Formaldehyde Emissions from Chinese Manufactured Laminate Flooring: Is There a Proposition 65 Exposure Issue?

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Abstract

There has been much in the news recently about formaldehyde emissions from laminate flooring manufactured in China, but little in the scientific literature regarding the potential exposures of individuals who installed this laminate flooring. This presentation provides a comprehensive assessment of cancer risks from formaldehyde emissions from Chinese manufactured laminate flooring based on California's Safe Drinking Water and Toxic Enforcement Act of 1986, Proposition 65, model for carcinogenic risk assessment. Under Proposition 65, products posing a potential average daily dose of formaldehyde >40 μg/day must be properly labeled as containing this carcinogen. We initially conducted a probabilistic exposure assessment based on emission test for 26 types of Chinese manufactured laminate flooring to gain an understanding of the likely range of initial and time weighted average (TWA) formaldehyde concentrations that laminate customer may experience. This preliminary analysis was followed by a comprehensive residence-specific exposure assessment based emission tests of laminate flooring and survey information from ~900 residences with installed Lumber Liquidators Chinese manufactured laminate flooring. To properly account for the reduction in formaldehyde emissions with time following installation, both assessments are based on emission decay models. Both the initial and refined assessments produced lifetime TVA daily formaldehyde doses of <20 μg/day, acceptable levels under California's Proposition 65 regulations and indicating that no warning is required for this product.
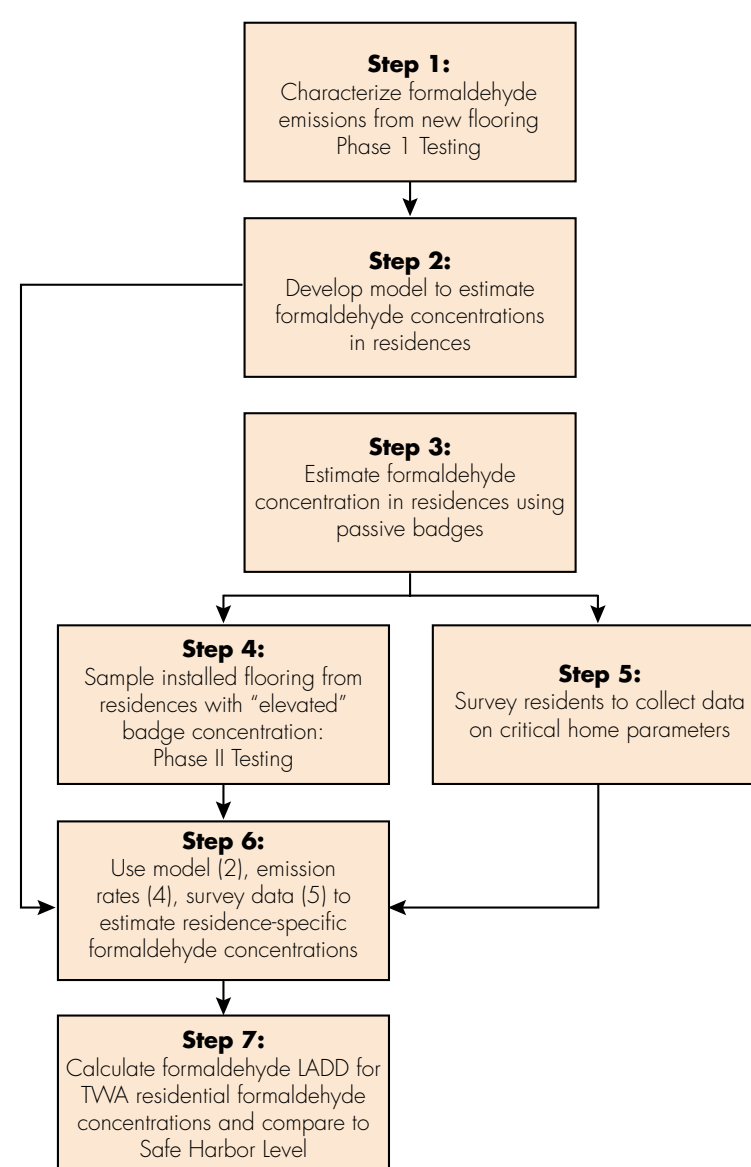
Introduction

Lumber Liquidators sold Chinese manufactured laminate flooring with a formaldehyde-containing core in California and elsewhere in the United States from 2009 to early 2015. Formaldehyde is listed by California under Proposition 65 regulations as a chemical known to State to cause cancer. As such, when questions were raised in a 2015 60 Minutes presentation about exposure to formaldehyde emissions from Lumber Liquidator (LL) Chinese manufactured laminate flooring, one of the early regulatory concern raised was whether this laminate floorings was compliant with the Proposition 65 safe harbor level for formaldehyde (40 μg/day), which is a cancer risk-based exposure standard established to warn consumers using formaldehyde-containing products. This presentation describes the comprehensive evaluation undertaken to address formaldehyde emissions from installed Chinese manufactured laminate flooring in California residences and provides initial and refined assessments of potential customer exposure and associated cancer risk from this laminate flooring product.

Assessment Methods and Results

Evaluation Approach

The evaluation approach to characterize potential consumer exposures to formaldehyde from Chinese manufactured laminate flooring and associated health risk information is shown in Figure 1.

Figure 1.
The seven step evaluation approach used to assess consume risk from installed Chinese manufactured laminate flooring.

Step 1: Characterize formaldehyde emissions from new flooring Phase 1 Testing

Step 2: Develop model to estimate formaldehyde concentrations in residences

Step 3: Estimate formaldehyde concentration in residences using passive badges

Step 4: Sample installed flooring from residences with "elevated" badge concentration: Phase II Testing

Step 5: Survey residents to collect data on critical home parameters

Step 6: Use model (2), emission rates (4), survey data (5) to estimate residence-specific formaldehyde concentrations

Step 7: Calculate formaldehyde LADD for TWA residential formaldehyde concentrations and compare to Safe Harbor Level

Step1: Characterized Formaldehyde Emissions from New Laminate Flooring: Phase 1 Testing

Chamber tests with new "out of the package" Chinese manufactured laminate flooring samples were conducted to characterize rates of formaldehyde emissions. Laminate flooring samples were tested in small environmental chambers using either ASTM D 6007-02 *Standard Test Method for Determining Formaldehyde Concentrations in Air from Wood Products using a Small Scale Chamber* (ASTM Method) or California Department of Public Health *Standard Method for the Testing and Evaluation of Volatile Organic Chemical Emissions from Indoor Sources Using Environmental Chambers* (CDPH Method). Contrary to the CDPH Method, which is very specific requirements, the ASTM method is less prescriptive. We tested the boards with a "standard" application of the ASTM Method, i.e. a single board cut to appropriate dimensions with edges taped with aluminum tape to only allow emissions from surfaces (Figure 2a). For testing done using the CDPH method, two boards were cut to appropriate dimensions, clipped together with edges taped with aluminum tape and the bottom surface covered to measure emissions only from the clipped laminate surfaces (Figure 2b).
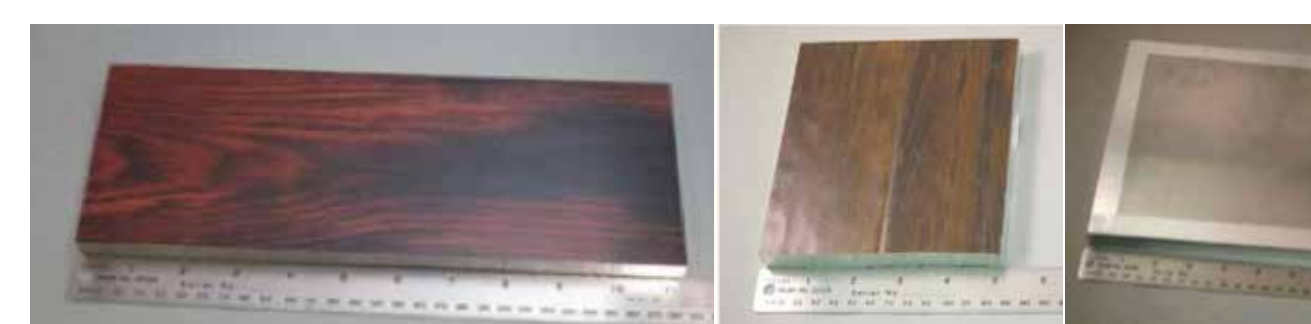
Figure 2a.
ASTM method preparation

Figure 2b.
CDPH method preparation

Table 1 summarizes the 399 samples of new out-of-the-package Chinese manufactured laminate flooring samples tested. The distribution of emissions rates from the initial 26 samples was used in the initial residential air model and the distribution of emission rates from the total 399 samples was used to assess differences in the rates of emissions for new laminate boards and laminate boards installed in residences for various time periods.

Table 1 summarizes the 399 new out of the package Chinese manufactured laminate flooring samples tested. The distribution of emissions rates from the initial 26 samples was used in the initial residential air model and the distribution of emission rates from the total 399 samples was used to assess differences in the rates of emissions for new laminate boards and laminate boards installed in residences for various time periods.

Table 1.
Summary of new Chinese manufactured laminate flooring samples tested to characterize formaldehyde emission rates

Sample Description	Sample Number	Method
New Laminate, Initial Samples	26	ASTM Method
New Laminate, Additional Samples	51	ASTM Method
New Laminate, Different Method	19	CDPH Method
New Laminate, Inventory Samples	303	ASTM Method

The average emission rate (ER) from new Chinese manufactured laminate flooring samples was found statistically indistinguishable from the average ER of the laminate flooring tested by the Consumer Product Safety Commission (CPSC; see Figure 3).
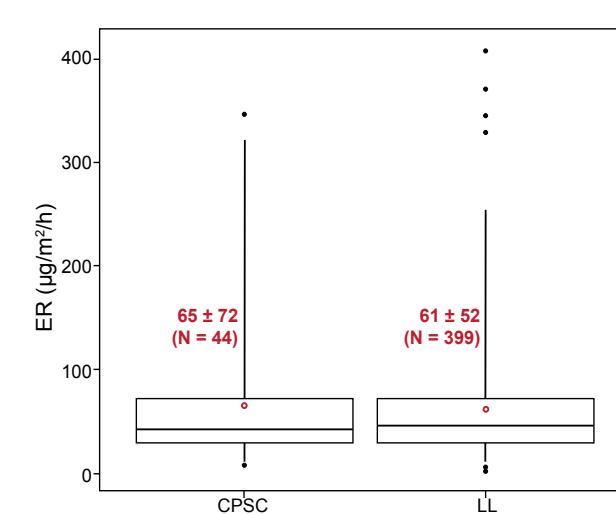
Figure 3.
Emission rate comparison by source of testing

Step 2: Develop Residential Air Model

The initial formaldehyde concentration in residences shortly after installation of Chinese manufactured laminate flooring was calculated as follows:

$$C_{home,0\ (\mu g/m^3)} = ER \times (A_{laminate}/A_{home})(A_{home}/V_{home})/AE_{home}$$

where,

ER	=	formaldehyde emission rate (μg/m²/h)
$A_{laminate}$	=	installed area of laminate in residence (m²)
A_{home}	=	floor area of residence (m²)
V_{home}	=	volume of home (m³)
AE_{home}	=	air-exchange rate (per h)

or,

$$= ER \times F_{laminate} /(AE_{home} \times H)$$

where,

$F_{laminate}$ = fraction of home floor area covered with laminate (unitless)

H = average home ceiling height (8.5 feet or 2.59 m)

To represent the distribution of residential conditions expected in homes with installed Chinese manufactured laminate flooring, a probabilistic modeling approach was used, where:

- ER was based on the lognormal distribution of initial 26 laminate samples tested
- $A_{laminate}$ was based on record of LL laminate flooring purchased in California 2013–2014
- A_{home} was based on builders records of flooring installed in the U.S. in 2008 remodeling and new construction
- AE_{home} was based on lognormal distribution from EPA data for U.S. residences (GM = 0.45/h)

Emission Decay with Time

There are no published studies of decay in formaldehyde emissions specific to laminate products. Data from Zinn et al. (1990) were used by the California Air Resources Board (CARB) to model formaldehyde emissions decay from particle board and have been assumed to also be representative of laminate. However, this model is unrealistic because it predicts negative emissions after approximately ~12 years. Therefore, the same data were used to fit a new bi-exponential model defined below to characterize emissions from Chinese manufactured laminate flooring (Figure 4):

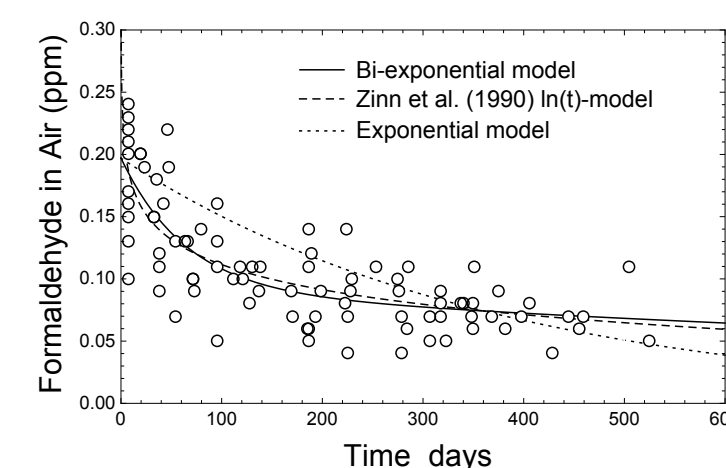$$A\ biexp(p, k_1, k_2) = A[p\ exp(-k_1\ t) + (1-p)exp(-k_1\ t)]$$

Figure 4.
Least-squares nonlinear regression fits of three models to formaldehyde decay data fit by Zinn et al. (1990). The bi-exponential model fit is slightly (but not statistically significantly) better (R^2 = 0.63) than the fit (R^2 = 0.61) of a ln(t) model of the form described by Zinn et al. (1990) and used by the CARB.

The probabilistic model incorporating bi-exponential model emission rate decay was used to estimate TWA formaldehyde concentration in residences from Chinese manufactured laminate flooring (Figure 5).

Figure 5.
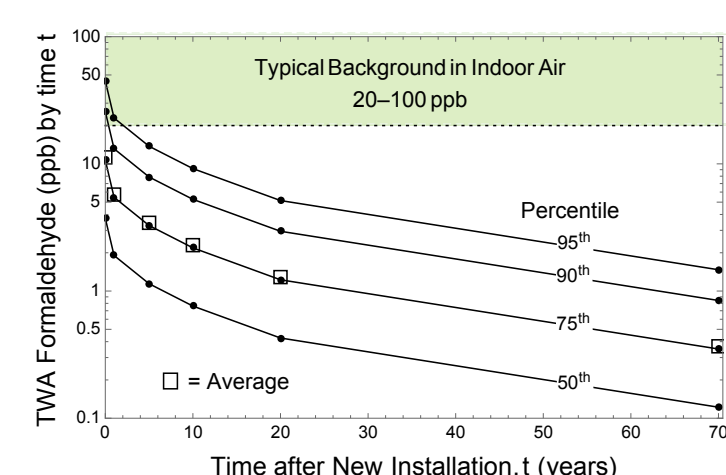
Probabilistic estimates of TWA contributions to residential formaldehyde to residential air from installed laminate flooring, in relation to time after installation. Square points are arithmetic mean.

Step 3: Sample Formaldehyde in Residences with Installed Laminate Flooring

In early 2015, laminate flooring customers were given an opportunity to sample formaldehyde in their residences to achieve three objectives:

- Characterize formaldehyde concentrations in individual residences from all sources
- Characterize distribution of formaldehyde concentrations in large population of residences that have installed laminate flooring
- Identify residences with elevated formaldehyde levels for additional flooring-specific evaluations

This was a self-directed voluntary program. Residents who requested the badge(s) were provided with badge(s) and instructions on how to deploy them. Samples were analyzed by certified analytical laboratories (NIOSH 2016 modified or OSHA 1007). Results were reported to residents and compiled in a database.

Badge Back / Badge Front

Figure 6.
Typical passive sampling device provided to residents.

Sampling results (represent all sources of formaldehyde in residences):

- Approximately 32,000 badge samples from more than 19,000 residences have been analyzed
  - Approximately 91% had formaldehyde concentrations ≤100 μg/m³ or ≤81ppb (WHO Guideline); substantial majority were <50 μg/m³ or <40 ppb
  - Approximately 9% (~2900 residences) had concentrations >100 μg/m³ ("elevated" badge concentrations)
    - These residences were selected to focus further evaluations of flooring-specific contributions to residential formaldehyde concentrations

Step 4: Collect Survey Data for Residences with Elevated Formaldehyde Concentrations

Survey data were collected from sampled Phase II residences to facilitate interpretation of flooring-specific formaldehyde concentrations also from larger LL California laminate customer population.

Key survey results:

- ~1,600 completed surveys out of ~2900 residences
- Age of residence used to assign a representative AE
  - **44% ≤20 years old**
  - **56% >20 years old**

Residence floor area (5 different categories): combined with area of laminate flooring purchased to estimate flooring-specific $F_{laminate}$

- **Mean Flaminate = 0.46**
- **5.8% Flaminate = 1.0 (100% coverage)**

Key laminate customer results:

- Age of residence
  - **25% residences constructed after 1990** with possible "tight" construction
  - **75% residences constructed in decades before 1990**
    - Fraction of floor area as LL laminate
      - **Mean Flaminate = 0.32**
    - **79% of customers have $F_{laminate}$ ≤0.50**
    - **0.02% have $F_{laminate}$ of 1.0 (100% coverage)**

Step 5: Characterize Formaldehyde Emission Rates for Installed Laminate Flooring

Approximately 900 laminate samples were removed from residences that had reportedly "elevated" badge sample concentrations and were tested in a chamber using ASTM D6007-02 method to estimate emission rates. Based on LL catalogs, it was possible to estimate the amount of time that the boards were installed in the residences. Using these time-specific emission rates data (Phase II) along with the 399 Phase I formaldehyde emissions data from brand new flooring, i.e. at time 0 (Step 1), a decay curve was fit specific to laminate flooring. This is a model fit to "real-world" data and thereby provides a representative estimate of formaldehyde emissions from laminate flooring in residences at various time points. Phase II installed board emission rates were lower and significantly different than Phase I new board emission rates (Figure 7)
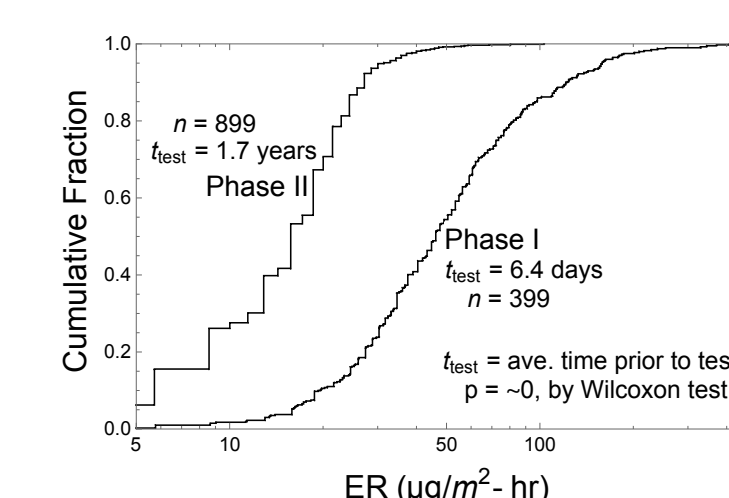
Figure 7.
Comparison of the distribution of emission rates of new and installed laminate flooring.

Combining Phase I and Phase II emissions rate data supports a fit of decay with time of use post installation (Figure 8)
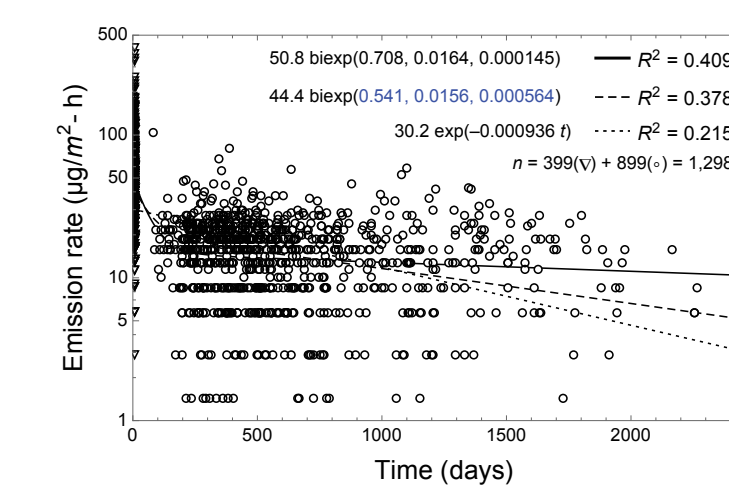
Figure 8.
Bi-exponential decay in formaldehyde for installed Chinese manufactured laminate flooring. Parameters shown in blue color are those from the fit to Zinn et al. (1990) data shown in Figure 4.

Step 6: Calculate Refined Residence-Specific TWA Formaldehyde Concentrations

Calculation Model:

$$CTWA = ER \times F_{laminate} / (AE \times H)$$

- ER = emission rate from residence specific Phase II testing or mean rate from distribution (testing)
- $F_{laminate}$ = fraction calculated from purchased ft² and survey floor area ft² or mean fraction (survey)
- AE = air exchange 0.329/h for houses ≤20 years of age (survey; assumed tight construction rate, Persily et al. 2010) or 0.621/h for houses 20 years age (survey; assumed typical older construction rate, conditional on ≤20 year plan)
- H = average ceiling height = 2.59 m (average from CDPH [2010], Table B-1)
- C_{TWA} takes into account decay for years of interest

Compare Initial and Refined Residential TWA Formaldehyde Concentrations

TWA concentrations are compared for three durations of laminate flooring in residences:

- 12 years (average duration of residency in (U.S. EPA)
- 20 years (anticipated use life of laminate flooring (manufacturer)
- 26 years (90th percentile duration of residency (U.S. EPA)

Table 2 compares estimated residential TWA-formaldehyde-concentrations based on the initial probabilistic model and those based on the refined deterministic model and Phase II residence-specific emission rate estimates.

Step 7: Calculate Lifetime Average Daily Dose (LADD) of Formaldehyde from Installed Chinese Manufactured Laminate Flooring and Compare to Safe Harbor Level

For a Proposition 65 exposure assessment, LADD is calculated for the average use condition.

$$LADD = C_{TWA} \times IR \times EF \times ED$$

Where,

C_{TWA}	=	median or average TWA residential formaldehyde concentration at 12, 20 or 26 years
IR	=	daily inhalation rate (20 m³/day, Proposition 65 guidance)
EF	=	exposure frequency expressed as the average fraction of the day spent in residence (0.66, U.S. EPA)
ED	=	exposure duration as fraction of a 70 year lifetime (12/70, 20/70 or 26/70)

Estimated LADDs of formaldehyde for consumers with installed Chinese manufactured flooring based on the initial and refined models are compared in Table 3.

Table 2.
Residential TWA formaldehyde concentration estimates

Residence Time (years)	Predicted Residential TWA Formaldehyde Concentration (μg/m³)			
	Initial Model		Refined Model	
	Median	Mean	Median	Mean
12	0.80	2.4	4.2	5.3
20	0.53	1.6	3.4	4.3
26	0.45	1.3	3.0	3.8

Table 3.
Lifetime average daily dose estimates for consumers with Chinese manufactured laminate flooring

Residence Time (years)	Predicted Lifetime Average Daily Dose (μg/day)			
	Initial Model		Refined Model	
	Median	Mean	Median	Mean
12	1.8	5.5	8.5	11
20	2.0	6.0	12	15
26	2.1	6.6	13	17

The LADD estimates from both the initial and refined models are well below the Proposition 65 Safe Harbor Level for formaldehyde based on 1 in 100,000 cancer risk of 40 μg/day. The primary difference in initial and refined LADD estimates is attributed to difference in formaldehyde decay as initially estimated from the Zinn et al. particle board study data and later from the tests with new and installed Chinese manufactured laminate flooring samples.

Conclusions

Analyses showed that testing installed laminate boards from residences was crucial to characterizing the decay in emissions of Chinese manufacture laminate floor, as well as generating residence-specific emission rate and survey data to support refined estimates of residence-specific TWA formaldehyde concentration to which consumers may be exposed from their Chinese manufactured laminate flooring. This assessment shows that potential formaldehyde doses from this laminate flooring pose a negligible risk to Lumber Liquidator laminate customers based on the Proposition 65 cancer risk model.