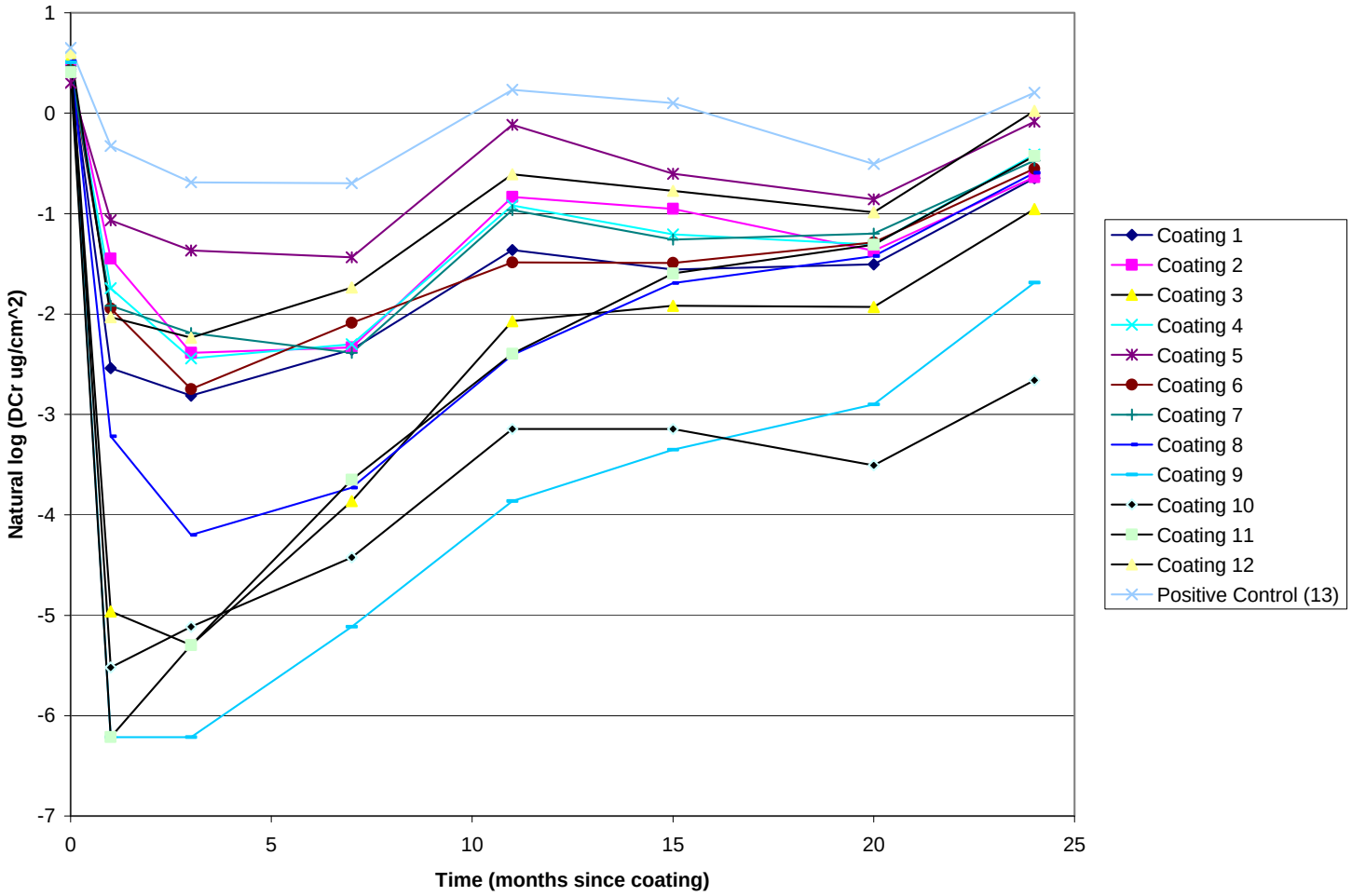


Figure 3-9. Average DCr vs. Time for All Coatings

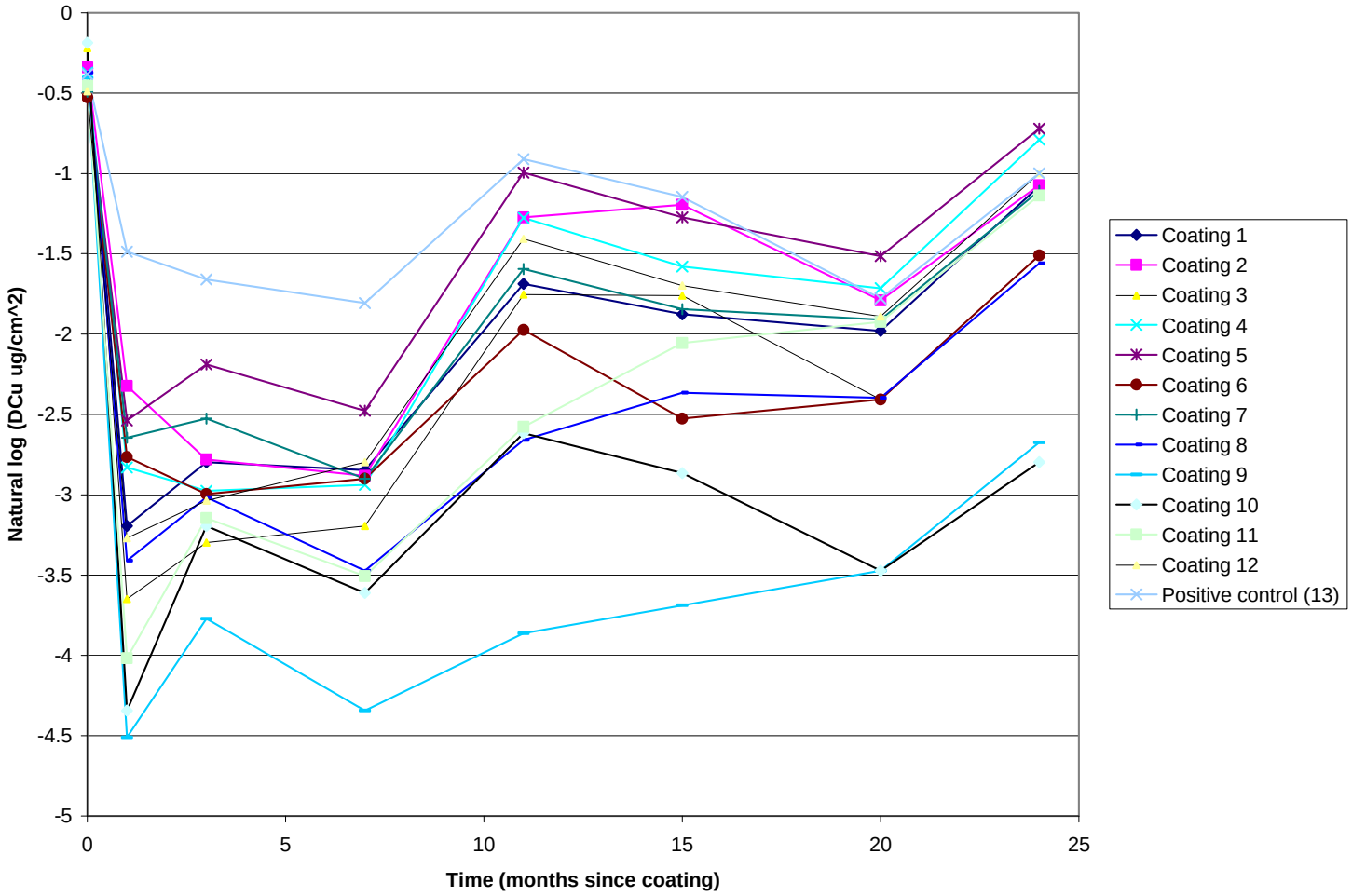


Figure 3-10. Average DCu vs. Time for All Coatings

The experiment included several factors and a comprehensive graphical summary of the data, while very enlightening, requires an understanding of why and how certain graphical elements were constructed. First the data and the graphical display for a single minideck are described. A composite data display in which all of the data from the thirty-nine minidecks, displayed on a single page, is then presented. This graphic and other composite data displays facilitate comparison among coatings. Next, plots of various averages designed to illustrate the effects of source deck, grain orientation, time and coating type are presented. Finally, a grand composite display that includes all of the relevant graphical elements on a single page is presented.

3.2.2.1 Single Minideck Data Plot

The data from Minideck 9-A is used to illustrate below how similar plots were generated for each minideck. Minideck 9-A was chosen for illustration because individual data points are well spread out and easily identified; and because it is "typical" in the sense of manifesting certain patterns and trends that are common to other minidecks. Figure 3-11 shows all of its PSA DAs data graphically and Table 3-4 presents the same data in tabular form.

Each minideck contains four CCA-treated specimens, with each specimen having different source and grain characteristics: Source Deck A, Grain Up; Source Deck A, Grain Down; Source Deck C, Grain Up; and Source Deck C, Grain Down. Figure 3-11 and subsequent minideck data plots are color coded according to board source deck and grain orientation as shown in Table 3-3.

Table 3-3. Legend for Individual Minideck Data Plots

Color	Source	Grain Orientation
Dark Blue	A	Up
Green	C	Up
Cyan (Light Blue)	A	Down
Red	C	Down

Each specimen contributes eight measurements of DAs to the study: one baseline measurement and seven post-baseline measurements at successive time points after treatment with one of the thirteen coatings (actually twelve coatings plus the uncoated control). Thus, each minideck plot displays thirty-two DAs measurements. However, the manner in which the measurements are plotted is different for the baseline and post baseline measurements.

Baseline (time = 0) measurements are plotted as horizontal lines extending the full width of the plot. Note that even though the baseline measurement is plotted over the entire length of the time axis, there is only one baseline measurement per specimen (at time = 0). One reason that the baseline values are plotted in this manner is because the baseline measurements may serve as the “before treatment” measurement for each of the “after treatment” measurements.

The post baseline measurements are plotted in time-order sequence with filled-circles of the color matching the specimen characteristics (source, grain orientation), as indicated in Table 3-3. The lines connecting the points are for clarity, and should not be misconstrued as to infer that DAs values necessarily changed linearly (or even smoothly) between successive time periods. Note, from Table 3-4, that the log-transformed baseline values (column Time = 0) are 1.090, 0.402, -0.291, and -0.740 for the A-Up, A-Down, C-Up, and C-Down boards respectively. These values are plotted in Figure 3-11 as the dark blue (Bl), cyan (Cy), green (Gr), and red (Re) horizontal lines respectively. The same color coding is used in plotting the post baseline measurements versus time. The log-transformed DAs values plotted in the graph are from the data table columns with headings “1 mo.” through “24 mos.”. For example, for Board A-T-M3 (Source Deck A, Grain Up), the seven time-ordered, post baseline, natural log-transformed As values (-4.065, -3.976, -3.043, -2.917, -2.067, -1.967, -1.407) are plotted versus time with dark blue circles and connecting lines.

One purpose of presenting the baseline measurements is to explain some of the variability in the post-baseline measurements. A specimen with higher than average initial DAs measurements could reasonably be expected to have higher-than-average post baseline DAs measurements as well. Thus, in Figure 3-11, for Minideck 9-A, it can be seen that the Source Deck A specimens had both higher baseline, and post-baseline, measurements than did the Source Deck C specimens, regardless of grain orientation or time period.

Note that the dark blue and cyan time plots (Source Deck A) overlap considerably and that the red and green time plots (Source Deck C) also overlap to a lesser extent. However, the blue and cyan curves lie entirely above the red and green curves. Thus, for this minideck, the observed differences in DAs measurements between grain orientation from the same source deck appear to be less pronounced than the differences between specimens from different source decks.

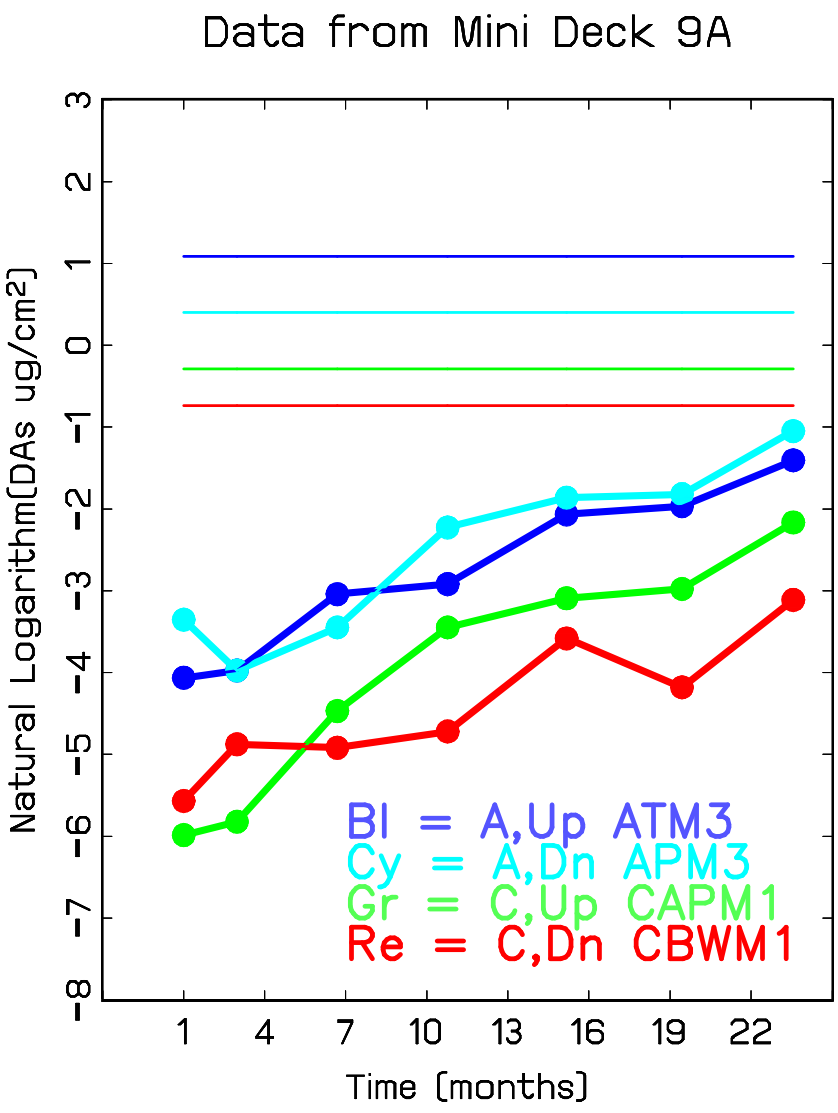


Figure 3-11. Data Plot for Minideck 9A

Table 3-4. DAs Data for Minideck 9-A, as used in Figure 3-13

Color	Spec ID	Source	Grain	Baseline	1 mo.	3 mos.	7 mos.	11 mos.	15 mos.	20 mos.	24 mos.
Raw (Not Natural Log Transformed) Data											
Blue	A-T-M3	A	Up	2.974	0.017	0.019	0.048	0.054	0.127	0.140	0.245
Cyan	A-P-M3	A	Down	1.495	0.035	0.019	0.032	0.108	0.156	0.162	0.350
Green	C-AP-M1	C	Up	0.747	0.003	0.003	0.012	0.032	0.046	0.051	0.115
Red	C-BW-M1	C	Down	0.477	0.004	0.008	0.007	0.009	0.028	0.015	0.045
Natural Log Transformed Data											
Blue	A-T-M3	A	Up	1.090	-4.065	-3.976	-3.043	-2.917	-2.067	-1.967	-1.407
Cyan	A-P-M3	A	Down	0.402	-3.353	-3.976	-3.448	-2.224	-1.861	-1.819	-1.050
Green	C-AP-M1	C	Up	-0.291	-5.987	-5.823	-4.470	-3.448	-3.090	-2.978	-2.167
Red	C-BW-M1	C	Down	-0.740	-5.568	-4.876	-4.919	-4.721	-3.583	-4.182	-3.112

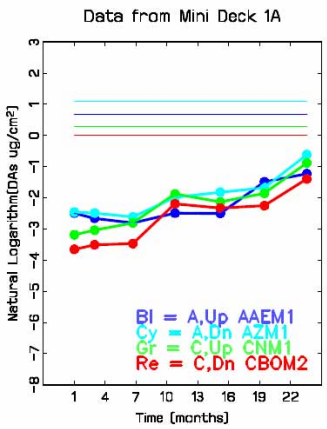
Finally, a noticeable feature of this graph is the increasing trend in DAs measurements over time, regardless of board type. With the exception of one point from the “A-Down” board (Cy = cyan-colored line), the time plots are strictly increasing with time. DAs measurements are lowest at the first post-baseline measurement and highest at the final post-baseline measurement for each board type, yet the final post-baseline measurement is still less than the corresponding baseline DAs measurement.

3.2.2.2 Data Plots for Other Minidecks

Plots were constructed for all thirty-nine minidecks in the same fashion as the Minideck 9-A example in Figure 3-11. These plots (and corresponding data tables, similar to Table 3-4 for the minideck 9-A example) are shown as Figures 3-12 through 3-24. These figures enable detailed visual inspection of the data for individual minidecks. These figures can be found in full-page size in Appendix O.

3.2.2.3 All Thirty-nine Minidecks Plotted Together

A composite graphic displaying all of the data is provided as Figure 3-25. It facilitates comparisons among coatings and also illustrates the repeatability of the experimental method which bears on the experimental method’s validity.

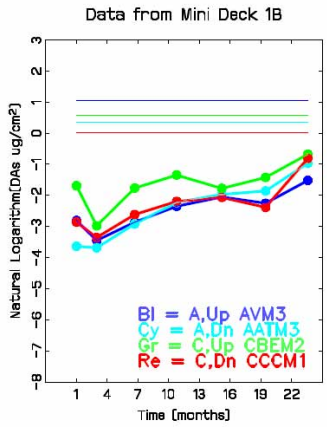


Raw Data (ug/cm^2 DAs):

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AAEM1	A	Up	1.9559	0.0827	0.0700	0.0604	0.0827	0.0821	0.2258	0.2926
Cy	AZM1	A	Down	3.0054	0.0859	0.0827	0.0732	0.1368	0.1619	0.1876	0.5407
Gr	CNM1	C	Up	1.3358	0.0413	0.0477	0.0604	0.1527	0.1183	0.1558	0.4134
Re	CBOM2	C	Down	1.0018	0.0258	0.0299	0.0312	0.1113	0.0973	0.1050	0.2481

Log Transformed Data:

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AAEM1	A	Up	0.671	-2.493	-2.660	-2.806	-2.493	-2.500	-1.488	-1.229
Cy	AZM1	A	Down	1.100	-2.455	-2.493	-2.615	-1.990	-1.821	-1.673	-0.615
Gr	CNM1	C	Up	0.289	-3.186	-3.043	-2.806	-1.880	-2.134	-1.859	-0.883
Re	CBOM2	C	Down	0.002	-3.659	-3.510	-3.468	-2.195	-2.330	-2.254	-1.394

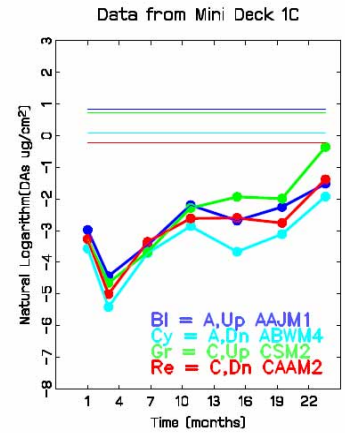


Raw Data (ug/cm^2 DAs):

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AVM3	A	Up	2.8305	0.0604	0.0318	0.0572	0.0954	0.1285	0.1050	0.2194
Cy	AATM3	A	Down	1.4153	0.0264	0.0251	0.0541	0.1081	0.1399	0.1558	0.3816
Gr	CBEM2	C	Up	1.7651	0.1845	0.0509	0.1717	0.2608	0.1698	0.2417	0.5089
Re	CCCM1	C	Down	1.0177	0.0572	0.0350	0.0732	0.1113	0.1272	0.0922	0.4452

Log Transformed Data:

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AVM3	A	Up	1.040	-2.806	-3.448	-2.860	-2.350	-2.052	-2.254	-1.517
Cy	AATM3	A	Down	0.347	-3.634	-3.684	-2.917	-2.224	-1.967	-1.859	-0.963
Gr	CBEM2	C	Up	0.568	-1.690	-2.978	-1.762	-1.344	-1.773	-1.420	-0.676
Re	CCCM1	C	Down	0.018	-2.860	-3.353	-2.615	-2.195	-2.062	-2.383	-0.809



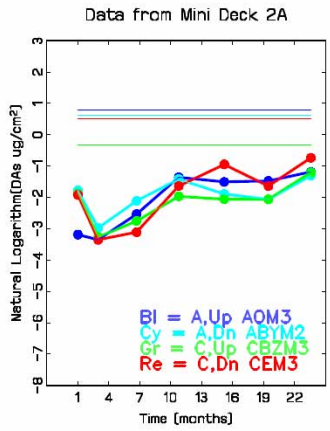
Raw Data (ug/cm^2 DAs):

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AAJM1	A	Up	2.3058	0.0509	0.0118	0.0315	0.1113	0.0684	0.1050	0.2194
Cy	ABWM4	A	Down	1.0813	0.0283	0.0044	0.0245	0.0572	0.0255	0.0445	0.1463
Gr	CSM2	C	Up	2.0672	0.0382	0.0095	0.0254	0.1018	0.1447	0.1368	0.6997
Re	CAAM2	C	Down	0.7951	0.0382	0.0067	0.0350	0.0732	0.0744	0.0636	0.2512

Log Transformed Data:

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AAJM1	A	Up	0.835	-2.978	-4.442	-3.458	-2.195	-2.683	-2.254	-1.517
Cy	ABWM4	A	Down	0.078	-3.565	-5.415	-3.709	-2.860	-3.669	-3.112	-1.922
Gr	CSM2	C	Up	0.726	-3.266	-4.652	-3.671	-2.285	-1.933	-1.990	-0.357
Re	CAAM2	C	Down	-0.229	-3.266	-5.009	-3.353	-2.615	-2.598	-2.755	-1.381

Figure 3-12. Data from Minideck 1A, Data from Minideck 1B, Data from Minideck 1C

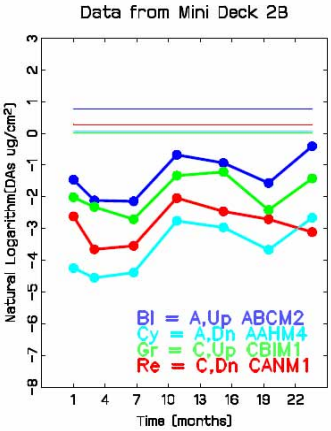


Raw Data (ug/cm^2 DAs):

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AOM3	A	Up	2.1945	0.0413	0.0350	0.0795	0.2576	0.2223	0.2290	0.3053
Cy	ABYM2	A	Down	1.8605	0.1686	0.0509	0.1208	0.2417	0.1504	0.1272	0.2703
Gr	CBZM3	C	Up	0.7156	0.1527	0.0382	0.0636	0.1399	0.1279	0.1272	0.2989
Re	CEM3	C	Down	1.6697	0.1463	0.0350	0.0445	0.1940	0.3880	0.1940	0.4770

Log Transformed Data:

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AOM3	A	Up	0.786	-3.186	-3.353	-2.532	-1.356	-1.504	-1.474	-1.186
Cy	ABYM2	A	Down	0.621	-1.780	-2.978	-2.113	-1.420	-1.894	-2.062	-1.308
Gr	CBZM3	C	Up	-0.335	-1.880	-3.266	-2.755	-1.967	-2.057	-2.062	-1.207
Re	CEM3	C	Down	0.513	-1.922	-3.353	-3.112	-1.640	-0.947	-1.640	-0.740

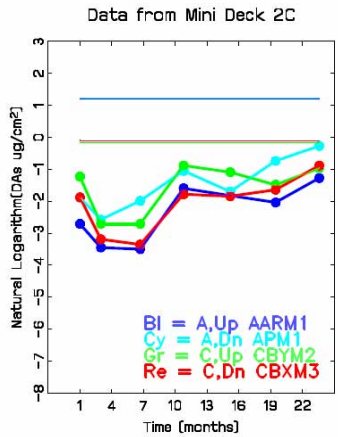


Raw Data (ug/cm^2 DAs):

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	ABCM2	A	Up	2.1467	0.2322	0.1208	0.1177	0.5089	0.3944	0.2099	0.6679
Cy	AAHM4	A	Down	1.0813	0.0143	0.0105	0.0124	0.0636	0.0515	0.0254	0.0700
Gr	CBIM1	C	Up	1.0177	0.1336	0.0986	0.0668	0.2640	0.2980	0.0891	0.2417
Re	CANM1	C	Down	1.3199	0.0732	0.0258	0.0289	0.1304	0.0855	0.0668	0.0445

Log Transformed Data:

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	ABCM2	A	Up	0.764	-1.460	-2.113	-2.140	-0.676	-0.930	-1.561	-0.404
Cy	AAHM4	A	Down	0.078	-4.247	-4.556	-4.390	-2.755	-2.966	-3.671	-2.660
Gr	CBIM1	C	Up	0.018	-2.013	-2.317	-2.706	-1.332	-1.211	-2.419	-1.420
Re	CANM1	C	Down	0.278	-2.615	-3.659	-3.543	-2.037	-2.459	-2.706	-3.112



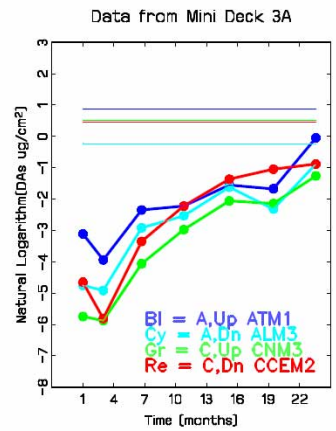
Raw Data (ug/cm^2 DAs):

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AARM1	A	Up	3.2758	0.0668	0.0318	0.0302	0.2035	0.1622	0.1304	0.2799
Cy	APM1	A	Down	3.3871	0.1527	0.0763	0.1368	0.3498	0.1832	0.4770	0.7633
Gr	CBYM2	C	Up	0.8428	0.2926	0.0668	0.0668	0.4134	0.3371	0.2258	0.3816
Re	CBXM3	C	Down	0.9064	0.1527	0.0413	0.0350	0.1686	0.1584	0.1940	0.4134

Log Transformed Data:

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AARM1	A	Up	1.187	-2.706	-3.448	-3.500	-1.592	-1.819	-2.037	-1.273
Cy	APM1	A	Down	1.220	-1.880	-2.573	-1.990	-1.050	-1.697	-0.740	-0.270
Gr	CBYM2	C	Up	-0.171	-1.229	-2.706	-2.706	-0.883	-1.087	-1.488	-0.963
Re	CBXM3	C	Down	-0.098	-1.880	-3.186	-3.353	-1.780	-1.843	-1.640	-0.883

Figure 3-13. Data from Minideck 2A, Data from Minideck 2B, Data from Minideck 2C

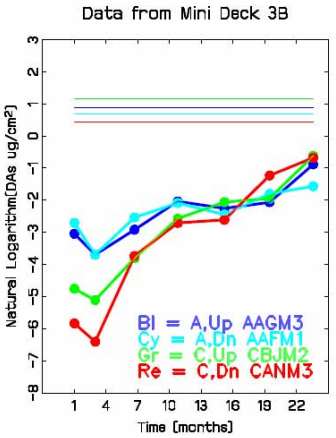


Raw Data (ug/cm^2 DAs):

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	ATM1	A	Up	2.3694	0.0445	0.0194	0.0954	0.1081	0.2112	0.1876	0.9541
Cy	ALM3	A	Down	0.7951	0.0086	0.0073	0.0541	0.0795	0.1975	0.0986	0.4134
Gr	CNM3	C	Up	1.6697	0.0032	0.0028	0.0172	0.0509	0.1275	0.1177	0.2831
Re	CCEM2	C	Down	1.5584	0.0095	0.0030	0.0350	0.1081	0.2544	0.3498	0.4134

Log Transformed Data:

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	ATM1	A	Up	0.863	-3.112	-3.942	-2.350	-2.224	-1.555	-1.673	-0.047
Cy	ALM3	A	Down	-0.229	-4.757	-4.919	-2.917	-2.532	-1.622	-2.317	-0.883
Gr	CNM3	C	Up	0.513	-5.751	-5.878	-4.065	-2.978	-2.059	-2.140	-1.262
Re	CCEM2	C	Down	0.444	-4.652	-5.812	-3.353	-2.224	-1.369	-1.050	-0.883

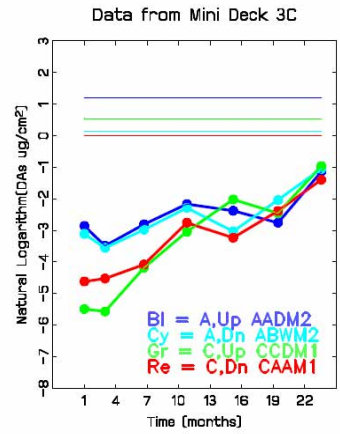


Raw Data (ug/cm^2 DAs):

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AAGM3	A	Up	2.4012	0.0477	0.0248	0.0541	0.1304	0.1050	0.1272	0.4134
Cy	AAFM1	A	Down	1.9718	0.0668	0.0248	0.0795	0.1240	0.0868	0.1654	0.2099
Gr	CBJM2	C	Up	3.1963	0.0086	0.0060	0.0223	0.0763	0.1279	0.1431	0.5407
Re	CANM3	C	Down	1.5425	0.0029	0.0017	0.0238	0.0668	0.0735	0.2926	0.5089

Log Transformed Data:

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AAGM3	A	Up	0.876	-3.043	-3.697	-2.917	-2.037	-2.254	-2.062	-0.883
Cy	AAFM1	A	Down	0.679	-2.706	-3.697	-2.532	-2.087	-2.444	-1.800	-1.561
Gr	CBJM2	C	Up	1.162	-4.757	-5.109	-3.805	-2.573	-2.057	-1.944	-0.615
Re	CANM3	C	Down	0.433	-5.833	-6.407	-3.736	-2.706	-2.611	-1.229	-0.676



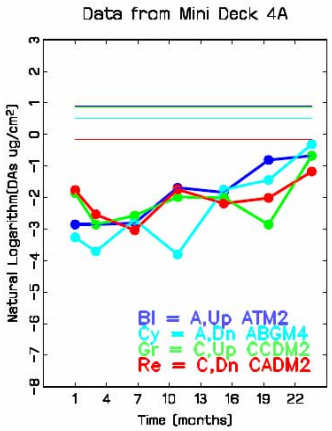
Raw Data (ug/cm^2 DAs):

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AADM2	A	Up	3.3076	0.0572	0.0305	0.0604	0.1145	0.0929	0.0636	0.3180
Cy	ABWM2	A	Down	1.1449	0.0445	0.0286	0.0509	0.1018	0.0483	0.1304	0.3498
Gr	CCDM1	C	Up	1.7174	0.0041	0.0038	0.0153	0.0477	0.1323	0.0859	0.3816
Re	CAAM1	C	Down	1.0018	0.0099	0.0108	0.0169	0.0636	0.0394	0.0922	0.2481

Log Transformed Data:

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AADM2	A	Up	1.196	-2.860	-3.489	-2.806	-2.167	-2.377	-2.755	-1.146
Cy	ABWM2	A	Down	0.135	-3.112	-3.554	-2.978	-2.285	-3.029	-2.037	-1.050
Gr	CCDM1	C	Up	0.541	-5.489	-5.568	-4.182	-3.043	-2.023	-2.455	-0.963
Re	CAAM1	C	Down	0.002	-4.619	-4.527	-4.083	-2.755	-3.233	-2.383	-1.394

Figure 3-14. Data from Minideck 3A, Data from Minideck 3B, Data from Minideck 3C

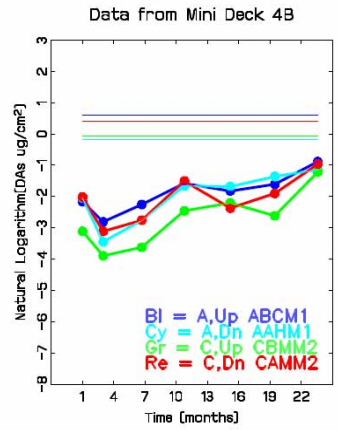


Raw Data (ug/cm^2 DAs):

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	ATM2	A	Up	2.4648	0.0572	0.0572	0.0604	0.1845	0.1600	0.4452	0.5089
Cy	ABGM4	A	Down	1.6379	0.0382	0.0245	0.0668	0.0223	0.1730	0.2354	0.7315
Gr	CCDM2	C	Up	2.3694	0.1558	0.0572	0.0763	0.1368	0.1349	0.0572	0.5089
Re	CADM2	C	Down	0.8428	0.1717	0.0795	0.0477	0.1749	0.1119	0.1336	0.3085

Log Transformed Data:

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	ATM2	A	Up	0.902	-2.860	-2.860	-2.806	-1.690	-1.833	-0.809	-0.676
Cy	ABGM4	A	Down	0.493	-3.266	-3.709	-2.706	-3.805	-1.754	-1.447	-0.313
Gr	CCDM2	C	Up	0.863	-1.859	-2.860	-2.573	-1.990	-2.004	-2.860	-0.676
Re	CADM2	C	Down	-0.171	-1.762	-2.532	-3.043	-1.743	-2.190	-2.013	-1.176

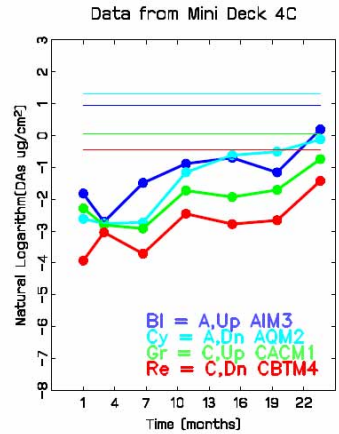


Raw Data (ug/cm^2 DAs):

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	ABCM1	A	Up	1.8446	0.1145	0.0604	0.1050	0.2067	0.1622	0.2004	0.4134
Cy	AAHM1	A	Down	0.8269	0.1304	0.0318	0.0636	0.1908	0.1857	0.2576	0.3180
Gr	CBMM2	C	Up	0.9382	0.0445	0.0204	0.0267	0.0859	0.1107	0.0732	0.2958
Re	CAMM2	C	Down	1.4948	0.1336	0.0445	0.0636	0.2226	0.0935	0.1495	0.3816

Log Transformed Data:

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	ABCM1	A	Up	0.612	-2.167	-2.806	-2.254	-1.576	-1.819	-1.608	-0.883
Cy	AAHM1	A	Down	-0.190	-2.037	-3.448	-2.755	-1.656	-1.683	-1.356	-1.146
Gr	CBMM2	C	Up	-0.064	-3.112	-3.895	-3.622	-2.455	-2.201	-2.615	-1.218
Re	CAMM2	C	Down	0.402	-2.013	-3.112	-2.755	-1.502	-2.370	-1.901	-0.963



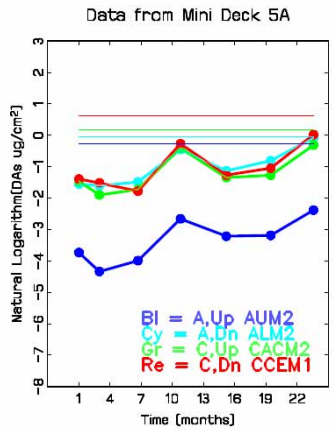
Raw Data (ug/cm^2 DAs):

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AIM3	A	Up	2.5920	0.1622	0.0668	0.2258	0.4134	0.4961	0.3149	1.2085
Cy	AQM2	A	Down	3.6733	0.0732	0.0636	0.0652	0.3149	0.5407	0.6043	0.8905
Gr	CACM1	C	Up	1.0495	0.1018	0.0604	0.0541	0.1781	0.1453	0.1813	0.4770
Re	CBTM4	C	Down	0.6361	0.0197	0.0477	0.0245	0.0859	0.0620	0.0700	0.2417

Log Transformed Data:

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AIM3	A	Up	0.952	-1.819	-2.706	-1.488	-0.883	-0.701	-1.156	0.189
Cy	AQM2	A	Down	1.301	-2.615	-2.755	-2.730	-1.156	-0.615	-0.504	-0.116
Gr	CACM1	C	Up	0.048	-2.285	-2.806	-2.917	-1.725	-1.929	-1.708	-0.740
Re	CBTM4	C	Down	-0.452	-3.926	-3.043	-3.709	-2.455	-2.780	-2.660	-1.420

Figure 3-15. Data from Minideck 4A, Data from Minideck 4B, Data from Minideck 4C

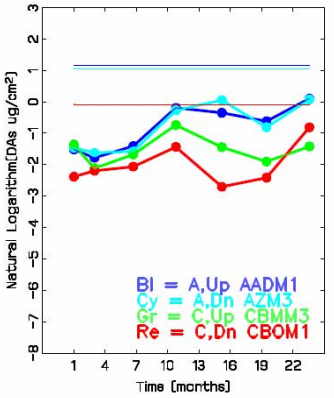


Raw Data (ug/cm^2 DAs):

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AUM2	A	Up	0.7633	0.0238	0.0130	0.0185	0.0700	0.0401	0.0413	0.0922
Cy	ALM2	A	Down	0.9541	0.2131	0.2004	0.2258	0.6361	0.3212	0.4452	0.9223
Gr	CACM2	C	Up	1.1926	0.2322	0.1495	0.1781	0.6679	0.2598	0.2799	0.7315
Re	CCEM1	C	Down	1.8764	0.2481	0.2194	0.1686	0.7633	0.2808	0.3498	1.0177

Log Transformed Data:

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AUM2	A	Up	-0.270	-3.736	-4.340	-3.993	-2.660	-3.217	-3.186	-2.383
Cy	ALM2	A	Down	-0.047	-1.546	-1.608	-1.488	-0.452	-1.136	-0.809	-0.081
Gr	CACM2	C	Up	0.176	-1.460	-1.901	-1.725	-0.404	-1.348	-1.273	-0.313
Re	CCEM1	C	Down	0.629	-1.394	-1.517	-1.780	-0.270	-1.270	-1.050	0.018

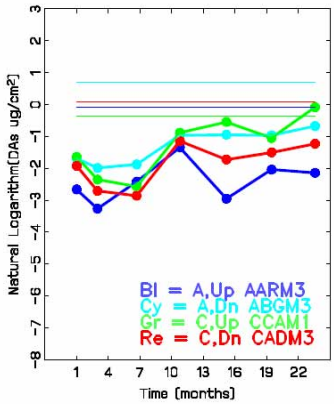


Raw Data (ug/cm^2 DAs):

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AADM1	A	Up	3.1485	0.2194	0.1686	0.2449	0.8269	0.7060	0.5407	1.1131
Cy	AZM3	A	Down	2.8782	0.2322	0.1972	0.2067	0.7633	1.0591	0.4452	1.0813
Gr	CBMM3	C	Up	0.9064	0.2576	0.1208	0.1876	0.4770	0.2363	0.1495	0.2417
Re	CBOM1	C	Down	0.9223	0.0922	0.1113	0.1272	0.2385	0.0671	0.0891	0.4452

Log Transformed Data:

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AADM1	A	Up	1.147	-1.517	-1.780	-1.407	-0.190	-0.348	-0.615	0.107
Cy	AZM3	A	Down	1.057	-1.460	-1.624	-1.576	-0.270	0.057	-0.809	0.078
Gr	CBMM3	C	Up	-0.098	-1.356	-2.113	-1.673	-0.740	-1.443	-1.901	-1.420
Re	CBOM1	C	Down	-0.081	-2.383	-2.195	-2.062	-1.433	-2.701	-2.419	-0.809



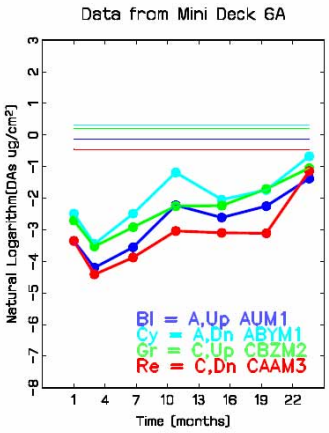
Raw Data (ug/cm^2 DAs):

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AARM3	A	Up	0.9223	0.0700	0.0382	0.0891	0.2608	0.0522	0.1304	0.1177
Cy	ABGM3	A	Down	2.0195	0.1845	0.1368	0.1527	0.3816	0.3880	0.3816	0.5089
Gr	CCAM1	C	Up	0.6997	0.1940	0.0954	0.0763	0.4134	0.5788	0.3498	0.9223
Re	CADM3	C	Down	1.0972	0.1463	0.0668	0.0572	0.3180	0.1781	0.2226	0.2926

Log Transformed Data:

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AARM3	A	Up	-0.081	-2.660	-3.266	-2.419	-1.344	-2.953	-2.037	-2.140
Cy	ABGM3	A	Down	0.703	-1.690	-1.990	-1.880	-0.963	-0.947	-0.963	-0.676
Gr	CCAM1	C	Up	-0.357	-1.640	-2.350	-2.573	-0.883	-0.547	-1.050	-0.081
Re	CADM3	C	Down	0.093	-1.922	-2.706	-2.860	-1.146	-1.725	-1.502	-1.229

Figure 3-16. Data from Minideck 5A, Data from Minideck 5B, Data from Minideck 5C

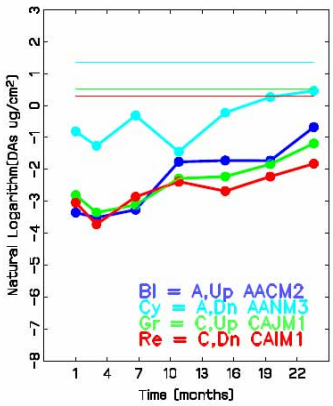


Raw Data (ug/cm^2 DAs):

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AUM1	A	Up	0.8746	0.0350	0.0150	0.0286	0.1081	0.0732	0.1050	0.2512
Cy	ABYM1	A	Down	1.3835	0.0827	0.0318	0.0827	0.3053	0.1294	0.1749	0.5089
Gr	CBZM2	C	Up	1.2244	0.0668	0.0293	0.0541	0.1050	0.1069	0.1813	0.3498
Re	CAAM3	C	Down	0.6361	0.0350	0.0121	0.0207	0.0477	0.0452	0.0445	0.3180

Log Transformed Data:

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AUM1	A	Up	-0.134	-3.353	-4.203	-3.554	-2.224	-2.615	-2.254	-1.381
Cy	ABYM1	A	Down	0.325	-2.493	-3.448	-2.493	-1.186	-2.045	-1.743	-0.676
Gr	CBZM2	C	Up	0.202	-2.706	-3.532	-2.917	-2.254	-2.236	-1.708	-1.050
Re	CAAM3	C	Down	-0.452	-3.353	-4.415	-3.879	-3.043	-3.098	-3.112	-1.146

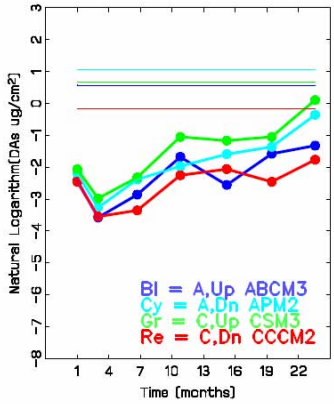


Raw Data (ug/cm^2 DAs):

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AACM2	A	Up	1.6697	0.0350	0.0299	0.0382	0.1717	0.1787	0.1781	0.5089
Cy	AANM3	A	Down	3.8800	0.4452	0.2831	0.7315	0.2354	0.8015	1.3039	1.5902
Gr	CAJM1	C	Up	1.6856	0.0604	0.0350	0.0445	0.1018	0.1078	0.1590	0.3053
Re	CAIM1	C	Down	1.3517	0.0477	0.0242	0.0572	0.0922	0.0684	0.1081	0.1622

Log Transformed Data:

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AACM2	A	Up	0.513	-3.353	-3.510	-3.266	-1.762	-1.722	-1.725	-0.676
Cy	AANM3	A	Down	1.356	-0.809	-1.262	-0.313	-1.447	-0.221	0.265	0.464
Gr	CAJM1	C	Up	0.522	-2.806	-3.353	-3.112	-2.285	-2.227	-1.839	-1.186
Re	CAIM1	C	Down	0.301	-3.043	-3.723	-2.860	-2.383	-2.683	-2.224	-1.819



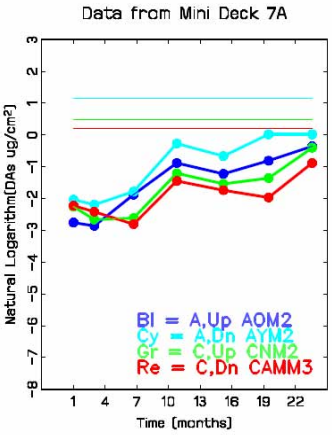
Raw Data (ug/cm^2 DAs):

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	ABCM3	A	Up	1.7651	0.0891	0.0280	0.0572	0.1876	0.0776	0.2067	0.2672
Cy	APM2	A	Down	2.9100	0.1113	0.0382	0.0922	0.1399	0.2042	0.2576	0.6997
Gr	CSM3	C	Up	1.9241	0.1272	0.0509	0.0986	0.3498	0.3114	0.3498	1.1131
Re	CCCM2	C	Down	0.8428	0.0859	0.0289	0.0350	0.1050	0.1279	0.0859	0.1717

Log Transformed Data:

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	ABCM3	A	Up	0.568	-2.419	-3.576	-2.860	-1.673	-2.556	-1.576	-1.320
Cy	APM2	A	Down	1.068	-2.195	-3.266	-2.383	-1.967	-1.589	-1.356	-0.357
Gr	CSM3	C	Up	0.654	-2.062	-2.978	-2.317	-1.050	-1.167	-1.050	0.107
Re	CCCM2	C	Down	-0.171	-2.455	-3.543	-3.353	-2.254	-2.057	-2.455	-1.762

Figure 3-17. Data from Minideck 6A, Data from Minideck 6B, Data from Minideck 6C

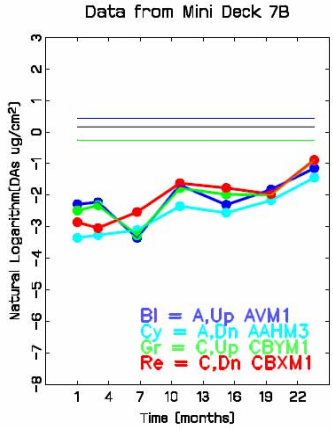


Raw Data (ug/cm^2 DAs):

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AOM2	A	Up	3.1804	0.0636	0.0572	0.1527	0.4134	0.2935	0.4452	0.6997
Cy	AYM2	A	Down	3.1326	0.1304	0.1113	0.1686	0.7633	0.5152	1.0177	1.0177
Gr	CNM2	C	Up	1.6061	0.1050	0.0700	0.0732	0.2989	0.2144	0.2576	0.6679
Re	CAMM3	C	Down	1.2244	0.1081	0.0891	0.0604	0.2354	0.1756	0.1399	0.4134

Log Transformed Data:

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AOM2	A	Up	1.157	-2.755	-2.860	-1.880	-0.883	-1.226	-0.809	-0.357
Cy	AYM2	A	Down	1.142	-2.037	-2.195	-1.780	-0.270	-0.663	0.018	0.018
Gr	CNM2	C	Up	0.474	-2.254	-2.660	-2.615	-1.207	-1.540	-1.356	-0.404
Re	CAMM3	C	Down	0.202	-2.224	-2.419	-2.806	-1.447	-1.740	-1.967	-0.883

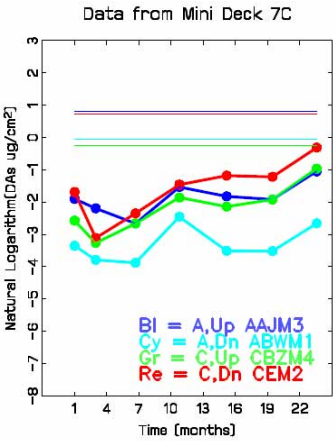


Raw Data (ug/cm^2 DAs):

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AVM1	A	Up	1.5266	0.1018	0.1081	0.0350	0.1876	0.0999	0.1622	0.3180
Cy	AAHM3	A	Down	1.1926	0.0350	0.0382	0.0445	0.0954	0.0773	0.1145	0.2354
Gr	CBYM1	C	Up	0.7792	0.0827	0.0986	0.0382	0.1686	0.1383	0.1368	0.4134
Re	CBXM1	C	Down	1.1608	0.0572	0.0477	0.0795	0.1972	0.1702	0.1399	0.4134

Log Transformed Data:

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AVM1	A	Up	0.423	-2.285	-2.224	-3.353	-1.673	-2.304	-1.819	-1.146
Cy	AAHM3	A	Down	0.176	-3.353	-3.266	-3.112	-2.350	-2.560	-2.167	-1.447
Gr	CBYM1	C	Up	-0.250	-2.493	-2.317	-3.266	-1.780	-1.978	-1.990	-0.883
Re	CBXM1	C	Down	0.149	-2.860	-3.043	-2.532	-1.624	-1.771	-1.967	-0.883



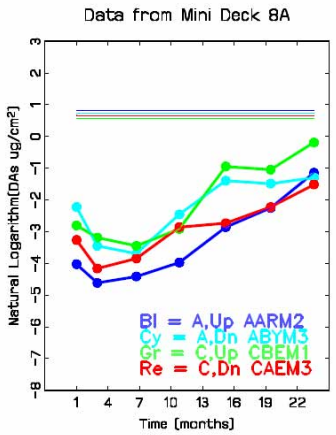
Raw Data (ug/cm^2 DAs):

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AAJM3	A	Up	2.2422	0.1495	0.1113	0.0700	0.2163	0.1612	0.1463	0.3498
Cy	ABWM1	A	Down	0.9541	0.0350	0.0226	0.0207	0.0859	0.0298	0.0296	0.0700
Gr	CBZM4	C	Up	0.7792	0.0763	0.0382	0.0700	0.1558	0.1177	0.1463	0.3816
Re	CEM2	C	Down	2.0672	0.1845	0.0445	0.0954	0.2322	0.3069	0.2958	0.7315

Log Transformed Data:

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AAJM3	A	Up	0.807	-1.901	-2.195	-2.660	-1.531	-1.825	-1.922	-1.050
Cy	ABWM1	A	Down	-0.047	-3.353	-3.791	-3.879	-2.455	-3.513	-3.521	-2.660
Gr	CBZM4	C	Up	-0.250	-2.573	-3.266	-2.660	-1.859	-2.140	-1.922	-0.963
Re	CEM2	C	Down	0.726	-1.690	-3.112	-2.350	-1.460	-1.181	-1.218	-0.313

Figure 3-18. Data from Minideck 7A, Data from Minideck 7B, Data from Minideck 7C

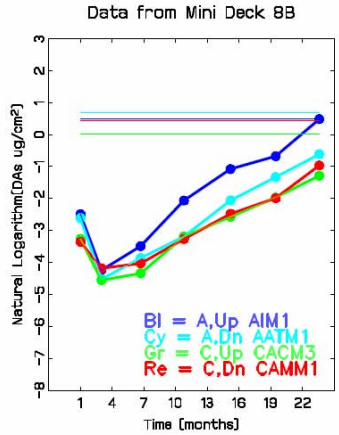


Raw Data (ug/cm^2 DAs):

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AARM2	A	Up	2.2422	0.0178	0.0099	0.0121	0.0188	0.0572	0.1050	0.3180
Cy	ABYM3	A	Down	2.0831	0.1081	0.0318	0.0248	0.0859	0.2481	0.2258	0.2735
Gr	CBEM1	C	Up	1.7810	0.0604	0.0413	0.0318	0.0541	0.3880	0.3498	0.8269
Re	CAEM3	C	Down	1.9400	0.0382	0.0156	0.0213	0.0572	0.0649	0.1081	0.2194

Log Transformed Data:

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AARM2	A	Up	0.807	-4.028	-4.619	-4.415	-3.976	-2.860	-2.254	-1.146
Cy	ABYM3	A	Down	0.734	-2.224	-3.448	-3.697	-2.455	-1.394	-1.488	-1.296
Gr	CBEM1	C	Up	0.577	-2.806	-3.186	-3.448	-2.917	-0.947	-1.050	-0.190
Re	CAEM3	C	Down	0.663	-3.266	-4.162	-3.849	-2.860	-2.735	-2.224	-1.517

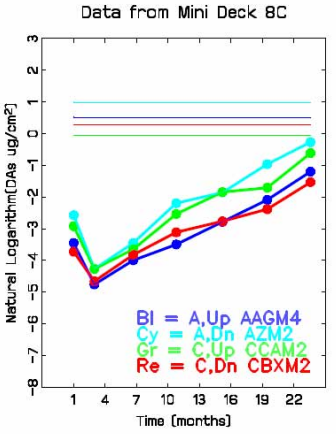


Raw Data (ug/cm^2 DAs):

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AIM1	A	Up	1.6220	0.0827	0.0143	0.0305	0.1272	0.3403	0.5089	1.6220
Cy	AATM1	A	Down	1.9877	0.0732	0.0108	0.0210	0.0413	0.1279	0.2640	0.5407
Gr	CACM3	C	Up	1.0177	0.0382	0.0105	0.0130	0.0413	0.0766	0.1399	0.2767
Re	CAMM1	C	Down	1.5266	0.0350	0.0153	0.0178	0.0382	0.0840	0.1368	0.3816

Log Transformed Data:

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AIM1	A	Up	0.484	-2.493	-4.247	-3.489	-2.062	-1.078	-0.676	0.484
Cy	AATM1	A	Down	0.687	-2.615	-4.527	-3.864	-3.186	-2.057	-1.332	-0.615
Gr	CACM3	C	Up	0.018	-3.266	-4.556	-4.340	-3.186	-2.569	-1.967	-1.285
Re	CAMM1	C	Down	0.423	-3.353	-4.182	-4.028	-3.266	-2.477	-1.990	-0.963



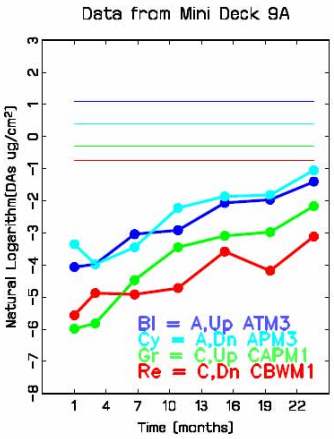
Raw Data (ug/cm^2 DAs):

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AAGM4	A	Up	1.6697	0.0318	0.0086	0.0185	0.0302	0.0617	0.1240	0.3021
Cy	AZM2	A	Down	2.6874	0.0763	0.0140	0.0318	0.1113	0.1565	0.3816	0.7633
Gr	CCAM2	C	Up	0.9541	0.0541	0.0140	0.0261	0.0795	0.1584	0.1813	0.5407
Re	CBXM2	C	Down	1.3039	0.0242	0.0095	0.0219	0.0445	0.0630	0.0922	0.2163

Log Transformed Data:

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AAGM4	A	Up	0.513	-3.448	-4.757	-3.993	-3.500	-2.785	-2.087	-1.197
Cy	AZM2	A	Down	0.989	-2.573	-4.269	-3.448	-2.195	-1.855	-0.963	-0.270
Gr	CCAM2	C	Up	-0.047	-2.917	-4.269	-3.647	-2.532	-1.843	-1.708	-0.615
Re	CBXM2	C	Down	0.265	-3.723	-4.652	-3.819	-3.112	-2.765	-2.383	-1.531

Figure 3-19. Data from Minideck 8A, Data from Minideck 8B, Data from Minideck 8C

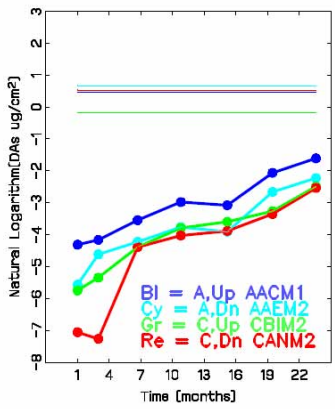


Raw Data (ug/cm^2 DAs):

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	ATM3	A	Up	2.9736	0.0172	0.0188	0.0477	0.0541	0.1266	0.1399	0.2449
Cy	APM3	A	Down	1.4948	0.0350	0.0188	0.0318	0.1081	0.1555	0.1622	0.3498
Gr	CAPM1	C	Up	0.7474	0.0025	0.0030	0.0115	0.0318	0.0455	0.0509	0.1145
Re	CBWM1	C	Down	0.4770	0.0038	0.0076	0.0073	0.0089	0.0278	0.0153	0.0445

Log Transformed Data:

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	ATM3	A	Up	1.090	-4.065	-3.976	-3.043	-2.917	-2.067	-1.967	-1.407
Cy	APM3	A	Down	0.402	-3.353	-3.976	-3.448	-2.224	-1.861	-1.819	-1.050
Gr	CAPM1	C	Up	-0.291	-5.987	-5.823	-4.470	-3.448	-3.090	-2.978	-2.167
Re	CBWM1	C	Down	-0.740	-5.568	-4.876	-4.919	-4.721	-3.583	-4.182	-3.112

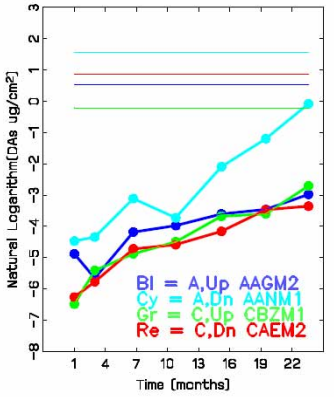


Raw Data (ug/cm^2 DAs):

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AACM1	A	Up	1.5902	0.0134	0.0156	0.0289	0.0509	0.0461	0.1272	0.2004
Cy	AAEM2	A	Down	1.9559	0.0038	0.0099	0.0146	0.0232	0.0201	0.0700	0.1081
Gr	CBIM2	C	Up	0.8269	0.0032	0.0048	0.0124	0.0226	0.0274	0.0382	0.0827
Re	CANM2	C	Down	1.7015	0.0009	0.0007	0.0124	0.0178	0.0206	0.0350	0.0795

Log Transformed Data:

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AACM1	A	Up	0.464	-4.315	-4.162	-3.543	-2.978	-3.077	-2.062	-1.608
Cy	AAEM2	A	Down	0.671	-5.568	-4.619	-4.225	-3.763	-3.907	-2.660	-2.224
Gr	CBIM2	C	Up	-0.190	-5.751	-5.345	-4.390	-3.791	-3.597	-3.266	-2.493
Re	CANM2	C	Down	0.532	-7.059	-7.264	-4.390	-4.028	-3.883	-3.353	-2.532



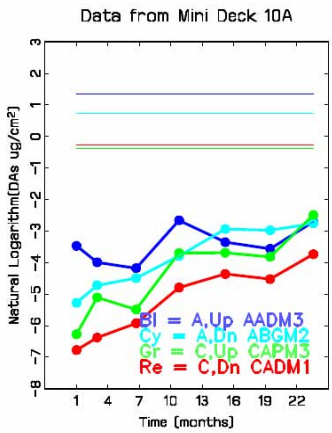
Raw Data (ug/cm^2 DAs):

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AAGM2	A	Up	1.6856	0.0076	0.0035	0.0153	0.0188	0.0273	0.0315	0.0509
Cy	AANM1	A	Down	4.7705	0.0115	0.0130	0.0445	0.0242	0.1234	0.3021	0.9223
Gr	CBZM1	C	Up	0.8110	0.0015	0.0044	0.0076	0.0111	0.0252	0.0273	0.0668
Re	CAEM2	C	Down	2.3853	0.0019	0.0031	0.0089	0.0102	0.0156	0.0312	0.0350

Log Transformed Data:

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AAGM2	A	Up	0.522	-4.876	-5.655	-4.182	-3.976	-3.599	-3.458	-2.978
Cy	AANM1	A	Down	1.562	-4.470	-4.340	-3.112	-3.723	-2.092	-1.197	-0.081
Gr	CBZM1	C	Up	-0.209	-6.482	-5.415	-4.876	-4.498	-3.679	-3.599	-2.706
Re	CAEM2	C	Down	0.869	-6.261	-5.770	-4.721	-4.587	-4.157	-3.468	-3.353

Figure 3-20. Data from Minideck 9A, Data from Minideck 9B, Data from Minideck 9C

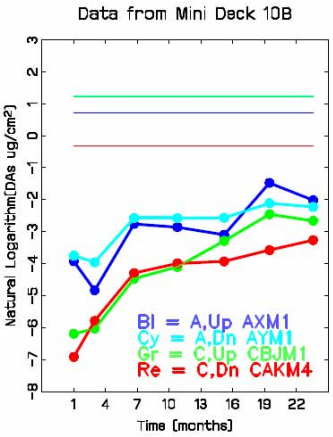


Raw Data (ug/cm^2 DAs):

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AADM3	A	Up	3.8323	0.0312	0.0185	0.0153	0.0700	0.0350	0.0283	0.0668
Cy	ABGM2	A	Down	2.0831	0.0051	0.0089	0.0111	0.0226	0.0531	0.0509	0.0636
Gr	CAPM3	C	Up	0.6838	0.0019	0.0060	0.0041	0.0248	0.0250	0.0219	0.0827
Re	CADM1	C	Down	0.7633	0.0011	0.0017	0.0027	0.0083	0.0127	0.0108	0.0238

Log Transformed Data:

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AADM3	A	Up	1.343	-3.468	-3.993	-4.182	-2.660	-3.353	-3.565	-2.706
Cy	ABGM2	A	Down	0.734	-5.280	-4.721	-4.498	-3.791	-2.935	-2.978	-2.755
Gr	CAPM3	C	Up	-0.380	-6.276	-5.109	-5.489	-3.697	-3.689	-3.819	-2.493
Re	CADM1	C	Down	-0.270	-6.777	-6.383	-5.926	-4.795	-4.365	-4.527	-3.736

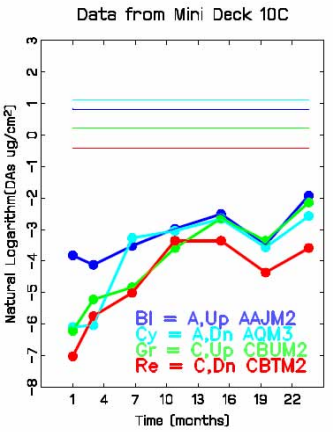


Raw Data (ug/cm^2 DAs):

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AXM1	A	Up	2.0195	0.0197	0.0079	0.0636	0.0572	0.0452	0.2290	0.1336
Cy	AYM1	A	Down	3.4507	0.0235	0.0191	0.0763	0.0763	0.0770	0.1208	0.1081
Gr	CBJM1	C	Up	3.3553	0.0020	0.0024	0.0115	0.0165	0.0372	0.0859	0.0700
Re	CAKM4	C	Down	0.7315	0.0010	0.0031	0.0137	0.0185	0.0196	0.0280	0.0382

Log Transformed Data:

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AXM1	A	Up	0.703	-3.926	-4.835	-2.755	-2.860	-3.098	-1.474	-2.013
Cy	AYM1	A	Down	1.239	-3.749	-3.959	-2.573	-2.573	-2.564	-2.113	-2.224
Gr	CBJM1	C	Up	1.211	-6.195	-6.036	-4.470	-4.102	-3.291	-2.455	-2.660
Re	CAKM4	C	Down	-0.313	-6.918	-5.793	-4.292	-3.993	-3.930	-3.576	-3.266



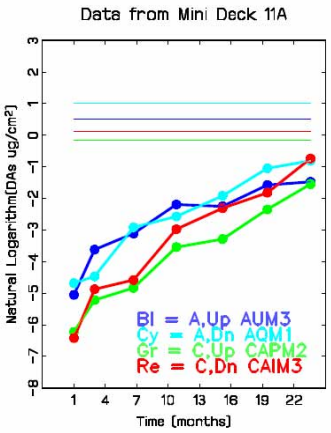
Raw Data (ug/cm^2 DAs):

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AAJM2	A	Up	2.2740	0.0219	0.0162	0.0296	0.0509	0.0817	0.0309	0.1463
Cy	AQM3	A	Down	3.0213	0.0023	0.0024	0.0382	0.0477	0.0700	0.0283	0.0763
Gr	CBUM2	C	Up	1.2403	0.0020	0.0054	0.0079	0.0277	0.0712	0.0350	0.1177
Re	CBTM2	C	Down	0.6520	0.0009	0.0032	0.0067	0.0350	0.0350	0.0127	0.0277

Log Transformed Data:

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AAJM2	A	Up	0.822	-3.819	-4.122	-3.521	-2.978	-2.504	-3.479	-1.922
Cy	AQM3	A	Down	1.106	-6.092	-6.036	-3.266	-3.043	-2.660	-3.565	-2.573
Gr	CBUM2	C	Up	0.215	-6.215	-5.220	-4.835	-3.587	-2.642	-3.353	-2.140
Re	CBTM2	C	Down	-0.428	-7.024	-5.751	-5.009	-3.353	-3.353	-4.365	-3.587

Figure 3-21. Data from Minideck 10A, Data from Minideck 10B, Data from Minideck 10C

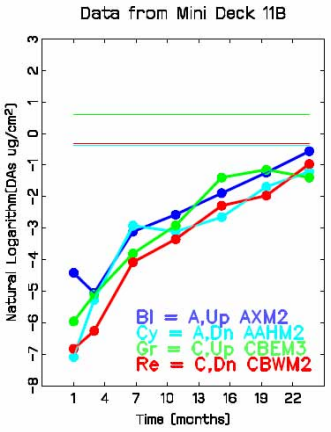


Raw Data (ug/cm^2 DAs):

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AUM3	A	Up	1.6379	0.0064	0.0267	0.0445	0.1113	0.1053	0.2067	0.2290
Cy	AQM1	A	Down	2.7192	0.0092	0.0115	0.0541	0.0763	0.1466	0.3498	0.4452
Gr	CAPM2	C	Up	0.8587	0.0020	0.0054	0.0079	0.0289	0.0372	0.0954	0.2131
Re	CAIM3	C	Down	1.1290	0.0016	0.0076	0.0102	0.0509	0.0992	0.1622	0.4770

Log Transformed Data:

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AUM3	A	Up	0.493	-5.058	-3.622	-3.112	-2.195	-2.251	-1.576	-1.474
Cy	AQM1	A	Down	1.000	-4.686	-4.470	-2.917	-2.573	-1.920	-1.050	-0.809
Gr	CAPM2	C	Up	-0.152	-6.230	-5.220	-4.835	-3.543	-3.291	-2.350	-1.546
Re	CAIM3	C	Down	0.121	-6.425	-4.876	-4.587	-2.978	-2.310	-1.819	-0.740

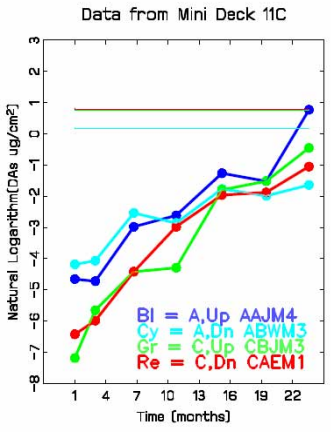


Raw Data (ug/cm^2 DAs):

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AXM2	A	Up	1.8287	0.0121	0.0064	0.0445	0.0763	0.1508	0.2894	0.5725
Cy	AAHM2	A	Down	0.6838	0.0008	0.0051	0.0541	0.0445	0.0703	0.1845	0.2989
Gr	CBEM3	C	Up	1.8128	0.0026	0.0060	0.0223	0.0541	0.2477	0.3180	0.2481
Re	CBWM2	C	Down	0.7315	0.0011	0.0019	0.0169	0.0350	0.1018	0.1399	0.3816

Log Transformed Data:

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AXM2	A	Up	0.604	-4.415	-5.058	-3.112	-2.573	-1.892	-1.240	-0.558
Cy	AAHM2	A	Down	-0.380	-7.094	-5.280	-2.917	-3.112	-2.655	-1.690	-1.207
Gr	CBEM3	C	Up	0.595	-5.960	-5.109	-3.805	-2.917	-1.395	-1.146	-1.394
Re	CBWM2	C	Down	-0.313	-6.831	-6.261	-4.083	-3.353	-2.285	-1.967	-0.963



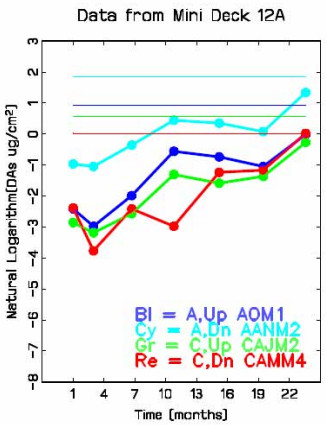
Raw Data (ug/cm^2 DAs):

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AAJM4	A	Up	2.2104	0.0095	0.0089	0.0509	0.0732	0.2821	0.2194	2.1626
Cy	ABWM3	A	Down	1.1926	0.0153	0.0172	0.0795	0.0572	0.1708	0.1368	0.1940
Gr	CBJM3	C	Up	2.1467	0.0008	0.0035	0.0121	0.0137	0.1666	0.2194	0.6361
Re	CAEM1	C	Down	2.1945	0.0016	0.0025	0.0121	0.0509	0.1409	0.1527	0.3498

Log Transformed Data:

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AAJM4	A	Up	0.793	-4.652	-4.721	-2.978	-2.615	-1.265	-1.517	0.771
Cy	ABWM3	A	Down	0.176	-4.182	-4.065	-2.532	-2.860	-1.767	-1.990	-1.640
Gr	CBJM3	C	Up	0.764	-7.182	-5.655	-4.415	-4.292	-1.792	-1.517	-0.452
Re	CAEM1	C	Down	0.786	-6.425	-5.987	-4.415	-2.978	-1.960	-1.880	-1.050

Figure 3-22. Data from Minideck 11A, Data from Minideck 11B, Data from Minideck 11C

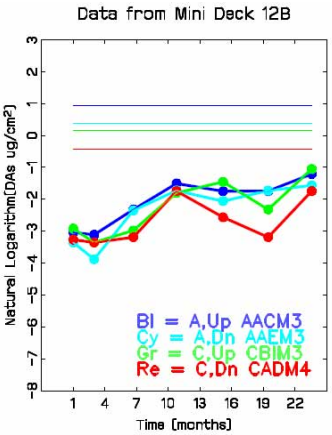


Raw Data (ug/cm^2 DAs):

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AOM1	A	Up	2.5284	0.0891	0.0509	0.1368	0.5725	0.4770	0.3498	0.9859
Cy	AANM2	A	Down	6.3607	0.3816	0.3498	0.6997	1.5584	1.4216	1.0813	3.8164
Gr	CAJM2	C	Up	1.7810	0.0572	0.0413	0.0763	0.2703	0.2048	0.2544	0.7633
Re	CAMM4	C	Down	1.0177	0.0922	0.0231	0.0891	0.0509	0.2900	0.3117	1.0177

Log Transformed Data:

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AOM1	A	Up	0.928	-2.419	-2.978	-1.990	-0.558	-0.740	-1.050	-0.014
Cy	AANM2	A	Down	1.850	-0.963	-1.050	-0.357	0.444	0.352	0.078	1.339
Gr	CAJM2	C	Up	0.577	-2.860	-3.186	-2.573	-1.308	-1.586	-1.369	-0.270
Re	CAMM4	C	Down	0.018	-2.383	-3.770	-2.419	-2.978	-1.238	-1.166	0.018

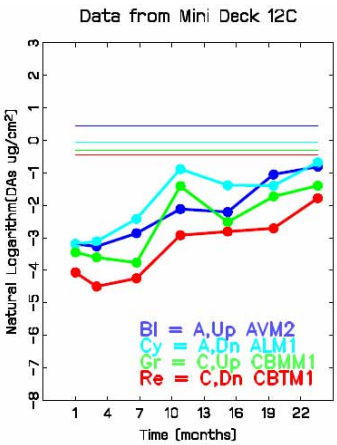


Raw Data (ug/cm^2 DAs):

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AACM3	A	Up	2.5602	0.0477	0.0445	0.0986	0.2226	0.1743	0.1749	0.2989
Cy	AAEM3	A	Down	1.4471	0.0350	0.0207	0.0954	0.1781	0.1279	0.1781	0.2099
Gr	CBIM3	C	Up	1.1608	0.0541	0.0350	0.0509	0.1654	0.2341	0.0986	0.3498
Re	CADM4	C	Down	0.6520	0.0382	0.0350	0.0413	0.1749	0.0773	0.0413	0.1749

Log Transformed Data:

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AACM3	A	Up	0.940	-3.043	-3.112	-2.317	-1.502	-1.747	-1.743	-1.207
Cy	AAEM3	A	Down	0.370	-3.353	-3.879	-2.350	-1.725	-2.057	-1.725	-1.561
Gr	CBIM3	C	Up	0.149	-2.917	-3.353	-2.978	-1.800	-1.452	-2.317	-1.050
Re	CADM4	C	Down	-0.428	-3.266	-3.353	-3.186	-1.743	-2.560	-3.186	-1.743



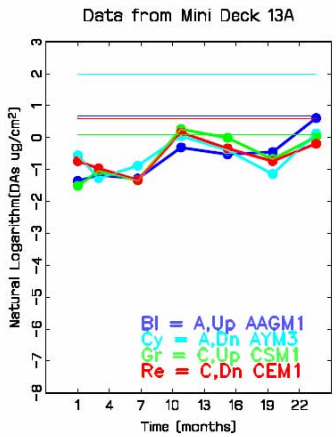
Raw Data (ug/cm^2 DAs):

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AVM2	A	Up	1.5584	0.0413	0.0382	0.0572	0.1208	0.1104	0.3498	0.4452
Cy	ALM1	A	Down	0.9541	0.0413	0.0445	0.0891	0.4134	0.2509	0.2481	0.5089
Gr	CBMM1	C	Up	0.7315	0.0318	0.0273	0.0232	0.2449	0.0811	0.1781	0.2481
Re	CBTM1	C	Down	0.6361	0.0172	0.0111	0.0143	0.0541	0.0604	0.0668	0.1686

Log Transformed Data:

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AVM2	A	Up	0.444	-3.186	-3.266	-2.860	-2.113	-2.204	-1.050	-0.809
Cy	ALM1	A	Down	-0.047	-3.186	-3.112	-2.419	-0.883	-1.383	-1.394	-0.676
Gr	CBMM1	C	Up	-0.313	-3.448	-3.599	-3.763	-1.407	-2.512	-1.725	-1.394
Re	CBTM1	C	Down	-0.452	-4.065	-4.498	-4.247	-2.917	-2.806	-2.706	-1.780

Figure 3-23. Data from Minideck 12A, Data from Minideck 12B, Data from Minideck 12C

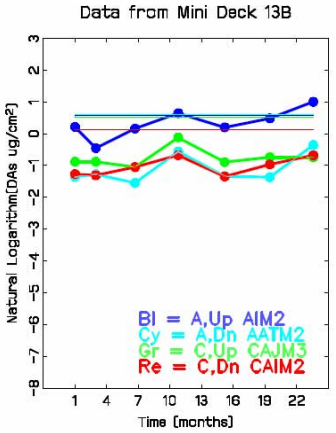


Raw Data (ug/cm^2 DAs):

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AAGM1	A	Up	1.9877	0.2576	0.3085	0.2767	0.7315	0.5916	0.6361	1.8446
Cy	AYM3	A	Down	7.3148	0.5725	0.2799	0.4134	1.0495	0.6742	0.3180	1.1449
Gr	CSM1	C	Up	1.0972	0.2194	0.3498	0.2608	1.3039	0.9923	0.5089	1.0177
Re	CEM1	C	Down	1.8287	0.4770	0.3816	0.2640	1.1767	0.7124	0.4770	0.8269

Log Transformed Data:

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AAGM1	A	Up	0.687	-1.356	-1.176	-1.285	-0.313	-0.525	-0.452	0.612
Cy	AYM3	A	Down	1.990	-0.558	-1.273	-0.883	0.048	-0.394	-1.146	0.135
Gr	CSM1	C	Up	0.093	-1.517	-1.050	-1.344	0.265	-0.008	-0.676	0.018
Re	CEM1	C	Down	0.604	-0.740	-0.963	-1.332	0.163	-0.339	-0.740	-0.190

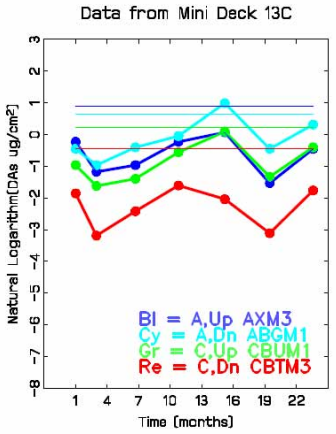


Raw Data (ug/cm^2 DAs):

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AIM2	A	Up	1.7969	1.2403	0.6361	1.1767	1.9082	1.2244	1.6220	2.7351
Cy	AATM2	A	Down	1.8128	0.2576	0.2799	0.2131	0.5725	0.2633	0.2544	0.6997
Gr	CAJM3	C	Up	1.7015	0.4134	0.4134	0.3498	0.8905	0.4103	0.4770	0.4770
Re	CAIM2	C	Down	1.1290	0.2799	0.2703	0.3498	0.5089	0.2608	0.3816	0.5089

Log Transformed Data:

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AIM2	A	Up	0.586	0.215	-0.452	0.163	0.646	0.202	0.484	1.006
Cy	AATM2	A	Down	0.595	-1.356	-1.273	-1.546	-0.558	-1.334	-1.369	-0.357
Gr	CAJM3	C	Up	0.532	-0.883	-0.883	-1.050	-0.116	-0.891	-0.740	-0.740
Re	CAIM2	C	Down	0.121	-1.273	-1.308	-1.050	-0.676	-1.344	-0.963	-0.676



Raw Data (ug/cm^2 DAs):

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AXM3	A	Up	2.4330	0.7951	0.3085	0.3816	0.7951	1.0750	0.2163	0.6361
Cy	ABGM1	A	Down	1.8923	0.6361	0.3816	0.6679	0.9541	2.6938	0.6361	1.3676
Gr	CBUM1	C	Up	1.2403	0.3816	0.1972	0.2481	0.5725	1.1004	0.2640	0.6679
Re	CBTM3	C	Down	0.6361	0.1558	0.0413	0.0891	0.2004	0.1301	0.0445	0.1717

Log Transformed Data:

Col	Brd	Src	Gra	PRE	Months 1	3	7	11	15	20	24
Bl	AXM3	A	Up	0.889	-0.229	-1.176	-0.963	-0.229	0.072	-1.531	-0.452
Cy	ABGM1	A	Down	0.638	-0.452	-0.963	-0.404	-0.047	0.991	-0.452	0.313
Gr	CBUM1	C	Up	0.215	-0.963	-1.624	-1.394	-0.558	0.096	-1.332	-0.404
Re	CBTM3	C	Down	-0.452	-1.859	-3.186	-2.419	-1.608	-2.040	-3.112	-1.762

Figure 3-24. Data from Minideck 13A, Data from Minideck 13B, Data from Minideck 13C (all uncoated)

There is one minor difference between the minideck plots in Figure 3-25 and the plot depicted in Figure 3-11 for Minideck 9-A,. In Figure 3-11, the baseline values were plotted as straight horizontal lines. With the decreased resolution inherent in Figure 3-25, many of the straight horizontal baseline lines would overlay and obscure one another. So in the plots in Figure 3-25, the baseline measurements horizontal lines have been replaced by lines that have been intentionally “wiggled” or “jittered” to avoid complete over plotting. This is an established graphical technique for increasing the resolution of crowded graphs.

Each separate minideck plot can be examined for the effects of source deck, grain orientation and time as was done for Minideck 9-A. However, this is not the intended purpose of the composite plot (rather, the larger data plots in Figures 3-12 through 3-24 should be used to examine the data for specific minidecks). Here the primary interest is in comparing patterns in DAs measurements among the thirteen coatings, and, secondarily, in visually assessing repeatability of the experimental method by easily comparing results among the three replicate minidecks treated with the same coating.

Repeatability is indicated by the similarity in patterns and trends within coatings. For example, it is evident that Coating 13 (uncoated) exhibited the least trend with time (although Coating 5 is a close second), and that this relative lesser trend is manifested in all three minidecks. This is even more noticeable upon consideration of other coatings that exhibit more pronounced trends with time; for example, Coatings 9, 10, and 11 and to a lesser extent, Coatings 3, 8, and 12. It is evident that certain coatings yielded time-series DAs measurements with different patterns than did Coating 13 (the uncoated control), and furthermore that these patterns were generally consistent among minidecks treated with the same coating.

As stated earlier, the DCCA observed at any point in time is a function of the time elapsed since the previous wipe event and weathering, among other potential factors. The two paints (products 9 and 10) and the vinyl elastic product (product 11) had the lowest initial postcoat (1 month) values and, generally, DCCA showed a continuously increasing trend with time for these products. Most of the other plots in Figure 3-27 exhibit an upward slanting down/up/down/up pattern, suggesting that, for some periods between samples, other factors which lower the DCCA measurement had a greater effect than the time/weathering effect on DCCA, which is assumed to always yield an upward trend, or greater DCCA over time. These other factors may include a surface cleaning effect caused by the wipe sampling. Additionally, it is possible that climatic conditions, surface moisture, or other variables which vary more inconsistently over time may affect sampling and DCCA measurements.

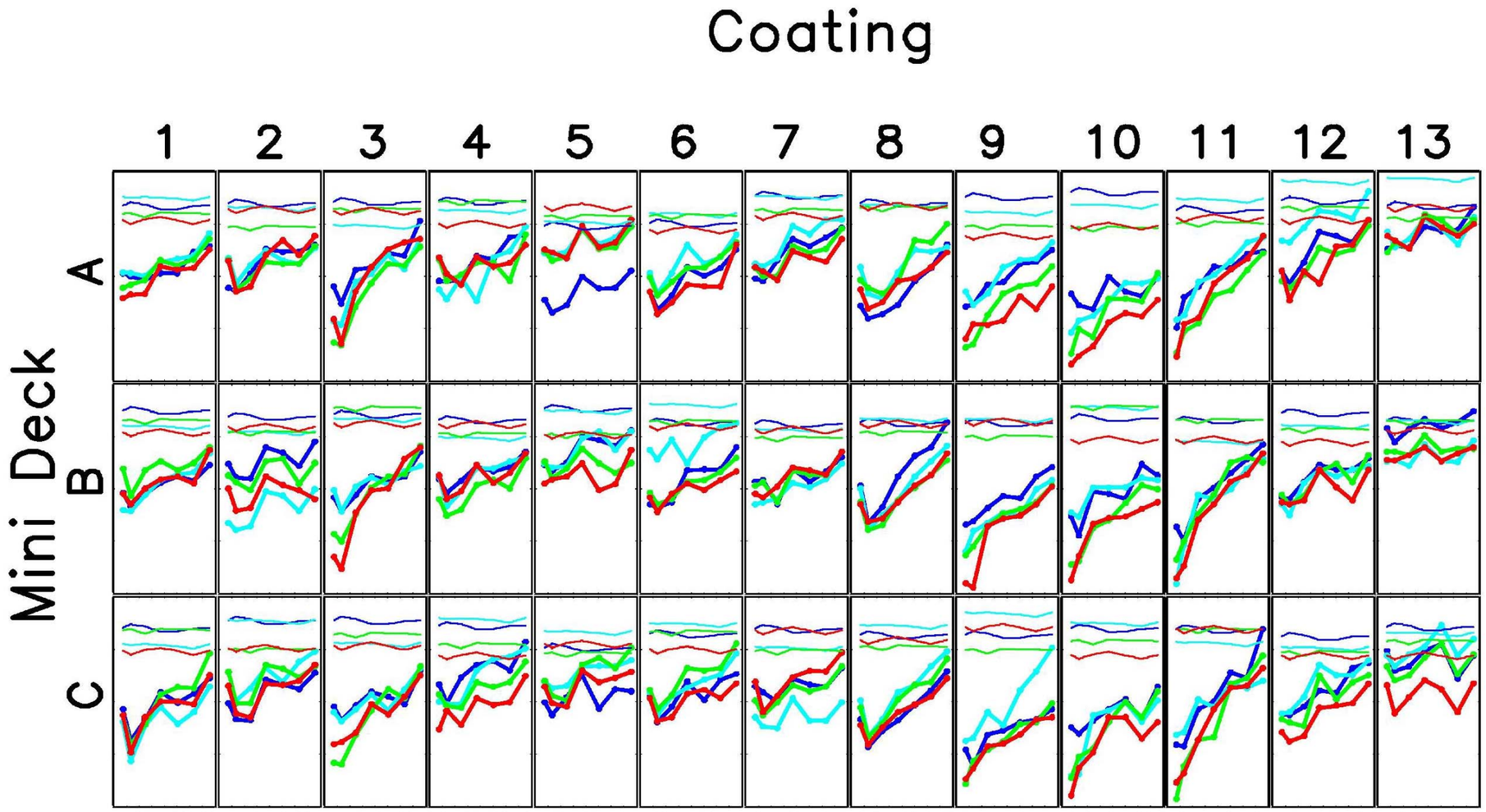


Figure 3-25. Composite Data Plot of All 39 Minidecks (note that scale and axis labels are the same as for Figure 3-11)

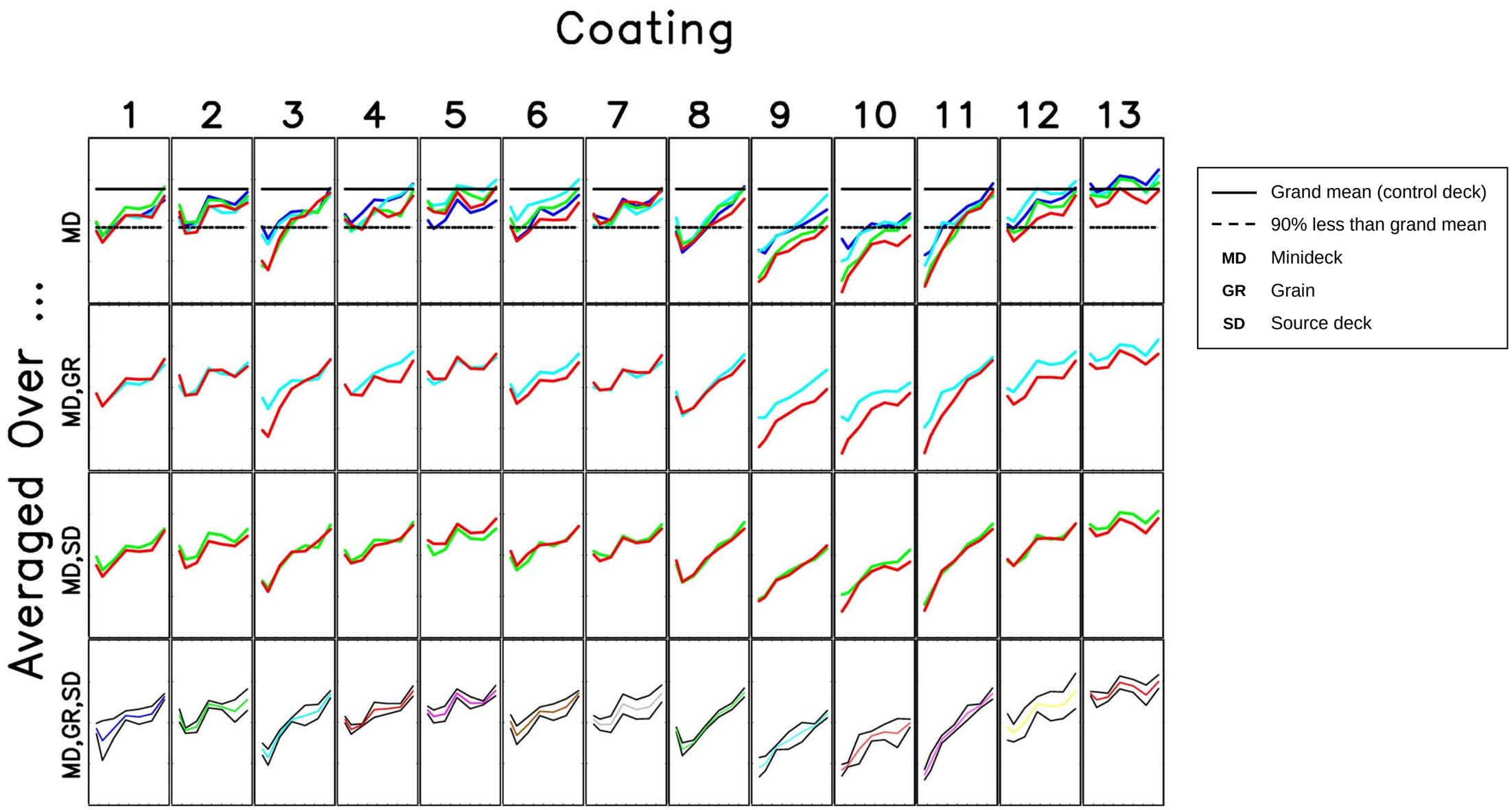


Figure 3-26. Averages from All Thirty-nine Minidecks (See Section 3.2.2.4 for further explanation)

Before proceeding to the next graphical display, one more observation should be made that bears on the validity of the experimental method, and the role and utility of the baseline measurements in particular. A critical scan of all thirty-nine minideck plots reveals two minidecks where the DAs measurements from a single board are noticeably lower, for all time periods, than the DAs measurements from the other boards on the same minideck: minidecks 5-A and 13-C (uncoated). For minideck 5-A, the board with noticeably low post baseline DAs values also had the lowest baseline DAs measurement of all boards, even though it was from Source Deck A, which generally yielded higher-than-average DAs measurements. In other words, this is a board for which the baseline measurement was noticeably low and also resulted in noticeably-low post baseline values. For Minideck 13-C (uncoated), the board with noticeably-low DAs measurements came from Source Deck C and had the lowest baseline DAs measurements of all boards on that minideck.

3.2.2.4 Averages from All Thirty-nine Minidecks

Figure 3-26 displays a series of plots of average DAs, which are constructed to isolate and illustrate the effect of different factors in the experiment. The variables of interest are: source deck, grain orientation and time. In order to reveal the effects of these factors, Figure 3-26 presents a series of averages over coating or minideck (MD), source deck (SD), grain orientation (GR), and combinations thereof.

3.2.2.4.1 Averages over Minidecks

The first row of plots in Figure 3-26 displays coating-specific averages over the three replicate minidecks. The color coding is the same as the plots of the data in the previous data displays, as indicated in Table 3-3. Statistically, these plots are the least variable manifestations of the patterns and trends in DAs measurements as they relate to source deck, grain orientation and time period (least variable because they are averaged over all replicate minidecks).

In this first row of plots, two horizontal lines have been added to facilitate comparison with Coating 13, the uncoated control. The upper, solid black line is plotted at the grand mean of all post baseline Coating 13 (uncoated) DAs measurements. Recall that Coating 13 (uncoated) exhibited little trend over time and thus the grand mean is an appropriate indicator of overall average Coating 13 (uncoated) DAs value. The upper, black line makes it easy to see how much less the other coating measurements are than the Coating 13 (uncoated) grand mean, although keep in mind that these differences are on a logarithmic scale. The lower, dashed black line is plotted at a value equal to ln(10) less than the upper black line. In order to understand its relevance, let DAs_{13} denote the Coating 13 (uncoated) grand mean. Then, $DAs_{13}/10$ is the value equal to 90 percent less than the Coating 13 (uncoated) grand mean, and on the log scale this is

$\ln(DAs_{13}/10) = \ln(DAs_{13}) - \ln(10)$.

Thus the lower black line appears at a level corresponding to a 90 percent reduction from the Coating 13 (uncoated) grand mean.

3.2.2.4.2 Averages over Minidecks and Grain

The second row of plots in Figure 3-26 displays coating-specific DAs values averaged over minideck (MD) and grain orientation (GR). The purpose is to illustrate more clearly the effects of source deck. The color coding for this row of plots necessarily differs from the previous plots. In this case, cyan (Cy) denotes averages from Source Deck A, and red (Re) denotes averages from Source Deck C. In effect, the cyan curves are the averages of the cyan and dark blue curves from the plots in row one; and the red curves are the averages of the red and green curves from the plots in row one. The feature to note is that when the averages differ noticeably, it is generally the case that the red curve lies below the cyan curve, indicating that DAs measurements from Source Deck A boards were generally greater than those from Source Deck C boards.

3.2.2.4.3 Averages over Minidecks and Source Deck

The third row of plots in Figure 3-26 displays coating-specific DAs values averaged over minideck (MD) and source deck (SD). Its purpose is to illustrate more clearly the effects of grain orientation. The color code for this is row of plots necessarily differs from the previous plots. In this case green (Gr) denotes averages for Grain Up boards, whereas red (Re) denotes averages from Grain Down boards. In effect, the green curves are the averages of the Green and Dark Blue curves from the plots in row one; and the red curves are the averages of the Red and Cyan curves from the plots in row one. The primary feature to note is that the separation between the red and green curves in the third row is generally less than that between the different colored curves in the second row, meaning that the observed effects of grain orientation on measured DAs is noticeably less than that of source deck.

3.2.2.4.4 Averages over Minidecks, Grain, and Source Deck

The fourth and bottom row of Figure 3-26 displays averages of measured DAs averaged over minideck (MD), grain orientation (GR) and source deck (SD). The purpose is to illustrate the effect of time for the thirteen different coatings *averaged over the other factors*. Each coating is now plotted with its own unique color. The black lines surrounding the time plots are pointwise error bands and are included to give a visual assessment of the variability in the averages. Each colored curve is the average of the four curves in the top row of Figure 3-26. At each time point, the error-bands were calculated as twice the standard error of the average of the three numbers

obtained by first averaging ln DAs values over the four boards on each of the three replicate minidecks.

3.2.2.5 The Comprehensive Plot

Figure 3-27, is a composite of all the previous plots presented in Figures 3-25 and 3-26. Its primary advantage is that all of the graphical information presented thus far is compactly displayed on a single page. This necessarily entails some loss of resolution, but has the advantage that the larger, and thus practically more significant, relevant patterns and trends are still apparent, and can be seen entirely in one graphic. The subplots are displayed in a seven-by-thirteen display with columns corresponding to coatings. The first three rows are the same as in Figure 3-25; and the bottom four rows are the same as in Figure 3-26.

3.2.3 Analysis of Variance of Coatings by Time

The top row of plots in Figure 3-28 is similar to the seventh row in Figure 3-27, but there are important differences. As in the former figure, average ln(DAs) values (averaged over minidecks and board types) are plotted versus time. However, in these new plots the thickness of the plotted line corresponds approximately to estimation variability. The widths of the lines are approximately two standard errors of the difference between two means. The standard error used to determine line thickness was determined from the analysis of variance modeling. It is approximate because the analysis of variance standard errors differ from one mean to the next due to imbalance (two missing values) and the covariate adjustment. However, the approximation is sufficient for visual comparisons.

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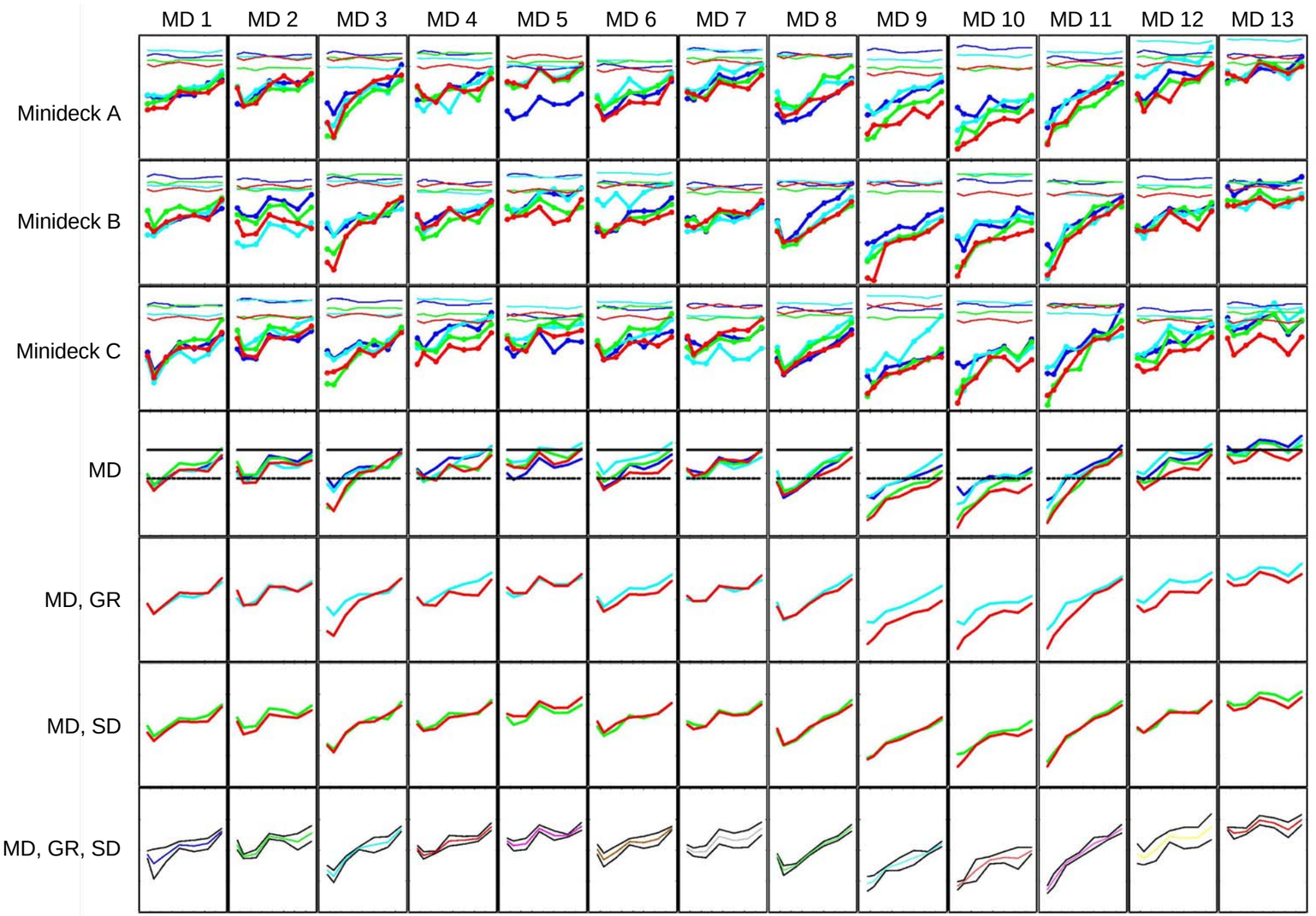

Figure 3-27. Comprehensive Data Plot (note that scale and axis labels are the same as for Figure 3-11)

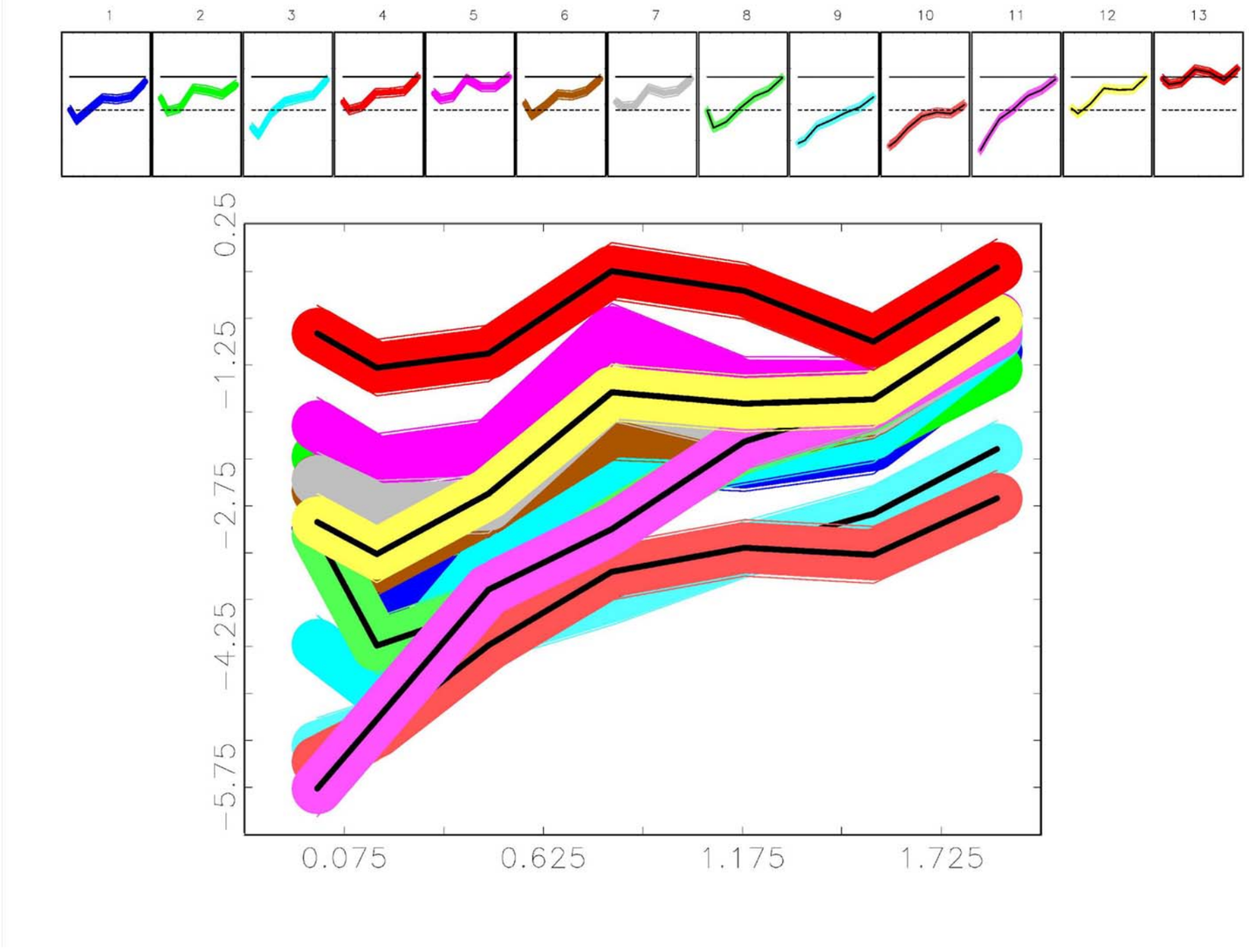

Figure 3-28. Analysis of Variance Plot of Coatings by Time [each subplot has ln(DAs) as its y-axis and time, in years, as its x-axis]

The widths of the lines plotted in Figure 3-28 were determined to provide a rough visual assessment of statistical significance. The widths are approximately equal to twice the standard error of the difference between two means. It follows that when two of these curves are overlaid, points where the lines touch are not significantly different; whereas points where they do not touch are significantly different (at the 0.05 level of significance with no adjustment for multiple tests).

The black horizontal lines are the same as those in the fourth row of plots in Figure 3-27. The top row of plots serves as a legend for the large graph displaying the overlaid coatings-by-time plots. Except for the overplotting, the larger plot makes it is easy to compare means at various time points and to get a rough assessment whether they are significantly different (not touching) or not (touching). In light of the approximations involved and the lack of adjustment for multiple tests we caution against over interpretation when inspecting this figure.

3.2.4 Analysis of Variance of Coating Pair Comparisons by Time

Figure 3-29 overcomes the overplotting deficiencies of the large plot in Figure 3-28 by plotting all possible pairs of coating-by-time plots. There are 13 coatings and thus there are "13 choose 2" or 78 possible pairwise comparisons among them. Figure 3-29 displays all 78 possible comparisons of the coatings-by-time plots. Running down the diagonal (top left to bottom right plot) are the 13 individual time plots (1 to 13, in order). In row j, the time plot of coating j is overlaid with the time plot of coating k (for k = j+1,...,13). Color coding is established by the diagonal plots and is maintained in the off-diagonal plots. Figure 3-29 makes visual comparisons easy and relevant.

The results presented above pertain only to DAs on the true time scale measured in years from start date.

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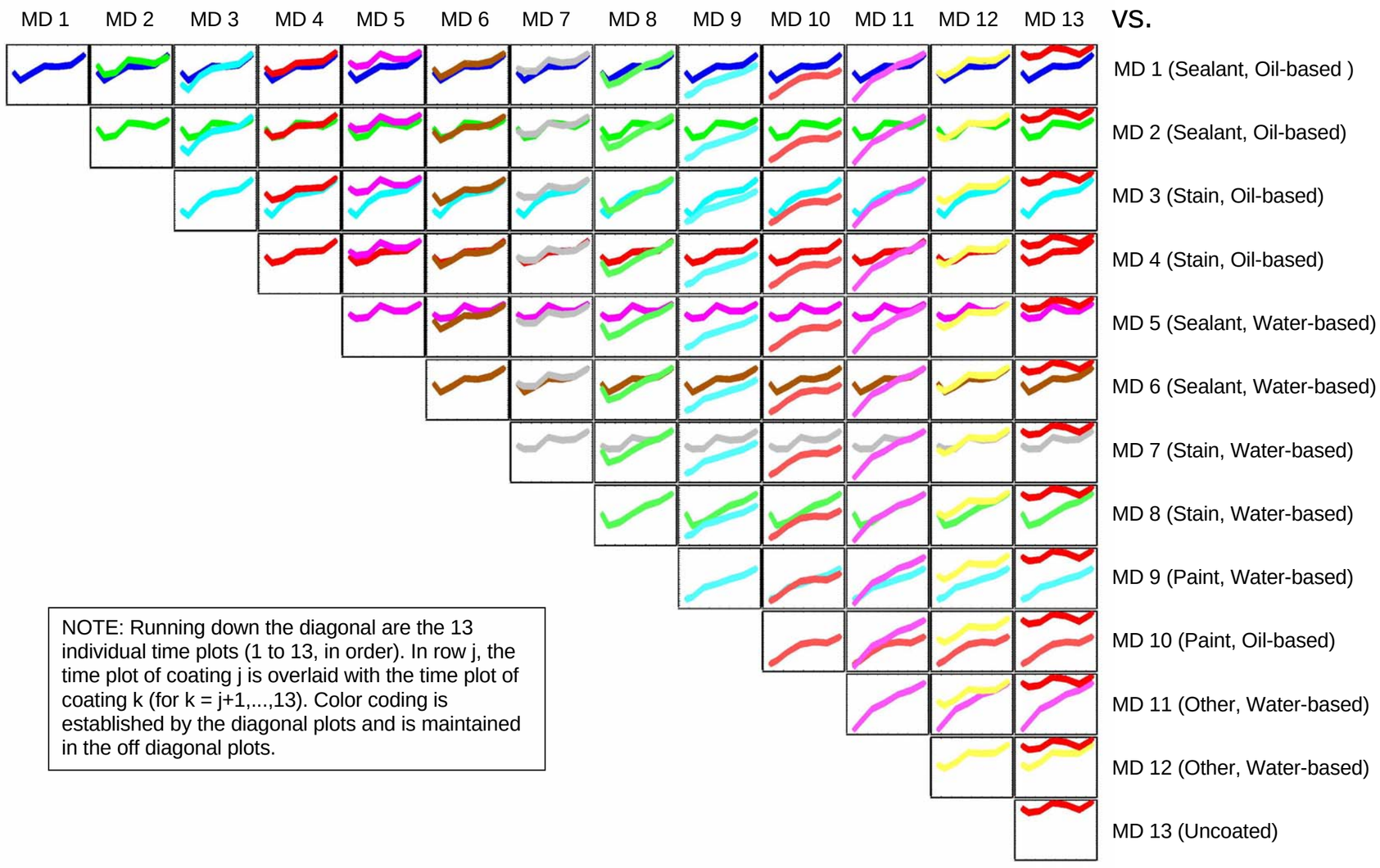

Figure 3-29. Analysis of Variance Plot of Coating Pair Comparisons by Time [each subplot has ln(DAs) as its y-axis and time, in years, as its x-axis]

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3.2.5 Analysis of Variance Modeling Results

We now present results from statistical analyses designed to investigate the ability of study coatings to attenuate dislodgeable arsenic residues on the surfaces of CCA treated wood compared to washing alone. The statistical models used to analyze the data were chosen because of their simplicity and ability to complement the graphical analyses in Figures 3-25 through 3-29, establish the robustness (lack of sensitivity) of major conclusions to statistical modeling choices, and guide future experimentation by identifying the major sources of variation and dependencies in the data.

The salient feature of Figures 3-25, 3-26, and 3-27 is the increasing time trend in DA for several of the coatings. Given that the statistical significance of the effect of time is not in doubt, we focus on separate analyses of DAs at each time period. These time period-specific analyses avoid modeling and inference issues related to changes in the magnitude of measured DAs over time and temporal dependence among repeated measurements.

The analysis variable (dependent variable) in the time period-specific analyses is the natural logarithm of DAs adjusted by the corresponding baseline measurement:

$$Y = \ln(DAs/baseline)$$

$$= \ln(DAs) - \ln(baseline).$$

An alternative to direct adjustment of the DAs measurements by baseline values is to use the baseline values as covariates in the statistical models. In Section 3.2.5.5 we show that the latter approach to baseline adjustment results in nearly identical conclusions about coating performance.

3.2.5.1 Time Period Specific Modeling

For a given time period the design of the experiment is a that of a standard split-plot and the basic analysis is a split-plot analysis with Coating as the whole plot treatment and Source Deck and Board Bark Face as split plot factors. Table 3-5 summarizes select results from time-period specific analyses using split-plot models with homoscedastic error structures. Main table entries are p-values for the whole-plot factor Coating (coat1) and split-plot factors Board Bark Face (bbf), Source Deck (sdeck), and the their interactions. Note that p-values in Table 3-5 have not been adjusted for multiple testing across time periods. Below the main table entries are the whole-plot variance (mdeck(coat1)) and the residual error variance (residual) estimates (with 95 percent lower and upper confidence limits). Column DF in Table 3-5 displays the degrees of freedom for each effect tested.

Table 3-5. P-Values for Split-Plot Models with Homoscedastic Error Structures

		Time (months after coating)						
Effect	**DF**	**1**	**3**	**7**	**11**	**15**	**20**	**24**
coat1	12	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Bbf	1	0.5169	0.6251	0.1571	0.5836	0.5452	0.8661	0.4392
coat1*bbf	12	0.5881	0.6121	0.1223	0.3363	0.3802	0.1000	0.4684
sdeck	1	0.5354	0.5653	0.1548	0.0853	0.0132	0.4518	0.0228
coat1*sdeck	12	<.0001	0.0008	<.0001	0.1579	0.2557	0.2203	0.3149
Bbf*sdeck	1	0.5930	0.1757	0.0528	0.3496	0.0033	0.0215	0.0655
coat1*bbf*sdeck	12	0.2818	0.6278	0.5397	0.2241	0.4108	0.7013	0.5332
mdeck(coat1)		0	0.04947	0.03824	0.01411	0.05267	0.05371	0
residual		0.4144	0.4284	0.2512	0.3226	0.3189	0.3046	0.3635
lower		0.3214	0.3199	0.1875	0.2412	0.2384	0.2278	0.2819
upper		0.5549	0.6034	0.3540	0.4537	0.4484	0.4283	0.4868

3.2.5.2 Fixed Effects

The most noteworthy feature of the ANOVA summaries in Table 3-5 is the persistently strong statistical significance of Coating (coat1) across time periods, thus confirming the visual assessment of differences among coatings in Figure 3-25. With regard to the other factors, Board Bark Face (bbf) and its two- and three-way interactions are, with the exception of its interaction with Source Deck (sdeck) in samples taken at 15, 20 and 24 months after coating, not statistically significant; whereas the statistical evidence for Source Deck and its interactions is stronger.

The pattern of statistical significance suggests that much of the variability in DAs is explained by coat1 and sdeck; that is, bbf contributes least to the fit of the models. Likelihood ratio tests comparing the full models in Tables 3-5 to corresponding models without any bbf terms have p-values, 0.0399, 0.0673, 0.0779, 0.0544, 0.0223, 0.0381, and 0.0619, for samples taken at 1, 3, 7, 11, 15, 20, and 24 months, respectively. Thus, the statistical evidence for bbf is marginal (all p-values are close to the 0.05 level of significance). Examination of Akaike Information Criteria (AIC) for the two sets of models reveals that for every time period, the model without bbf terms has the lower AIC value. In other words, model selection based on AIC identifies the models without bbf terms. However, these conclusions are based on the separate analyses and thus do not account for the accumulation of evidence across time periods. A complementary assessment of models with and without sdeck terms in them (but keeping bbf terms in the model) was also conducted. In this case, the p-values for testing reduced models (no sdeck terms) versus full models, are <0.0001, <0.0001, 0.0001, 0.0133, 0.0035,

0.0717and 0.0130. Thus the statistical significance of sdeck is more firmly established than for bbf, especially in the early time periods. The AIC values for these models are smaller for the full models for the 1-, 3- and 7-month data, and smaller for the reduced model in the subsequent four time periods.

3.2.5.3 Random Effects

Table 3-5 also displays variance components for each of the time period-specific models. In all time periods, the whole-plot error variance (between-deck variance) is small relative to the residual variance (within-deck variance). Although boards on the same minideck are neighboring and thus might be expected to vary in unison in response to shared external effects, the scale of the experiment is such that boards were exposed to essentially identical environmental influences whether they were on the same minideck or not. In this experiment, all boards on a minideck were prepared and coated more or less simultaneously, and thus whole plot variation is likely largely due to variation in the preparation and coating processes. That the whole plot error variance is small suggests that the protocol for building, preparing, and coating decks is well-replicated.

Finally, we note that the residual variance estimates in Table 3-5 do not differ in magnitude over time, nor do their standard errors which range from 0.04 to 0.07 (not reported in Table 3-5).

3.2.5.4 Coating Comparisons

Our primary interest lies in comparing the performances of Coatings 1-12 to that of the control Coating 13 (washing only). For each of the time-period specific analysis of variance models, we calculated statistical tests comparing the main effects of Coatings 1-12 to Coating 13.

Table 3-6 summarizes the coating performance rankings and p-values of the tests, adjusted using Dunnett's multiple comparison procedure within each time period. No adjustments to p-values were made for the multiple time periods. In Table 3-6, for each time period, the left hand column lists the coatings in order of performance relative to the control coating, and the p-value associated with the test. For example, after 1 month: Coating 11 performed best followed by Coatings 10, 9, 3, etc.; also, with the exception of Coating 5, all coatings performed significantly better than Coating 13 at the 0.05 level of significance.

Table 3-6. Coating Performance Rankings and P-Values of Tests Adjusted using Dunnett's Multiple Comparison Procedure

1 month		3 months		7 months		11 months		15 months		20 months		24 months	
11	<0.0001	10	<0.0001	10	<0.0001	9	<0.0001	10	<0.0001	10	<0.0001	10	<0.0001
10	<0.0001	9	<0.0001	9	<0.0001	10	<0.0001	9	<0.0001	9	0.0001	9	<0.0001
9	<0.0001	11	<0.0001	8	<0.0001	8	<0.0001	3	<0.0001	1	0.0165	2	0.0024
3	<0.0001	3	<0.0001	11	<0.0001	11	<0.0001	1	<0.0001	3	0.0200	1	0.0133
8	<0.0001	8	<0.0001	3	<0.0001	3	<0.0001	8	<0.0001	2	0.0785	3	0.0273
1	<0.0001	1	<0.0001	1	<0.0001	1	<0.0001	11	0.0005	8	0.2435	8	0.1203
12	<0.0001	6	<0.0001	2	<0.0001	6	<0.0001	6	0.0006	6	0.3396	7	0.1830
6	<0.0001	12	0.0002	6	<0.0001	4	<0.0001	7	0.0024	7	0.3678	6	0.2001
7	<0.0001	2	0.0002	7	<0.0001	2	0.0010	4	0.0036	4	0.3707	11	0.2005
4	<0.0001	4	0.0003	4	0.0002	7	0.0011	2	0.0089	11	0.5729	4	0.5434
2	0.0002	7	0.0027	12	0.0004	12	0.0019	12	0.0213	12	0.7404	12	0.7101
5	0.0885	5	0.2471	5	0.0973	5	0.7416	5	0.1746	5	0.9994	5	0.9635

The preponderance of highly significant p-values (< .0001) in Table 3-6 indicates that several coatings attenuate dislodgeable arsenic residues compared to washing alone for various lengths of time after application. With the exception of Coating 5, the effects of the coatings (relative to initial washing only) remain statistically significant through 15 months and, for some coatings, throughout the length of the study.

A number of patterns in Table 3-6, suggest possible hypotheses for testing in future studies. Coatings 9 and 10 exhibited the most consistently good relative performance, ranking 1, 2 or 3 in all time periods and clearly outperforming washing alone throughout the duration of the experiment. The relative performance of Coating 2 was low initially, but improved in the last two time periods, whereas the relative performances of Coatings 1, 3, 4, 6, 7, and 8 were relatively stable over time. Finally, the relative performances of Coatings 11 and 12 deteriorated with time, although they were significantly better than washing through 15 months.

In summary there is strong evidence that coatings (with the exception of Coating 5) have detectable positive effects relative to washing alone through 15 months after coating, but the ability to detect differences after 15 months is much diminished, due primarily to diminished performance (higher DAs) and not increased variation (in light of the nearly constant experimental error variance estimates in Table 3-5). This does not mean that positive effects of coatings were absent in the later time periods, but rather that the effect magnitudes were not statistically significant.

3.2.5.5 Statistical Model Sensitivity Analysis

We now present comparisons like those in Table 3-6 obtained from select alternative statistical models fit to the data. Our intent is to establish the lack of sensitivity of our primary conclusions to variations in the statistical models used to analyze the data. We consider only comparisons at 24 months after coating, because variations in the coatings comparisons due to the choice of statistical model will be most evident in the later time periods where the power to detect differences is smallest (alternatively, the effects of coatings in the earlier time periods are so large that almost any analysis will reveal them).

The alternative models (AM) we chose to investigate are:

AM1 – The basic split-plot model used for the results in Table 3-6 is augmented with a random effect for “parent board.” The specimens used to construct the minidecks were cut from larger “parent’’ boards. Thus it would not be unexpected for minideck specimens from the same parent board to respond to treatment similarly.

AM2 – The model in AM1 with ln(baseline) as a linear covariate. This shows that the method of adjusting for baseline values is not critical.

AM3 – The model in AM2 with residual variances depending on bbf and sdeck. This model is explained in more detail in Section 3.2.5.6.

AM4 – The model in AM3 with board dominant wood type (heartwood/sapwood) as a fixed factor. Minideck boards were classified into three categories: predominatly sapwood; predominantly heartwood; and nearly equally mixture of heartwood and sapwood.

The first two columns of Table 3-7 are identical to the last two columns of Table 3-6. The columns labeled AM1-AM4 are p-values for the comparison of the coating identified in column 1 to the control coating for the four alternative models. Thus p-values in the same row are comparable in the sense thay are testing the same comparison. The differences among the p-values are due to the fact they are derived from different statistical models fit to the data. That these differences in p-values are small, and do not result in any substantial qualitatively different conclusions about coating performance relative to the control coating, indicate the robustness of our primary conclusions to choice of statistical model. In other words, accounting for parent board effect, using baseline values for covariate adjustment (as opposed to direct adjustment), allowing for non-constant error variation, and adjusting for board dominant wood type, do not substantially alter the primary coatings comparisons results reported in Table 3-6.

Table 3-7. Sensitivity Analysis of 24-month Coatings Comparisons p-values

From Table 3-6		AM1	AM2	AM3	AM4
10	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
9	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
2	0.0024	0.0036	0.0085	0.0079	0.0175
1	0.0133	0.0156	0.0282	0.0254	0.0318
3	0.0273	0.0578	0.0956	0.0962	0.2458
8	0.1203	0.1274	0.1551	0.1470	0.1733
7	0.1830	0.1677	0.1540	0.1561	0.2903
6	0.2001	0.2030	0.1723	0.1607	0.1343
11	.2005	0.3444	0.3102	0.2802	0.4607
4	0.5434	0.5847	0.5137	0.5801	0.6835
12	0.7101	0.8110	0.6713	0.7331	0.8325
5	0.9635	0.9952	0.9333	0.9091	0.9249

3.2.5.6 Checking for Heteroscedasticity

In the previous section, we used a model allowing variances to depend on bbf and sdeck to demonstrate the robustness of our main conclusions. We now consider a similar model to shed light on the performance of the wipe sampling method.

The lower portion of Table 3-5 shows that the error variances do not change much over time, but does not shed light on possible residual error variance dependence on the experimental factors. We fit several heteroscedastic variance models for the twin purposes of exploratory analysis and to check the robustness of the conclusions based on the homoscedastic error models used in Table 3-5. Variance model assessment via the Bayesian Information Criteria (BIC) indicated that homoscedastic variance models were best for three of the seven time periods and, in the other four time periods, variance models depending on source deck or bark face were marginally preferable to homoscedastic error models. Thus, the case for using models with heteroscedastic error variances is not strong.

However, as both sdeck and bbf relate to the physical characteristics of the board, and the sampling equipment depends critically on board-to-sampling wipe contact, there is reason to conjecture that residual error variation might be dependent on the factors bbf and sdeck. Thus we present one final set of time period specific analyses derived from

fitting statistical models that allow the residual error variance to differ for different levels of the factors bbf and sdeck. A summary of the analysis of variance results appears in Table 3-8.

Table 3-8. Heteroscedastic Analysis of Variance Models

Effect	DF	1 mo.	3 mos.	7 mos.	11 mos.	15 mos.	20 mos.	24 mos.
coat1	12	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
bbf	1	0.5171	0.6198	0.1576	0.5839	0.5487	0.8641	0.4393
coat1*bbf	12	0.5884	0.6004	0.1235	0.3386	0.3961	0.0896	0.4689
sdeck	1	0.5356	0.5652	0.1553	0.0858	0.0141	0.4451	0.0229
coat1*sdeck	12	<.0001	0.0007	<.0001	0.1606	0.2705	0.2017	0.3158
bbf*sdeck	1	0.5932	0.1715	0.0533	0.3500	0.0037	0.0199	0.0657
coat1*bbf*sdeck	12	0.2843	0.6116	0.5401	0.2267	0.4268	0.6782	0.5334
Mdeck (coat1)		0	0.06786	0.04111	0.01366	0.04519	0.06841	0
Residual Down A		0.6792	0.5206	0.3588	0.5188	0.4781	0.4117	0.3659
Residual Down C		0.4043	0.6244	0.1760	0.1935	0.2460	0.1503	0.3781
Residual Up A		0.3260	0.2723	0.3308	0.2760	0.3317	0.4727	0.4796
Residual Up C		0.2482	0.2633	0.1372	0.3032	0.2412	0.1470	0.2307

A comparison of the analysis of variance portions of Tables 3-5 and 3-8 shows very little difference between corresponding p-values, suggesting the robustness of the former to possible violations of the assumption of homoscedastic error variation. (A comparison of the corresponding p-values for comparings coatings to the controls in the manner of the previous section also shows only minor differences and thus is not presented here.) However, although the tests of factor effects differ little between the two sets of analyses, there are interesting and potentially useful insights suggested by the latter. The means over time (with simple standard errors) of the residual variances over time are reported in Table 3-9.

Table 3-9 Mean Residual Variances from Table 3-8

BBF	SDECK	Mean	Std Err
Down	A	0.476	(.042)
Down	C	0.310	(.064)
Up	A	0.356	(.033)
Up	C	0.224	(.023)

Because of the longitudinal aspect of the study, there is no reason to assume a priori that the estimated variances are independent over time; thus, the reported standard errors likely underestimate variability. However, the magnitude of the standard errors is such that even this rough analysis of the residual variances suggests that variation in DAs measurements differs in a manner related to source deck and board bark face. A detailed confirmatory analysis of this conjecture is beyond the scope (and data) of the current report. It is presented here primarily for the benefit of those designing future experiments that make use of the wipe sampling procedure used in this study.

The suggested conclusions are that measurements from the older sdeck-A boards are more variable; and to a lesser extent so too are boards with a bbf=Down orientation.

3.2.5.7 Combined Data Modeling

We now present select results from models fit to the combined data. Six variance models were used from the collection of options in the SAS Proc Mixed procedure: three that incorporate different levels of departure from compound symmetry (CS, CSH, and CS, with parameters dependent on bbf*sdeck) and three that incorporate time dependence [AR(1), ARH(1), and SP(POW), with time measured in months] and variance heterogeneity in the case of the ARH(1) model. Table 3-10 displays a summary of the results of fitting the alternative variance models to the combined data set. The dependent variable is ln(DAs) adjusted by ln(baseline DAs).

The six alternative variance models result in very similar ANOVA tables with a few exceptions (marked by * in the column to the right of DF). The temporal dependence models (AR(1), ARH(1), SP(POW)) suggest effects of coat1*bbf and coat1*bbf*sdeck whereas the others do not. Also coat1*sdeck*time is highly significant in the non-AR models, but borderline significant in the AR models.

Note that the exceptions partition the AR models from the non-AR models. An evaluation using BIC indicates greater suitability of the non-AR models compared to the AR models. Also recall from Table 3-5 that neither coat1*bbf nor coat1*bbf*sdeck were found to be statistically significant in the time-period specific analyses.

Table 3-11 is comparable to Table 3-6 in that each coating is compared with Coating 13 at each time period based on the analyses of the combined data (all time periods) using the CS variance model. In Table 3-11, p-values were adjusted using a Bonferroni adjustment within each time period. The key finding is that there are no practical differences between Table 3-6 and Table 3-11. Tables like Table 3-11 for the other five variance models are comparably similar to Table 3-6 and not shown.

Table 3-10. Summary of Results of Alternative Variance Modeling

	Variance Models							
			CS	CSH	CS(B*S)	AR(1)	ARH(1)	SP(POW)
Effect	DF		p-value	p-value	p-value	p-value	p-value	p-value
coat1	12		<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
bbf	1		0.7122	0.7084	0.7116	0.6598	0.6624	0.6439
sdeck	1		0.2835	0.2704	0.2839	0.1893	0.1875	0.1673
bbf*sdeck	1		0.0417	0.0369	0.0423	0.0124	0.0124	0.0086
coat1*bbf	12	*	0.2025	0.1675	0.2077	0.0259	0.0254	0.0125
coat1*sdeck	12		0.0027	0.0019	0.0037	<.0001	<.0001	<.0001
coat1*bbf*sdeck	12	*	0.3534	0.3096	0.3557	0.0794	0.0789	0.0459
time	6		<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
coat1*time	72		<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
bbf*time	6		0.4921	0.3335	0.4939	0.3764	0.2556	0.4670
sdeck*time	6		0.0007	0.0002	0.0007	0.0011	0.0004	0.0019
bbf*sdeck*time	6		0.2990	0.3030	0.2999	0.3692	0.3792	0.3917
coat1*bbf*time	72		0.9987	0.9984	0.9987	0.9997	0.9994	0.9999
coat1*sdeck*time	72	*	<.0001	<.0001	<.0001	0.0578	0.0603	0.0269
coat1*bbf*sdeck*time	72		0.9913	0.9834	0.9914	0.9967	0.9941	0.9984
-2LL			1421.0	1403.2	1406.8	1455.3	1442.5	1473.2
BIC			1428.3	1436.2	1439.8	1466.3	1475.5	1484.2

Table 3-11. Coatings Comparisons from the Combined Data Modeling

Model CS													
1 month		3 months		7 months		11 months		15 months		20 months		24 months	
11	<0.0001	10	<0.0001	10	<0.0001	9	<0.0001	10	<0.0001	10	<0.0001	10	<0.0001
10	<0.0001	9	<0.0001	9	<0.0001	10	<0.0001	9	<0.0001	9	<0.0001	9	<0.0001
9	<0.0001	11	<0.0001	8	<0.0001	8	<0.0001	3	<0.0001	1	0.0007	2	0.0024
3	<0.0001	3	<0.0001	11	<0.0001	11	<0.0001	1	<0.0001	3	0.0010	1	0.0157
8	<0.0001	8	<0.0001	3	<0.0001	3	<0.0001	8	<0.0001	2	0.0138	3	0.0351
1	<0.0001	1	<0.0001	1	<0.0001	1	<0.0001	11	<0.0001	8	0.1262	8	0.1907
12	<0.0001	6	<0.0001	2	<0.0001	6	<0.0001	6	<0.0001	6	0.2393	7	0.3141
6	<0.0001	2	<0.0001	6	<0.0001	4	<0.0001	7	<0.0001	7	0.2798	6	0.3500
7	<0.0001	12	<0.0001	7	<0.0001	2	0.0001	4	<0.0001	4	0.2848	11	0.3507
4	<0.0001	4	<0.0001	4	<0.0001	7	0.0001	2	0.0002	11	0.6930	4	0.9999
2	<0.0001	7	<0.0001	12	<0.0001	12	0.0002	12	0.0010	12	0.9999	12	0.9999
5	0.0810	5	0.0621	5	0.0708	5	0.9999	5	0.0618	5	0.9999	5	0.9999

3.2.6 Summary of Coating Comparison Results

Inspection of the 13th column in Figure 3-29 reveals that each coating mitigated DAs somewhat when compared to the positive control. However, recall that the visual comparisons made possible in Figure 3-29 are not precise and not adjusted for the effects of multiple hypothesis testing.

Table 3-12 summarizes the differences between the performance of each coating versus the positive control [minideck 13 (uncoated)] as well as the statistical significance of the differences at each time interval. The color-coding of cells indicates level of significance: blue indicates a p-value of less than 0.01; green indicates a p-value between 0.01 and 0.1; and beige indicates a p-value of greater than 0.1. The p-values and estimated differences under the columns labeled “1 Mo.” – “24 Mo.” were calculated form the time period specific analyses reported in Tables 3-5 and 3-6. The p-values and estimated differences under the column labeled “Combined” were calculated from the CS analysis of variance model reported in Tables 3.10 and 3.11. In this case the estimated difference is the difference in estimated main effects over all time periods. When justified, combining data over all time periods results in more power for detecting differences in main effects of coatings. This is seen, for example, with Coating 5, for which the time-period specific differences are mostly far from significant; whereas the difference from the combined data analysis is borderline nonsignificant (p-value = .0846).

From inspection of the pairwise tests summarized in Table 3-12, the adjusted p-value for comparing the main effects of coatings 5 and 13 (uncoated) is only marginally significant at the .05 level of significance for two time periods. Thus, there is little evidence of a difference in performance between coatings 5 and 13 (uncoated). All of the other coatings exhibited statistically significant differences in performance versus the control through the 11-month sampling event, or after approximately one year of weathering. The paints were the only products that continued to show statistically significant performance differences versus the control throughout the two-year study period. All of these results are borne out visually in the graphical presentation in Sections 3.2.2 through 3.2.4.

Table 3-12. Summary of Estimated ln(DAs) Difference and Associated Statistical Significance between Each Coating and Control [#13 (uncoated)] Minidecks at Each Time Interval

Coating		Time After Coating							
		1 Mo.	3 Mo.	7 Mo.	11 Mo.	15 Mo.	20 Mo.	24 Mo.	Combined
1	p-value	<.0001	<.0001	<.0001	<.0001	<.0001	0.0165	0.0133	<.0001
	est. diff. (ln)	-1.9863	-2.3589	-1.7905	-1.8829	-1.7465	-1.0185	-0.8097	-1.6562
2	p-value	0.0002	0.0002	<.0001	0.0010	0.0089	0.0758	0.0024	<.0001
	est. diff. (ln)	-1.1823	-1.7118	-1.6411	-1.1558	-1.1052	-0.8194	-0.9411	-1.2224
3	p-value	<.0001	<.0001	<.0001	<.0001	<.0001	0.0200	0.0273	<.0001
	est. diff. (ln)	-3.3198	-3.4487	-2.1945	-2.2290	-1.7697	-0.9944	-0.7487	-2.1007
4	p-value	<.0001	0.0003	0.0002	<.0001	0.0036	0.3707	0.5434	<.0001
	est. diff. (ln)	-1.4124	-1.6170	-1.3988	-1.4880	-1.2137	-0.5672	-0.4034	-1.1618
5	p-value	0.0885	0.2471	0.0973	0.7416	0.1746	0.9994	0.9635	0.0846
	est. diff. (ln)	-0.6806	-0.7028	-0.6919	-0.3457	-0.7032	-0.1633	-0.2338	-0.5030
6	p-value	<.0001	<.0001	<.0001	<.0001	0.0006	0.3396	0.2001	<.0001
	est. diff. (ln)	-1.5275	-1.9779	-1.5046	-1.5669	-1.4131	-0.5837	-0.5467	-1.3029
7	p-value	<.0001	0.0027	<.0001	0.0011	0.0024	0.3678	0.1830	<.0001
	est. diff. (ln)	-1.4183	-1.3527	-1.4666	-1.1477	-1.2618	-0.5687	-0.5574	-1.1105
8	p-value	<.0001	<.0001	<.0001	<.0001	0.0001	0.2435	0.1203	<.0001
	est. diff. (ln)	-2.1129	-2.9301	-2.6787	-2.6567	-1.6222	-0.6423	-0.6050	-1.18926
9	p-value	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
	est. diff. (ln)	-4.2475	-3.6731	-2.8327	-3.3215	-2.6053	-1.6803	-1.7832	-2.8776
10	p-value	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
	est. diff. (ln)	-4.5213	-3.8432	-3.0658	-3.1612	-2.6961	-2.2269	-2.4219	-3.1338
11	p-value	<.0001	<.0001	<.0001	<.0001	0.0005	0.5729	0.2005	<.0001
	est. diff. (ln)	-4.6796	-3.5821	-2.3494	-2.5833	-1.4385	-0.4751	-0.5465	-2.2364
12	p-value	<.0001	0.0002	0.0004	0.0019	0.0213	0.7404	0.7101	<.0001
	est. diff. (ln)	-1.8045	-1.7526	-1.2906	-1.0874	-0.9965	-0.4052	-0.3492	-1.0911

Table 3-12 reports estimated differences of the means of the natural logarithms of DAs. This is the best scale for the statistical analysis, but not the best scale for interpretation. A preferable scale for interpretation is percent reduction relative to the control (#13) minidecks. The estimated differences of logs in Table 3-12 were converted to estimated percent reductions relative to the control minidecks by exponentiating the differences, subtracting from 1, and multiplying by 100. These estimated percent reductions are reported in Table 3-13 along with lower and upper 95 percent confidence limits (LCL /UCL) for all coatings and time periods. The confidence limits

were calculated by first constructing 95 percent confidence intervals for the estimated differences of the logs and then transforming those lower and upper bounds using the same formula for converting the estimated differences of logs to percent reductions.

Table 3-13. Estimated Percent Reduction for Each Coating and Estimated 95 Percent Confidence Intervals (color-coding same as in Table 3-12)

		Time After Coating						
Coating		1 Month	3 Month	7 Month	11 Month	15 Month	20 Month	24 Month
1	%Reduction	86	91	83	85	83	64	56
	LCL/UCL (%)	71/93	75/96	64/92	68/93	58/93	13/85	11/78
2	%Reduction	69	82	81	69	67	56	61
	LCL/UCL (%)	36/85	53/93	58/91	33/85	20/86	-6/82	22/80
3	%Reduction	96	97	89	89	83	63	53
	LCL/UCL (%)	92/98	92/99	76/95	77/95	59/93	11/85	5/76
4	%Reduction	76	80	75	77	70	43	33
	LCL/UCL (%)	49/88	48/92	46/89	52/89	28/88	-36/76	-34/67
5	%Reduction	49	50	50	29	51	15	21
	LCL/UCL (%)	-6/76	-30/81	-8/77	-50/67	-20/80	-104/65	-58/60
6	%Reduction	78	86	78	79	76	44	42
	LCL/UCL (%)	54/90	64/95	52/90	56/90	41/90	-34/77	-16/71
7	%Reduction	76	74	77	68	72	43	43
	LCL/UCL (%)	49/88	32/90	50/89	33/85	31/88	-36/76	-15/71
8	%Reduction	88	95	93	93	80	47	45
	LCL/UCL (%)	75/94	86/98	85/97	85/97	52/92	-26/78	-9/73
9	%Reduction	99	97	94	96	93	81	83
	LCL/UCL (%)	97//99	93/99	87/97	92/98	82/97	55/92	66/92
10	%Reduction	99	98	95	96	93	89	91
	LCL/UCL (%)	98/99	94/99	90/98	91/98	84/97	74/96	82/96
11	%Reduction	99	97	90	92	76	38	42
	LCL/UCL (%)	98/100	93/99	79/96	84/96	43/90	-49/74	-16/71
12	%Reduction	84	83	72	66	63	33	29
	LCL/UCL (%)	65/92	54/94	40/87	29/84	11/85	-60/72	-41/65

Table 3-13 further illustrates what has been demonstrated graphically in Figure 3-29; that is, product performance for the reduction of dislodgeable arsenic residues decreases with time. For the products tested, the paints ranked highest, followed by multi-coat stains and sealants and the vinyl elastic encapsulant, followed by the single-

coat products. However, confidence intervals for estimated percent reduction are relatively large, challenging any attempts to rank and compare product performance based upon estimates of percent reduction. Nevertheless, the information in Table 3-13 provides an easily interpreted picture of the range of product performance and, if used in conjunction with the information in Figure 3-29, makes is possible to easily differentiate between individual products and compare the relative performance of products at any point in time.

The study design stipulated the use of deck surface preparation protocols recommended by the coating manufacturer. Accordingly, minidecks for ten of the products were cleaned using a specific recommended cleaning agent followed by a water rinse, whereas minidecks coated with Product 3, an oil-based stain, received only a water rinse, and the minidecks coated with Product 7, a water-based stain, were neither cleaned nor rinsed. The positive control minidecks were rinsed with water but not treated with a cleaning agent. As seen in Table 3-12, DAs for minidecks coated with Product 7 were statistically different than the positive controls through the first 15 months of weathering. This evidence suggests that coating may be more effective than rinsing with water, at least through a one-year period. The decks coated with Product 3 received the same treatment as the positive controls and DAs was significantly less than the positive controls through 15 months. Again, these limited observations suggest that coating (with most products) is more effective than washing alone in reducing DAs. However, the experimental design does not evaluate the impact of periodic washing or periodic re-treatment with a coating product.

3.3 Coating Appearance

Coating appearance throughout the study was qualitatively assessed in person and by recording and reviewing photographs of each minideck at each sampling event (precoat and after 1 month, 3 months, 7 months, 11 months, 15 months, 20 months and 24 months of weathering). The photos are provided in Appendix D. Notable observations are summarized in Table 3-14.

3.4 Weather Data

A number of meteorological measurements were made during this study, as described in Section 2.7. The most relevant parameters in terms of coating performance and sampling are Solar Radiation, Rainfall, and Temperature. Tables 3-15 and 3-16 summarize key weather parameters by sampling interval, where the two numbers in the first column refer to the sequentially numbered sampling events defining the period over which the weather parameters are summarized. Figures 3-30 through 3-32 are plots of key weather-related parameters versus time. In each of these plots, vertical bars indicating the dates of the sampling events are superimposed for reference. Complete weather data collected are provided in Appendix P.

Table 3-14. Summary of Visual Observations of Minidecks

Coating #	Product Type	Base	Cover	Pigmentation	Main Ingredients	Summary of Visual Observations
Coating 1	Sealant	Oil	Semi	"Cedar"	Aliphatic, Napthalene	Deep red coloration. Some wear-through where wiped.
Coating 2	Sealant	Oil	Clear	"Clear"	Acrylic, alkyd, urethane	No visible signs of coating. Relatively light and bright wood appearance.
Coating 3	Stain	Oil	Clear	"Deep Tone Base" (no pigment added)	Acrylic	Extensive black mold or mildew on untreated boards, with varying amounts, from slight to extensive, on treated boards. Growth appeared between 7 and 11 months after coating. Otherwise, no visible signs of coating, although when freshly coated the wood appearance was significantly darkened.
Coating 4	Stain	Oil	Clear	"Clear Stain"	Alkyd	No visible signs of coating. Some mold or mildew on untreated boards.
Coating 5	Sealant	Water	Clear	"Clear"	Unknown*	No visible signs of coating. Relatively dark (gray) wood appearance.
Coating 6	Sealant	Water	Clear	"Clear"	Acrylic, alkyd	Slightly yellow tint to treated boards. Some wear-through where wiped.
Coating 7	Stain	Water	Semi	"Cedar"	Alkyd	Light red coloration. Wear-through where wiped.
Coating 8	Stain	Water	Clear	"Tint base, solid" (no pigment added)	Acrylic	Very slight tint on treated boards, but generally no visible signs of coating. Relatively light and bright wood appearance.
Coating 9	Paint	Water	Opaque	Gray	Acrylic	Retained gray paint coloration, but moderate-to-extensive chipping, especially at cracks, starting around 7 months.
Coating 10	Paint	Oil	Opaque	Gray	Alkyd, polyurethane	Retained gray paint coloration, slight-to-moderate chipping at cracks. Some black mold or mildew on untreated boards.
Coating 11	Other		Clear	Clear	Elastic vinyl	Extensive black mold or mildew on untreated boards with varying amounts, from none to moderate, on treated boards. Growth appeared between 7 and 11 months after coating. Seems to visually perform better on A source than C source. Some limited chipping and peeling at large cracks. General appearance is slick and waxy, with an amber coloration that held well on treated boards.
Coating 12	Other		Clear	Clear	Polymer	No visible signs of coating.
Coating 13	No coating					No visible signs of coating. Some mold and mildew on untreated boards.

** MSDS does not include any ingredients >1 percent by weight*

Table 3-15. Summary of Key Weather Parameters

Sampling Interval	Total Solar Radiation ($W/m^2 \times day$)	Avg. Solar Radiation (W/m^2)	Total Rainfall (inches)	Precip Events >0.25" (#)	Precip Events >0.10" (#)
0-1	6075	196.0	4.71	5	7
1-2	8567	142.8	4.63	4	10
2-3	11953	105.8	8.54	13	17
3-4	26801	216.1	11.14	13	18
4-5	23980	179.0	24.53	22	24
5-6	15145	116.5	9.02	11	16
6-7	27860	222.9	13.36	13	18

Table 3-16. Summary of Temperature Measurements

Sampling Interval	Avg. Temp. (degrees F)	Avg. High Temp (degrees F)	Avg. Low Temp (degrees F)	Max. High Temp (degrees F)	Min. Low Temp (degrees F)
0-1	74.5	86.0	68.1	95.4	52.9
1-2	61.1	73.5	51.7	86.3	31.8
2-3	41.3	54.0	32.3	82.2	9.5
3-4	65.3	77.3	55.7	95.1	21.3
4-5	69.8	78.8	59.4	95.9	28.0
5-6	44.3	56.3	34.5	78.0	11.0
6-7	70.8	82.3	59.3	103.3	35.0

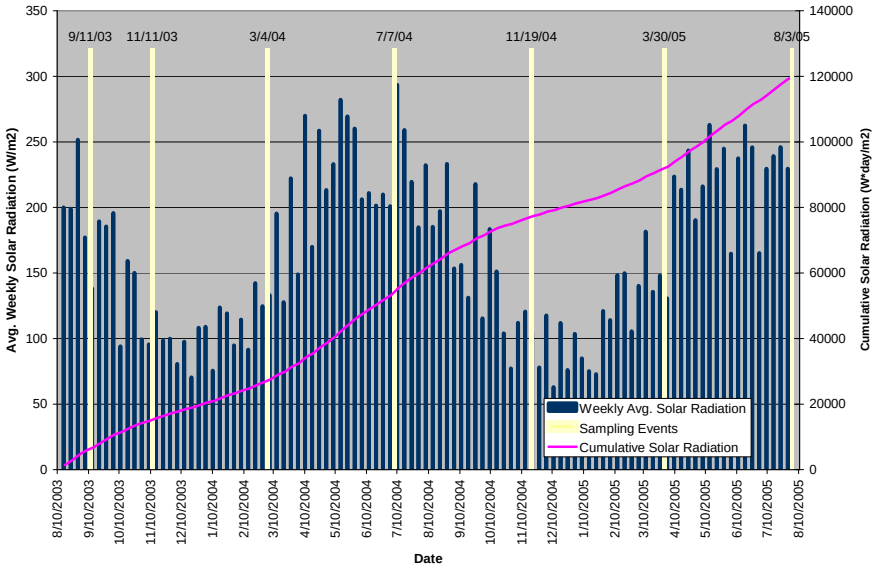

Figure 3-30. Solar Radiation Data Summary

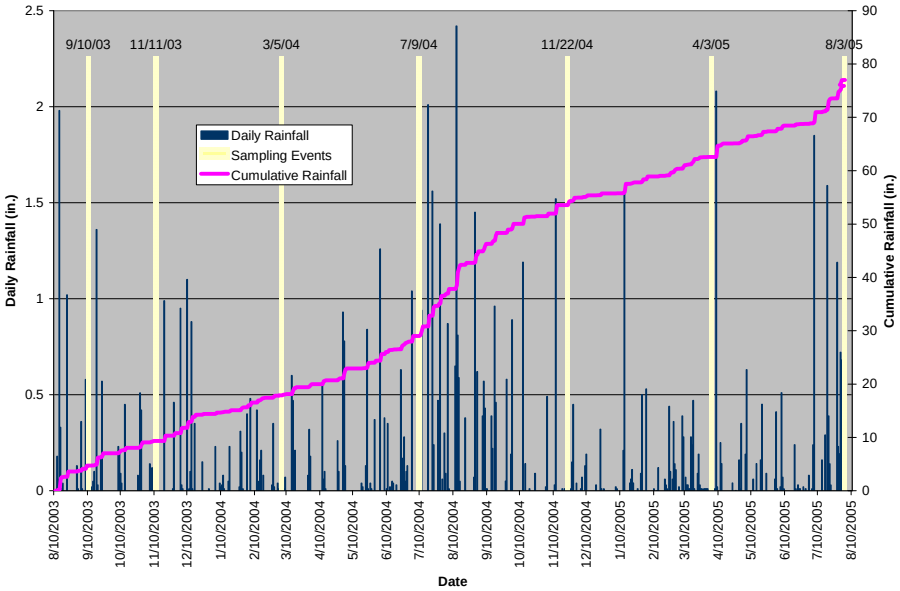

Figure 3-31. Rainfall Data Summary

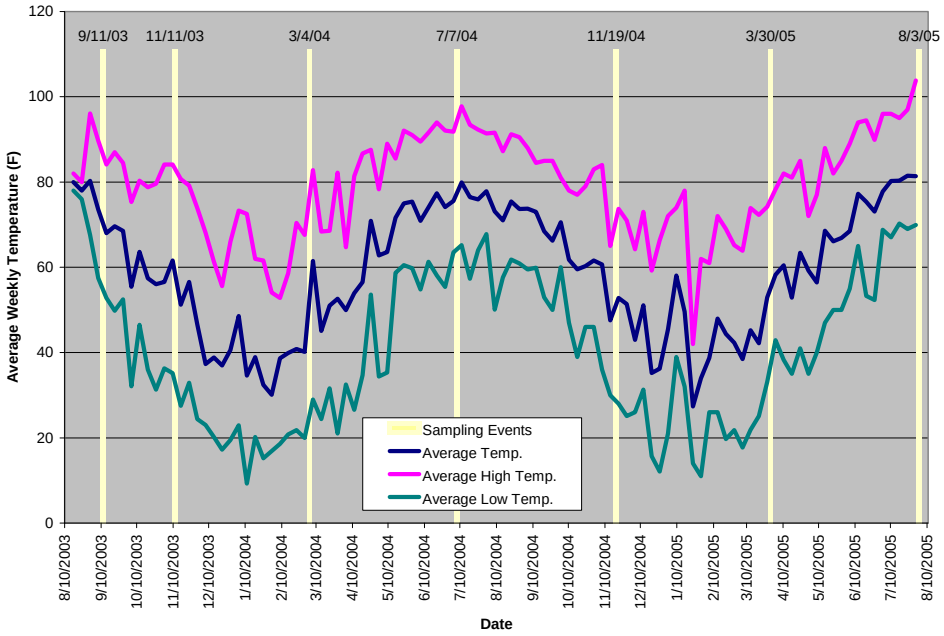

Figure 3-32. Temperature Data Summary

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4. Study Limitations, Exploratory Analyses and Future Studies

The primary objective of the testing described in this report was to evaluate coatings for their efficacy in reducing DCCA from the surfaces of pressure-treated wood subjected to outdoor weathering because of concern of potential health consequences due to ingestion of dislodgeable CCA residues through hand-to-mouth behaviors of young children that contact CCA-treated wood. Thus, the study was designed to provide insight into the utility of a potential risk management strategy that is readily available and commonly used by consumers to maintain the appearance and durability of decks.

EPA used a modification of a wipe-sampling protocol developed by the staff of the CPSC. CPSC staff had previously developed linkages between the amounts of DCCA determined by the wipe-sampling protocol and amounts of DCCA transferred to hands by contact with CCA-treated wood. Due to uncertainties regarding the relationship between dose and risk and regarding the sensitivity of the wipe-sampling method to detect changes in DCCA on coated surfaces, EPA modified the CPSC wipe-sampling method to improve the sensitivity of the method to detect changes in DCCA. Additionally, the project was focused in a way that precluded the ability to answer all of the myriad questions raised in the development of the test protocol employed, execution of the project, and evaluation of the results. The objective of the following discussion, therefore, is to better define study limitations, present exploratory data analyses that may identify unanswered questions, and suggest future research work and considerations for subsequent studies.

4.1 Substrate Characteristics

Only two sources of aged CCA-treated wood were tested, which is not likely to be representative of the universe of CCA wood structures currently in service. In particular, the two sources represented two different ages and conditions (one-year and seven year) of the same species wood (SYP).

Outdoor structures like residential decks may have service lives of 20 years or more. As CCA treated wood is no longer widely used to construct such structures, the average age of those currently in use is continually increasing. As such, testing of CCA-treated wood from sources in service for longer than seven years may be warranted in future studies.

In addition to southern yellow pine, other species such as hemlock fir, Douglas fir, spruce-pine fir, red pine, ponderosa pine and radiata pine may be regionally popular and thus could be tested in future studies.

Nailholes, knots, and other surface irregularities can be expected to have an impact on wipe sampling and DCCA measurements. As such, these surface features were

avoided to the extent possible in this study. In particular, nailholes were completely avoided during wipe sampling events (wipe samples were taken between adjacent sets of nailholes). Furthermore, existing nailholes were reused when assembling minidecks. Other surface irregularities were avoided to the extent practical when selecting specimens to be used for assembling minidecks.

To the extent that such irregularities could not be avoided, each specimen and sampling area were characterized visually in two ways: by filling out a specimen characterization form (described further in Section 2.2 and reported in Appendix B) and via a photo record of each specimen, which included pre- and post-coating photographs of each minideck and photographs of each minideck prior to each regular sampling event.

Defects recorded included number of knots and the degree of splintering, cracking, and rotting for each specimen. The characteristics recorded included predominant grain type (flat versus edge grain), predominant ring spacing (tight, medium, wide), predominant wood season (early versus late wood), and predominant wood type (heartwood versus sapwood). The only wood characteristic explicitly controlled during the study was predominant grain orientation (up versus down). The effect of grain orientation was minor compared to other factors in the experiment. Heartwood/sapwood classification (predominantly HW, predominantly SW, even mix) of the boards was not significant when as added as fixed main effect to the analysis of variance models. However, this factor was not controlled in the experiment, and the determination of heartwood/sapwood was subject to misclassification, thus the power to detect such an effect was likely compromised.

Additional work could be conducted to determine the specific impacts of various wood surface characteristics on DCCA and coating performance. It is known that certain wood characteristics affect CCA retention. In particular, heartwood – the nonliving center of the tree – typically contains little CCA after treatment (Lebow et al., 2003). Additionally, large differences in wood erosion rates (where it is speculated that DCCA correlates positively with wood erosion) between earlywood and latewood were observed in vertically-oriented test specimens weathered at a site in Wisconsin over an exposure period of 7 years or longer (Williams et al., 2001a, 2001b, 2001c).

4.2 Geography/Climatic Effects

Experiments were conducted at an outdoor site in Research Triangle Park, NC, which is representative of southeastern or mid-Atlantic US climatology and features summer weather conditions characterized by intense solar radiation, high humidity, and frequent thermal shock from rain showers, but mild average conditions throughout the remainder of the year, relative to more northerly US geographic regions. CPSC staff

conducted their companion study in Gaithersburg, MD, which features similar climatic conditions.

The wood and coating industries typically conduct product testing in extreme climates represented by two geographical regions in the US, the deep south for moisture and photodegradation and the Snow Belt for cyclic freeze-thaw stresses. Future studies should consider testing in more extreme and/or representative locations in the US. In addition to the two extremes mentioned, other major climatic regions could be considered, including Northwestern, High Plains, Midwest/Ohio Valley, upper New England/Mid-Atlantic, lower Southeast, Southern and Southwestern.

In addition to geographic location, directional exposure effects (e.g., south- versus north-facing decks), particularly of the source structures, could be important variables in studies similar to that which was conducted.

4.2.1 Exploratory Analysis of Potential Weather Effects

It is possible and perhaps even likely that the effects of weather on coating performance will differ from one coating to another—film formers might be affected by weathering differently than penetrating coatings, for example. Thus, in searching for possible weather effects, it is necessary to consider coatings individually. For this project, the effects of weather and time were jointly examined using regression methods for each of the 13 coatings. The response variables in these analyses are the ln(DAs) values averaged over grain and source deck—the ln(DAs) averages plotted in the bottom row of Figure 3-26. Weather effects were investigated using multiple linear regression models with time as one predictor and a second predictor corresponding to one of the climatological variables taken in succession. For these analyses it is assumed that the averaged ln(DAs) values vary linearly with time and the included weather variable. That is, with time and one weather variable, we assumed the following statistical model:

ln(DAs) = b0 + b1*time + b2*weather + (random error)

The limitation of this analysis is that there are only 7 data points to fit such a model. Nevertheless, it can be done and the question becomes whether b2, the coefficient of the weather variable, is significantly different from 0.

A total of 15 weather variables, as listed in Table 4-1, were selected for analysis. Since there were 13 coatings by 15 weather variables, 13 x 15 = 195 such regressions were conducted. The results are summarized in a 13-by-15 array and one figure.

Table 4-1. List of Weather Variables Considered in Statistical Analysis

#	Weather Variable	Description
1	TSRad	Total solar radiation
2	Cum_TSR	Cumulative solar radiation
3	Rad_Int	Average solar radiation
4	TRain	Total rainfall
5	#HRain	Number of rain events greater than 0.25"
6	#LRain	Number of rain events greater than 0.10"
7	AT	Average temperature
8	AHT	Average high temperature
9	MHT	Maximum high temperature
10	ALT	Average low temperature
11	MLT	Minimum low temperature
12	0-#Frz	Number of freezing events
13	ATDiff	Average daily temperature difference
14	#LTDiff	Number of days with a temperature difference greater than 26 F
15	#STDiff	Number of days with a temperature difference greater than 32 F

The array provides the partial correlations between ln(DAs) and the weather variables after adjusting for time effects. Table 4-2 includes the correlations for all cases in this array where the p-value < .10. These are the only correlations worthy of further consideration.

Table 4-2. Partial Correlations for Pairs with p-values < 0.10

Coating	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	----	----	0.79	----	----	----	----	----	0.73	----	----	----	----	----	----
2	----	----	0.87	----	----	----	0.75	0.75	0.74	0.77	----	----	----	-0.8	----
3	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
4	----	----	0.93	----	----	----	0.82	0.84	0.86	0.84	0.79	----	----	-0.77	----
5	0.76	----	0.87	----	----	----	----	----	----	----	----	----	----	----	----
6	----	----	0.78	----	----	----	----	----	----	----	----	----	----	----	----
7	----	0.74	0.93	----	----	----	0.8	0.82	0.74	0.81	----	0.77	----	-0.73	----
8	----	----	----	----	----	----	----	----	----	----	0.83	----	-0.77	-0.8	-0.75
9	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
10	0.82	----	----	----	0.77	0.86	----	----	----	----	----	----	----	----	----
11	----	----	----	----	0.78	0.91	----	----	----	----	-0.74	----	----	----	----
12	0.83	----	0.78	----	----	----	----	----	----	----	----	----	----	----	----
13 (uncoated)	0.88	----	0.9	----	----	----	0.74	0.74	0.85	0.73	----	----	----	----	----

Figure 4-1 shows the 195 partial regression plots resulting from the 13 x 15 matrix of coating x weather factor. Columns correspond to the 15 weather variables shown in Table 4-1, while rows correspond to coatings 1, 2,..., 13. Partial regression plots are constructed to show how ln(DAs) relates to weather after the linear effects of time are removed. Each plot contains 7 points and also the partial regression line. A black solid line means that the correlation is statistically significant at .10 significance level (.10 is used because of the exploratory nature of the evaluation—so as to not miss relationships that might exist but are weak).

The black lines in columns 7, 8, 9, 10 and 11 of Figure 4-1 are all temperature variables and are essentially the same for the purposes of this analysis. So if one of them is significant then it is highly likely that the others will also be significant (or close to significant).

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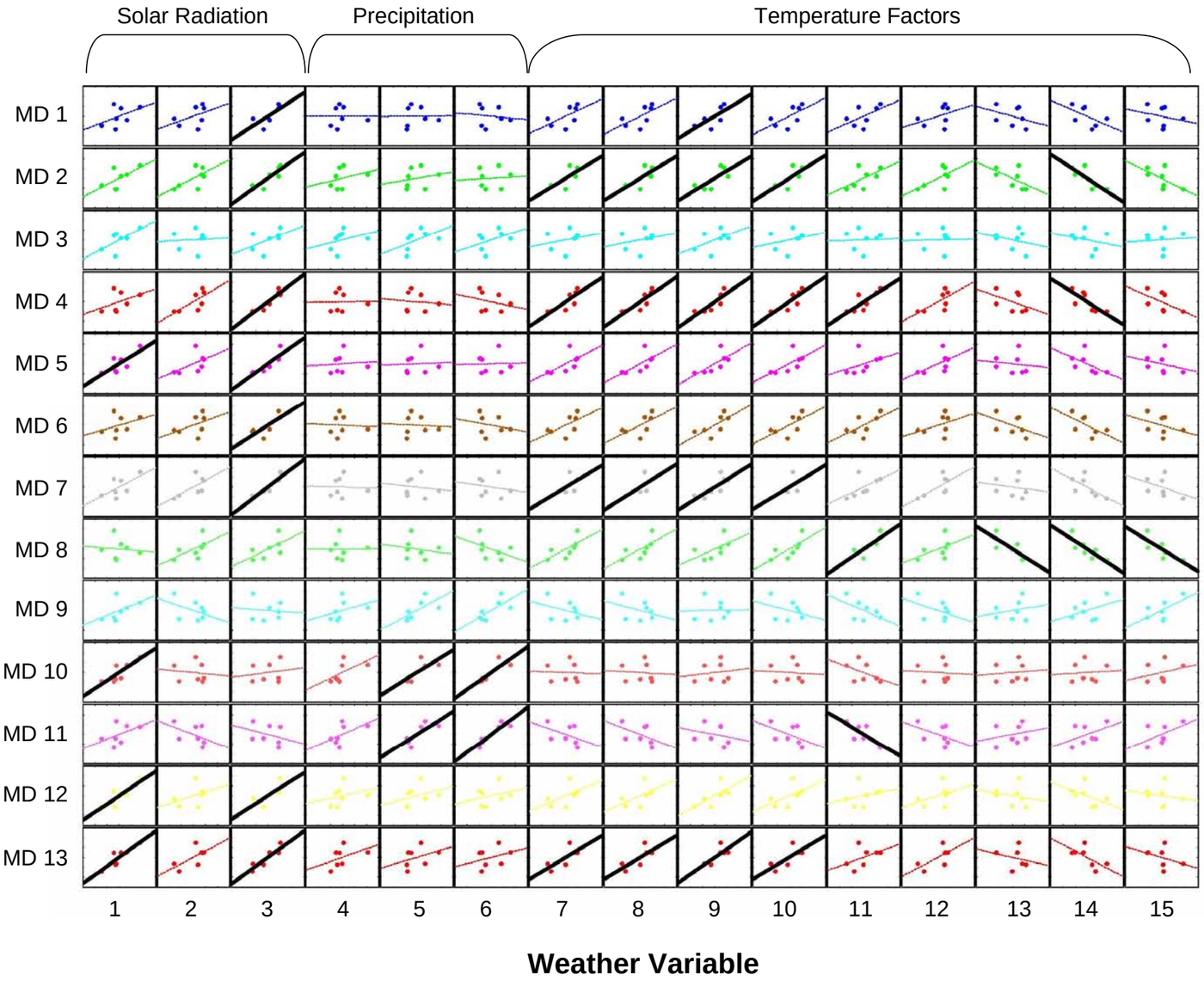

#	Weather Variable	Description
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7	AT	Average temperature
8	AHT	Average high temperature
9	MHT	Maximum high temperature
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14	#LTDiff	Number of days with a temperature difference greater than 26 °F
15	#STDiff	Number of days with a temperature difference greater than 32 °F

= Partial correlation significant at 0.1 level

Figure 4-1. Partial Regression Plots of Coating × Weather Factor ([each subplot has ln(DAs) as its y-axis and the weather variable as its x-axis]

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The largest correlations (0.93) are associated with Rad_Int; nine of the thirteen treatments correlated significantly with at least one of the radiation measures. Two of the products - both film-formers - had a significant correlation with number of precipitation events greater than 0.1 and 0.25 inches, consistent with the expectation that shrink and swell due to moisture and thermal shock may impact the performance of film-forming products. Significant temperature correlations were observed for about one-half the treatments, and in nearly all cases, those treatments also responded positively to a solar radiation measure. No significant correlations were observed for products #3 and #9, products that performed relatively well in terms of reduction of DCCA.

4.3 Coating Type and Selection

The coatings tested in this study represented a convenience sample readily available to the project team with limited numbers of representatives from the major classes of consumer products. It was not intended to be fully representative of the universe of available coatings. Additionally, products within a given classification can vary considerably in formulation and effectiveness and the products selected for this study were not intended to be representative of their respective categories. Nevertheless, exploratory analyses were conducted to assess differences among subgroups of coatings as identified by information on the product label or MSDS.

Previous efforts in coating formulation, as reported in the literature, have focused on the efficacy of coatings and surface preparation in resisting weathering as measured by erosion rate and leaching of CCA into water from simulated or actual precipitation. Lebow, et al. (2003) in a thorough review of published literature suggest that water repellent content, pigment concentration, binder system and additives may affect the ability of coatings to reduce DCCA.

In addition to the pairwise tests reported in Section 3.2.5, differences among certain identifiable subgroups of coatings were also tested. The results of these exploratory analyses are reported in Table 4-3 (the p-values are not adjusted for multiplicity). Note that all of the comparisons presented in Table 4-3 were done without coatings 9 and 10 (the paints) in the analytical model with the exception of the “Multi-Coat versus Single Coat” comparison.

Table 4-3. Pairwise Comparisons of Coating Characteristics

Comparison	t-statistic	p-value
Sealant vs. Stain	1.5810	<.0001
Penetrating vs. Film-Former	8.0861	<.0001
No Acrylic vs. Acrylic	8.0752	0.0002
No Alkyd vs. Alkyd	-9.1344	<.0001
Oil-Based vs. Water-based	-4.3004	0.0444
Multi-coat vs. Single Coat	-7.5055	<.0001
Clear Cover vs. Semi-Transparent	-0.4443	0.6076

The "sealant vs. stain" comparison tested the average difference in ln(DAs) between sealants and stains. Sealants had higher average ln(DAs) than stains (p-value < 0.0001), meaning that the sealants performed worse than the stains in these experiments. Penetrating coatings had higher average ln(DAs) than the film formers (p-value < 0.0001), non-acrylics had higher average ln(DAs) than the acrylics (p-value = 0.0002), and non-alkyds had lower average ln(DAs) than the alkyds (p-value < 0.0001). The difference in performance between oil- and water-based products was not significant at the 0.05 level when paints were excluded from the analysis (p-value = 0.0444); a potentially useful observation in light of the phase-out of oil-based products in response to phased implementation of the Clean Air Act amendments restricting the atmospheric release of volatile organic compounds. The products for which more than one coat was recommended (and applied) performed significantly better than the products for which a single coat was recommended (p-value <0.0001). However, the number of coats is confounded with both the recommended application procedure and with the product. As such, one cannot infer from this observation that multiple coats of a product provide improved reduction of DCCA because the study design did not examine this question directly by testing multiple application levels for any product. However, inspection of Tables 3-6 and 3-9 reveals that all six of the single-coat products ranked lowest of the twelve pair-wise comparisons through the first five sampling intervals and five ranked in the lowest six at sampling periods six and seven. Finally, no significant difference in performance was detected between products with clear versus semi-transparent covers.

In this study, a convenience sample of products was tested for a purpose for which most were not advertised or designed. Future studies should investigate the impact of coatings specifically formulated for their ability to mitigate DCCA (note that two products advertised to reduce exposure to CCA were tested in this study). As such, this test protocol, or a modification of this protocol, may be useful in efforts to evaluate and demonstrate the efficacy of products specifically formulated for their ability to

reduce DCCA on appropriate substrates in various climatic regions and for specific use conditions.

4.4 Surface Preparation, Coating Application and Reapplication

In this study, manufacturers' instructions for surface preparation prior to coating were strictly followed. As such, minideck surfaces for ten of the products were cleaned using a specific recommended cleaning agent followed by a water rinse, thus confounding surface preparation method with coating for these products. Minidecks coated with Product 3, an oil-based stain, received only a water rinse, and the minidecks coated with Product 7, a water-based stain, were neither cleaned nor rinsed, per strict adherence to the manufacturers instructions (or lack thereof) on the product label. The positive control decks were rinsed with water but not treated with a cleaning agent. The results associated with these products allowed for a preliminary assessment of the impacts of surface preparation on DCCA.

As seen in Table 3-12, DAs for minidecks coated with Product 7 were statistically different than the positive controls through the first 15 months of weathering. This evidence suggests that coating may be more effective than rinsing with water, at least through approximately a one-year period. The decks coated with Product 3 received the same treatment as the positive controls and DAs was significantly less than the positive controls through 15 months. Again, these limited observations suggest that coating (with most products) is more effective than washing alone in reducing DAs.

However, the project did not investigate the comparative performance of coatings versus periodic (e.g., monthly, quarterly) cleaning of the surface of the deck over time. Periodic cleaning may mitigate dermal CCA exposure and its effects could be compared with the impacts of coatings on DCCA in future studies.

The preparation of the wood surface prior to coating may be important in several ways. First, it is possible that the surface preparation method itself may constitute a significant exposure activity. For example, sanding CCA wood surfaces without proper respiratory equipment may facilitate exposure via inhalation. The surface preparation technique may also impact the pre-coat DA levels as well as future migration of DCCA to the surface of the wood. In this study, the coating manufacturer's printed instructions with regards to surface preparation were followed strictly. Baseline measurements, used in some calculations of efficacy, were taken prior to any surface preparation or rinse step so we did not obtain data to systematically evaluate the impact of preparation steps on DCCA. Future studies could consider this issue more directly and, compare the efficacy of periodic cleaning procedures with the efficacy of periodic treatment with coating products.

It is possible that the method of applying coatings may also affect DCCA measurements. Wood was prepared and coatings were applied per manufacturer's

instructions. A brush application coating technique was used for each coating based upon the assumption that brush application represents the most common method employed by residential users of deck coatings. Additional studies could consider the effect of coating application technique on coating performance and DCCA measurements.

4.4.1 Exploratory Analysis of Coating and Paint Chip Samples

Preparing CCA surfaces for the reapplication of a coating may represent a potential for exposure. For example, the removal of film-forming products in preparation for recoating may subject users to increased exposure to CCA chemicals associated with associated particulates, including dusts. During the minideck study, it was noted that the painted surfaces were peeling (more notably for the water-based paint than the oil-based paint) and, the peeling materials were sampled for an exploratory analysis of CCA in the paint chips. The methodology associated with this testing is described in Section 2-14.

The results of raw coating analyses are presented in Table 4-4 expressed in µg of total arsenic, chromium and copper per g of raw (wet) coating and per g of dry coating. While the paints, coatings #9 and 10, had higher concentrations than did the other coatings, all of the concentrations were relatively low. A “U” entry in Table 4-4 is a qualifier indicating that the result was below reporting limits, meaning that the of concentration in the fluid used to digest the raw coating was less than 2 µg/L.

Table 4-4. Raw Coating CCA Analyte Concentrations (raw/wet weight basis)

Coating	Dry Solids	raw concentration (µg/g)			dry concentration (µg/g)		
		As	Cr	Cu	As	Cr	Cu
1	25.7 percent	0.62	2.09	2.09	2.42	8.15	8.15
2	28.3 percent	U	0.32	0.59	U	1.13	2.08
3	44.2 percent	0.41	1.14	1.21	0.93	2.58	2.74
4	35.6 percent	U	0.46	0.78	U	1.29	2.19
5	8.8 percent	U	0.38	0.71	U	4.32	8.07
6	13.6 percent	U	0.74	1.57	U	5.46	11.58
7	10.3 percent	U	0.47	1.3	U	4.54	12.57
8	28.8 percent	U	1.23	3.21	U	4.28	11.16
9	55.4 percent	1.64	1.89	18.87	2.96	3.41	34.07
10	67.2 percent	3.99	20.48	6.86	5.94	30.49	10.21
11	48.1 percent	U	3.07	1.25	U	6.38	2.60
12	17.9 percent	U	1.08	0.42	U	6.03	2.34
Primer	34.1 percent	0.90	1.53	0.77	2.65	4.50	2.25

By contrast, Table 4-5 summarizes the results of the paint chip sampling and analysis. There are several key points:

1. The concentrations of total arsenic, chromium and copper in the paint chips taken from the treated wood are significantly higher than in the paint chips from the untreated wood.

2. The concentrations of total arsenic, chromium and copper in the paint chips taken from the treated wood are significantly higher than in the raw paint, even after accounting for weight reductions due to volatile losses upon drying of the paints.

3. No matrix effects appear to be confounding the analyses. This is evidenced by the close agreement in concentration between the split samples of paint chips with different masses.

Table 4-5. Paint Chip CCA Analyte Concentrations

Sample	Mass of paint chips (g)	Concentration (ug/g)		
		As	Cr	Cu
Paint 9 Treated	1.00	225	100	110
Paint 9 Treated	0.50	220	118	108
Paint 9 Untreated	0.70	13	8	29
Paint 9 Untreated	0.34	15	22	33
Paint 10 Treated	0.25	249	247	165
Paint 10 Treated	0.10	310	330	190
Paint 10 Untreated	1.00	12	32	16
Paint 10 Untreated	0.50	12	38	16

Additionally, archived subsamples of paint chips from Paint 9 Treated and Paint 10 Untreated were manually examined using a LEO/Zeiss Model 440 SEM equipped with a PGT IMIX energy-dispersive X-ray spectrometer (EDX) to generate elemental composition information on individual particles. This examination confirmed that arsenic was associated with the top and bottom surfaces of the paint chips recovered from the CCA-treated boards of deck 9. The full analysis report is included in Appendix Q.

While these results suggest that higher levels of CCA chemicals are associated with paint chips from the surfaces of CCA-treated wood surfaces, it is unclear whether the increases can be attributed to wood fibers associated with the peeling paints, migration and uptake of CCA chemicals into the coating products, or some other association.

4.5 Test Specimen Dimensions

Due to the relatively small size of the minidecks, the stress factors associated with attached specimens during weathering are not likely to be representative of those of full-sized, in-use structures.

Future studies may also evaluate the impact of attachment points (nail and screw) on DCCA. For example, it is possible that the surface penetration associated with the fasteners facilitates mobilization of CCA chemicals to the substrate surface. This may require modifications to the sampling methodology due to the potential for hang-up of the polyester sampling material on wood splinters associated with penetrations.

The performance of coatings on wood of different dimensions and on wood members with original vertical or angled orientations could also be investigated. Horizontally-oriented surfaces, as utilized in the study, receive more overall direct solar exposure and more indirect UV radiation than vertically-oriented surfaces, like fences. In Williams, et al. (2001c), the wood erosion rate for horizontally-oriented boards was measured to be two to three times more rapid than for vertically-oriented boards.

4.6 Abrasion Effects

The effects of abrasion (e.g., by repeated contact and walking) have not been directly tested in this project. However, an attempt was made to derive some indication of its impacts using the data collected under the assumption that repeated wipe sampling was a source of abrasion.

Although the experiment was not designed to provide information about the effects of wipe frequency and the number of previous wipe samples taken from a given sampling area, the data collected provided a limited opportunity to investigate these factors. Our analyses were inconclusive and thus we do not report them here. However, we do discuss the rational underlying our attempts at understanding the abrasion issue as it may prove useful should future studies be designed to address abrasion directly.

It was postulated the wipe sampling method itself could have one or two (or both) unintended effects on DCCA. The first is a cleansing effect of removing DCCA from the surface, leaving less DCCA available for the next sampling event. Presumably this effect would be more noticeable when the time between wiping and subsequent wipe-sampling measurement was short. The second is an abrasion effect whereby the rubbing of the wipe against the sampling surface might have a substantial abrading

effect, thereby adversely affecting the coating surface and its ability to block DCCA migration to the surface. Presumably such an effect might increase the amount of DCCA available by compromising the coating and exposing fresh CCA-treated wood fibers.

We attempted to tease these possible effects of rewiping from the data by constructing two predictive variables defined for the purpose of quantifying the amount of previous wiping and the elapsed time since the previous wipe:

NOPW = number of previous wipes
TSPW = time (months) since the previous wipe

NOPW is a surrogate for total prior post-coat abrasion; and TSPW measures wipe frequency, or more specifically, the time interval between wipe samples on a given sampling area. Possible effects of these two factors were investigated using the combined dataset [i.e., both the primary sampling area (M) and baseline sampling area (BL) DCCA results], though it must be noted that resampling of the BL areas were only done through 11 months post-coating. The analysis strategy was to include these variables as linear predictors in statistical models that incorporated all of the main-study factors, with statistically significant upward or downward trends for these variables shedding light the issues of abrasion and cleansing.

This exercise revealed no evidence of trends with TSPW, but weak evidence of a downward trend with NOPW. That is, the greater the number of previous wipes, the lower the DCCA level. The direction of the trend is opposite what would be expected if wiping had abraded coatings and reduced their effectiveness, but consistent with the hypothesis of a cleansing effect. In light of the weak effect, and possible confounding, we view this finding with a healthy dose of skepticism. Because the experiment was not designed for assessing abrasion and wipe frequency, there is not much relevant information in the data, and it is difficult to claim with any certainty that the method of analysis we used is the best way to mine the available data to teasing out abrasion and rewipe information (from each other and from the other effects).

The effect of abrasion on DCCA as well as on coating efficacy for reducing DCCA does not appear to have been directly addressed in previously reported studies but should be addressed in future study efforts. It is important to note that there are many variables that may potentially confound the effects of abrasion, including UV degradation, surface preparation, moisture content of the wood surface, history of coatings on the surface and wood characteristics.

Since purposeful abrasion (e.g., simulated walking) was not a factor in our study, the results likely represent the upper limits of DCCA reduction performance of the tested coating projects. As such, the coatings industry should adapt the test protocol that has been developed to include an abrasion component. Related to abrasion, the transfer of

CCA analytes via feet, pets, and other potential contact routes may be important but has not been addressed by this study.

4.7 CCA Transport from Treated Specimens

In addition to providing some buffer space between test specimens, the untreated boards separating the CCA-treated test specimens on each deck served as control surfaces for assessing cross-contamination potential. During each wipe sampling event, one untreated (but coated, for minidecks 1 - 12) specimen from each minideck was wipe-sampled. Because there were five untreated specimens on each minideck, there were a total of ten potential sampling areas. The specific areas sampled during each routine sampling event were randomly selected for each minideck but were kept different for each sampling event. The results of these samples were used to assess the potential for cross-contamination between adjacent sampling areas. Cross-contamination could hypothetically be the result of splash-over of rainwater from one specimen to the next or possibly other transfer mechanisms.

Cross-contamination potential was assessed by comparing the cross-contamination results for the thirteen minidecks (the uncoated control boards) versus the results from the non-CCA control minideck. These results are summarized in Table 4-6, while the full non-CCA minideck dataset is provided in Appendix L and the full non-CCA "spacer" board contamination control dataset is provided in Appendix M. The cross-contamination data for all of the coatings are summarized in Appendix C (Table C-7).

Table 4-6. Summary of Cross-Contamination and Blank Control Minideck Results

Non-CCA Minideck	DAs (µg/cm^2)	DCr (µg/cm^2)	DCu (µg/cm^2)
Average	0.001	0.003	0.034
Std. Dev.	0.0006	0.004	0.011
Non-CCA Boards on Minidecks			
Average	0.007	0.009	0.056
Std. Dev.	0.021	0.028	0.042

As summarized in Table 4-6, DCCA on the control boards was insignificant in relation to the DCCA measurements used in the coating efficacy data analysis. While the DAs results of all of the untreated wood wipe samples are, with a few exceptions early in the study, very low in comparison with those from the treated wood specimens, on average there appears to be more DCCA from the cross-contamination control surfaces versus the non-CCA (negative control) minidecks.

To further analyze the cross-contamination control results, two series of plots were developed: Figure 4-2 and 4-3.

In Figure 4-2, thirteen plots and presented, one for each coating, with Coatings 1, 2 and 3 on the top row, 4, 5 and 6 on the next row, and so forth. The horizontal and vertical axes are ln(DAs) in all plots, where the x-axis is the average of DAs over all CCA boards for the minidecks associated with that coating at each of the seven time periods (denoted by the number next to the data point, where time periods 1,...,7 correspond to sampling events at 1, 3, 7, 11, 15, 20, and 24 months after coating respectively) and the y-axis is DAs averaged over all non-CCA boards for that coating at the corresponding time period. The superimposed line is from the ordinary least fit. This plot shows that as DAs increased over time on the CCA boards, so too the DAs increased on non-CCA "spacer" boards.

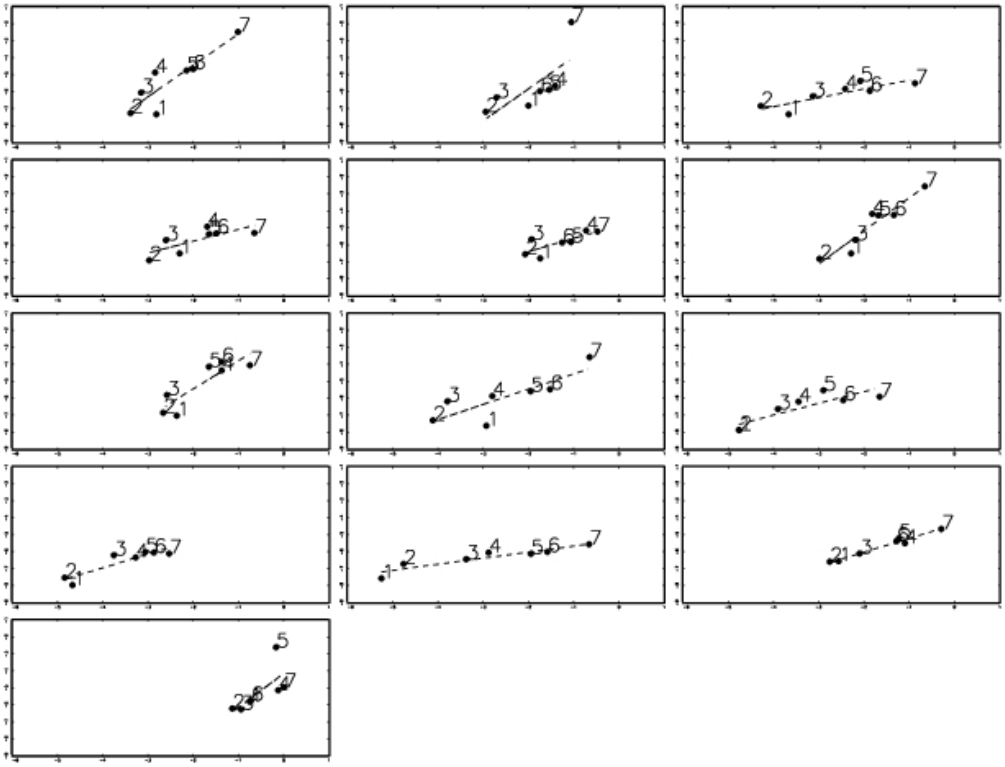

Figure 4-2. Average Spacer Board DAs versus Average CCA board DAs at Each of Seven Time Intervals, plotted by Coating.

In Figure 4-3, seven plots and presented, one for each time period, with sampling events at month 1, 3 and 7 represented on the top row, 11, 15 and 20 on the next row, and 24 on the bottom. The horizontal and vertical axes are ln(DAs) in all plots, where the x-axis is the average of DAs over all CCA boards for the minidecks associated with each coating (denoted by the number next to the data point, where coatings 1 through 9 are identified directly and coatings 10 through 13 are denoted by the letters A, B, C, and D respectively) at the indicated time period and the y-axis is DAs averaged over all

non-CCA boards for the corresponding coating at the given time period. The superimposed line is from the ordinary least fit. This plot shows that DAs on non-CCA boards was higher when those boards neighbored CCA with higher DAs.

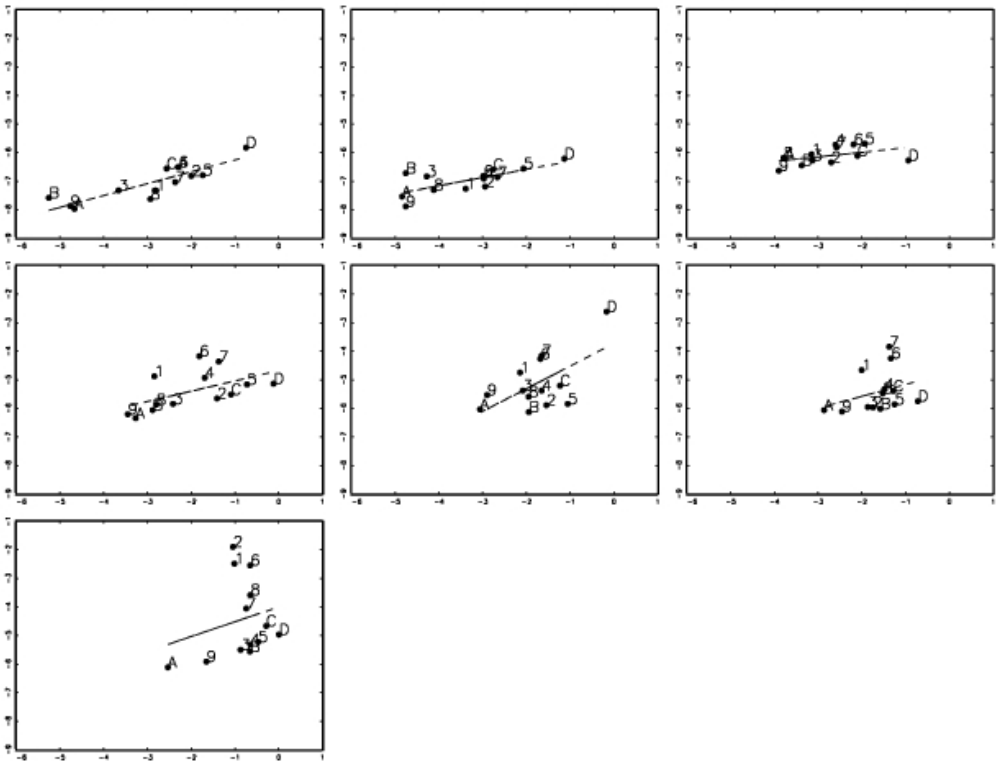

Figure 4-3. Average Spacer Board DAs versus Average CCA board DAs for Each of Thirteen Coatings, plotted by Time Inteval (note that letter A = Coating 10, B = Coating 11, C = Coating 12, and D = Coating 13).

4.8 Sampling Methodology

Various aspects of the wipe sampling method could be studied to improve understanding of sampling factors that may impact DCCA measurements and for refining of the method. These include the following:

- Surface moisture: a measure of surface moisture would ideally be made prior to taking each wipe sample, although robust, reliable and non-destructive moisture measurement protocols would need to be developed.

- Wipe stroke and snagging: the impacts of variable sampling stroke durations and temporary pauses in sampling due to the wipe material catching on surface irregularities could be studied in more detail to ascertain whether these issues affect DCCA and, if so, how those effects might be mitigated.

- Splinter removal: The impacts of removing splinters larger than a grain of rice (as specified in the sampling protocol) on DCCA measurements could be investigated, particularly from a risk perspective. That is, do larger particles get ingested and if so, are they biologically available and/or active.

- Soluble and particulate DCCA: The sampling method does not differentiate between particulate and soluble DCCA fractions unless collected particles are the size of a grain of rice, in which case they are removed from the wipe prior to extraction/digestion and analysis. Although no protocols currently exist for doing so, soluble and particulate DCCA could be separately quantified yielding data to inform the risk assessment and potentially also the manner in which exposure risks can be best mitigated.

- CCA analytes and speciation: The speciation of CCA analytes could be an important determinant of exposure risks. Only total arsenic, total chromium, and total copper were routinely measured in this study, due to resource limitations, as speciating CCA analytes is significantly more complex and costly.

- Cross-contamination controls: The results of analyses of untreated specimens between each treated CCA specimen on the minidecks showed that DAs from the untreated boards generally increased over time, but still represented only fractions of the measured DAs on treated (coated and uncoated) boards. As such, it may not be necessary to rigorously sample these cross-contamination controls, but they should still be provided as buffers between boards in future studies.

4.8.1 Baseline (Pre-Coat) Measurement

A significant logistical issue arises as a result of the sampling process itself and the fact that the wipe sampling technique may affect the surface of the wood in at least two ways: by removing the CCA on the surface of the wood, and by potentially abrading the wood or its coating (as described in Section 4.6).

Ideally, given the relative variability in DCCA between samples taken from areas along the length of treated wood boards, initial surface wipe samples would be taken from each sampling area to be further tested. However, several studies suggest that, as could reasonably be expected, the act of wipe sampling the surfaces of CCA-treated wood removes a considerable amount of the DCCA from a test specimen (CPSC staff 2003a; Stilwell et al., 2003). Furthermore, wipe sampling may cause some abrasion which is suspected to be a significant variable in determining both uncoated DCCA as well as durability and efficacy of tested coatings.

Because of these potential complications and their implication for affecting the results of subsequent samples, the PSAs (i.e., those areas that were wipe-sampled during

each post-coat sampling event) were not sampled prior to coating. Instead, sampling areas on the minidecks adjacent to the PSAs (termed “baseline areas” because they were used to calculate specimen-specific baseline DCCA values) were sampled prior to coating. Individual specimen-specific baseline values of DCCA were then determined for each PSA to be coated and tested by averaging the DCCA from the two adjacent wipe sampling areas on either side of the PSA.

This method of baseline determination was selected in part because existing data suggested that intraboard (within-board) variability was relatively low. Research by Stilwell et al. (2003) showed an intraboard variability (RSD) of 17% versus an interboard (between-board) variability of 39%. It was further assumed that the variability would be even less for sampling areas that were closer to one another (intraboard, interspecimen variability between adjacent sampling areas) than for sampling areas that were further apart, although this assumption was not supported by the data gathered for this project.

Consideration was given to alternate methods of assessing pre-coat DCCA concentrations of the PSAs and it is worth mentioning them here.

- *Wipe sampling the PSAs prior to coating and then waiting or even exposing the test specimen to weathering to induce more migration of DCCA to the surface of the specimen prior to coating.* While this concept may be sound, the existing data supporting the design of such a method is fairly limited (Stilwell et al., 2003). That is, it had not yet been well-established how much time must elapse or under what conditions specimens must be maintained to ensure that surficial CCA analyte concentrations have rebounded to pre-wipe conditions. This may vary with climate, amount of abrasion, and other factors.

- *Taking an average of a number of initial DCCA measurements taken from sampling areas that would then be discarded and not used for the study in any other way.* In such an approach, the baseline values used would not be unique to a specific PSA. Instead, a single baseline DCCA value might be used for numerous PSAs or even for all of the PSAs in the study. However, it was thought that this option might not provide the level of data resolution and statistical power required to adequately assess coating efficacy for this project.

- *Wipe sampling the undersides of the test specimens to establish the baseline DCCA for each specimen.* This was seen as a potentially good option for new CCA-wood specimens, but not for aged specimens, as their top faces are well defined and of much greater interest (given that these faces are the ones to which users are most likely to be exposed) than their bottom faces. The top faces of aged CCA wood specimens would be expected to have considerably different characteristics than their bottom faces, because, for example, they may have been exposed to direct sunlight, abrasion, and so forth, while their bottom faces

have not. While the same is not necessarily true of new CCA wood, CPSC staff data suggests that sample variability along the length of a given board is less than the variability between the top and bottom faces of a specimen, even for new CCA-treated lumber (CPSC staff 2003a). As such, and as previously indicated, the weathering test employed a method whereby the DCCA of adjacent sampling areas were averaged in order to establish unique baseline DCCA values for each individual PSA.

4.8.2 Wipe Sampling Method Comparisons

As described in Section 2.2.2, baseline measurements were made using acid-washed sampling wipes and termed the “A2” sampling method, as described in Section 2.8.3.1. The “2X” sampling method utilized unwashed wipes and was the method used for subsequent sampling events; it is described in Section 2.8.3.2. Side experiments were conducted to determine factors for converting results between the two methods. The results are presented in Section 2.2.2 and the complete report on this series of experiments is provided as Appendix A.

4.9 Potential Future Studies

Future studies could be directed to address any of the issues highlighted in this section; certainly any future studies should at least consider these issues.

While there are many outstanding methodological issues, the results of the primary experiment described in this report indicate that method is fairly robust (the results are reproducible across many variables that were addressed in the protocol). With this in mind, several avenues for immediate future studies are suggested:

- An abrasion element should be developed for use in future coating DCCA mitigation efficacy studies.

- The study scope should be expanded to improve representation across: type and condition of wood used, geographic and climatic regions tested, and coating selection (preferably in coordination with manufacturers to specifically develop products for reducing DCCA).

- Surface preparation, including the effects of periodic cleaning or other mitigation strategies versus coating, and coating reapplication issues should be studied specifically. These issues are important both with respect to the performance of coatings over time as well as to address potential secondary issues that may impact mitigation strategies.

Given the expectation that coating performance may vary significantly with climatic region, surface preparation, and use pattern, the cost-effectiveness of future studies

will be enhanced by testing products specifically developed by the coatings industry to reduce DCCA with consideration given to these critical factors.

5. Quality Assurance and Quality Control

5.1 Assessing DQI Goals

This section summarizes the assessment of data quality goals. Full QA/QC summary reports for each dataset are included in Appendix R. The critical measurements for the outdoor weathering tests were total arsenic, total chromium, and total copper concentrations (in wipe sample extraction fluid). Data quality indicator (DQI) goals for concentration in terms of accuracy, precision, and completeness, as established in the QAPP for this project, are shown in Table 5-1.

Table 5-1. Data Quality Indicator Goals for Critical Measurements

Analyte	Method	Accuracy (Percent Recovery)	Precision (Percent RSD/RPD)	Completeness (Percent)
Arsenic (total)	SW-846 Method 6020 (modified)	90-110	10	90
Chromium (total)	SW-846 Method 6020 (modified)	90-110	10	90
Copper (total)	SW-846 Method 6020 (modified)	90-110	10	90

Note: EPA Method 200.8 substituted for Method 6020. See Section 1.5.1 below for explanation.

5.1.1 Summary of Accuracy and Precision Measurement Results

Over the course of the outdoor weathering study, fifty spike samples at concentrations of 1, 50, 1,000 and 10,000 ug/L were submitted to the analytical laboratory. One sample was disqualified due to spiking error that occurred prior to submission. Completion rates for precision and accuracy were less than the 90% completion targets for measures of precision and accuracy. However, as discussed below, review of the data quality indicators clearly demonstrates that the data is of sufficient quality to meet the purposes of the study. Ninety-three percent (93%) of the data meet a precision criteria of ±15% RPD for duplicate sample extracts with reported concentrations of 1 µg/L and above, and for spike levels >1 µg/L, ninety-five percent (95%) of the spiked extracts met accuracy recovery targets of 100±15%. Completion rates of fifty-eight percent (58%) for an accuracy target of 100±15% at the 1 µg/L spike level with average recovery of 114%, indicates that the method is less reliable in quantification of very small levels of DCCA. The QA results indicate a need for inclusion of spikes at additional levels between 1 and 50 µg/L in future studies to better define the ability of the method to quantify very low levels of DCCA.

Wipe extracts concentrations of <10 µg/L As, Cr, or Cu correspond to DCCA levels of < 0.0032 µg/cm^2. For this study, the wipe extracts from 30 primary sampling area (PSA) samples (about 2.7% of the PSA datapoints), all in the first three time intervals, through 7 months of weathering fell into the concentration range of <10 µg/L. Other samples

that fell into the region of increased analytical uncertainty included samples collected from the untreated control minideck (minidecks BC and NC) samples, samples from the untreated "buffer" or "cross-contamination control" boards that were placed between treated boards on the minidecks, and several BL samples (samples used to assess effects of frequency and number of previous wiping events). The increased measurement uncertainty observed at very low levels of DCCA do not impact interpretation of coatings performance.

5.1.2 Precision

Precision of analysis of split wipe extract samples, is expressed as the RPD of the duplicated measurement and is calculated using Equation 5.1, where Y1 is the concentration of the first sample and Y2 is the concentration of the duplicate sample.

$$RPD = \frac{(Y1 - Y2)}{\overline{Y}} * 100 \qquad \text{(Equation 5.1)}$$

One hundred forty-five blind field duplicates (wipe samples split following extraction) or 7% of the total number of samples collected, were delivered to the laboratory for analysis. Results for three of the split samples were reported by the analytical laboratory as <0.5 or <1.0 µg/L As and Cr. Therefore, numbers of duplicate pairs available for evaluation of precision are 142, 143, and 145 for As, Cr, and Cu, respectively. For the majority of samples, agreement between field duplicates was very good. In only one set of duplicate samples was RPD >50% for each analyte; this was the only sample set where the data was qualified as estimated "J" due to the RPD. Achieved completeness was >80% for all three analytes, which did not meet the DQI goal of 90% established in the QAPP. However, >90% of the duplicate samples met a precision goal of ±15% RPD and this may be more realistic and adequate expectation of precision for these types of samples,

5.1.3 Accuracy and Bias

The accuracy of the measurement is expressed in terms of recovery of a known spike. Recovery is calculated by Equation 5.2, where R is the measured concentration and C is the spiked (i.e., target) concentration.

$$\text{Recovery} = \frac{R - C}{C} x\,100 \qquad \text{(Equation 5.2)}$$

Spiked samples at a minimum of three of four possible concentration levels (10,000 µg/L, 1,000 µg/L, 50 µg/L and 1 µg/L) were analyzed by the laboratory along with the

samples from each sampling event. Overall mean recovery of As was 104% for forty-nine reported spike samples averaged across all spike concentration levels. Completion rates at 100±10% were below the 90% target completion rate, primarily due to low completion rates at the lowest spike level of 1 µg/L. Completion rates of fifty-eight percent (58%) for an accuracy target of 100±15% at the 1 µg/L spike level with average recovery of 114%, indicates decreased reliability of the overall method in quantification of very small levels of DCCA. The QA data indicate a need for inclusion of spikes at additional levels between 1 and 50 µg/L in future studies to better define the ability of the method to quantify very low levels of DCCA.

5.2 Completeness

The ratio of the number of valid data points taken to the total number of data points planned is defined as data completeness. Achieved completeness was >80 percent for all three analytes, but did not meet the DQI goal of 90 percent originally established in the QAPP. Results suggest that the DQI goal of ±10 percent for precision between duplicates may be too ambitious. There was no acceptance criteria given in the analytical method for agreement between duplicate samples and, based on the results of this project, it appears that a DQI goal of ±15 percent RPD may be more realistic for these types of samples. If DQI goals of ±15 percent RPD, completeness would have been greater than 90 percent for all three analytes. Also, the analytical method cites acceptance criteria for recovery of spiked blanks as 85-115 percent which is slightly higher than the DQI goal of 90-110 percent. Using the analytical method criteria, completeness of accuracy results would improve. DQI goals should be reviewed and revised as appropriate for future studies.

5.2 Data Validation Summary

The analytical laboratory was required to submit calibration and QC data along with each data package. All data packages received by ARCADIS/EPA were internally validated by a qualified staff scientist according to the QA/QC criteria set forth in the U.S. EPA *Contract Laboratory Program National Functional Guidelines for Inorganic Data Review,* July 2002 (NFG). When parameters called out in the NFG were different from those established in the QAPP or the analytical method (EPA Method 200.8), the more stringent criteria were used. Validation reports were prepared for each sample delivery group and the reported data were qualified as appropriate. These reports are also included in Appendix R. All of the data collected were used in the analysis of results (i.e., no datapoints were disqualified).

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6. Conclusions

This study evaluated the effect of coatings on DCCA on the surfaces of CCA treated Southern Yellow Pine.

Each coating, as well as the positive (uncoated) controls, exhibited a significant decrease in DCCA between baseline (prerinse and precoat) measurements and samples taken 1 month after coating, demonstrating that a simple rinsing step reduces DCCA, although it should be noted that evaluating the impact of rinsing or surface preparation prior to coating was not an objective of the project and not explicitly factored into the experimental design. The coated minidecks all had lower DCCA than the positive controls, which indicates that coating (using any of the coatings tested) reduces DCCA to some degree, although not always at a statistically significant level, and that the reduction due to coating is greater than that attributable to rinsing. Over the course of the two-year study, DCCA increased with time after coating, although relatively small decreases in DCCA were sometimes observed between sampling intervals, presumably where the sum of removal processes (previous wipe sampling events, rinsing due to rain, etc.) had a greater impact on DCCA than weathering and other factors that may increase DCCA.

The coatings that were tested were compared against one another and uncoated CCA-treated positive controls based on their performance in reducing DAs. Several coatings exhibited DAs reductions estimated to be between 75 and 100 percent (lower and upper 95 percent CI) compared with the positive control minidecks for through at least the first year of weathering. These relatively high-performing products all utilized multiple coats and included two penetrating products: product #3, an oil-based stain with acrylic and product #8, a water-based stain with acrylic; and three film-forming products: the two paints (products #9 and 10) and product #11, a vinyl elastic coating marketed to reduce DCCA.

The efficacy of each product decreased over the study period and by 24 months after coating, only two of the products (products #9 and 10, the paints) had DAs levels that were significantly different than the positive controls. Additionally, the reductions of DAs for one product (#5), a water-based sealant, were generally not statistically different from the positive controls over the course of the study.

While exploratory statistical tests indicated that film-forming products performed significantly better than non-film-formers in these tests, elevated arsenic concentrations were measured in paint chips recovered from the painted CCA-treated minidecks (note that CCA treated wood fibers may be associated with the tested paint chips). This finding is also considered exploratory and warrants further investigation. The occupational exposures due to sanding and milling CCA-treated wood, as reported by Decker et al., (2002), and Nygren et al., (1992), underscore the need for research that evaluates potential exposures to CCA chemicals due to preparation and maintenance

activities; for instance, particle generation due to scraping and sanding of CCA-treated wood to remove cracked, chipped, or weathered coatings.

The protocol utilized in this investigation yielded results that provide a coherent picture of the changes in DCCA as coated CCA wood weathers and, with appropriate development or modification, may serve as a useful tool for the coatings industry or product testing laboratories in efforts to develop new coatings and to measure coating performance for reducing dislodgeable CCA. Specific findings that may inform future use of the protocol include:

- There were significant differences in DCCA (pre- and post-coat) between the two different source decks. That is, source deck is an important variable. Grain orientation, however, was only a marginally significant variable in this study.

- The effects of abrasion resulting from the wipe sampling method used for this study appear to be negligible, thus avoiding potential complications, or false positive interferences, as a result of the sampling methodology. However, rewipe effect – that is, the reduction in DCCA by "cleaning" the surface by sampling – may be significant.

- As with any pilot experiment, there were many potentially important variables that this study did not address, including: impact of stresses associated with full-scale decks, impact of climatic regions, abrasion, multiple coats of the same product, surface preparation procedures, and periodic recoating. Abrasion (e.g., resulting from foot traffic on in-service deck surfaces), in particular, is considered likely to be an important coating performance factor.

Taken as a whole, the results of this study suggest that typical deck coating products (sealants and stains) need to be re-applied periodically in order to maintain significant levels of DAs mitigation. However, this study did not examine the effect on DAs of recoating after a period of weathering, and the results of this study may not be indicative of the reduction in DAs that may be achieved with periodic re-treatment. However, minor adaptation of the methodology should enable evaluation of this and other important variables.

The differences in efficacy observed among products in reducing DCCA suggests that products could be tailored to reduce DCCA. Broad-based testing of products may be needed to empower consumers to make informed choices. The paint chip results also indicate a need to better understand and characterize the potential impacts of recoat preparation steps, particularly for film forming products.

7. References

CPSC staff 2003(a). “Statistical Analyses of CCA-Treated Wood Study Phases I and II.” Memorandum from Mark S. Levenson to Susan Ahmed and Russell Roegner, dated January 10, 2003. Consumer Products Safety Commission.

CPSC staff. 2003(b). Memorandum from David Cobb to Patricia Bittner, “CCA-Pressure Treated Wood Analysis – Exploratory Studies Phase I and Laboratory Studies Phase II,” in the Briefing Package, “Petition to Ban Chromated Copper Arsenate (CCA)-Treated Wood in Playground Equipment (Petition HP 01-3), U.S. Consumer Product Safety Commission, Washington, D.C., February 4, 2003. pp 229. http://www.cpsc.gov/LIBRARY/FOIA/FOIA03/brief/briefing.html. April 27, 2005.

Decker, P., Cohen, B., Butala, J.H., and Gordon, T. Exposure to wood dust and heavy metals in workers using CCA pressure-treated wood. *AIHA J*, 2002, No. 63 (2): 166-171.

Hatlelid, K. et al., 2004. Exposure & Risk Assessment for Arsenic from CCA-Treated Wood Playground Equipment. Journal of Children’s Health, Vol 2, Nos. 3-4, pp. 215-241.

Kwon, E., Zhang, H., Wang, Z., Jhangri, G.S., Lu, X,. Fok, N., Gabos, S., Li, X., and Le, X.C. Arsenic on the Hands of Children after Playing in Playgrounds. *Environmental Health Perspectives On-line*, Online 17 June, 2004, doi:10.1289/ehp.7197 (available at **http://dx.doi.org/**).

Lebow, S. 1996. “Leaching of Wood Preservative Components and Their Mobility in the Environment. Summary of Pertinent Literature.” Forest Products Laboratory, U.S. Department of Agriculture. General Technical Report FPL-GTR-93. August 1996.

Lebow, S., R.S. Williams, P. Lebow. 2003. "Effect of Simulated Rainfall and Weathering on the Release of Preservative Elements from CCA Treated Wood." Environ. Sci. Technol. Vol. 37, No. 18, p. 4077-4082

Lebow, Stan. USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin. Personal communication, 2006.

Levenson, M. et al., 2004. A Field Study of Dislodgeable Arsenic from CCA-Treated Wood Using Human-Hand and Surrogate Wipes. Journal of Children’s Health, Vol 2, Nos. 3-4, pp. 197-213.

Nygren, O., Nilsson, C. A., and Lindahl, R. Occupational exposure to chromium, copper and arsenic during work with impregnated wood in joinery shops. *Ann. Occup. Hyg*. 1992, No. 36 (5): 509-517.

SAP Minutes No. 2007-02. EPA's Science Inventory: www.epa.gov/si/, Record 150970

SPC. 2006. "What is Pressure-Treated Lumber?" http://www.southernpine.com/whatisptlumber.shtml

Stilwell, D., M. Toner, B. Sawhney. 2003. "Dislodgeable Copper, Chromium and Arsenic from CCA-Treated Wood Surfaces." The Science of the Total Environment. 312 (2003). 123-131.

Thomas, T. et al., 2004. The Development of a Standard Hand Method & Correlated Surrogate Method for Sampling CCA-Treated Wood Surfaces for Chemical Residue. Journal of Children's Health, Vol 2, Nos. 3-4, pp. 181-196.

U.S. EPA. 2003. "Evaluation of the Effectiveness of Coatings in Reducing Dislodgeable Arsenic, Chromium, and Copper from CCA Treated Wood. Revision 6." U.S. EPA, Research Triangle Park, NC, September 24, 2003.

U.S. EPA. 2005. "Evaluation of the Effectiveness of Coatings in Reducing Dislodgeable Arsenic, Chromium, and Copper from CCA Treated Wood - Interim Data Report." EPA Report: EPA/600/R-05/050; U.S. EPA, Research Triangle Park, NC, May 9, 2005.

Ursitti, F., Vanderlinden, L., Watson, R., Campbell, M. Assessing and managing exposure from arsenic in CCA-treated wood play structures. *Canadian Journal of Public Health*, **2004**, 95, 429-433.

Williams, R.S. and Feist, W.C. Finishing Wood Decks. Wood Design Focus, Volume 4, Number 3. U.S.D.A. Forest Products Laboratory, 1993.

Williams, R.S., Knaebe, M.T., Evans, J.W., Feist, W.C. Erosion rates of wood during natural weathering. Part III. Effect of exposure angle on erosion rate. *Wood Fiber Sci.* **2001**(c), *33*(1), 50 – 57.

Williams, R.S., Knaebe, M.T., Feist, W.C. Erosion rates of wood during natural weathering. Part II. Earlywood and latewood erosion rates. *Wood Fiber Sci.* **2001**(b), *33*(1), 43 – 49.

Williams, R.S., Knaebe, M.T., Sotos, P.G., Feist, W.C. Erosion rates of wood during natural weathering. Part I. Effects of species, grain angle and surface roughness. *Wood Fiber Sci.* **2001**(a), *33*(1), 31 – 42.

Zartarian, V.G., Xue, J., Ozkaynak, H., Dang, W., Graham, G, Smith L., and Stallings, C. A Probabilistic Arsenic Exposure Assessment for Children Who Contact CCA-Treated Playsets and Decks, Part I: Model Methodology, Variability Results, and Model Evaluation. *Risk Analysis*, **2006**, 26, No. 2, 515-531.