

Sampling and Characterizing Wildfire Smoke Residues

IAQ Radio
Webinar
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Webinar Presentation

- **First CSC study**
 - Compare the relative performance of wet wipe and tape lift samples for evaluating the impact of surface char from wildfire smoke
 - **Franco Seif**
- **Second CSC Study**
 - Characterize several factors that can affect the evaluation of wildfire smoke residues
 - **Joe Spurgeon**

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First Study

- **Objective**
 - **Compare the relative performance of the wet wipe and tape lift sampling methods for evaluating impact**
- **Tape lift and wet wipe samples are two commonly used methods for sampling wildfire smoke residues**
- **Assumption: The choice of sampling method may affect the evaluation of the impact of wildfire smoke residues**

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Description

- **Compare the wet wipe and tape lift sampling methods for the collection of surface char by collecting side-by-side samples**
- **Compare the results for perimeter penetrations and interior surfaces by sampling**
 - **Perimeter locations (Interior Window Sills)**
 - **Interior locations (Interior Hard Surfaces)**

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Houses Sampled

- **48 houses were sampled in so. CA**
 - **Potentially impacted by one of five wildfires**
 - **Elapsed times between wildfire and inspection**
 - **90 – 120 days**
 - **Distances from wildfire to houses varied from**
 - **less than 1 mile to 15 miles**

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Sample Collection

- **Replicate (side-by-side) tape lift and wet wipe samples were collected in each house**
 - **Tape lifts – 2x4 in² BVDA tape**
 - **Wet wipe – 1x1 in² BD alcohol pads**
- **Individual samples were collected from 3-5 spots**
 - **Composited by the laboratory into 192 samples**
- **Interior window sills**
 - **48 tape lift and 48 wet wipe composite samples**
- **Interior hard surfaces**
 - **48 tape lift and 48 wet wipe composite samples**
 - **Tables, baseboards, floors, dressers, bed frames**

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Sample Analysis

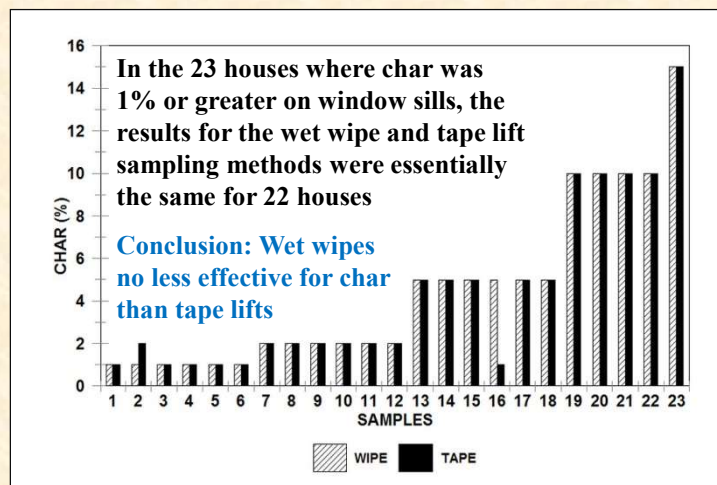
- Analysis by EMSL Laboratories
 - Composited, sonicated, filtered, then analyzed
 - Samples examined by stereo-microscopy, reflected light microscopy, TEM/EDX, and SEM/EDX
 - Soot and ash were not detected in any sample
 - Laboratory confirmed this result was not unusual or specific to the wet wipe method
 - Char analysis by polarized light microscopy (PLM) and concentration (%-char) reported using the Visual Area Estimation method
- Comparison of methods based on %-char

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Perimeter Window Sills

Was the interior exposed to a wildfire smoke residues?

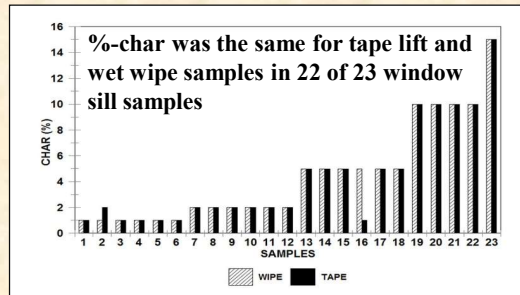


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Laboratory Analysis

Did sonication or filtering of wet wipe samples affect the concentration of char?



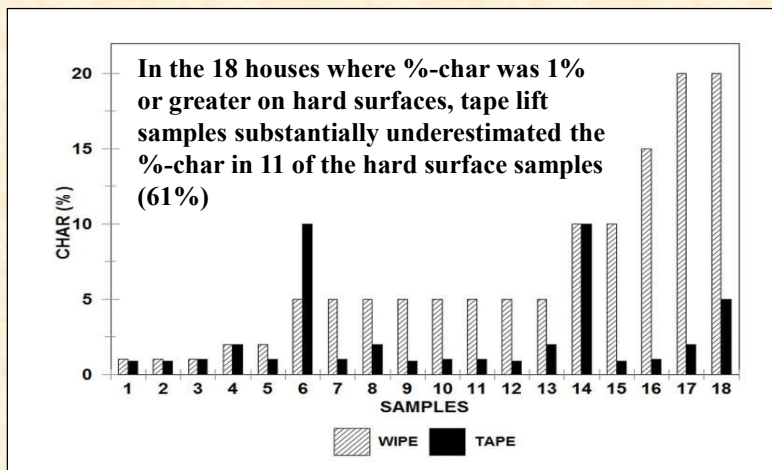
Conclusion: Sample preparation of the wet wipe samples by the laboratory did not affect the concentration of char

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Interior Hard Surfaces

What was the impact of the wildfire plume?

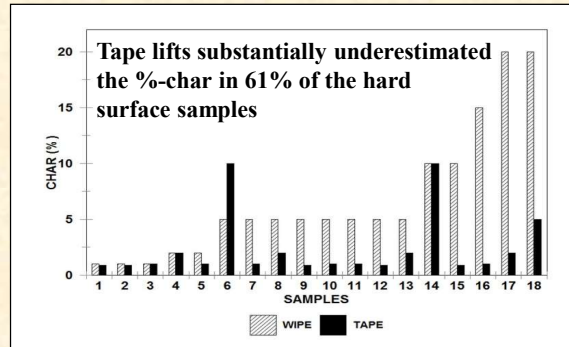


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Surface Effects

Why was there such a difference between interior window sills and hard surfaces?



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Wet Wipe v Tape Lift

| | Windows | Windows | Interiors | Interiors |
|------|---------|---------|-----------|-----------|
| CHAR | Wipe | Tape | Wipe | Tape |
| <1% | 25 | 25 | 30 | 34 |
| 1% | 6 | 6 | 3 | 6 |
| 2% | 6 | 7 | 2 | 5 |
| 5% | 6 | 5 | 8 | 1 |
| 10% | 4 | 4 | 2 | 2 |
| >10% | 1 | 1 | 3 | 0 |

Results:

Wet Wipes => 63% with <1%, 27% with %-char => 5%

Tape Lifts => 71% with <1%, 23% with %-char of 1%-2%

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Wet Wipe v Tape Lift

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|------|---------|---------|-----------|-----------|
| CHAR | Wipe | Tape | Wipe | Tape |
| <1% | 25 | 25 | 30 | 34 |
| 1% | 6 | 6 | 3 | 6 |
| 2% | 6 | 7 | 2 | 5 |
| 5% | 6 | 5 | 8 | 1 |
| 10% | 4 | 4 | 2 | 2 |
| >10% | 1 | 1 | 3 | 0 |

- %-char of 5% or greater for 27% of wet wipe samples compared to 6% of tape lift samples
- %-char of 1%-2% for 10% of wet wipe samples compared to 23% of tape lift samples

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Choice of Sampling Method

- **Different methods for different objectives**
- **If the objective is to determine if**
 - The structure was exposed to a wildfire plume
 - The interior was exposed to wildfire residues
 - Then may sample interior window sills using either tape lifts or wet wipes, for example
- **If the objective is to evaluate the impact of wildfire smoke residues**
 - Then may prefer to sample interior hard surfaces using wet wipes, for example

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Conclusions

- **Char was the primary wildfire smoke residue**
 - Soot and Ash were not detected in any of the 192 samples
- **Sample preparation of the wet wipe samples by the laboratory did not affect the concentration of char**
 - %-char for wet wipes and tape lifts was the same for interior window sills
- **Background char was “less than 1%”**
 - %-char was less than 1% in 63% of wet wipe samples and 71% of tape lift samples

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Conclusions

- **The wet wipe sampling method detected higher levels of char, and in a higher percentage of houses on interior hard surfaces**
 - %-char of 5% or greater for 27% of wet wipe samples compared to 6% of tape lift samples
- **The wet wipe sampling method was no less effective than the tape lift method for detecting char**
 - Essentially identical results for interior window sills
 - May have had an advantages for evaluating the impact of char when sampling interior hard surfaces

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Second Study

Characterization of Wildfire Smoke Residues

Joe Spurgeon

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Objective

- Lot's of industry experience and knowledge, but difficult to find published documentation of that knowledge
- Objective
 - Characterize the factors that can affect the evaluation of wildfire smoke residues in a public forum
 - Frequency of detecting char, ash, and soot
 - Effect of
 - Distance from the wildfire
 - Elapsed time since the wildfire
 - Sampling location
 - Background concentration of char
 - Conditional Areas

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Sample Collection

2,058 wet wipe samples were collected for

- Char, Ash and Soot
 - Composites of 3-5 individual samples
- Samples were collected from 343 houses affected by 22 wildfires over a four year period (2017-2020)
- Sampling locations included
 - Exterior surfaces
 - Interior hard surfaces
 - Attic surfaces
 - Air return plenums
 - Interior window sills
 - Clothing

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Sampling Location Wildfire Smoke Residues

Percentage of samples positive for residues in the 343 Houses
 "Positive" means [equal to or greater than 1%]

| LOCATION | CHAR | ASH | SOOT |
|---------------------------|--------------|-------------|-------------|
| SAMPLES (=> 1%) | 368 | 37 | 4 |
| SAMPLES (%) | 17.9% | 1.8% | 0.2% |
| Window Sills | 39.7 % | 2.6 % | 0.6 % |
| Exterior Surfaces | 38.5 % | 5.8 % | 0.6 % |
| Interior Surfaces | 14.3 % | 1.2 % | |
| Attic Surfaces | 9.0 % | 1.2 % | |
| Return Plenums | 4.4 % | | |
| Clothing | 1.5 % | | |

Char was detected on interior surfaces in 43% of the 343 houses

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Primary Smoke Residue

- **Conclusion: Char was the only residue that was useful for evaluating the impact of wildfire smoke residues**
 - Neither Ash nor Soot were considered useful due to their low frequency of detection
- **Paying for the analysis of Ash and Soot was not a good use of resources in these two studies**
- **Following discussions based on %-Char**

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Sampling Location Variation of %-Char

Positive percentages based on
343 samples per sampling location

| %-CHAR | Exteriors | Attics | Window Sills | Interiors |
|----------------------|--------------|--------------|--------------|--------------|
| %-Char <1% | 61.5% | 91.0% | 60.4% | 85.7% |
| 1% | 0.3% | 0.0% | 11.1% | 4.1% |
| 2% | 0% | 0.3% | 11.1% | 3.8% |
| 3% - 5% | 7.3% | 2.2% | 5.6% | 1.7% |
| >5% - 10% | 6.9% | 1.1% | 0.3% | 0% |
| >10% | 23.5% | 5.4% | 11.7% | 3.8% |

Conclusions:

- **60%-90% of samples were less than 1% char**
- **Four apparent ranges of %-char for interior samples**
 - <1%, 1%-2%, 3%-10%, >10%

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Sampling Location Average %-Char

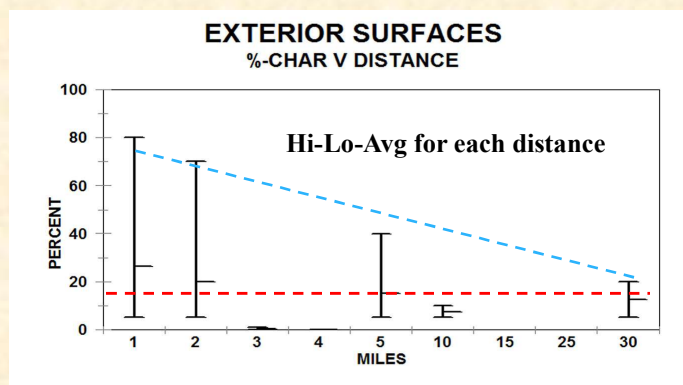
| LOCATION | AVG %-CHAR | SAMPLES |
|------------------------|------------|---------|
| Exterior Surfaces | 23.2% | 132 |
| Attic Surfaces | 19.6% | 31 |
| Interior Hard Surfaces | 11.7% | 49 |
| Interior Window Sills | 8.0% | 136 |
| Return Plenums | 4.9% | 15 |
| Clothing | 3.8% | 5 |

Conclusion: Average %-char on exterior and attic Surfaces was about twice that on interior surfaces (20% v 10%)

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Effect of Distance

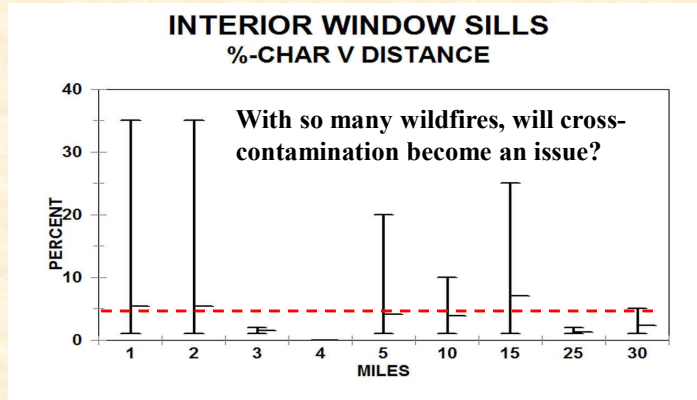


Conclusion: No association between average %-char and distance from the wildfire for exterior surfaces

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Effect of Distance



Conclusion: No association between average %-char and distance from the wildfire for interior window sills

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Elapsed Time Effect on Ash

| Exterior Surfaces | | | Window Sills | |
|-------------------|-----|-----|--------------|-------|
| DAYS | ASH | % | ASH | CUM % |
| 30 | 10 | 48% | 3 | 33.3% |
| 60 | 11 | 52% | 4 | 44.4% |
| 90 | | | 2 | 22.2% |

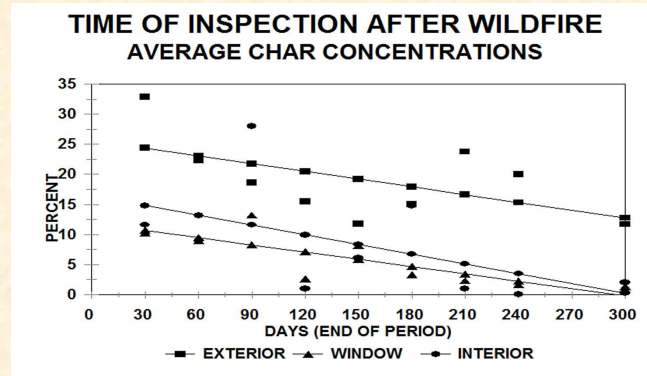
- Ash was only detected in the first 90 days
- Char continued to be detected over time, from 9 days through 1,270 days (3.5 years)

Conclusion: Char could be used to evaluate impact in 100% of inspections over a 3 ½ year period; Ash in 11% of inspections over a 90 day period.

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Elapsed Time Effect on Char



- Data were variable, but the average %-char decreased during the first 300 days – as might be expected
- Decreased at different rates on different surfaces

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Elapsed Time Effect on Char

- %-char decreased at:
 - 1.1% / month on interior window sills [Light cleaning]
 - 1.3% / month on exterior surfaces [Weathering effects]
 - 1.7% / month on interior hard surfaces [Occupant activities]
- Actual numbers not that important, can be variable, but provide order-of-magnitude estimates
- **Conclusion: Elapsed time between wildfire and inspection should be considered when estimating initial conditions**

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Detection Required Sampling

| LOCATIONS | HOUSES | PERCENT |
|-----------|--------|---------|
| 1 / 6 | 95 | 28% |
| 2 / 6 | 58 | 17% |
| 3 / 6 | 30 | 9% |
| 4 / 6 | 13 | 4% |
| 5 / 6 | 3 | 1% |

- Char was only detected in 1 of 6 sampling locations in 28% of houses; and in 1 - 2 locations in 45% of houses
- Sampling multiple locations increased the chance of detecting char

Conclusion: Composite samples were useful for sampling by allowing multiple locations to be sampled cost-effectively

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Background %-Char

| %-CHAR | Exteriors | Attics | Window Sills | Interiors |
|------------|-----------|--------|--------------|-----------|
| %-Char <1% | 61.5% | 91.0% | 60.4% | 85.7% |

| LOCATIONS | HOUSES | PERCENT |
|-----------|--------|---------|
| 0 / 6 | 144 | 42% |

- No consensus guidelines for background concentrations of wildfire smoke residues, HOWEVER
- The background char was less than 1% in 63% of the 48 houses and in 42% of the 343 houses for wet wipe samples

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Background %-Char

- The houses included in these studies were selected from houses potentially exposed to wildfire plumes
 - So background concentrations of char were expected to be higher than in the general housing stock, not lower
- Therefore: “Less than 1% char” was a rational definition for background char in these two studies

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2011 Wildfire Study*

- 64 houses potentially exposed to a 2011 wildfire
- Distances from the wildfire were 6-60 miles
- Elapsed times were 3-8 months
- Wet wipe sampling method
 - 1” BD alcohol pad
 - 3 samples collected per house on interior surfaces
 - Average %-char was reported for each house
 - Composited samples after analysis (Research Study)

* Ward T (2014) “Evaluating the Use of Indoor Residential Wet Wipe Samples Following a Wildfire”; *Intermountain Journal of Sciences*; 20(1), 1-3

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Comparison of Three Studies

Wildfires

64 houses: 2011 48 houses: 2019
343 houses: 2017-2020 (65% in 2020)

| %-Char | 64 Houses | 48 Houses | 343 Houses |
|---------|-----------|-----------|------------|
| <1% | 22% | 60% | 42% |
| 1% - 2% | 58% | 10.5% | 7.9% |
| 3% - 5% | 11.1% | 16.7% | 5.5% |
| >5% | 5.0% | 10.4% | 3.8% |

Has the percentage of houses with less than 1% char increased with time?

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Inspection Protocol

- If 40% or more of houses included in inspections may not have been exposed to wildfire smoke residues
 - Need to acknowledge that with a cost-effective inspection protocol
- Inspection Protocol
 - Phase 1
 - Screening inspection to identify impacted properties
 - Phase 2
 - Follow up inspection to characterize impacted properties

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Summary of 2011 Study

- Ash was not reported in any of the 64 houses, similar to the two studies of 48 and 343 houses
- Not a strong correlation between distance from the wildfire and %-char, similar to this study
 - Association was with direction from the wildfire
 - Prevailing winds, not distance from wildfire
- %-char was less than 1% in 22% of the 64 houses compared to 42% in the later 343 house study
- Composite samples – Sample results are typically averaged (composited) either before or after analysis

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Using Conditional Areas in the Inspection and Sampling Strategies for Wildfires

Sampling Locations as Conditional Areas* (*Residue Impact Areas) (*Similar Restoration Areas)

Broad concept

Developed by British Occupational Health & Safety in the 1950's
Commonly used in Environmental Sciences and Industrial Hygiene

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IICRC* Standard S520 for Mold

*Institute of Inspection Cleaning and Restoration Certification

- **Condition 1**
 - Unaffected areas, normal conditions
- **Condition 2**
 - Areas affected by settled mold spores
- **Condition 3**
 - Areas subject to mold growth
- **Asking if the same concept - Residue Impact Areas (RIA) useful (necessary?) for wildfire inspections?**

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343 Houses Exterior v Interior

61 houses with less than 1% char
in Exterior Surface samples

Essentially no char detected on 61 exterior surfaces,
but char was detected in

- 54 interior window sill samples
- 13 interior hard surface samples

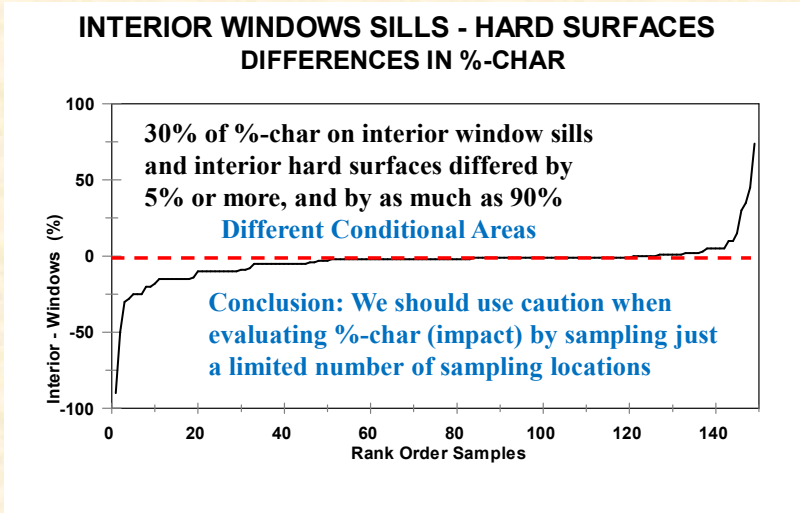
Conclusion: Little association of %-char between exterior & interior sampling locations – separate Conditional Areas

| %-CHAR | <1% | 1%-2% | 3%-5% | >5% |
|-------------------|-----|-------|-------|-----|
| Interior Windows | 12% | 72% | 12% | 5% |
| Interior Surfaces | 79% | 15% | 2% | 5% |

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343 Houses



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Differences: Interior Surfaces

Difference in %-char between interior window sills and hard surfaces

| DIFFERENCE (%) | SAMPLES | SAMPLES (%) |
|----------------|---------|-------------|
| 1% | 43 | 30.0% |
| 2% | 37 | 25.9% |
| 3% | 4 | 2.8% |
| 5% | 19 | 13.3% |
| 10% | 14 | 9.8% |
| 15% | 10 | 7.0% |
| >15% | 16 | 11% |

Conclusion: We should use caution when evaluating %-char (impact) by sampling just a limited number of sampling locations

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Sampling Locations as Conditional Areas

- 149 houses in which char was detected on interior window sills or interior hard surfaces
- Could we predict %-char

| On Surface | By Sampling | R-Value |
|-------------------|----------------|---------|
| Hard Surfaces | Window Sills | 0.23 |
| Attic Surfaces | Window Sills | 0.17 |
| Exterior Surfaces | Window Sills | 0.37 |
| Exterior Surfaces | Attic Surfaces | 0.21 |

Could maybe do this if $r = 0.9$ or higher

IMPORTANT RESULT !!

- **Conclusion:** Could not use %-char from one sampling location to evaluate the impact of char for other sampling locations
 - Six sampling locations were each separate Conditional Areas
 - Each sampling location was an independent Residue Impact Areas

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Sampling Transportation Accidents

US Air Flight 1549 [2009]



Continental Flight 3407 [2009]



Amtrak, Fallon, NV [2011]



Raytheon, El Segundo, CA [2011]



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Items and Materials Tested in Transportation Fires

- Luggage
- Clothing
- Shoes & Belts
- Coats & Furs
- Electronics
- Jewelry
- Toys
- Hard plastics
- Soft plastics
- Synthetic fabrics
- Natural fabrics
- Wood
- Paper & Cardboard
- Glass & Metal

Similar items as in a house fire

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Fire Zones Are Conditional Areas

Fire Zones = Conditional Areas = Residue Impact Areas

| Items Tested | Control Zone | Water Zone | Smoke Zone | Burn Zone |
|------------------------|--------------|------------|------------|-----------|
| FIRE ZONE | 1 | 2 | 3 | 4 |
| Area, Room, Box, Item* | | | | |

*Aircraft or Office

Conclusion: Using Conditional Areas in fire sampling is not a “new concept”. I used Conditional Areas for sampling transportation fires in 2009.

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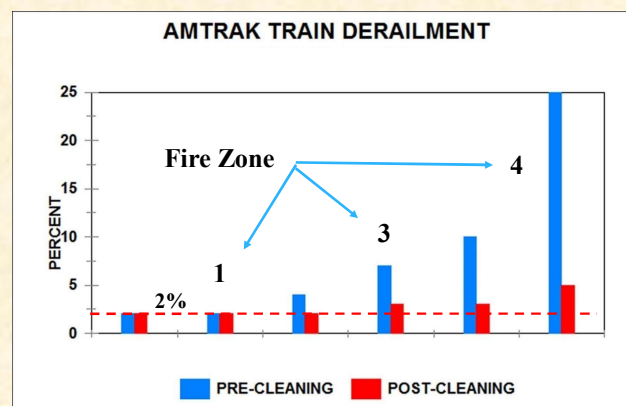
Combustion Particulate PCM Cassette Samples

- 6 pieces of luggage (Amtrak)
 - Closed-face 25 mm cassette
 - 0.8 um MCE filter
- % Char and Opaque [soot-like] particulate
 - Direct PLM and SEM/TEM Analysis



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Six Suitcases: Percent Soot



Conclusion: Fire Zones (Conditional Areas) were associated with restorability, and return to initial condition

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Wildfire Smoke Residues Alternative Wipe Samples

- Quartz fiber filters for sample collection
- Lab analysis using Mod EGA/TOR Method
 - Report as Total Carbon, Organic Carbon, Elemental Carbon
 - Can also reported as %-Char and %-Soot
 - Cost range of \$70-\$125 per sample



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Wildfire Smoke Residues Evaluation

- Ward (2011) concluded
 - “The wet wipe sampling method was useful for qualitatively assessing wildfire smoke impacts in indoor environments.”
 - Also applies to the tape lift method
- Microscopy method itself not sufficiently sensitive or accurate
 - For example, difference between 3% & 5% char
 - Lab reported 1%, 2%, 5%, 10%, 15%, 20%

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Sensitivity and Accuracy

Total Carbon (TC) using the NIOSH 5040/TOR Methods

- Differences in traffic levels between the Control Houses?
- Control, Restored, and Unrestored houses in three ranges
- Comparison of TC and Tape Lifts

| HOUSE | CONDITION | TC | Char* |
|---------|------------------------------|-------|-------|
| Control | Residential (Light Traffic) | 424 | |
| Control | (US 1 Coast Highway Traffic) | 760 | |
| 1 | Walls painted (owner) | 1,040 | 7% |
| 2 | Cleaned (owner) | 2,080 | 5% |
| 3 | Cleaned (professional) | 2,430 | 27% |
| 4 | Remodeled (owner) | 2,800 | 8% |
| 5 | Contents (steam cleaned) | 3,070 | 20% |
| 6 | Not restored | 5,688 | 14% |

*Char sampled by tape lift (PLM)

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Ranges of %-Char for 199 Impacted Houses

| %-CHAR | Exteriors | Attics | Window Sills | Interiors |
|------------|-----------|-----------|--------------|-----------|
| SAMPLES | 132 | 31 | 136 | 49 |
| 1% | 0.8% | 0% | 28% | 28.6% |
| 2% | 0% | 3% | 28% | 26.5% |
| 3% - 5% | 19% | 26% | 14% | 12% |
| >5% - 10% | 18% | 13% | 0.7% | 0% |
| >10% | 61% | 58% | 29.4% | 26.5% |
| Range >10% | 15% - 80% | 15% - 60% | 15% - 90% | 15% - 99% |

Average %-Char for Interior Spaces

| %-CHAR | <1% | 1%-2% | 3%-10% | >10% |
|--------|-----|-------|--------|------|
| HOUSES | 42% | 56% | 13% | 28% |
| RIA * | 1 | 2 | 3 | 4 |

*RIA: Residue Impact Areas; same concept as the (2009) Fire Zones

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Using Residue Impact Areas in Wildfire Inspections

- **Using RIA as part of an inspection and sampling strategy**
 - Encourage the Inspector to define and use RIA
 - Encourage inspection of each RIA
 - Each RIA should be sampled if resources permit
 - Use caution if estimating impact by sampling a limited number of RIA
 - Compositing samples should only be collected within each RIA
 - All 3-5 samples from interior window sills, for example

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Wildfire Inspections Residue Impact Areas (RIA)

- **Conditional Areas may be defined differently in the inspection and restoration phases**
- **Inspections and Restorations have different objectives**
 - Sample interior window sills and hard surfaces
 - Restore living rooms and dining rooms
- **Objective of using Conditional Areas**
 - Link the inspection results to the Restoration Work Plan
 - Allocate resources more efficiently, and where needed most (by area rather than structure)
- **Results for each RIA can be summarized to define**
 - Similar Restoration Areas in the Restoration Work Plan

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Wildfire Restorations Similar Restoration Areas (SRA)

CRITERIA FOR DEFINING SRA

- Visual Inspection
- Incident History
- Occupant Interview
- Odor Detection
- Visual Wipe Tests
- Sample Results (RIA)

SIMILAR RESTORATION AREAS (Defined by Inspector)

- By Area
- By Room
- By Floor
- By System

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Wildfire Restorations Similar Restoration Areas (SRA)

SIA

- Window sill, Hard Surfaces
- Carpet
- Soft surfaces
- Return plenum, Supply

SRA

- Living Room, First floor
- Carpets, Carpet in LR
- Soft surfaces
- Air delivery system

Conditional Areas:

- SIA defined for the Inspector in the Inspection Phase
- SRA defined for the Restoration Contractor in the Restoration Work Plan

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Example Similar Restoration Areas

| % Char* | SRA | IMPACT | Restoration Work Plan |
|----------|-----|----------|-----------------------------|
| < 1% | 1 | None | Background; Control Area |
| 1% - 2% | 2 | Low | Wiping, HEPA-Vac |
| 3% - 10% | 3 | Moderate | Restoration |
| >10% | 4 | Heavy | Discard, Systems, Occupants |

*Other criteria, as well (Visual, Odor, etc.)

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PRESENTATION SUMMARY

- **The wet wipe sampling method detected higher levels of char, and in a higher percentage of houses compared to the tape lift method**
 - **The wet wipe sampling method resulted in a higher evaluation of the impact of char in 88% of the smoke-impacted houses**
- **Collecting composite samples was a reasonable methodology for sampling a large number of surfaces at a reasonable cost**
 - **Samples, or sample results, are typically composited for assessment either prior to, or following, analysis**

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PRESENTATION SUMMARY

- **Char was the only wildfire smoke residue that was useful for evaluating impact since Ash and Soot were not detected with sufficient frequency to be useful**
- **63% of the 48 houses and 42% of the 343 houses had a %-char of “less than 1%”, which was a reasonable definition of background concentration in the two studies**
- **The concept of Conditional Areas was useful, even necessary, for properly evaluating the impact of wildfire smoke residues in the inspection of the 343 houses**
 - **%-char was not correlated between sampling locations, and each sampling location was an independent Conditional Area**

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