A Comparison of the Wet Wipe and Tape Lift Methods for Sampling Surface Char in Residential Properties Impacted by Wildfire Smoke

By Joe C. Spurgeon, Ph.D., Franco Seif, and Euginia Mirica, Ph.D.

Introduction

This study had three objectives. The first objective was to compare the wet wipe and tape lift sampling methods for the collection of wildfire smoke residues. The comparison of sampling methods was based on the collection of replicate (side-by-side) wet wipe and tape lift char samples from 48 houses potentially impacted by wildfire smoke plumes. The second objective was to compare the use of perimeter (interior window sills) and interior (hard surfaces) sampling locations for evaluating the impact of wildfire smoke residues. The third objective was to compare the two sampling methods on the basis of percent char as well as the assessed impact of char using example guidelines established by the authors for this purpose.

The initial inspection of a property following a wildfire is often limited to a walkthrough visual inspection, odor evaluation, and surface sampling to detect wildfire smoke residues that may be present on surfaces. Surface residues typically include char, soot, and ash. These residues can be sampled using tape lift, swab, wet or dry wipe, or microvacuum sampling methods.[1, 2, 3] Samples collected using those methods can be analyzed by optical microscopy and/or submitted for analysis using methods providing more detailed information.[3, 4, 5]

Wildfires are expected to impact the built environment on a more frequent basis in the near future due to the continued expansion of the woodland-urban interface as well as changing environmental factors.[6] Therefore, methods for evaluating the impact of wildfire smoke on indoor spaces is a current and important topic and is likely to become more important in the future. Wildfire smoke contains a variety of chemicals and particulates, which can infiltrate into properties

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SYNOPSIS

Wildfires are expected to impact the built environment on a more frequent basis in the near future. Therefore, methods for evaluating the impact of wildfire smoke on indoor spaces is a current and important topic. Wildfire smoke contains a variety of chemicals and particulates, which can infiltrate into properties affected by the smoke plume. Wildfire smoke not only affects structures, contents and building systems, but semi-volatiles from residues deposited on surfaces may contribute to occupant exposures.

This study compared the wet wipe and tape lift methods for evaluating the impact of wildfire smoke residues. The study had three objectives. First, compare the wet wipe and tape lift sampling methods for the collection of wildfire smoke residues. Second, compare the use of perimeter (interior window sills) and interior (hard surfaces) sampling locations. Third, compare the two sampling methods on the basis of percent char as well as the assessed impact of char using example guidelines established by the authors.

Inspections were performed on 48 houses potentially impacted by the Saddleridge, Tick, Maria, Tenaja and Hill fires in southern California in October 2019. The houses had not been professionally cleaned or restored prior to the inspections.

A total of 96 tape lift and wet wipe samples were collected in the 48 properties. Replicate tape lift and alcohol wet wipe samples were collected by using both methods to sample the same surfaces on adjacent spots. The sample locations were selected by conducting a visual inspection to identify potentially contaminated surfaces.

The study's findings included:

- The sampling methods were equivalent when sampling interior window sills for the purpose of evaluating exposure of the structures to a wildfire smoke plume.
- Both sampling methods were useful for identifying those properties that had not been impacted by wildfire smoke residues.
- The wet wipe sampling method was better for assessing the impact of wildfire smoke residues compared to the tape lift sampling method for interior hard surface locations. The wet wipe sampling method detected higher levels of char, and in a higher percentage of houses.
- There was no significant difference in percent char between perimeter and interior sampling locations for the wet wipe sampling method, with positive and negative differences between the two sampling locations essentially equally distributed. There was a significant difference in percent char between perimeter and interior sampling locations for the tape lift sampling method, with reported percent char for perimeter locations equal to or greater than percent char reported for the interior locations.
- The choice of sampling method would have potentially affected the assessed impact of the percent char, and presumptively the restoration work plan, in 88% of the smoke-impacted houses.
- The stratification of interior spaces to better target restoration activities was a useful concept when assessing the impact of wildfire smoke residues. The results of the study suggested stratification of interior spaces to better target restoration activities may have been useful in 45% to 61% of the smoke-impacted houses.

affected by the smoke plume.[7] Wildfire smoke not only affects structures, contents, and building systems, but semi-volatiles from residues deposited on surfaces may contribute to occupant exposures.[8] Unless the wildfire residues are adequately remediated and the affected properties are properly restored, property damage can continue post-incident, and occupants may continue to report symptoms consistent with exposure to sensory and respiratory irritants.[8, 9, 10]

The preliminary determination resulting from the initial inspection and surface sampling of a property often provides the basis for a restoration work plan. Therefore, the selection of the sampling method(s) used to collect the initial samples may have a substantial influence on the assessed impact of a wildfire smoke plume. However, there are few studies available in the published literature comparing the relative performance of wet wipe and tape lift samples.[1, 2, 3]

Methods

Inspections were performed on 48 houses potentially impacted by the Saddleridge, Tick, Maria, Tenaja and Hill fires in southern California in October 2019. The Saddleridge and Tick fires were located in the San Fernando Valley and Canyon Country of Los Angeles County, the Maria fire was located in the Somis area of Ventura County, and the Maria and Hill fires were located in San Diego County. The distances of the houses from the wildfires ranged from a few hundred yards to 15 miles. The inspections were performed in January and February 2020. The houses had not been professionally cleaned or restored prior to the inspections.

A total of 96 tape lift and wet wipe samples were collected in the 48 properties. Replicate tape lift and alcohol wet wipe samples were collected by using both methods to sample the same surfaces on adjacent spots. Tape lift samples were collected as close to the wet wipe sample locations as possible. The samples were collected in both interior and perimeter sampling locations by sampling interior horizontal hard surfaces and interior window sills, respectively. Interior hard surfaces included tables, floors, baseboards, doors, bedframes, and dressers. The sample locations were selected by conducting a visual inspection to identify potentially contaminated surfaces.

Each sample analyzed by the laboratory was a composite of individual samples that had been collected from three to five surfaces. The number of individual samples that were collected varied based on the available surfaces in a particular space and the visual assessment of the surfaces. However, the number of individual samples composited for each replicate wipe and tape sample were matched. The limit of detection (LOD) was not expected to vary substantially for variations between three and five samples.

Tape lift samples were collected using BVDA International forensic tape measuring 2 × 4 square inches. Samples were collected by grasping one end of the tape and gently pressing the adhesive side of the tape on the hard surface, carefully lifting it then placing it back on the card that was included with the sampling tool. This process was repeated on three to five hard surfaces, with the total area sampled varying from 24 to 40 square inches depending on the number of surfaces sampled.

The tape lift samples were analyzed by EMSL Laboratories using the following procedures:

- The tape lifts were screened by stereo-microscopy (SM) which allowed any overloaded sections of tape to be avoided during analysis.
- During the analysis by SM and reflected light microscopy (RLM), the sample was inspected to observe the characteristics of the particles such as color, size, morphology, and evidence of cellular morphology.
- A representative section of the sample that was not overloaded was mounted on a glass slide, refractive index (RI) oil added, and the sample was analyzed by polarized light microscopy (PLM) using the Visual Area Estimation (VAE) method (EPA/600/R-93/116).
- The reporting limit of the method was 1%. Detectable char at less than 1% was reported at a concentration of 0.9%, and for concentrations greater than 2% the results were reported in 5% increments due to counting rules established by the laboratory.

Wipe samples were collected using BD alcohol pads containing 70% isopropyl alcohol and measuring 1 × 1 square inches. A pad was used to wipe approximately 8 square inches of the hard surface, which was then placed into a plastic bag, sealed, and labeled. This process was repeated on three to five hard surfaces inside each property, using a fresh pad for each surface. The individual samples were then combined by the laboratory for analysis to provide a composite sample, with the area sampled varying from 24 to 40 square inches depending on the number of surfaces sampled.

The wet wipe samples were analyzed by EMSL Laboratories using the following procedures:

- The wet wipes were examined by SM, composited, sonicated for 10 to 15 minutes in isopropanol, and

the suspension was filtered onto a polycarbonate or mixed cellulose ester filter with a pore size of 0.45 or 0.8 micron.
- The particle density on the filter was observed by SM and epi-RLM to determine the overall loading on the filter.
- The characteristics of the particles were observed, including color, size, morphology, and evidence of cellular characteristics.
- A representative aliquot of the sample was mounted on a glass slide with refractive index oil for analysis by PLM.
- The PLM technique was used for identification of char and ash along with screening/presumptive analysis of soot clusters.
- TEM/EDX analysis was performed on an aliquot from the unfiltered suspension. This method was applied to confirm the presence of soot/black carbon based on the aciniform morphology and size in the nanometer range.
- Scanning Electron Microcopy (SEM/EDX) was used to obtain morphological details and elemental composition of char and ash.
- The samples were analyzed for the presence of char, soot, and ash, but the results for soot and ash in all the samples were at non-detect or less than 1%. Therefore, only the results for char particles are discussed in this investigation.

Results

Thirty of the 48 wet wipe samples and 29 of the tape lift samples collected on window sills were reported with a percent char of less than 1%, which was interpreted as indicating no detectable or substantial exposure to a wildfire smoke plume. Both sampling methods, when used to collect samples from interior window sills, were capable of identifying properties that had not been substantially impacted by wildfire smoke residues. The interior window sills, as sampling locations, were easily sampled using both wet wipes and tape lifts, and surface char was detected by both sampling methods even 60 to 90 days post-fire. Window sills are often subject to infiltration, and are convenient sampling locations that may be useful for evaluating exposure to a wildfire smoke plume. It should be noted that this purpose is distinct from evaluating the *impact* of wildfire smoke residues.

Figure 1 illustrated the difference between wet wipe and tape lift samples collected on interior window sills. The differences for eight of the 48 samples exceeded 2% char, with positive differences evenly distributed between the two sampling methods.

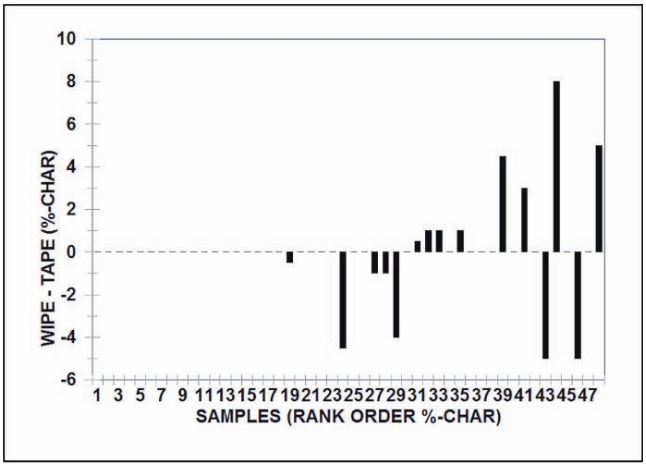

Figure 1. Differences in %-char between replicate wet wipe and tape lift samples collected on interior window sills.

Figure 2 illustrated the difference between wet wipe and tape lift samples collected on interior hard surfaces. The differences for 11 of the 48 samples exceeded 2% char, with wet wipe samples detecting a higher percent char in seven of the 11 samples (64%) compared to the replicate tape lift sample.

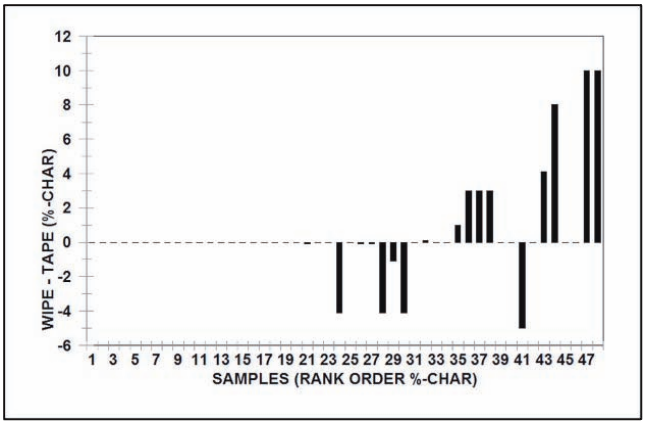

Figure 2. Differences in %-char between replicate wet wipe and tape lift samples collected on interior hard surfaces.

Figure 3 compares the wet wipe and tape lift samples for the 23 samples with percent char of 1% or greater that were collected from perimeter locations (interior window sills). As previously noted, a percent char of less than 1% was reported for 30 of the wet wipe samples, and those samples were not included in Figures 3 and 4 for clarity. These were the properties presumed to have been potentially impacted by smoke plumes. The same percent char was reported for 22 of the 23 samples in Figure 3 with a percent char greater than or equal to 1%. A Wilcoxon Signed Rank statistical test comparing the two methods for interior window sills could not be performed since only two of 23 samples had a non-zero W statistic.

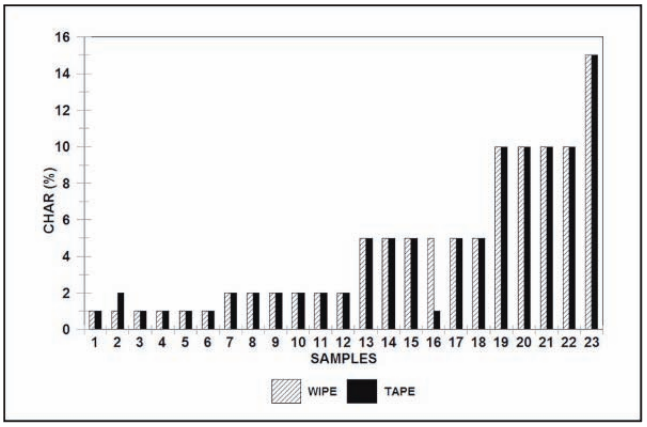

Figure 3. Comparison of wet wipe and tape lift samples collected from perimeter locations on interior window sills.

Figure 4 compared the 18 wet wipe and tape lift samples with a percent char of 1% or greater that were collected from hard surfaces.

The comparison of the two sampling methods for samples collected from interior locations (hard surfaces) in Figure 4 indicated the following:

- Tape lift samples resulted in more "false negatives" compared to wet wipe samples. The 18 wet wipe samples had a percent char between 1% and 20%, while five of the 18 replicate tape lift samples (28%) had a percent char of less than 1%. In addition, tape lift samples consistently underestimated the percent char and presumptively the assessed impact of smoke residues. The tape lift samples detected a lower percent char in 11 of the 18 samples (61%), a similar percent char in six samples (33%), and a higher percent char in only one sample (6%).
- When the tape lift samples detected char, usually they underestimated the percent char, and presumptively the assessed impact and the required level of restoration. Thirteen (72%) of the wet wipe samples detected a percent char of 5% or greater compared to three (17%) tape lift samples.
- Wet wipe samples detected a wider range of char concentrations, even though they were composite samples and the results were averaged. Five of the wet wipe samples detected 10% to 20% char while two tape lift samples detected a maximum of 10% char.

The purpose of this comparison was to evaluate the relative ability of the two sampling methods to evaluate the impact of wildfire smoke residues. For example, except for sample 14, the percent char was higher for the wet wipe sample in each pair of replicate samples. The difference in percent char in 12 of the 18 samples (67%) was sufficiently large that the choice of sampling method would have affected the assessed impact of the wildfire smoke residues. The percent char was higher for the wet wipe samples in 11 of those samples.

The Wilcoxon Signed Rank statistical test was used to compare the two methods for hard surfaces. This review had W = 97 with $W_{critical}$ = 40 for a sample size of 18 at $\alpha = 0.05$. This review rejected the hypothesis that there was no difference between the two methods. Indeed, the statistical review based on the Wilcoxon method indicated a significant difference between the results of the two methods. Compared to the wet wipe sampling method, sampling interior hard surfaces using the tape lift sampling method was prone to "false negatives." The tape lift method detected lower concentrations of char compared to the wet wipe method, and detected elevated char in a lower percentage of houses. The wet wipe sampling method characterized the impact of wildfire smoke residues better than the tape lift sampling method.

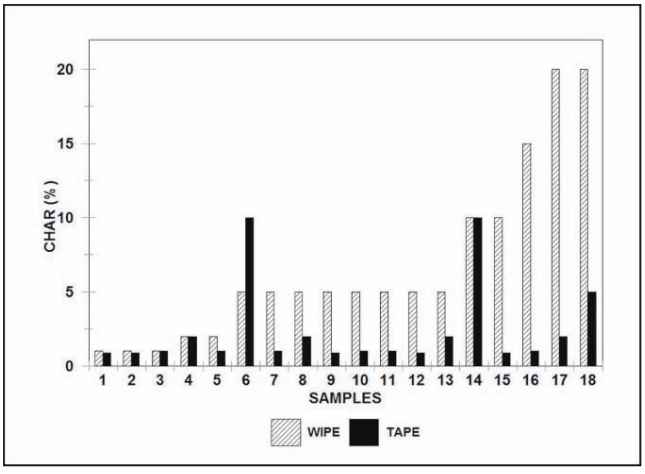

Figure 4. Comparison of wet wipe and tape lift samples collected from interior locations on hard surfaces.

The samples collected from perimeter and interior locations using the wet wipe method were compared. Sampling either perimeter or interior locations with the wet wipe method identified 30 properties (63%) that had a percent char less than 1%, suggesting those properties had not been substantially impacted by wildfire smoke residues.

The 17 samples with a percent char greater than or equal to 2% had a higher percent char for five perimeter samples and seven interior samples, with an equal percent char for five samples. The differences in percent char of 3% or more between window sills and hard surfaces in eight (47%) of the 17 wet wipe samples may have been sufficient to affect the assessed impact of smoke residue.

The tape lift method identified 27 of the 48 samples (56%) collected from interior window sills or hard surfaces that had a percent char less than 1%. The perimeter samples collected using tape lift samples resulted in an equal or greater reported percent char compared to the interior samples. The differences in percent char between the two sampling locations were sufficiently large to affect the reported concentration range in 13 (72%) of the 17 samples with a percent char greater than or equal to 2%. The magnitude of the differences in these 13 samples could have potentially affected the assessed impact of wildfire smoke residues. It was concluded that the tape lift sampling method was more suitable for sampling window sills rather than hard surfaces in these 17 houses.

Assessing Residue Impact

The primary objective of this study was to compare the tape lift and wet wipe sampling methods. The stratification strategy illustrated in Table 1 was used to determine if the difference in the concentration of char detected by the two sampling methods would have resulted in a different assessment of impact, and possibly a difference in the level of restoration. The four concentration ranges in Table 1, designated as Residue Impact Areas (RIA) 1–4, were selected arbitrarily to illustrate a possible stratified sampling strategy for wildfire smoke residues. A stratified sampling strategy is common in industrial hygiene investigations and has been recommended by multiple organizations for use in mold inspections.[11, 12, 13]

% Char	RIA	INSPECTION	RESTORATION
< 1%	1	Non-detect	No Impact; no restoration
1% – 2%	2	Detected	Low Impact; cleaning, HEPA-vac
3% – 5%	3	Moderate	Moderate Impact; restoration
> 5%	4	Elevated	Heavy Impact; systems, occupant exposure, specialists

Table 1. Ranges of % char on interior surfaces and residue impact area.

The RIA designation may be applied to a specific area within a structure or to the entire structure, as appropriate. The impact of wildfire smoke on interior spaces may not always be uniform within a structure, with multiple RIA within the structure. The restoration in those structures can be more efficient if each space can be associated with the appropriate level of restoration. During an actual wildfire inspection, the impact of wildfire smoke may be estimated based on criteria such as visual inspection and odor detection, and may include the collection of surface samples to confirm and measure wildfire smoke residues. In this study, only the sample results for surface char were used to define the RIA in Table 1.

The first assumption included in Table 1 was that the impact of wildfire smoke on interior spaces may not always be uniform within a structure, with multiple RIA present within a structure. The second assumption included in Table 1 was that the different concentration ranges may affect the recommendations included in the restoration work plan prepared by the inspector, which would then result in different responses by the restoration contractor. The third assumption was that if the two sampling methods resulted in a difference in char concentration, but did not result in a difference in the RIA, then there was no practical difference between the two methods. For example, a reported percent char of 10% for method 1 and 20% for method 2 would result in an assessment of RIA-4 for both methods, and the same response by the restoration contractor.

The concentration of char in the samples collected on interior surfaces was used as the criterion to assess the impact of wildfire smoke residues in Table 2. The interior spaces in the 48 houses were assigned to one of four RIA on the basis of the percent char reported in the wet wipe samples collected from interior surfaces. The percentages in the wet wipe and tape lift sample columns indicate the percent of samples of that type that were included in each concentration range.

% Char	RIA	WET WIPES	TAPES	AGREEMENT
< 1%	1	63%	71%	97% [29/30]
1% - 2%	2	10%	23%	18% [2/11]
3% - 5%	3	17%	2%	0% [0/9]
> 5%	4	10%	4%	16% [1/6]

Table 2. Distribution of residue impact area by sampling method.

Discussion

This study compared the wet wipe and tape lift methods for evaluating the impact of wildfire smoke residues. Restoration work plans include the presumption that sample results are representative of the impact of the wildfire smoke residues. If the sample results do not properly reflect the impact of the smoke residues, then the scope of the work plan may not be sufficiently inclusive to adequately restore the property. Therefore, the sampling method that provides a better characterization of the impact of smoke residue should be preferred for preparing the restoration work plan.

Because there can be multiple inspection objectives, there can be multiple factors involved in selecting sampling methods. A wildfire inspection can have at least three broad assessment objectives:

- Identify the source of the smoke residues.
- Assess the impact of smoke residues on the structure.
- Assess occupant exposure potentials.

Different objectives will typically require the use of different sampling methods. Identifying the source of the smoke residues as the subject wildfire may require the collection of tape lift samples, which are intended to preserve the spatial, structural, and morphological characteristics of the smoke residues on surfaces. However, once samples have been collected to evaluate the source of the residues, other sampling methods may be preferred to assess the impact of wildfire smoke residues or to assess occupant exposures. For example, the wet wipe sampling method may be preferred for evaluating the impact of wildfire smoke residues, as discussed in this study.

However, a difference in the char concentration (percent char) may or may not result in a difference in the assessed impact of wildfire smoke residue. A realistic comparison of sampling methods should also consider if the methods result in a difference in the assessed impact rather than simply in a difference in the reported percent char. For example, the difference between a percent char of 2% and 5% may or may not affect the assessment of impact, and potentially the recommended level of restoration. This would depend on the assessment guidelines specified in the restoration work plan.

Therefore, arbitrary guidelines were used to illustrate the concept of comparing the two sampling methods based on the assessment of impact rather than simply the reported percent char. Basing the comparison on guidelines rather than percent char resulted in a more useful comparison of the two sampling methods. The comparisons of assessed impact for the two sampling methods assumed that each example range of percent char represented a different impact level and recommended level of restoration. The example impact levels were based on percent char as follows: less than 1%, 1% to 2%, 5%, greater than 5%.

The two sampling methods were in good agreement for those surfaces on which wildfire smoke residues were not detected (RIA-1), with 29 of the 30 RIA-1 samples (97%) in agreement as to the assessed RIA and lack of impact by wildfire smoke. However, the two methods were not in good agreement when even light char (RIA-2) was present on interior surfaces. The samples collected from interior surfaces using the two sampling methods would have resulted in a different RIA, and therefore different restoration work plans, for 82% of the RIA-2, 100% of the RIA-3, and 84% of the RIA-4 samples. These differences would have affected the presumptive assessment in 48% of all the houses and 88% of the smoke impacted houses.

The two sampling methods were compared for 18 interior hard surfaces with RIA 2-4 in Figure 3:

- Five of the wet wipe and tape lift samples were both assessed as RIA-2.
- Thirteen of the wet wipe samples were assessed as RIA-4. Three of those tape lift samples were assessed as RIA-4, with the remaining 10 assessed as RIA-2.
- Collecting samples on interior hard surfaces with wet wipes as compared to tape lifts would have resulted in a higher level of restoration for 10 (39%) of the smoke-impacted houses.

It was assumed that the impact of wildfire smoke on interior spaces may not always be uniform within a structure. The results for 18 wet wipe samples with RIA 2-4 that were collected from perimeter and interior locations were compared. Eight of the replicate samples, representing 45% of the properties impacted by wildfire smoke residues, were assessed to be in different RIA. A similar analysis of the 18 tape lift samples indicated that 11 of the replicate samples (61%) were in different RIA.

Thus, the impact of wildfire smoke residues on interior spaces was not uniform in 45% to 61% of the 18 houses that were impacted by wildfire smoke and 17% to 23% of the 48 houses included in the study. This result suggested that assessing the impact of smoke residues using conditional areas such as RIA may improve the efficiency of the restoration process. If the inspector uses RIA as the basis for the inspection report, then the restoration contractor has the basis for a more effective, targeted, and cost-effective restoration. A stratified approach, as recommended in IICRC S520, would allow the restoration work plan to be less generalized and better associated with impact, and the restoration possibly more cost effective. Therefore, based on the results obtained in these 48 houses, the stratification of interior spaces to better target restoration activities may be a useful concept when assessing the impact of wildfire smoke residues.

Conclusions

This study compared the wet wipe and tape lift sampling methods when used to assess houses

potentially impacted by wildfire smoke plumes. The study's findings included:

- The sampling methods were equivalent when sampling interior window sills for the purpose of evaluating exposure of the structures to a wildfire smoke plume.
- Both sampling methods were useful for identifying those properties that had not been impacted by wildfire smoke residues.
- The wet wipe sampling method was better for assessing the impact of wildfire smoke residues compared to the tape lift sampling method for interior hard surface locations. The wet wipe sampling method detected higher levels of char, and in a higher percentage of houses.
- There was no significant difference in percent char between perimeter and interior sampling locations for the wet wipe sampling method, with positive and negative differences between the two sampling locations essentially equally distributed. There was a significant difference in percent char between perimeter and interior sampling locations for the tape lift sampling method, with reported percent char for perimeter locations equal to or greater than percent char reported for the interior locations.
- The choice of sampling method would have potentially affected the assessed impact of the percent char, and presumptively the restoration work plan, in 48% of the total houses and in 88% of the smoke impacted houses.
- The stratification of interior spaces to better target restoration activities was a useful concept when assessing the impact of wildfire smoke residues. The results of the study suggested stratification of interior spaces to better target restoration activities may have been useful in 45% to 61% of the smoke impacted houses.

Study Limitations

The results suggested that about 30 of the 48 houses included in the study had not been substantially affected by a smoke plume. A percent char equal to or greater than 1% was only reported in 18 of the 48 the houses. This is a limitation that affects field studies in general and was beyond the control of the investigators.

Second, only four composite samples were collected in each house, which included one sample with each sampler and at each sampling location. The composite samples were both a strength and potential weakness of the investigation. The composite samples reduced sample size, allowing more surfaces to be sampled per unit cost. They also provided an average value for each house that was presumably more representative of the interior environment. However, composites also reduced the number of samples available for statistical analysis.

Third, only char was detected in the samples. Although soot is a commonly detected smoke residue, the absence of soot and ash were confirmed by TEM/SEM.

Fourth, the distances of the 48 houses from either the centers or perimeters of the various wildfires were not reported. Therefore, it was not possible to associate percent char with proximity to the wildfire. JCS

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