FINAL REPORT

RESPIRATORY HEALTH STUDY OF THE WOOD PROCESSING INDUSTRY

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I. INTRODUCTION

The present study examines nonmalignant respiratory effects of dust exposures in wood processing. It was undertaken to address deficiencies or inconsistencies in the existing knowledge base of the subject. Limitations in the scope and design of previous studies have included small populations, single process exposures, exotic or allergenic wood species, variable and often sparse environmental sampling, diverse response variables (sometimes, only symptoms), external controls of dubious comparability, inadequate assessment of lung function, and unorthodox statistical analyses.

The more difficult problems derive mainly from the diverse natures of the materials and processes. The various species of woods include some with known particular effects, usually, the ability to cause respiratory allergic diseases. These can be excluded when attempting to assess effects of a hypothetical "generic" wood, on grounds that special measures must be taken to protect workers with exposure to allergens. There remains, however, the problem of determining the effects of the wood *per se*, from gravimetric dust samples that always contain other materials that in many instances outweigh the wood. In this study, a method was devised to measure the major non-volatile constituents of wood, (hereafter, "wood solids") in samples of collected airborne particulate. When this is done, the remainder of sample weight (hereafter, "residual particulate matter") is composed of some materials derived from wood (water and wood volatiles); contaminants related to its storage and/or processing; and background particulate contaminants generally present in industrial facilities.

Contaminants related to storage of unprocessed and processed wood are mainly microorganisms such as bacteria, fungi, and protozoans, and their products (endotoxins, glucans). These are notably found in the sawmill environment.[1,2,3,4,5,6,7] Such contaminants are known to have health effects. The endotoxins and glucans can be measured to assess, respectively, the relative level of bacterial and fungal contamination, and viable organisms can be cultured. These approaches were not part of the current study but could be employed to refine the analyses.

Contaminants derived from other sources might include silica and other mineral particles, adhesives, paints and coatings, and resins. There were also unmeasured inhalants with potential respiratory effects, such as solvents and smokes. Comprehensive measurement of these was beyond the scope of the study. For certain of these contaminants, potential effects were gauged by identifying the subjects exposed to each and including them in separate categories for multiple regression analyses.

The principal health outcome examined was annual change in lung function (spirometry), in relation to concurrently measured dust exposures. In this study, spirometric data were collected in the participating plants, using standardized methods and equipment and rigorous quality assurance. Slopes of least squares regression lines were computed for each subject who had good quality measurements and the minimum length of followup and number of data points meeting inclusion criteria. Other outcomes examined were symptoms and level of lung function. Potential confounders were assessed from medical and smoking data.

Most of the medical literature indicates that dust from processing of (non-allergenic) woods is likely to cause, if effects are detected, symptoms and lung function manifestations of a bronchial response.[8] The possible symptoms are those of bronchitis: cough, sputum, wheezing, and shortness of breath. The corresponding functional effects, when present, are those of slowed exhalation – reduction of FEV_1 and FEV_1/FVC ratio – i.e., "obstruction" of expiratory airflow, with preserved lung size. Chronic exposures that affect the bronchi can lead to either simple chronic bronchitis, defined as chronic coughing and sputum production without significant lung function effects, or chronic obstructive pulmonary disease (COPD), with persistent symptoms and airflow obstruction.

There have been some reports, however, of "wood dust" exposures associated with an airspace or alveolar reaction, wherein the lungs' volume is reduced i.e., "restriction," while the speed of exhalation is preserved, or even increased,[9,10,11,12] with corresponding functional effects of reduced FVC with increased FEV_1/FVC ratio. This pathophysiologic response is seen in such conditions as farmer's lung and pigeon breeder's diseases, and it represents a form of allergy that is rare compared to hay fever or bronchial asthma. Such conditions can be manifest by recurrent attacks of pneumonia ("hypersensitivity pneumonitis" [HP] also sometimes referred to as "extrinsic allergic alveolitis" [EAA]). They can also be manifest as an indolent, asymptomatic loss of lung functions, including volumes and gas transfer (diffusing capacity). Either overt hypersensitivity pneumonias or the indolent reaction can, if sufficiently protracted or severe, lead to lung scarring.

Details of the design, execution, and analysis of the study are given below. The results include some evidence of bronchial dust effects associated with milling and alveolar effects associated with a sawmill-plywood operation. In both cases, the significant relationships were not to the wood solids fraction of the dust (mostly cellulose, hemicellulose, lignin, proteins, pigments, inorganic salts, and any other non-volatile components normally present in whole wood), but rather to the residual particulate matter that includes the adsorbed water and other wood volatiles (terpenes, essential oils, etc.) normally present in whole green wood, and other non-wood derived particulate matter.

II. PRELIMINARY WORK: IDENTIFYING CANDIDATE STUDY PLANTS

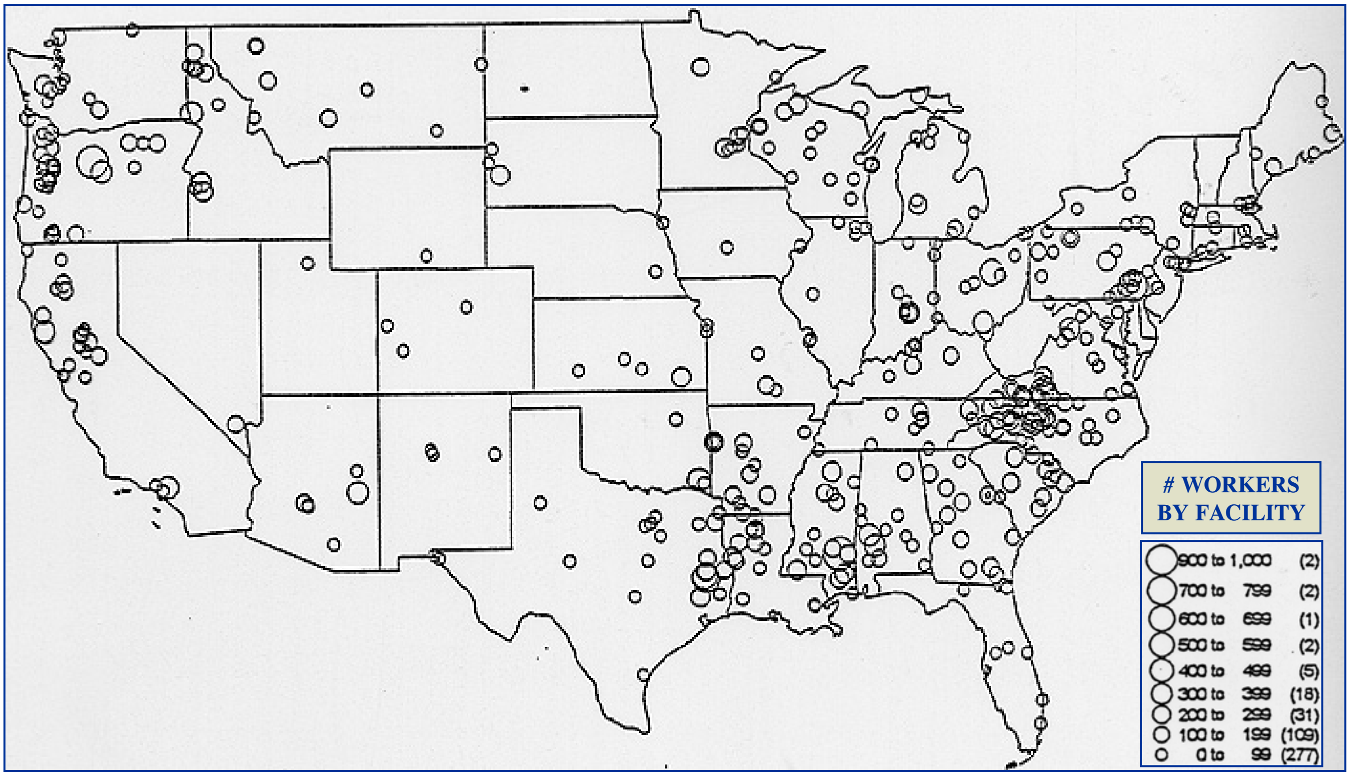
Prior to commencement of the study, a research team comprised of Tulane and AF&PA investigators conducted a scoping study. During the scoping study the team visited 5 plants representing various industry segments including saw- and planing-mills, millworks, hardwood flooring mills, and furniture factories. These site visits focused on the industrial hygiene aspects of each of these types of facilities with emphasis placed on an understanding of the process flow, types of operations and job tasks performed at each, classes of workers/occupations typically found in each, the prevalence of personal protective equipment usage, and the likelihood of any confounding exposures.

After the site visits, Tulane investigators, with input from the AF&PA and wood product association representatives, developed a survey designed to provide plant specific information needed to identify candidate plants for the proposed study. This information included: completeness of employee records; estimates of number of workers in each of sawing, milling and sanding operations; total numbers of workers exposed to wood dust; wood products manufactured; percentage of hardwood and softwood used; use of personal protective equipment, and the existence of confounding exposures. This survey was distributed from the AF&PA to association members who, in turn, sent the surveys to their individual member companies for further distribution to individual plants who were asked to return the completed survey to Tulane. A total of 480 responses from U.S. plants were received at Tulane by April 24, 1998. Of these, 281 had less than 100 workers estimated to be exposed to wood dust, 110 have 100-199, 55 have 200-299, 18 have 300-399, 5 had 400-499, 2 had 500-599, 1 had 600-699, 2 had 700-799, and 2 had 900-1,000 workers estimated to be exposed to wood dust, respectively. Their location and number of workers estimated to be exposed to wood dust are shown in Figure 1. Eighteen plants located in Canada are not represented.

From the pool of candidate plants, the investigators identified a group of plants that reported complete historical records for current employees (start and stop dates worked in all positions and work areas since initial employment), and had sufficient numbers of workers in areas associated with both hardwood and softwood dust exposures to provide an adequate number of participants for the study.

FIGURE 1

480 U.S. RESPONDERS TO WOOD STUDY SURVEY
48,748 WORKERS POTENTIALLY EXPOSED TO WOOD DUST



III. RESEARCH DESIGN AND METHODS

A. Plant/Population Cohort

Table 1 presents descriptive data for the study plants at initiation of follow-up. Plant information includes: the type of facility; major wood products used or manufactured; hardwood/softwood mix; number of sawers, millers, and sanders; and the additional number of workers around milling and sanding operations. These plants provide a potentially large cohort of workers in plants using hardwood and/or softwood in a variety of operations and processes.

The study targeted approximately 300 wood-processing workers per plant, where available. Since study participation was voluntary, plant personnel were trained by Tulane investigators to administer a consent form to potential participants.

Table 1
Description of Study Plants at Initiation of Follow-Up

Type of Facility	Major Products*	%Hard/ Soft Wood	Sawers	Millers (routing, boring, shaping, etc.)	Sanders	Around Millers Sanders
Furniture	SL, DL, PB, FH, MD, MM, FR	99/1	79	125	106	450
Furniture	FR	95/5	140	70	75	205
Furniture	FR	90/10	45	90	60	275
Furniture	FR	73/27	50	70	60	90
Furn-Cab-Parts	MM, KC	80/20	75	550	50	35
Cabinet	KC	99/1	70	60	80	85
Cabinet	KC	90/10	40	30	50	400
Plywood	PL	0/100	63	13	15	51
Milling	MM	0/100	60	190	43	25
Saw-Plan-Ply	SL, DL, PL	10/90	80	60	4	30

*** Major Products Codes**

FR: Furniture
SL: Sawed Lumber
DL: Dimensional Lumber
WD: Windows & Doors
PL: Plywood
KC: Kitchen Cabinets
PB: Particleboard
FH: Fiberboard Hardboard
MM: Molding & Millwork
MD: Medium Density Fiberboard

B. Medical Surveillance

Standardized testing of all study participants was accomplished through the Tulane Pulmonary Surveillance Program that included standardized training of plant personnel to administer the consent form, computer resident questionnaires and spirometric tests, in conjunction with a network approach to data collection and transmission.[13]

i. Standardized training of plant personnel

At the beginning of the study, and periodically throughout the study when necessary, plant personnel (usually two individuals from the facility) attended three-day training seminars conducted at Tulane University. These seminars were all conducted by the investigators of the study and addressed all aspects of the study protocol, recruitment of study participants, administration of consent forms, administration of the initial and follow-up questionnaires, and the administration of spirometric testing. In addition, the training was conducted as part of a NIOSH approved course (Lic. #002) in spirometric testing, administered by the principal investigator of the study (HWG).

ii. Spirometric testing

Spirometry is routinely used both clinically and epidemiologically to investigate effects on the respiratory health of individuals and cohorts, respectively. The sensitivity of longitudinal spirometric testing in identifying abnormal rates of decline is well documented, and the investigators from Tulane have published reports studying the factors that influence annual change in lung function,[14,15,16] and have utilized spirometry to quantify airways effects of a variety occupational pollutants.[17,18,19,20,21,22]

The plant personnel spirometric test training, noted above, utilized Medical Work Stations (MWS), like that shown in Figure 2, consisting of a PC, on-line dry rolling-seal spirometer, internal modem, 3-L calibrating syringe, and battery backup UPS. These MWS were provided to each facility for the duration of the study, and were utilized for the collection of demographic, questionnaire and spirometric data.

Figure 2 - MWS

The MWS software utilized calibration, calculation, and data reduction methods recommended by the American Thoracic Society (ATS).[23] Spirometric results were computed from at least three acceptable tests with good initial effort (extrapolated volume [EV] less than 5% of the FVC, with distinct superimposable peaks evident from the flow-volume curves), good continued effort for at least 5-7 seconds, and repeatable FEV_1 and FVC values within 5% or 100 ml. The results included the largest forced expired volume in 1 second (FEV_1); the largest forced vital capacity (FVC), the ratio of the FEV_1 to FVC (FEV_1/FVC(%)), and the forced expired flow computed from 25 to 75% of the FVC (FEF_{25-75}) computed from the test with the largest sum of FEV_1 + FVC.

During spirometric testing the quality assurance software graphically displayed the three best tests computed as having the largest sum of FEV_1 + FVC with the volume-time curves back extrapolated and superimposed at zero extrapolated time, and the flow-volume curves superimposed at the beginning of forced exhalation. Numerically, the display also showed the measured, predicted and percent of predicted values for FEV_1, FVC, and FEF_{25-75}; the test number for the displayed three best tests; the percent difference between the two largest FEV_1 and FVC values; and the FET. The display also indicated when three tests had been collected that meet all ATS quantitative test criteria for test acceptability,[16] with a repeatability code set for transmission with the test results. Since these are minimum acceptability criteria, the plant personnel were trained to quality assure the graphic results and continue testing until acceptable test quality has been obtained.[24] Validation of the accuracy of this spirometric system[25] indicates that it complies with both the original[23] and updated[26] ATS spirometric test criteria.

iii. Centralized quality assurance and interpretation

During the study, all test results, including the demographics, questionnaire responses (see below), numeric spirometry results and the three best volume-time and flow-volume tracings were transmitted daily to Tulane for quality assurance and interpretation (by HWG), and archiving. Hard copies of the interpreted tests were mailed back to the plant site for distribution to the study participants, and any substandard test were identified with a request that the subject be retested.

iv. Medical, smoking and occupational questionnaire

An initial and follow-up computerized medical, smoking and occupational questionnaire was administered to the study participants at the same time they were scheduled for their breathing test. The questionnaire was screen-scrolled on the MWS, and programmed to automatically skip not applicable questions. It is based on a modified version of the standardized questionnaire reported by Burrows and coworkers,[27] and together with the collected demographics accounts for a variety of putative and established risk factors and potential confounders for the development of airways disease including asthma, allergic disease, historical confounding exposures, serious childhood respiratory illness, cigarette smoking history, environmental tobacco smoke, and age, gender and race.

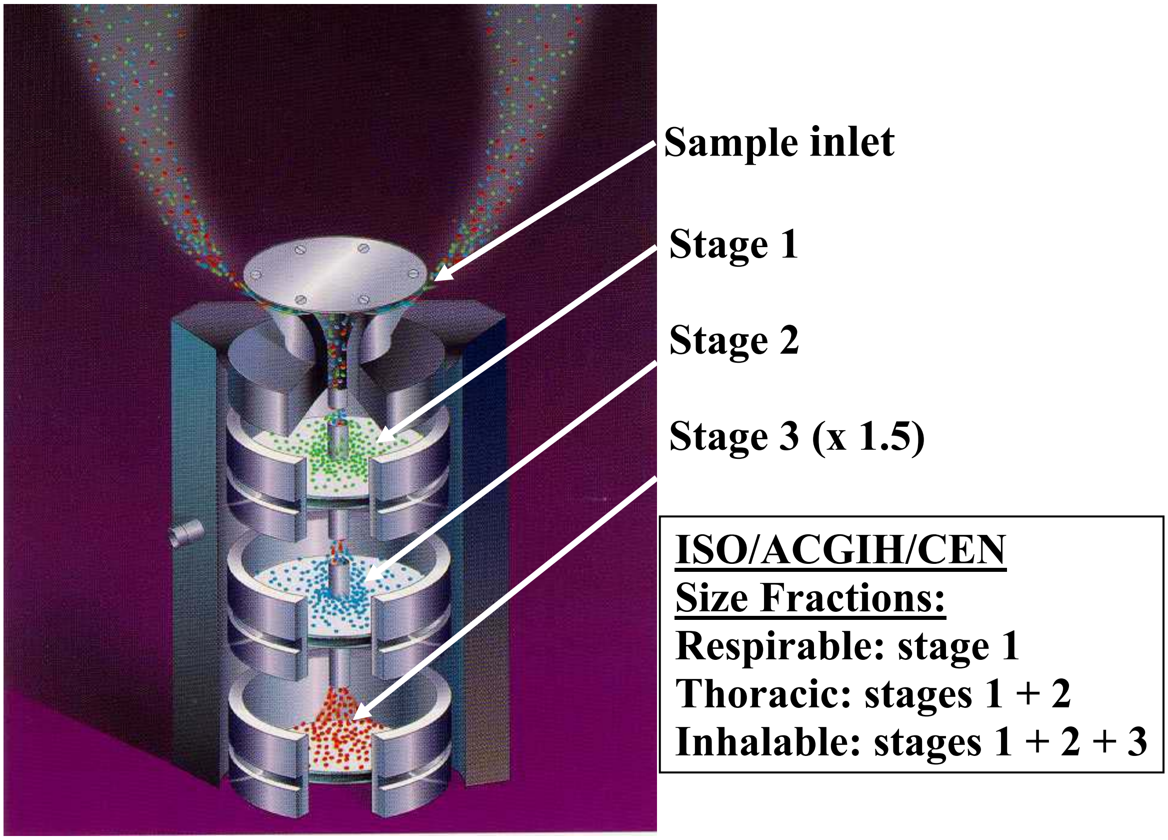
C. Exposure Assessment

Current exposure to size-fractionated wood processing dust, wood solids, and potential confounders such as formaldehyde was assessed for the study subjects. Wood processing dust and wood solids (cellulose, hemicellulose, lignin, proteins, pigments, inorganic salts, and any other non-volatile components normally present in whole wood, absent water normally present in whole green wood and other volatiles such as terpenes, essential oils, etc.) were determined by personal exposure monitoring with gravimetric and infrared spectroscopic analyses, respectively. The exposure monitoring results were used to develop homogeneous exposure groups (HEG) in each of the study plants, and average exposures were determined for each of the HEGs to create a job/exposure matrix. Study subjects' individual work histories (See D: Abstraction Of Job Histories) were then linked with the job/exposure matrix to calculate their respective average and cumulative exposures over the study period.

i. Dust exposure monitoring

Dust exposures were determined by personal sampling with the Respicon (TSI Inc.), that is shown schematically in Figure 3. The Respicon is a personal sampling device that consists of a multi-stage virtual impactor with each stage containing a 37-mm filter for collection of particles size fractionated according to the ACGIH/ISO/CEN criteria (Figure 4). Airborne particles are drawn in through a perimeter ring gap at the top of the sampler which has a sampling efficiency curve in compliance with the inhalable particle fraction criteria. The particles are then separated into the respirable and tracheobronchial fractions by two virtual impactors positioned one after the other. The remaining extra-thoracic particles pass through and are collected on the final filter stage of the device.

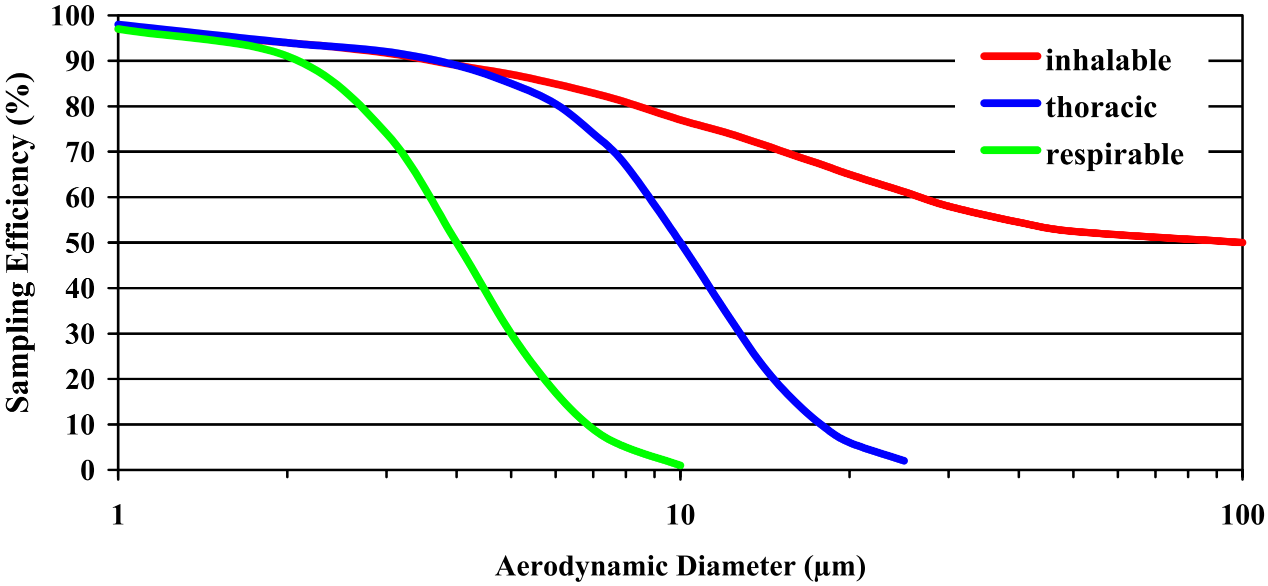
Figure 3 - Respicon



The unique characteristics of the Respicon sampler made it particularly useful for this project. These characteristics include:

- It simultaneously measures the three size fractions of particulate matter as defined by the ISO/CEN/ACGIH sampling criteria: inhalable, thoracic, and respirable.
- It uses virtual impaction for separation of the size fractions. Virtual impaction obviates problems common in cascade impactors including particle bounce and re-entrainment, inter-stage losses of particles on walls and other interior surfaces, and excessive particle build-up on impaction stages. These problems can be particularly acute with wood processing dusts because of the relatively high dust concentrations seen in many parts of the wood industry and because of the unique aerodynamic properties of wood dust particles resulting from their low density, odd morphology, and extremely wide range of sizes.
- It uses common membrane filters as collection substrates. Membrane filters are less susceptible to particle overload than non-porous impaction plates, and in addition, they are amenable to accurate gravimetric and chemical analysis.
- It operates at a flow rate of 3.1 L/min. This is well within the capabilities of most battery-powered personal air sampling pumps.
- Its small size, low weight, and rugged construction make it suitable for personal exposure monitoring.

Figure 4: ACGIH/ISO/CEN Size-Fractionated Particle Sampling Criteria



Each facility was visited approximately yearly during the study for a total of three or four site visits and two to three hundred personal samples per plant. The annual trips alternated throughout the seasons, in order to integrate climatic variability into the exposure estimates. The sampled population included all production jobs as well as those support personnel that primarily work in dusty areas. Participants wore the Respicon for periods ranging from approximately one half to the entire work shift depending upon the expected magnitude of airborne wood dust concentrations. The sampling devices were fixed to the participants via a harness that locates the Respicon in the breathing zone approximately at the upper sternum. Stages 1 and 2 were originally equipped with 37 mm glass fiber filters. Soon after the study began, stages 1 and 2 were changed to 2- micron pore size, 37-mm diameter Teflon filters in order to improve accuracy and precision in the gravimetric analysis. Stage 3 utilized 37-mm glass fiber filters (Omega Specialty Instruments Company) throughout the study. Gilair-5 sampling pumps (Gilian) were used to collect all samples at the nominal flow rate of 3.1 L/min. Pre-trip and post-trip flow rate calibrations, for both the RespiCon and sampling pumps, were conducted using the Accuflow digital soap bubble meter (SKC Inc.). Initially, field calibrations were conducted using a rotameter (SKC Inc.). Both laboratory and field calibrations were soon modified to the sole use of a DryCal (BIOS) graphite piston flow meter. Atmospheric conditions during sampling were monitored using a digital thermometer/hygrometer (Fisher). Variables including wood type, work rate, activity, task type, manual or automated, machine type, job title, potential confounders and engineering controls were also recorded at the time of sampling using a standardized field sampling form.

All samples were analyzed via gravimetric analysis. Filters were pre- and post-weighed 2-3 times each on a Sartorius microbalance (± 1 µg) and the average weight determined. Prior to weighing, filters were conditioned in a humidity chamber for at least 24 hours. Relative humidity in the chamber was maintained at approximately 55% using a saturated sodium dichromate solution. In addition, filters were electrostatically discharged for at least 20 seconds with a Staticmaster (NRD) prior to weighing. After final weights had been calculated, filters were archived in polystyrene Petri slides (Millipore).

The gravimetric result for each stage of the RespiCon was also subjected to a blank correction. The average weight change of the blanks associated with a particular sample trip was subtracted from each of that trip's sample filters prior to calculating the respirable (stage 1), thoracic (stages 1 and 2) and inhalable fractions (stages 1, 2 and 3), using the algorithm supplied by the manufacturer of the Respicon. Those samples that exhibited an apparent weight loss after adjustment for the blank values were determined to be invalid and were not used in subsequent analyses.

ii. Quality assurance/quality control

Elements of the quality assurance/quality control program for exposure assessment included: (1) written standard operating procedures for preparation, collection, and analysis of samples; (2) a recordkeeping/data entry system for tracking samples from the time of collection through analysis and final calculations; (3) periodic calibrations of sampling and analytical equipment (flowmeters, analytical balance, etc.); and (4) the use of field and laboratory sample blanks.

As part of the quality assurance program in this study, we also validated the performance of the Respicon for size-selective sampling of wood processing dust by field comparison of the Respicon against reference samplers in various locations in the study plants[28]. The reference size-selective sampling devices used were the SKC aluminum cyclone (SKC Inc., Eighty Four, PA) for the respirable fraction, the aluminum GK 2.69 cyclone (BGI Inc., Waltham, MA) for the thoracic fraction, and the conductive plastic IOM sampler (SKC Inc.) for inhalable dust. The cyclone filters and IOM filter/internal filter cassettes were handled as described above in terms of humidity conditioning, static discharge, and pre- and post-sample weighings.

Grouped samples, consisting of one Respicon sampler and one sampler of each type of reference size-selective sampling device, were collected near obvious sources of dust such as wood processing machines or manual workstations. Samples were collected in locations representing all common industrial wood processing activities including sawing, milling, sanding, gluing, and stacking. Stationary sampling was conducted in both the free-field and bluff-body modes, the latter simulating personal sampling with the Respicon mounted on the chest of the worker.

The results of the validation study showed that the Respicon reported higher respirable dust levels on average than did the reference sampler, but the correlation was generally quite good up to about 1 mg/m^3 of respirable dust at which point the Respicon appeared to oversample in comparison to the reference. Given that very few of the personal respirable dust sample results were in the range of 1 mg/m^3 or higher, it was decided not to apply any correction factor to the respirable dust fraction reported by the Respicon. For the inhalable fraction of industrial wood processing dust, a correction factor of 1.5x applied to stage 3 results, which was originally recommended by the Respicon manufacturer but later rescinded, was shown to be appropriate and necessary and was applied to all measurements with the Respicon. For the thoracic dust fraction, the device was shown to oversample the extrathoracic fraction of industrial wood processing dust by about 13%, resulting in a significant bias in measurement. A simple adjustment based on the apparent thoracic and corrected inhalable dust measures from the Respicon was developed and used to correct for the oversampling:[28]

$$Thoracic_{corrected} = 0.98 * Thoracic_{measured} - 0.107 * Inhalable$$

All personal thoracic dust measures collected in the study were adjusted using the above algorithm.

iii. Determination of wood solids in dust by DRIFTS

In support of this project, we developed and utilized a new technique for determining wood solids content.[29] Size-fractionated wood solids from 37-mm, glass fiber filter samples collected with the Respicon sampler was determined using a Mattson Galaxy 5000 FTIR spectrometer fitted with a translational diffuse reflectance apparatus that was modified to accept filter samples. The modification consisted of a special filter holder on the sample stage and a clockwork motor to drive the translational stage during infrared scanning, thus providing an average analysis across the filter face. Filter samples were pre-treated with ethyl acetate to uniformly redeposit dust onto the filter and extract potential chemical interferences. Two absorbance maxima (1251 and 1291 cm^{-1}) corresponding to the cellulose content of the wood, were suitable for quantitation of wood dust. Wood content was quantitated in comparison to size-fractionated dust standards of southern yellow pine or red oak prepared in the laboratory from dust collected during sanding of dimensional kiln-dried lumber obtained from local retail outlets. Prior to use in the analysis, the standard dusts were vacuum dried. Thus the results of wood solids reported here represent the combined mass of cellulose, hemicellulose, lignin, wood protein and other wood-derived biological macromolecules present in the collected particulate matter. The difference between the total particulate matter in the samples and the respective wood solids content represents the mass of residual particulate matter such as dirt, engine exhaust, environmental tobacco smoke, spray finish aerosols, etc, plus the adsorbed volatile components of the whole wood dust including water, terpenes, and essential oils.

A total of 527 sets of archived Respicon filters, roughly equally distributed across the study plants, were chosen for DRIFTS analysis and determination of wood solids content. The selection criteria included those samples collected on glass fiber filter, having a complete set of valid filters (Respicon stages 1, 2 and 3), preferably containing at least 100 μg of collected dust on each stage, and distributed across all homogeneous exposure groups in a given plant. Samples collected from facilities processing only softwood were analyzed against southern yellow pine dust standards at a wavelength of 1251 cm^{-1}, whereas samples from those facilities that processed any hardwood were analyzed against red oak dust standards at a wavelength of 1291 cm^{-1}.

iv. Homogeneous exposure groups (HEGs) & job exposure matrix (JEM)

Inferential and statistical techniques were used to develop homogeneous exposure groups (HEG) based on plant, department, job title, and job activity. Observations and information obtained during the industrial hygiene surveys was used to divide the workforce into rough groupings, most often based on the work department. Individual jobs within these rough groupings were then evaluated for similar exposures by analysis of variance (ANOVA) or t-test on log-transformed personal monitoring results with the thoracic dust exposure being the principal determinant. Based on the results of the ANOVA/t-tests, further subdivision of the rough groupings was performed as necessary to define those jobs with similar exposure profiles (no statistically significant differences).

Once the compositions of the HEGs were defined, the exposure assignment for each was determined as the arithmetic mean of the measured exposures for those jobs comprising the HEG. The arithmetic means of dust exposure for HEGs were calculated using the maximum likelihood estimator (MLE):

$$MLE = \exp\left\{\bar{y} + \frac{1}{2}\left(\frac{N-1}{N}\right)\sigma_y^2\right\},\quad y = \ln x$$

The MLEs were calculated for each dust size fraction separately and assigned to their respective HEGs. The percentage wood solids in each of the three size-fractions of dust for each HEG was taken as the respective arithmetic mean, calculated directly from DRIFTS analysis of samples from the respective HEG. The average wood solids percentage for each of the size fractions was then coupled with the assigned MLE for that size fraction to determine the final assignment of wood solids and residual particulate matter exposure for a given HEG. These final exposure assignments for wood solids and residual particulate matter, calculated for each job title appearing in the study subjects' job histories, constituted the job exposure matrix for the study.

A qualitative job exposure matrix was also developed for those conditions and factors related to workplace exposure that were believed to have the potential to act as confounders or determinants of biological response. Thus all identified jobs in the JEM were evaluated for likely exposure to wood type (greenwood or dry wood), wood species (hardwood or softwood), formaldehyde, and paint/stain/varnish aerosols. The qualitative JEM was set up with categorical exposures (yes v. no or ever v. never) for each of the factors identified above.

v. Individual exposure assignments

For each worker in the study, assigned exposures were determined by linking the individual's job history with the developed job exposure matrix. Job/work histories of the study cohort members were analyzed and each entry in the time period of interest was placed into the appropriate homogeneous exposure group (HEG). For each individual in the study, the average exposure was then calculated as:

$$E_{avg} = \frac{\sum E_i t_i}{\sum t_i}$$

where E_i is the assigned exposure for a given HEG over the given time period t_i. The term Σt_i represents the total time between first and last lung function measurement. Exposures were assigned by homogeneous exposure groups for the 3 sampling size fractions of dust (inhalable, thoracic and respirable) and for wood solids and residual particulate matter for each of these size fractions.

Because the three sampling fractions overlap (thoracic dust includes respirable dust, and inhalable dust includes thoracic dust) exposure assignments for the non-overlapping particle fractions of extrathoracic, tracheobronchial and respirable dust were calculated for each study participant. This was done to eliminate the possibility of statistical conflict in the multiple regression health effects models among exposure measures based on the overlapping sample size fractions. Prior to performing this recalculation, we verified that post exposure-assignment calculation of the non-overlapping fractions was mathematically equivalent to calculating these fractions at the level of the individual dust samples and carrying these through the subsequent calculation steps. Thus, the exposure assignments were refined by determining, for each individual in the study, the assigned exposures for the non-overlapping size-fractions of wood solids and residual particulate matter. These non-overlapping size-fractions (extrathoracic, tracheobronchial, respirable) were calculated from the sampling size-fractions as:

$$extrathoracic = inhalable - thoracic$$
$$tracheobronchial = thoracic - respirable$$

The respirable fraction is the same for both the sampling and non-overlapping size criteria.

Exposure was assigned for each job at each plant based upon multiple personal samples taken over the course of the study period. Job histories covering each participant's time in the study were compiled using quarterly reports supplied to the investigators by the individual plants. Time weighted average exposure assignments (TWA) were calculated for each study participant by summing all products of length of time in a particular job and the exposure assignment for that job, then dividing by each participants study duration as described above.

D. Abstraction of Job Histories

Spreadsheet files (Excel, dBase, Access) with identifying information on each employee were obtained from the participating plants. These files were converted to an Access database (one for each plant) containing name, unique identifier, job, department, and demographic information on all potential study participants. The Access files were preloaded onto the individual MWS's prior to shipment to the plants and were used to identify participant's jobs at the start of the study. Over the next five years, Tulane received quarterly updates from the plants concerning any changes in job, department, or work status for each of the study participants.

These data were supplemented by job history information collected directly through the MWS during annual testing, and information collected by Tulane industrial hygienists during the course of the study while visiting the facilities to conduct dust exposure monitoring. These job histories were periodically sent to each plant for confirmation, and at the end of the study were used to provide a job history profile for each individual, tracking their time spent in each homogeneous exposure group at that facility, in order to calculate their respective TWA exposures over the study period utilizing the exposure measures noted above.

E. Statistical Analyses

i. Baseline comparisons

The Analysis of Variance was used to compare mean baseline levels of age and the percent predicted lung functions (utilizing blue-collar normative values developed by the investigators[30]) between those with insufficient follow-up and those with sufficient follow-up or longitudinal analyses. The chi-square test was used to compare the sex and race distributions, as well as the baseline symptom prevalence between the longitudinal and non-longitudinal study groups.

Analysis of Variance was used to compare mean baseline levels of age and the percent predicted lung functions across the facility types. The chi-square test was used to compare the sex and race distributions, as well as the baseline symptom prevalence across the facility types.

ii. Longitudinal exposure-response analyses

For the spirometric measurements evaluated with exposure (FEV_1, FVC, FEV_1/FVC, FEF_{25-75}), the annual rates of change were analyzed in a two-stage procedure, where relationships with other factors were investigated by using multiple linear regression. This two-stage procedure produced estimates of the exposure-response relationship between exposure and annual change in lung function measures.

At the first stage, longitudinal estimates of annual change in lung function were estimated by individual least squares slopes of lung function measures versus time. At the second stage, linear models were used to relate the resulting slopes to indices of exposure, controlling for age, baseline pulmonary function, sex, percent of body-weight change over each participant's study duration, smoking amount, wood type (green wood versus dry wood and hard versus soft wood), and other potential exposures (paint, varnish or solvents, rubber wood, and formaldehyde).

Interaction terms were included in these models to determine whether the exposure-response effect was different for different demographic or risk factor groups. Cigarette smoking and exposure interactions as well as interactions between exposure and facility type were considered for possible synergistic effects.

Both wood solids and residual particulate matter fractions of each of the three non-overlapping time-weighted-average size-fractionated exposure indices were considered in the health effects model. To statistically select the exposure indices which were most significantly associated with annual decline in lung function, a multiple regression forward selection procedure was used. This method allows the most statistically significant exposure measure to enter into a regression model, and then only allows other exposure measures to enter if they are statistically significant after adjusting for the effects of the factors that are already in the model.

IV. RESULTS

A. Study Population Testing

Table 2 shows a frequency of testing for the participating facilities, presented in the same order as Table 1, by year. Two of the facilities, a furniture and a plywood facility, were not recruited until the second year of the study (2000). As anticipated in any longitudinal study, some of the facilities experienced personnel difficulties that limited their ability to collect data during certain periods of the follow-up. However, data were collected on 3,140 participants from the ten wood processing facilities, and 1,164 participants had adequate followup (at least 3 tests over a minimum of 2.5 years) to be analyzed longitudinally.

Table 2
Summary of Pulmonary Function/Questionnaire Data Collection

Facility	Number Of Tests By Year						All Years
	1999	2000	2001	2002	2003	2004	
Furniture	264	153	127	138	103	107	892
Furniture	311	262	196	181	73	132	1155
Furniture	192	163	133	106	62	68	724
Furniture	0	73	179	130	108	89	579
Furn-Cab-Parts	338	354	318	278	244	241	1773
Cabinet	156	225	272	350	231	200	1434
Cabinet	159	9	92	114	121	66	561
Plywood	0	336	329	39	408	242	1354
Milling	240	106	189	129	112	92	868
Saw-Plan-Ply	232	235	0	129	119	75	790
TOTAL	**1892**	**1916**	**1835**	**1594**	**1581**	**1312**	**10130**

B. Study Population Comparison: Longitudinal Versus Non-Longitudinal

Table 3A shows baseline demographic results for those with inadequate followup (non-longitudinal population) and those with adequate followup (longitudinal population). Mean age for the longitudinal population is comparable to that for the remainder of the participants (40.34 vs 38.56, respectively) as are percent male (66.92 vs 67.36) and percent African American (17.70 vs 14.52).

Table 3A
Baseline Comparison Demographics
Non-Longitudinal vs Longitudinal Population

Population	Smoking	N	Age*	%Male	%AfAmer
Non-Longitudinal	Curr	671	37.61±0.44	66.32	10.73
	Ex	452	42.35±0.61	70.58	13.50
	Nev	853	37.30±0.39	66.47	18.05
	Total	**1976**	**38.56±0.27**	**67.36**	**14.52**
Longitudinal	Curr	319	40.01±0.59	61.13	12.54
	Ex	233	43.79±0.65	75.54	14.59
	Nev	612	39.21±0.39	66.67	21.57
	Total	**1164**	**40.34±0..30**	**66.92**	**17.70**

*Mean ± SE

Table 3B shows baseline spirometric results for the non-longitudinal and longitudinal population. Baseline pulmonary function levels for FEV_1, FVC, FEV_1/FVC%, and FEF_{25-75} differ across these populations by less than 1%, with expected reductions in FEV_1, FEF_{25-75} and FEV_1/FVC observed in cigarette smokers for both populations.

Table 3B
Baseline Comparison Spirometry:
Non-Longitudinal vs Longitudinal Population

Population	Smoking	% Predicted Values (Baseline)*			
		FEV_1	**FVC**	**FEV_1/FVC**	**FEF_{25-75}**
Non-Longitudinal	Curr	90.14±0.59	93.38±0.54	96.35±0.33	83.11±1.06
	Ex	93.29±0.74	94.95±0.71	98.23±0.34	88.54±1.31
	Nev	94.16±0.49	94.71±0.49	99.47±0.23	93.05±0.85
	Total	**92.59±0.34**	**94.31±0.32**	**98.13±0.17**	**88.64±0.60**
Longitudinal	Curr	89.60±0.82	93.25±0.75	95.89±0.45	80.59±1.43
	Ex	91.08±0.97	92.63±0.92	98.33±0.45	87.41±1.78
	Nev	93.14±0.54	93.81±0.52	99.20±0.28	92.24±1.04
	Total	**91.76±0.41**	**93.42±0.39**	**98.12±0.21**	**88.10±0.78**

*Mean ± SE

In addition, questionnaire responses and spirometric results were used to define several symptom complexes. They are:

- COPD (Chronic Obstructive Pulmonary Disease): FEV_1/FVC% < 70% and FEV_1 percent predicted < 80%.

- URS (Upper Respiratory Symptoms): Ever had hay fever or ever had trouble with runny eyes or nose; or sneezes when around grass, pollen or animals.

- LRS (Lower Respiratory Symptoms): Usually coughed for certain periods of morning, day or night; or usually brought up phlegm from chest in morning, day or night; or gets short of breath walking on level ground with people their own age; or ever had attacks of wheezing with shortness of breath.

- Asthma: Ever had asthma.

- Pneumonia: Ever had pneumonia.

Table 3C shows that the prevalence of symptom complexes differs by less than 1% between the non-longitudinal and longitudinal population with the exception of LRS which is 4.85% higher in the non-longitudinal portion.

Table 3C
Baseline Comparison Symptoms And Conditions:
Non-Longitudinal Vs Longitudinal Population

Population	Smoking	N	% URS	% LRS	% COPD	% Asthma	% Pneumonia
Non-Longitudinal	Curr	671	42.47	51.27	7.30	10.13	27.42
	Ex	452	49.78	30.31	4.87	10.18	20.80
	Nev	853	45.60	29.66	1.76	9.14	19.34
	Total	**1976**	**45.50**	**37.15**	**4.35**	**9.72**	**22.42**
Longitudinal	Curr	319	38.18	48.28	5.96	7.84	25.71
	Ex	233	48.50	29.61	3.86	12.88	23.18
	Nev	612	45.75	25.00	2.61	11.11	18.63
	Total	**1164**	**44.50**	**32.30**	**3.78**	**10.57**	**21.48**

Preliminary exposure-response analyses, described in the following section, indicated that furniture-cabinetry (7 facilities), plywood (1 facility), milling (1 facility), and sawmill-planing-plywood (1 facility) should be analyzed separately. Table 3D shows the demographics, cigarette smoking histories, lung function and symptoms and conditions for the non-longitudinal and longitudinal populations within these four industry segments. Within each segment, age and gender were similar, but there was a greater percentage of African-Americans in the longitudinal sawmill-planing-plywood population as compared to its non-longitudinal population; however, racial differences have not been shown to influence the results of other longitudinal exposure-response studies conducted by Tulane or other investigators, and preliminary analyses indicated that racial differences did not influence the results of this study. There was a lower percentage of smokers in the longitudinal furniture-cabinetry, milling and sawmill-planing-plywood populations as compared to their non-longitudinal populations, but similar lifetime cumulative pack years (LCPY, here computed to baseline and averaged over all participants) were reported within all segments except for the sawmill-planing-plywood longitudinal population where it was reduced; however, the regression analyses will adjust for any differences in individual LCPY. Within each segment, the percent predicted lung function for the longitudinal populations were generally similar or slightly reduced when compared to their non-longitudinal populations, but these small differences do not support a potential healthy worker influence on the longitudinal analyses. Symptoms and conditions were also similar within each segment, except for a reduced %COPD in the sawmill-planing-plywood longitudinal population as compared to its non-longitudinal population, and was probably associated with the aforementioned reduced % current smoking and LCPY in the longitudinal population for this segment, but this will be adjusted in the analyses. There was also an increased % asthma reported in the longitudinal plywood and sawmill-planing-plywood segments compared to their non-longitudinal segments; however, this is self-reported and often unreliable. Overall, the within-segment baseline demographics, cigarette smoking histories, lung function, and symptoms and conditions were comparable between the respective longitudinal and non-longitudinal populations, and any noted differences should be adjusted by the regression analyses and should not be influenced by a healthy worker effect. Differences across the longitudinal segments are discussed in the next section.

Table 3D
Industry Segment Comparison of Baseline Mean Values
Non-Longitudinal (Non-Long) Vs Longitudinal Population (Long)

Baseline Mean Values	Furn-Cab		Plywood		Milling		Saw-Plan-Ply	
	Non-Long	Long	Non-Long	Long	Non-Long	Long	Non-Long	Long
N	1259	779	253	177	240	108	224	100
Age	39.1	41.3	36.9	37.9	35.7	38.3	40.3	39.6
%Male	59.3	60.0	90.9	90.3	68.8	62.0	84.4	85.0
%Af-Am	11.6	13.2	43.5	43.2	0	0	13.8	27.0
%CurrSmk	36.7	31.2	28.9	28.8	33.3	28.7	25.0	18.0
LCPY	11.2	10.6	8.8	8.6	7.8	8.7	11.2	6.4
%PFEV$_1$	92.2	91.9	91.3	88.6	98.0	97.3	90.4	90.1
%PFVC	94.0	93.7	91.9	90.2	100.8	99.3	92.0	90.8
%PFEV$_1$/FVC	98.0	98.1	99.3	98.1	97.3	97.7	98.4	98.9
%PFEF$_{25-75}$	87.9	87.8	90.0	85.2	92.0	94.1	87.6	89.1
%URS	44.7	44.7	38.7	32.9	49.6	50.9	53.1	56.0
%LRS	38.4	33.7	30.4	25.0	35.4	27.8	39.7	39.0
%COPD	5.2	4.2	2.4	2.8	2.1	3.7	4.5	2.0
%Asthma	10.6	10.3	6.7	11.9	8.3	8.3	9.4	13.0
%Pneumonia	23.6	21.2	17.0	19.9	20.0	19.4	24.6	29.0

C. Longitudinal Population: Description

The 1,164 participants studied longitudinally were employed at a variety of facilities with varied potential for exposure related effects, besides exposures related to processing wood dust, which was the focus of this study. Some of the furniture/cabinet facilities included finishing operations with potential exposures to paint, varnish or solvents, and facilities with plywood operations had potential exposures to uncured formaldehyde containing resins. Certain of the facilities processed various combinations of greenwood and/or dry wood, and softwood and/or hardwood. Also, one facility that manufactured chairs began using imported rubber wood, a potential allergen, early in the study. Initially, this information was used to identify workers who, during the follow-up, had potential confounding exposures within the following categories.

- Ever versus never exposed to paint, varnish or solvents
- Ever versus never potentially exposed to uncured formaldehyde containing resins

- Ever worked with rubber wood
- Ever versus never worked with greenwood
- Always versus not always worked with softwood

Preliminary analyses showed that only working with greenwood or softwood appeared to influence the exposure-response effects of wood processing dust on annual change in lung function, and the spirometric parameters affected were different for greenwood as compared to softwood. Further analyses indicated that the greenwood or softwood exposure-response effect was actually driven by workers at the sawmill-planing-plywood facility, who frequently worked with greenwood, or driven by workers at the milling facility, who always worked with softwood. It was also noted that the preliminary exposure-response effects noted in the sawmill-planing-plywood and the milling facility were very different from each other, and also different from that observed in the plywood facility, even though the sawmill-planing-plywood facility included plywood operations, and different from that observed in the furniture and cabinet facilities. Therefore, four mutually exclusive populations defined as furniture-cabinetry (7 facilities), plywood (1 facility), milling (1 facility), and sawmill-planing-plywood (1 facility) were analyzed separately.

Table 4A shows that ages of study subjects at baseline were very similar across these facility groupings. Sawmill/plywood and plywood facilities were largely male, while gender was closer to being evenly split for milling and furniture/cabinet. There were no African-Americans in the milling facility, but increasing percentages in furniture/cabinet, sawmill/plywood and plywood facilities.

Table 4A
Baseline Demographics:
Longitudinal Population by Facility Type

Facility Type	N	Age	%Male	%AfAmer
Furn-Cab	779	41.29±0.37	60.00	13.21
Plywood	177	37.88±0.65	90.34	43.18
Milling	108	38.29±1.01	62.04	0
Saw-Plan-Ply	100	39.59±0.91	85.00	27.00

*Mean ± SE

Table 4B shows that baseline spirometric levels were generally normal. Approximately 78% of the population had both the FEV_1 and FVC $\geq$ 80% predicted, but average results were somewhat higher in the milling facility with percentages in the upper 90s for both FEV_1 and FVC, as compared to the other facilities with percentages in the upper 80s to lower 90s for both FEV_1 and FVC. The differences in percent predicted lung function may also be due to the large percentage of Hispanics in the milling facility (14.8% versus less than 1% at furniture-cabinet, plywood and sawmill-planing-plywood facilities), because even though the predicted equations adjusted for Caucasians versus African-Americans, the Caucasian population used to develop the predicted equations included less than 1% Hispanics. In addition, the milling facility was the only facility located in the Northwestern United States, and differences in lifestyle may also have influenced the lung function of those workers.

Table 4B
Spirometry
Longitudinal Population by Facility Type

Facility Type	% Predicted Values (Baseline)*			
	FEV_1	FVC	FEV_1/FVC%	FEF_{25-75}
Furn-Cab	91.94±0.51	93.67±0.48	98.08±0.26	87.78±0.95
Plywood	88.57±1.03	90.18±0.98	98.14±0.50	85.23±1.91
Milling	97.25±1.30	99.33±1.19	97.70±0.74	94.08±2.62
Saw-Plan-Ply	90.05±1.38	90.79±1.17	98.92±0.74	89.09±2.64

*Mean ± SE

Table 4C shows cigarette smoking status, lifetime cumulative packyears (LCPY, current and ex smokers combined and computed to the end of each individuals followup), and study packs per day (SPPD, smoking averaged during the followup). There was a lower percentage of current smokers at the sawmill-planing-plywood facility, and both measures of amount smoked, lifetime or study duration, were generally lower at this facility. It should be noted that all 1,164 longitudinal participants had consistent smoking status (always current, ex or never smokers) throughout the entire followup.

TABLE 4C
Cigarette Smoke (%), Lifetime Cumulative Packyears (LCPY), and
Study Packs-Per-Day (SPPD)
Longitudinal Population by Facility Type

Facility Type	N	% Curr Smok	LCPY	SPPD
Furn-Cab	779	31.19	22.97±0.90 [4]	0.92±0.03 [8]
Plywood	177	28.81	22.36±2.44 [3]	0.94±0.06 [7]
Milling	108	28.70	17.01±2.44 [2]	0.81±0.07 [6]
Saw-Plan-Ply	100	18.00	15.94±2.73 [1]	0.84±0.07 [5]

*Mean ± SE
[1] n=44, [2] n=61, [3] n=76, [4] n=399, [5] n=18, [6] n=31, [7] n=51, [8] n=243

Table 4D shows that annual declines for FEV_1 and FVC were less steep in the milling and plywood facility than in the furniture-cabinet or the sawmill-planing-plywood facilities; however, the furniture-cabinet facilities had generally higher cigarette smoking measures whereas the sawmill-planing-plywood facility had generally lower cigarette smoking measures expressed as either percent current smokers, LCPY or SPPD.

Table 4D
Annual Decline (ml/year)
Longitudinal Population by Facility Type

Facility Type	Annual Change*			
	FEV_1 (ml/yr)	FVC (ml/yr)	FEV_1/FVC (%/yr)	FEF_{25-75} (ml/s/yr)
Furn-Cab	-51.24±2.44	-52.64±2.89	-0.27±0.03	-75.08±4.89
Plywood	-26.16±5.84	-0.51±7.02	-0.59±0.06	-111.29±12.92
Milling	-12.32±6.64	-3.18±7.77	-0.251±0.09	-59.00±16.00
Saw-Plan-Ply	-69.66±6.90	-71.45±8.22	-0.362±0.09	-94.52±15.28

*Mean ± SE

Table 4E shows symptom complexes and conditions for each of the facility types. The sawmill-planing-plywood facility had the highest prevalence for each symptom/condition with the exception of COPD which was the lowest, and is consistent with the sawmill-planing-plywood facility usually having the lowest cigarette smoking by %, LCPY or SPPD. Chi-square analysis indicated that upper respiratory symptoms (URS) were significantly elevated ($p<0.05$) for sawmill-planing-plywood compared to furniture-cabinet or plywood, and for milling and furniture-cabinet compared to plywood. Lower respiratory symptoms (LRS) were significantly elevated ($p<0.05$) for sawmill-planing-plywood and furniture-cabinet compared to plywood, and for sawmill-planing-plywood compared to milling ($p<0.1$). Prevalence of pneumonia in sawmill-planing-plywood was significantly elevated ($p<0.1$) compared to plywood or furniture-cabinet.

TABLE 4E
Selected Baseline Symptoms and Conditions
Longitudinal Population by Facility Type

Facility Type	N	%URS	%LRS	%COPD	%Asthma	%Pneumonia
Furn-Cab	779	44.74	33.72	4.23	10.26	21.15
Plywood	177	32.95	25.00	2.84	11.93	19.89
Milling	108	50.93	27.78	3.70	8.33	19.44
Saw-Plan-Ply	100	56.00	39.00	2.00	13.00	29.00

D. Dust Monitoring Results

A total of 3,488 sets of Respicon samples (10,464 individual filters) were collected/processed over the course of the study. Of these, 554 were reserved as blanks, 71 were area samples used in the field validation of the Respicon, 77 were collected using unweighed MCE filters in the Respicon and were archived for possible future microscopic analyses, 423 were determined to be invalid after collection due to pump failure, disconnected sample lines, mechanical damage to filters, and negative adjusted filter weight changes, and the remaining 2,363 sets of samples were valid personal samples used in the exposure assessment.

i. Respicon measures: dust level fractions

Table 5A summarizes the results of the dust monitoring for the ten plants in the study presented in the same order as tables 1 and 2. Overall, the inhalable dust levels were in the range of about 1 to 2 mg/m^3 and the thoracic and respirable dust levels were approximately 20% and 10% of the corresponding inhalable dust level, respectively. Comparing the plant types, the highest inhalable and thoracic dust exposures occurred in the furniture and cabinet plants whereas the lowest levels appeared in the sawmill and plywood plants. In contrast to the larger size fractions, the respirable dust levels were generally more consistent across the plants with no clearly discernable differences by plant type.

Table 5A
Summary of Results – Personal Dust Monitoring

Plant type	n	Respirable Dust (mg/m^3)		Thoracic Dust (mg/m^3)		Inhalable Dust (mg/m^3)	
		GM	GSD	GM	GSD	GM	GSD
Furniture	271	0.18	2.8	0.37	3.3	1.96	2.7
Furniture	198	0.21	3.5	0.40	4.1	2.10	2.4
Furniture	220	0.16	2.2	0.29	2.5	1.32	2.8
Furniture	288	0.23	2.3	0.49	2.2	1.86	2.3
Cabinet	290	0.22	2.7	0.43	2.3	1.61	2.4
Cabinet	244	0.19	2.2	0.54	2.2	2.51	2.3
Cabinet	205	0.16	2.1	0.35	2.0	1.23	2.1
Plywood	254	0.13	2.4	0.15	2.5	0.77	2.2
Milling	180	0.10	2.7	0.16	2.4	1.07	2.3
Saw-Plan-Ply	213	0.19	2.0	0.21	2.3	0.82	2.2
Overall	2363	0.18	2.6	0.33	2.8	1.45	2.7

ii. DRIFTS analysis: wood solids content

Table 5B shows a summary of the results of the DRIFTS analysis presented as percentage wood solids content by size fraction and grouped by plant in the same order as table 1, 2 and 5A. Overall, similar percentages of wood solids content were found in the thoracic and inhalable dust fractions (approximately 40% wood solids) with significantly less wood solids in the respirable dust. Given that size distributions of industrial wood processing dust are skewed towards the extrathoracic particles, these results are generally consistent with expectations. There were also clear differences in the wood solids content of the samples by plant type with the sawmill and plywood facilities showing significantly less wood solids in the dust than the other types of facilities. Given that green wood is being processed at these facilities and there can be significant emissions of resin binders in plywood production, these results are also within expectations.

Table 5B
Summary of Results: Wood Solids in Size-Fractionated Dust
Plant Average [Range]

Plant type	n	Respirable dust Wood Solids %	Thoracic dust Wood Solids %	Inhalable dust Wood Solids %
Furniture	50	11.9 [3.1–28.7]	77.6 [21.2–100]	54.4 [10.6–84.6]
Furniture	45	12.1 [1.3–31.0]	70.5 [1.0–100]	36.7 [2.0–53.4]
Furniture	45	19.5 [11.9–35.2]	70.4 [20.0–94.5]	52.4 [17.4–69.3]
Furniture	89	17.3 [3.8–27.3]	85.4 [23.0–100]	34.2 [19.4–49.3]
Cabinet	56	16.6 [0.2–42.9]	80.6 [27.7–100]	59.0 [29.8–82.9]
Cabinet	47	34.1 [2.7–79.2]	90.9 [38.4–100]	69.2 [21.4–100]
Cabinet	45	33.6 [3. –62.5]	78.7 [31.3–100]	53.9 [32.6–77.6]
Plywood	43	5.4 [0.3–21.4]	16.8 [0.2–43.7]	5.5 [0.9–29.5]
Milling	64	27.5 [5.5–94.6]	49.8 [35.2–100]	38.8 [21.8–66.3]
Saw-Plan-Ply	43	2.3 [1.0–4.7]	7.5 [3.7–28.3]	8.2 [6.7–15.5]
Overall	527	18.0 [0.2–94.6]	40.4 [1.0–100]	40.7 [0.9–100]

iii. Mean TWA's

Mean TWA's for the longitudinal study participants are presented in table 5C that show higher overall dust exposures for all three fractions for furniture and cabinet facility workers, a greater percentage of wood solids in the dust exposures for furniture, cabinet and milling facility workers, and a greater percentage of residual particulate matter in the dust exposures for sawmill and plywood facility workers.

Table 5C
Mean TWA Exposure (mg/m³)
Extrathoracic, Tracheobronchial & Respirable
Wood Solids (WS) and Residual Particulate Matter (RPM)
Longitudinal Population by Facility Type

Exposure	Facility Type	N	WS Mean±SE (mg/m^3)	WS Range (mg/m^3)	RPM Mean±SE (mg/m^3)	RPM Range (mg/m^3)
Extra-thoracic	Furn-Cab	779	0.902±0.038	0-6.966	1.115±0.038	0.147-10.153
	Plywood	177	0.024±0.002	0-0.107	0.580±0.020	0.081-1.544
	Milling	108	0.522±0.019	0.279-1.114	1.049±0.047	0.397-2.251
	Saw-Plan-Ply	100	0.081±0.004	0.014-0.170	0.872±0.038	0.407-1.771
Tracheo-bronchial	Furn-Cab	779	0.449±0.015	0-2.652	0.017±0.002	0-0.412
	Plywood	177	0.025±0.002	.0001-0.178	0.237±0.008	0.005-0.887
	Milling	108	0.110±0.009	0-0.358	0.021±0.003	0-0.141
	Saw-Plan-Ply	100	0.017±0.001	0.007-0.070	0.032±0.006	0.006-0.577
Respir-able	Furn-Cab	779	0.072±0.004	0-1.166	0.226±0.004	0.006-0.969
	Plywood	177	0.005±0.001	.0001-0.050	0.159±0.004	0.034-0.399
	Milling	108	0.039±0.003	0.009-0.134	0.147±0.008	0.005-0.319
	Saw-Plan-Ply	100	0.005±0.000	0.003-0.012	0.255±0.0069	0.144-0.419

E. Exposure-Response Analysis

Regression analysis (forward selection method) was conducted to determine the effect of the TWA on annual decline for FEV_1, FVC, FEV_1/FVC% and FEF_{25-75} for each of the four industry groupings. After adjusting for age, baseline pulmonary function level, sex, percent body-weight change over each participants study duration, and cigarette smoking (LCPY or SPPD with separate models and results reported), the wood solids (WS) and residual particulate matter (RPM) components for each of the three non-overlapping size fractions (extra-thoracic, tracheo-bronchial and respirable) were allowed to enter the model in order of highest significance, using a 0.05 entry level, and all statistically significant results at the 0.05 level are shown in bold. Non-significant exposure related results are shown as NS.

Furniture/Cabinetry: Preliminary analysis using multiple variable linear regression showed no significant effects for any of the exposure fractions, irrespective of whether the wood solids and residual particulate matter were analyzed simultaneously or separately. Tables 6A and 6B show the results from the multiple regression forward selection analysis. Again, irrespective of the definition of cigarette smoking used (LCPY or SPPD), no significant effects were found for any of the exposure fractions.

Table 6A
Furniture/Cabinet Facilities (N=779)
Multiple Regression Forward Selection
Wood Solids (WS) & Residual Particulate Matter (RPM)
Exposure Fraction Components (per-mg/m^3)
Lifetime Cumulative Packyears (LCPY)

Variable	FEV_1 (ml/yr)		FVC (ml/yr)		FEV_1/FVC (%/yr)		FEF_{25-75} (ml/s/yr)	
	Coef	p Value	Coef	p Value	Coef	P Value	Coef	p Value
Intercept	**92.12 ±22.94**	**<0.0001**	**145.10 ±26.73**	**<0.0001**	**2.99 ±0.47**	**<0.0001**	**139.82 ±33.82**	**<0.0001**
Age*	**-1.32 ±0.26**	**<0.0001**	**-1.90 ±0.30**	**<0.0001**	-0.0003 ±0.003	0.9126	**-1.72 ±0.505**	**0.0007**
Baseline*	**-23.32 ±4.08**	**<0.0001**	**-25.51 ±3.98**	**<0.0001**	**-0.039 ±0.005**	**<0.0001**	**-36.15 ±4.73**	**<0.0001**
Sex*	-0.47 ±6.22	0.9401	-3.97 ±7.59	0.6008	-0.02 ±0.06	0.7611	-5.01 ±10.33	0.6277
LCPY*	**-0.45 ±0.14**	**0.0014**	-0.24 ±0.16	0.1377	**-0.01 ±0.002**	**<0.0001**	**-1.06 ±0.291**	**0.0003**
%WtChg*	**-1.07 ±0.33**	**0.0015**	**-1.72 ±0.39**	**<0.0001**	**0.01 ±0.004**	**0.0187**	-0.62 ±0.67	0.3596
Exthor WS	--	NS	--	NS	--	NS	--	NS
Exthor RPM	--	NS	--	NS	--	NS	--	NS
Trabro WS	--	NS	--	NS	--	NS	--	NS
Trabro RPM	--	NS	--	NS	--	NS	--	NS
Respir WS	--	NS	--	NS	--	NS	--	NS
Respir RPM	--	NS	--	NS	--	NS	--	NS

* Forced into model

Table 6B
Furniture/Cabinet Facilities (N=779)
Multiple Regression Forward Selection
Wood Solids (WS) & Residual Particulate Matter (RPM)
Exposure Fraction Components (per-mg/m^3)
Study Packs Per Day (SPPD)

Variable	FEV_1 (ml/yr)		FVC (ml/yr)		FEV_1/FVC (%/yr)		FEF_{25-75} (ml/s/yr)	
	Coef	p Value	Coef	p Value	Coef	p Value	Coef	p Value
Intercept	**94.77 ±23.20**	**<0.0001**	**147.78 ±26.81**	**<0.0001**	**2.95 ±0.48**	**<0.0001**	**150.67 ±34.70**	**<0.0001**
Age*	**-1.51 ±0.26**	**<0.0001**	**-2.01 ±0.29**	**<0.0001**	-0.005 ±0.003	0.1074	**-2.18 ±0.502**	**<0.0001**
Baseline*	**-22.37 ±4.06**	**<0.0001**	**-25.24 ±3.98**	**<0.0001**	**-0.037 ±.005**	**<0.0001**	**-34.88 ±4.71**	**<0.0001**
Sex*	1.61 ±6.19	0.7942	-2.98 ±7.57	0.6944	0.003 ±0.064	0.9568	-1.28 ±10.28	0.9013
SPPD*	**-11.49 ±4.74**	**0.0156**	-7.10 ±5.50	0.1971	**-0.260 ±0.06**	**<0.0001**	**-28.84 ±9.70**	**0.0031**
%WtChg*	**-1.06 ±0.33**	**0.0016**	**-1.71 ±0.39**	**<0.0001**	**0.010 ±0.01**	**0.0195**	-0.61 ±13.87	0.3709
Exthor WS	--	NS	--	NS	--	NS	--	NS
Exthor RPM	--	NS	--	NS	--	NS	--	NS
Trabro WS	--	NS	--	NS	--	NS	--	NS
Trabro RPM	--	NS	--	NS	--	NS	--	NS
Respir WS	--	NS	--	NS	--	NS	--	NS
Respir RPM	--	NS	--	NS	--	NS	--	NS

* Forced into model

Plywood: Preliminary analysis using multiple variable linear regression showed no significant effects for any of the exposure fractions, irrespective of whether the wood solids and residual particulate were analyzed simultaneously or separately. Tables 7A and 7B show the results from the multiple regression forward selection analysis. Again, irrespective of the definition of cigarette smoking used (LCPY or SPPD), no significant effects were found for any of the exposure fractions.

Table 7A
Plywood Facility (N=177)
Multiple Regression Forward Selection
Wood Solids (WS) & Residual Particulate Matter (RPM)
Exposure Fraction Components (per-mg/m^3)
Lifetime Cumulative Packyears (LCPY)

Variable	**FEV_1 (ml/yr)**		**FVC (ml/yr)**		**FEV_1/FVC (%/yr)**		**FEF_{25-75} (ml/s/yr)**	
	Coef	**p Value**	**Coef**	**p Value**	**Coef**	**p Value**	**Coef**	**p Value**
Intercept	94.64 ±54.95	0.0868	71.26 ±64.63	0.2718	0.563 ±0.931	0.5463	**214.28 ±92.66**	**0.0219**
Age*	-0.554 ±0.813	0.4965	0.096 ±0.967	0.9212	-0.006 ±0.007	0.4304	-2.87 ±1.68	0.0887
Baseline*	**-25.76 ±9.01**	**0.0048**	-15.30 ±8.73	0.0814	-0.011 ±0.010	0.2910	**-53.97 ±11.78**	**<0.0001**
Sex*	-41.40 ±21.74	0.0585	-48.28 ±26.37	0.0689	0.018 ±0.197	0.9261	-51.29 ±44.63	0.2521
LCPY*	-0.238 ±0.346	0.4919	-0.153 ±0.420	0.7167	-0.004 ±0.003	0.2060	-0.62 ±0.75	0.4103
%WtChg*	-1.85 ±1.09	0.0922	**-2.97 ±1.32**	**0.0255**	0.009 ±0.011	0.4130	-0.42 ±2.36	0.8581
Exthor WS	--	NS	--	NS	--	NS	--	NS
Exthor RPM	--	NS	--	NS	--	NS	--	NS
Trabro WS	--	NS	--	NS	--	NS	--	NS
Trabro RPM	--	NS	--	NS	--	NS	--	NS
Respir WS	--	NS	--	NS	--	NS	--	NS
Respir RPM	--	NS	--	NS	--	NS	--	NS

* Forced into model

Table 7B
Plywood Facility (N=177)
Multiple Regression Forward Selection
Wood Solids (WS) & Residual Particulate Matter (RPM)
Exposure Fraction Components (per-mg/m^3)
Study Packs Per Day (SPPD)

Variable	**FEV_1 (ml/yr)**		**FVC (ml/yr)**		**FEV_1/FVC (%/yr)**		**FEF_{25-75} (ml/s/yr)**	
	Coef	**p Value**	**Coef**	**p Value**	**Coef**	**p Value**	**Coef**	**p Value**
Intercept	98.77 ±54.63	0.0723	76.07 ±63.88	0.2354	0.632 ±0.937	0.5008	**225.78 ±92.22**	**0.0154**
Age*	-0.702 ±0.775	0.3667	-0.024 ±0.914	0.9791	-0.008 ±0.007	0.2379	**-3.18 ±1.60**	**0.0488**
Baseline*	**-25.52 ±9.14**	**0.0058**	-15.54 ±8.89	0.0822	-0.011 ±0.010	0.3052	**-53.44 ±11.72**	**<0.0001**
Sex*	-40.90 ±22.04	0.0652	-48.76 ±26.79	0.0705	0.038 ±0.198	0.8494	-47.48 ±44.80	0.2907
SPPD*	-4.17 ±11.90	0.7265	-0.786 ±14.15	0.9569	-0.154 ±0.117	0.1912	-24.67 ±25.42	0.3332
%WtChg*	-1.89 ±1.09	0.0857	**-2.99 ±1.32**	**0.0251**	0.008 ±0.011	0.4632	-0.575 ±2.36	0.8079
Exthor WS	--	NS	--	NS	--	NS	--	NS
Exthor RPM	--	NS	--	NS	--	NS	--	NS
Trabro WS	--	NS	--	NS	--	NS	--	NS
Trabro RPM	--	NS	--	NS	--	NS	--	NS
Respir WS	--	NS	--	NS	--	NS	--	NS
Respir RPM	--	NS	--	NS	--	NS	--	NS

* Forced into model

Milling: Tables 8A and 8B show that for every mg/m^3 of respirable residual particulate matter, significant annual declines were noted for FEV_1 (-220.01 ml/yr with LCPY and -214.05 ml/yr with SPPD in model), $FEV_1/FVC\%$ (-3.34 %/yr with LCPY and -3.31 %/yr with SPPD in model), and FEF_{25-75} (-725.91 ml/s/yr with LCPY and -714.16 ml/s/yr with SPPD in model).

Table 8A
Milling Facility (N=108)
Multiple Regression Forward Selection
Wood Solids (WS) & Residual Particulate Matter (RPM)
Exposure Fraction Components (per-mg/m^3)
Lifetime Cumulative Packyears (LCPY)

Variable	FEV_1 (ml/yr)		FVC (ml/yr)		FEV_1/FVC (%/yr)		FEF_{25-75} (ml/s/yr)	
	Coef	p Value	Coef	p Value	Coef	p Value	Coef	p Value
Intercept	**153.66 ±69.50**	**0.0293**	**181.75 ±83.71**	**0.0322**	**5.295 ±1.132**	**<0.0001**	**412.75 ±103.31**	**0.0001**
Age*	-1.05 ±0.72	0.1493	-1.24 ±0.864	0.1544	-0.008 ±0.008	0.3237	-2.73 ±1.53	0.0767
Baseline*	-20.75 ±12.48	0.0995	**-25.64 ±12.69**	**0.0460**	**-0.057 ±0.013**	**<0.0001**	**-57.19 ±14.06**	**<0.0001**
Sex*	-24.19 ±20.83	0.2483	-41.72 ±24.99	0.0981	-0.020 ±0.161	0.8999	-50.08 ±36.05	0.1677
LCPY*	-0.340 ±0.445	0.4472	-0.083 ±0.531	0.8761	-0.009 ±0.005	0.0765	-1.14 ±0.990	0.2510
%WtChg*	-1.69 ±1.12	0.1356	-1.10 ±1.36	0.4214	-0.022 ±0.013	0.1029	-3.77 ±2.48	0.1308
Exthor WS	--	NS	--	NS	--	NS	--	NS
Exthor RPM	--	NS	--	NS	--	NS	--	NS
Trabro WS	--	NS	--	NS	--	NS	--	NS
Trabro RPM	--	NS	--	NS	--	NS	--	NS
Respir WS	--	NS	--	NS	--	NS	--	NS
Respir RPM	**-220.01 ±78.77**	**0.0062**	--	NS	**-3.34 ±0.93**	**0.0005**	**-725.91 ±172.46**	**<0.0001**

* Forced into model

Table 8B
Milling Facility (N=108)
Multiple Regression Forward Selection
Wood Solids (WS) & Residual Particulate Matter (RPM)
Exposure Fraction Components (per-mg/m^3)
Study Packs Per Day (SPPD)

Variable	FEV_1 (ml/yr)		FVC (ml/yr)		FEV_1/FVC (%/yr)		FEF_{25-75} (ml/s/yr)	
	Coef	p Value	Coef	p Value	Coef	p Value	Coef	p Value
Intercept	**165.01 ±69.86**	**0.0201**	**192.72 ±84.01**	**0.0238**	**5.252 ±1.155**	**<0.0001**	**434.32 ±104.91**	**<0.0001**
Age*	-1.31 ±0.695	0.0621	-1.35 ±0.814	0.1007	-0.014 ±0.008	0.0679	**-3.49 ±1.47**	**0.0193**
Baseline*	-20.98 ±12.19	0.0884	**-26.42 ±12.55**	**0.0377**	**-0.054 ±0.013**	**<0.0001**	**-55.83 ±13.61**	**<0.0001**
Sex*	-21.37 ±20.30	0.2951	-40.37 ±24.69	0.1051	0.021 ±0.164	0.8965	-40.57 ±35.31	0.2533
SPPD*	-20.88 ±15.61	0.1841	-19.15 ±18,80	0.3108	-0.211 ±0.188	0.2649	-48.81 ±34.41	0.1591
%WtChg*	-1.47 ±1.13	0.1968	-0.847 ±1.38	0.5401	-0.021 ±0.014	0.1234	-3.32 ±2.50	0.1876
Exthor WS	--	NS	--	NS	--	NS	--	NS
Exthor RPM	--	NS	--	NS	--	NS	--	NS
Trabro WS	--	NS	--	NS	--	NS	--	NS
Trabro RPM	--	NS	--	NS	--	NS	--	NS
Respir WS	--	NS	--	NS	--	NS	--	NS
Respir RPM	**-214.05 ±78.49**	**0.0075**	--	NS	**-3.31 ±0.94**	**0.0007**	**-714.16 ±172.30**	**<0.0001**

* Forced into model

Sawmill-planing-plywood: Tables 9A and 9B show that for every mg/m^3 of respirable residual particulate matter, significant annual changes were noted for the FEV_1 (-231.43 ml/yr with LCPY and -230.00 ml/yr with SPPD in the model), FVC (-403.84 ml/yr with LCPY and -405.38 ml/yr with SPPD in the model), and FEV_1/FVC% (+2.77 %/yr with LCPY and +2.91 %/yr with SPPD in the model). The respirable wood solids component also showed a significant effect for the FEV_1/FVC%; however, an increase in FEV_1/FVC% can only be considered an adverse effect in the presence of a reduced FVC, which is not the case for the wood solids.

Table 9A
Saw-Plan-Plywood Facility (N=100)
Multiple Regression Forward Selection
Wood Solids (WS) & Residual Particulate Matter (RPM)
Exposure Fraction Components (per-mg/m^3)
Lifetime Cumulative Packyears (LCPY)

Variable	FEV_1 (ml/yr)		FVC (ml/yr)		FEV_1/FVC (%/yr)		FEF_{25-75} (ml/s/yr)	
	Coef	p Value	Coef	p Value	Coef	p Value	Coef	p Value
Intercept	33.41 ±71.36	0.6407	**186.00 ±82.28**	**0.0261**	-1.204 ±1.396	0.3906	-105.00 ±110.95	0.3464
Age*	-0.880 ±0.862	0.3101	**-2.22 ±0.973**	**0.0247**	0.008 ±0.011	0.4309	-0.391 ±1.84	0.8321
Baseline*	-2.74 ±12.81	0.8311	-14.88 ±11.87	0.2130	-0.008 ±0.015	0.5928	-16.06 ±16.57	0.3349
Sex*	18.45 ±23.00	0.4244	9.83 ±26.36	0.7100	-0.118 ±0.250	0.6389	-8.23 ±44.67	0.8542
LCPY*	0.189 ±0.541	0.7280	0.659 ±0.599	0.2742	**-0.018 ±0.007**	**0.0119**	-1.07 ±1.21	0.3819
%WtChg*	-0.370 ±0.851	0.6649	-0.124 ±0.938	0.8953	-0.006 ±0.012	0.6258	-2.12 ±1.99	0.2890
Exthor WS	--	NS	--	NS	--	NS	--	NS
Exthor RPM	--	NS	--	NS	--	NS	--	NS
Trabro WS	--	NS	--	NS	--	NS	--	NS
Trabro RPM	--	NS	--	NS	--	NS	--	NS
Respir WS	--	NS	--	NS	**+111.45 ±44.4**	**0.0138**	--	NS
Respir RPM	**-231.43 ±100.06**	**0.0229**	**-403.84 ±112.46**	**0.0005**	**+2.77 ±1.29**	**0.0350**	--	NS

* Forced into model

Table 9B
Saw-Plan-Plywood Facility (N=100)
Multiple Regression Forward Selection
Wood Solids (WS) & Residual Particulate Matter (RPM)
Exposure Fraction Components (per-mg/m^3)
Study Packs Per Day (SPPD)

Variable	FEV_1 (ml/yr)		FVC (ml/yr)		FEV_1/FVC (%/yr)		FEF_{25-75} (ml/s/yr)	
	Coef	p Value	Coef	p Value	Coef	p Value	Coef	p Value
Intercept	39.97 ±73.03	0.5854	**185.25 ±83.94**	**0.0298**	-0.670 ±1.420	0.6383	-74.57 ±112.67	0.5097
Age*	-0.818 ±0.833	0.3285	**-1.89 ±0.937**	**0.0468**	-0.002 ±0.010	0.8164	-1.06 ±1.73	0.5422
Baseline*	-4.79 ±12.70	0.7070	-17.01 ±11.85	0.1545	-0.010 ±0.015	0.5181	-16.71 ±16.12	0.3027
Sex*	15.79 ±22.58	0.4860	4.76 ±26.11	0.8558	-0.053 ±0.248	0.8300	-5.04 ±43.75	0.9085
SPPD*	-5.45 ±20.42	0.7900	6.64 ±22.76	0.7712	**-0.716 ±0.262**	**0.0075**	-60.19 ±45.01	0.1844
%WtChg*	-0.332 ±0.843	0.6944	0.0022 ±0.940	0.9982	-0.010 ±0.012	0.3818	-2.46 ±1.96	0.2137
Exthor WS	--	NS	--	NS	--	NS	--	NS
Exthor RPM	--	NS	--	NS	--	NS	--	NS
Trabro WS	--	NS	--	NS	--	NS	--	NS
Trabro RPM	--	NS	--	NS	--	NS	--	NS
Respir WS	--	NS	--	NS	**+114.62 ±44.22**	**0.0111**	--	NS
Respir RPM	**-230.00 ±100.17**	**0.0239**	**-405.38 ±113.18**	**0.0005**	**+2.91 ±1.29**	**0.0263**	--	NS

* Forced into model

V. DISCUSSION AND CONCLUSIONS

A. Wood Solids

These results showed no statistically significant adverse effects to any wood solids exposure fraction for the levels encountered (TWAs up to approximately 6.97, 2.65 and 1.16 mg/m^3, for extrathoracic, tracheobronchial and respirable exposures, respectively). In addition, the highest individual and mean wood solids exposures (the latter being approximately 0.90, 0.45 and 0.07 mg/m^3, for extrathoracic, tracheobronchial and respirable exposures, respectively) were observed in the furniture and cabinet facilities that included the largest number of participants (779), and displayed expected statistically significant effects on lung function due to age, cigarette smoking and percent change in body weight over the follow-up, further validating the data from this segment of the population.

B. Residual Particulate Matter

There were no statistically significant adverse effects of any exposures to extrathoracic or tracheobronchial residual particulate matter encountered, up to approximately 10.15 and 0.88 mg/m^3, respectively. The only statistically significant exposure related effects were observed for the respirable residual particulate matter fractions in the milling facility and in the sawmill-planing-plywood facility.

i. Milling facility

The milling facility effect was consistent with obstruction, with the mean and maximum respirable residual particulate matter exposures at that facility of 0.147 and 0.319 mg/m^3 associated with approximate predicted changes in FEV_1 of -32 and -67 ml/yr, FEV_1/FVC of -0.48 and -1.03%, and $FEF_{25\text{-}75}$ of -0.11 and -0.22 l/s/yr, respectively. This bronchial effect of exposure would also be consistent with cigarette smoking. Since there was no statistically significant smoking effect on annual change in lung function observed at this facility, there is the possibility that smoking and exposure are correlated or confounded in some fashion, and that the noted exposure effect was actually a masked smoking effect. In addition, the investigators recently learned that increased health insurance premiums for smokers went into effect at this facility in 1999, prior to the start of the study, and this may have led to under-reporting of smoking by workers.

ii. Sawmill-planing-plywood facility

The sawmill-planing-plywood facility effect was consistent with restriction, with the mean and maximum respirable residual particulate matter exposures at that facility of 0.255 and 0.419 mg/m^3 associated with approximate predicted changes in FEV_1 of -59 and -97 ml/yr, FVC of -103 and -169 ml/yr and FEV_1/FVC of +0.71 and +1.17%, respectively. The response seen in this facility, unlike the milling facility, is not consistent with obstruction from cigarette smoking and is unlikely to be a masked smoking effect. On the other hand, the restrictive response seen here is similar to that seen in farmer's lung and pigeon breeder's diseases, which represents a form of allergy and can be manifest by recurrent attacks of pneumonia (and histories of pneumonia were significantly more prevalent in this facility). For these reasons as well as our observations of mold contaminated/stained veneer and lumber during field sampling activities at this facility, airborne fungi or bacteria are considered to be potential causative agents of the observed effect, and markers (*i.e.* endotoxins, glucans) of these contaminants should still be contained in the respirable dust samples collected during the study and archived at Tulane.

Unfortunately, we were unable to determine which processes within this facility were associated with the effect, because many of the workers moved throughout the facility during the study, and the potentially causative respirable dust is also very mobile and relatively comparable in magnitude across the facility.

VI. RECOMMENDATIONS – POTENTIAL RESPIRABLE RESIDUAL PARTICULATE MATTER HEALTH EFFECT

A. Milling Facility Findings

As noted above, the obstructive effect observed at this facility was not related to exposure to wood solids, was similar to that observed in cigarette smokers, and was possibly due to confounding of smoking and exposure and/or under-reporting of cigarette smoking. However, to further rule out an exposure related effect, we recommend that this facility conduct expanded employee health surveillance along with comprehensive industrial hygiene surveys for biological, organic, and inorganic exposures that may be elevated and potentially related to the noted changes in lung function.

B. Sawmill-Planing-Plywood Facility Findings

The only statistically significant adverse exposure effect we observed in this facility was associated with the respirable residual particulate matter fraction, and the noted restrictive effect was unlikely to be confounded with cigarette smoking, and more likely to be a real effect of exposure to bio-aerosols.

To further assist the industry in identifying the potentially causative exposures, help prevent associated potential adverse health effects, and determine if this facility is representative of other similar facilities, we recommend the following.

i. Step 1: Investigate potential causative exposures

We have begun a pilot study to establish the viability of measuring beta glucans and endotoxins (biomarkers for fungi and bacteria) from 100 archived respirable archived dust study samples (40 from the sawmill-plywood-planing facility, 20 from the plywood-only facility, 20 from the milling facility, and 20 from the cabinet and furniture facilities). This project has been delayed by Hurricane Katrina, but will be restarted later this year. If successful, this approach could be expanded and used to investigate the role of these biomarkers on the noted restrictive effect. We also recommend that the sawmill-planing-plywood facility conduct expanded employee health surveillance along with comprehensive industrial hygiene surveys for biological, organic, and inorganic exposures that may be elevated and potentially related to the noted changes in lung function. Both of these activities should be completed early next year.

ii. Step 2: Evaluate results of step 1

The results of the investigations conducted in Step 1 should be evaluated to determine what further steps should be taken to identify the potential causative agents of the restrictive effect noted in the sawmill-planing-plywood facility, and determine if this facility is representative of similar facilities.

iii. Possible further steps

Depending on the evaluation of the results of step 1, possible further steps include:

1) An expansion of the pilot study, if successful, could be conducted and include analysis of an additional 900 respirable dust samples for beta glucans and endotoxins, selected from all homogeneous exposure categories of all facilities. Estimates of exposure to beta glucans and endotoxins could then be assigned to all homogeneous exposure categories, and time weighted average exposures for these biomarkers could be assigned to each individual in this study. This would allow for statistical analyses to assess the effect of exposure to these biomarkers for fungi and bacteria on annual decline in lung function, after adjusting for potential confounders. This would take approximately 1 year to complete.

2) A sawmill-planing-plywood industry profile questionnaire survey could be conducted to identify specifics of processes and exposure potentials for the spectrum of these facilities existing in the United States. This could be accomplished through a coded survey, like that described in section II, and could be sent to US sawmills to identify specific factors at these facilities related to exposure (especially the potential for non-wood dust exposures), and describe the similarities and differences between the variety of US sawmill-planing-plywood facilities and the facility studied here. This would take about 3-6 months to complete.

3) A pilot sawmill-planing-plywood IH walk-through assessment, like that described in section II, could be conducted at several facilities representative of the various types of facilities described by the sawmill-planing-plywood industry profile questionnaire. This would include some exposure sampling to further provide information as to potential causative exposures, and would take an additional 3-6 months to complete.

4) Information obtained about beta glucans and endotoxins from an expanded pilot study, from the sawmill-planing-plywood facility expanded employee health surveillance and comprehensive industrial hygiene survey, from a US sawmill-planing-plywood profiles questionnaire survey, and/or from a pilot sawmill-planing-plywood IH walk-through assessment could provide the core material (exposures to be characterized and candidate facilities to be studied) to allow for the development of a sawmill-planing-plywood study (an estimated 5-10 facilities, not including the one studied here). During the planning phase, we will also consult with, and investigate possible collaboration with, experts in microbiology to assist us in identifying potential causative exposures. One of the primary objectives of this study would be to determine if the exposure-response effects and potential causative exposures found in the studied sawmill-planing-plywood facility are unique to that facility or type of facility, or are prevalent throughout the sawmill-planing-plywood industry in general. The type of study, cross-sectional and/or longitudinal, would depend on the objectives of the study.

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