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# Flock Workers' Exposures and Respiratory Symptoms in Five Plants

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**Background** *Sentinel cases of lymphocytic bronchiolitis in flock production and coating operations triggered a five-plant study of airborne respirable dust and fiber exposures and health symptoms.*
**Methods** *Job histories from 219 current workers were linked to a job-exposure matrix derived from personal exposure measurements of respirable dust and fibers. Univariate group comparisons and multivariate modeling tested for relations between indices of cumulative and current exposure, and respiratory and systemic symptom outcomes.*
**Results** *Respiratory symptoms and repeated flu-like illnesses were associated with use of compressed air to clear equipment (blow-downs) and with respirable dust exposure (current and cumulative) after controlling for smoking. Blow-downs had an equal or greater effect than smoking status on most symptoms.*
**Conclusions** *Eliminating compressed air cleaning, engineering control of dust exposure, and respirators are needed to limit exposures to particulates. Longitudinal follow up may provide guidance for a dust or fiber level without adverse respiratory health effects.* Am. J. Ind. Med. 47:144–152, 2005. *Published 2005 Wiley-Liss, Inc.*†

***KEY WORDS: occupational lung disease; interstitial lung disease; flock workers' lung; nylon; textiles***

## INTRODUCTION

Nylon flock workers in a flock production and application plant in Rhode Island were found to be at risk for interstitial pneumonitis [Kern et al., 1998; Washko et al., 2000] with unique histologic findings of lymphocytic bronchiolitis and peri-bronchiolitis with lymphoid aggregates [Eschenbacher et al., 1999]. High concentrations of respirable dust characterized processes associated with the highest risk for worker symptoms [Burkhart et al., 1999; Washko et al., 2000]. The dust incited intense acute inflammatory response in rats on intratracheal instillation [Porter et al., 1999]. In 1997, an occupational medicine physician reported to the National Institute of Occupational Safety and Health (NIOSH), two additional cases of biopsy-confirmed flock workers' lung in employees of two other companies whose plants had lower exposures than the Rhode Island plant. We report here the results from cross-sectional medical and industrial hygiene surveys in these five plants, including analyses of the relationships between respirable dust, fiber counts, and respiratory and systemic symptoms.

### Process Description

Four plants, owned by one company, produce flock, which is supplied to the other company's plant, where it is applied to backing materials. In these production plants, synthetic tow (nylon, rayon, polyester, and acrylic, existing as bundles of continuous fiber with diameters of 10–15 μm), is cut into flock (about 1 mm length), and then dried, screened, and bagged. The flock application facility receives

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the flock in 50-pound bags, which workers manually dump into hoppers for application to backing materials in flocking rooms. There, adhesive-coated backing is fed into enclosed flocking modules where loose flock fibers fall from hoppers and are aligned in an electric field for vertical imbedding into the adhesive layer on the backing material. The flocked material is then heat-cured and finished by printing or embossing as required. In all five plants, workers use compressed air to blow settled flock from equipment, clothing, and floors, between batches of product, in a ''blow-down'' cleaning procedure. At two of the flock production plants cotton fibers were processed; however, cotton flock is not considered further in this report because cotton processes were conducted in isolated parts of the production plants and involved very few workers.

## MATERIALS AND METHODS

### Questionnaire and Definitions

We invited all 262 workers employed during a 1-week period in November 1998 to participate during their usual shift. Written informed consent was completed. Trained interviewers administered a modified American Thoracic Society respiratory disease questionnaire [Ferris, 1978] for respiratory symptoms and smoking history, supplemented by questions on other symptoms and on symptom onset date, and past medical history. It also included questions on current job title, tasks over the last 12 months, and past jobs in the flock industry.

Guided by earlier flock worker studies [Kern et al., 1998; Washko et al., 2000], we selected symptom outcomes reflecting interstitial disease, including cough and shortness of breath (SOB). The possibility of airways disease, reflected in wheezing, and phlegm, was investigated because it has not been clinically evaluated in flock worker cohorts. Finally, systemic symptoms have been prominent in both bronchiolitis case-patients and cross-sectionally among flock workers.

We defined cough as a report of usually coughing as much as four to six times per day for 4 or more days out of the week, or cough on most days 3 or more consecutive months of the year. We defined cough + phlegm as phlegm with cough twice a day 4 or more days of the week, or on most days 3 or more consecutive months of the year. We defined SOB as being troubled when hurrying on level ground or walking up a slight hill, or having to walk slower than people of one's own age on level ground due to breathlessness (in the absence of a musculo-skeletal reason for difficulty in walking). We also analyzed the combination of cough + SOB when they occurred in the same worker together. We defined wheeze as the report of one's chest sounding wheezy or whistling most of the time, or having an attack of wheezing that made one feel short of breath. We defined systemic symptoms to be three or more episodes of fever or flu-like achiness in the last 12 months. Mucous membrane irritation (irritation) consisted of having three or more episodes of eye irritation or of throat irritation, soreness, or tickle in the last 12 months. We focused on prevalent symptoms, but also examined incident symptoms, i.e., current symptoms which were reported to have developed during flock industry employment.

### Exposure Assessment

We measured personal respirable dust exposures, in milligrams per cubic meter of air (mg/m$^3$), over approximate 8-hr intervals with nylon cyclone samplers at a flow rate of 1.7 L per min, using NIOSH method 0600 [NIOSH, 1994]. We calculated the arithmetic mean of job- and location-specific samples, assuming non-detectable samples to be half the minimum detectable concentration [Hornung and Reed, 1990]. We applied this representative average exposure for all workers in a particular job or location, and estimated cumulative exposure to respirable dust, in mg-years/m$^3$, for each worker by summing the products of job-specific dust measurement and years spent in each job in the flock industry. In addition, we conducted fiber counts using A- and B-rules of NIOSH method 7400 by phase contrast light microscopy [NIOSH, 1994].

For blow-down tasks (using compressed air to clear equipment and areas) and bagging tasks, we used a light-scattering monitor (personal DataRAM®—MIE, Inc.) to make personal direct-reading measurements of dust to investigate peak exposure task-specific activities. Workers who reported doing any blow-downs in an average week were considered to have current blow-down exposure. On the basis of analyses of the average number of blow-downs conducted per week over the previous 12 months in the current job, we classified workers who had previously worked as an inspector, utility man, flockman, or team leader at a flocking range as having had past blow-down exposures. Filling or emptying bags with synthetic flock was termed bagging, with current bagging defined as that occurring in the 12 months preceding the interview, and past bagging defined as that occurring in past jobs.

### Data Analysis

In assessing exposure–response relations, we related health outcome prevalences to flock exposure measurements in two ways. First, we divided the study population into three groups characterized by jobs with low, medium, and high current respirable dust exposures, using natural break points in the average concentrations to create roughly similar group sizes ($<0.04$, $\geq 0.04$ to $<0.09$, and $\geq 0.09$ mg/m$^3$). Second, to examine the influence of past and present exposures, we used three ranges of cumulative respirable dust exposures, defined by $<0.2$, $\geq 0.2$ to $<0.4$, and $\geq 0.4$ mg-years/m$^3$. We also

looked at measured current and past fiber exposures, but because the findings were similar to those for respirable dust exposure, we have not presented them in detail.

Since use of dust concentration or cumulative exposure indices did not take into account the excursions created by blow-downs and bagging, we also considered indicators for never, past, and current blow-downs, frequency of current blow-downs per week (<6, 6–10, >10), and never, past, and current bagging.

Univariate tabulations were undertaken using SAS statistical software (SAS Institute, Cary, NC); we considered *P* values less than 0.10 to represent associations unlikely to be due to chance. Differences across groups were evaluated using the $\chi^2$-test (two groups) or by the Cochran–Mantel–Haenzel (non-zero correlation) test. We used prevalence ratio regression to evaluate the association of health outcomes with dust exposure, controlling for potential confounding factors of age, smoking, and pre-existing asthma or hay fever. Using the SAS PHREG procedure, we performed a modification of Cox's proportional hazards model to determine the prevalence ratio as a measure of effect [Lee and Chia, 1993; Lee, 1994; Zocchetti et al., 1995]. The health outcomes were entered as categorical dummy variables (present or absent). We obtained partial likelihood estimates of the Cox regression coefficients, calculated prevalence ratios, and examined Pearson's correlation coefficients between various exposure variables. Exposure variables considered were performance of blow-downs (never, past, current <6, current 6–10, current >10), bagging tasks (never, past, current), and current or cumulative respirable dust.

# RESULTS

## Study Participants

Of 164 current workers in flock production, 133 (81%) participated, as did 86 of the 98 (88%) workers in the flock application operation, for an overall response rate of 84%. Most participants were white (86%) and male (87%); the average age was 38 years (20–67 years). Two-thirds had some smoking history, with 41% current smokers (mean pack-years = 22), and 26% former smokers (mean pack-years = 26). Average total tenure in flock work was 6.5 years (range: less than 1 month to 30 years).

## Dust Measurements

Personal respirable dust measurements by workplace location and job title are shown in Table I. Excluding dust measurements during blow-down activity, the overall average respirable dust concentration was 0.09 mg/m$^3$. Office workers had the lowest mean exposure at 0.01 mg/m$^3$ (all non-detectable). Most of the handling and production department workers had mean exposures in the range 0.05–0.09 mg/m$^3$. Apart from these, dryer operators had mean exposures at 0.19 mg/m$^3$, while flockers without blow-down activity had average levels of 0.24 mg/m$^3$. The highest concentrations were measured mostly on flockers performing blow-down activities in the flocking rooms, averaging 1.06 mg/m$^3$, i.e., four times higher compared to flocking without blow-downs, with a range from 0.68 to 1.63 mg/m$^3$.

**TABLE I.** Respirable Dust Measurements by General Location and Job Title at the Five Flock Plants, New England

| Workplace location: job title | Samples (n) | Mean dust concentration (mg/m$^3$) | Range (mg/m$^3$) |
|---|---|---|---|
| Office: administration | 6 | 0.01 | ND |
| Plant-wide: janitor/shipping and receiving | 8 | 0.03 | ND–0.05 |
| Research and development: laboratory worker/team leader | 20 | 0.03 | ND–0.09 |
| Offline: team leader/inspector | 8 | 0.04 | ND–0.07 |
| Extractor/loading dock: operator/materials handler | 11 | 0.04 | ND–0.07 |
| Flock area: team leader/head man | 18 | 0.05 | ND–0.13 |
| Cutting: team leader | 6 | 0.07 | 0.04–0.10 |
| Cutting: bagger | 14 | 0.08 | ND–0.30 |
| Flock area: utility man/inspector | 19 | 0.08 | ND–0.42 |
| Dye house: team leader/kettle operator | 8 | 0.09 | 0.03–0.22 |
| Cutting: cutter operator | 15 | 0.09 | ND–0.25 |
| Dryers: dryer operator | 5 | 0.19 | 0.13–0.30 |
| Plant-wide/dye house: maintenance | 14 | 0.23 | 0.04–1.15 |
| Flock area: flock man flocking | 15 | 0.24 | 0.03–0.73 |
| Flock area: flock man with blow-down activity | 4 | 1.06 | 0.68–1.63 |

mg/m$^3$, milligrams per cubic meter of air; ND, non-detectable (less than 0.02 mg of dust collected on the filter).

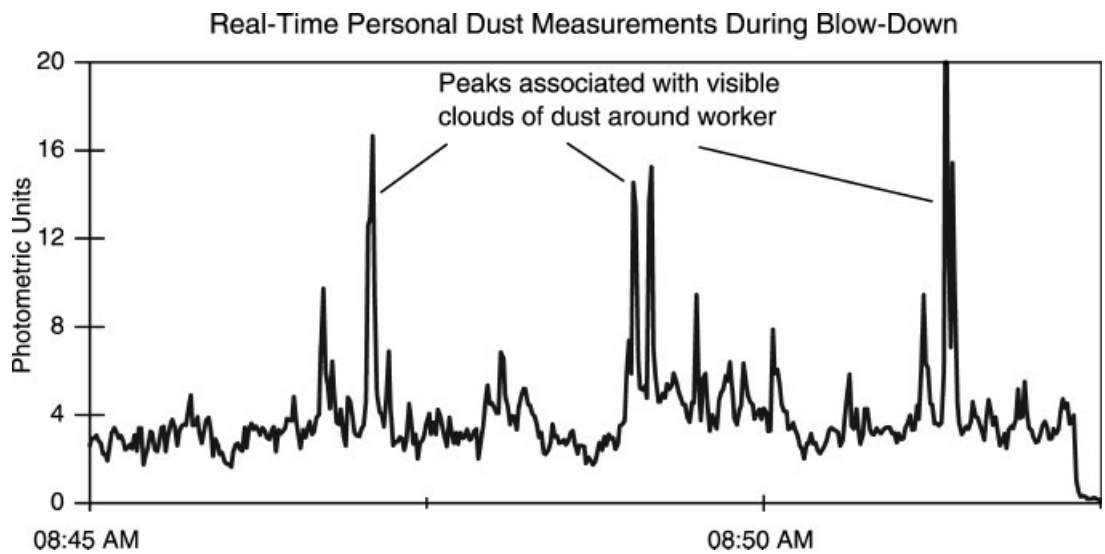


**FIGURE 1.** Personal direct-reading dust data during blow-down in a flock room, New England.

Figure 1 provides an example of direct-reading meter results collected on a worker engaged in the process of blow-down (measured in photometric units and not directly translatable to gravimetric dust concentrations in mg/m$^3$). The sharp peaks in concentration were associated with visible clouds of dust around the worker. Similar results were seen during the handling of bags of flock, supporting the use of blow-down, and bagging activities as qualitative exposure indices.

## Univariate Comparisons of Symptoms Across Groups

Table II gives the observed prevalences for the various symptoms and exposure indices for the 219 participants. The table also shows the statistical significance of comparisons across the groups (unadjusted for any other factor). Ever smokers had higher prevalences of all symptoms compared to never smokers, ranging from about a third higher for irritation to more than double for cough.

Workers conducting current blow-downs reported higher frequencies of all symptoms in comparison to those who had never conducted a blow-down (Fig. 2). These differences were most pronounced (i.e., about two to four times higher) for cough, cough + phlegm, cough + SOB, wheeze, and systemic symptoms. Workers with blow-down exposure only in the past also had higher symptom prevalences than those who never did blow-downs, these often being substantially higher than those for the current blow-down group (Fig. 2).

Frequency of blow-down exposure in the current blow-down group was clearly related to the symptoms in a dose-dependent way (Fig. 3), with workers conducting more than ten blow-downs per week having the highest symptom rates for all but cough + phlegm, and those involved in less than six blow-downs per week generally having the lowest prevalences. The differences across the five blow-down categories (never, past, and three frequency categories) were most evident for cough ($P < 0.05$), cough + phlegm ($P < 0.01$), cough + SOB ($P < 0.10$), and systemic symptoms ($P < 0.10$) (Table II).

Current baggers had higher symptom rates than never baggers for all symptoms, the differences being most evident for cough + phlegm ($P < 0.05$) and wheeze ($P < 0.05$) (Table II). Past-only baggers also had elevated rates compared to never baggers; these were generally similar to rates for current baggers (Table II). Since the same workers had often undertaken both bagging and blow-down jobs, the exposure variables for the two tasks were somewhat collinear. This was examined in the modeling explained later.

Apart from wheeze, respiratory symptom prevalences were 1.5–4 times higher in workers with average current personal respirable dust exposures of 0.04 to <0.09 mg/m$^3$, compared to the lowest exposure group (office, off-line, research and development, and plant-wide workers) (Table II). Workers in the highest exposure group also had higher symptom prevalences compared to the lowest exposure group, but were similar to those in the intermediate exposure group. The exposure effects were most obvious for cough ($P < 0.10$), cough + phlegm ($P < 0.10$), SOB ($P < 0.10$), and cough + SOB ($P < 0.05$).

The pattern of respiratory symptom prevalences across the three cumulative respirable dust exposure groups was similar to that of current dust exposure (Table II and Fig. 4), except that the highest exposure group generally had somewhat lower symptom prevalences than the intermediate group. Wheeze was the exception to this general trend, showing a small but consistent trend upwards with

**TABLE II.** Prevalence (P) and Incidence (I) of Symptoms During Flock Industry Employment by Smoking Status and Exposure Indices Among Employees at Five Plants, New England

| | | | Cough | | Cough + phlegm | | SOB | | Cough + SOB | | Wheeze | | Systemic symptoms | | Irritation | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Predictor** | **Factor** | **n[a]** | **P (%)** | **I (%)** | **P (%)** | **I (%)** | **P (%)** | **I (%)** | **P (%)** | **I (%)** | **P (%)** | **I (%)** | **P (%)** | **I (%)** | **P (%)** | **I (%)** |
| Smoking status | Never | 73 | 11** | 8* | 10 | 8 | 12* | 12 | 5 | 5 | 12 | 8 | 11 | 10 | 30 | 24* |
| | Ever | 146 | 25 | 17 | 15 | 13 | 22 | 16 | 10 | 8 | 19 | 14 | 16 | 15 | 41 | 37 |
| Blow-downs | Never | 71 | 13** | 7** | 4*** | 3 | 14 | 7** | 6* | 3*** | 8 | 3*** | 7* | 6** | 33 | 24** |
| | Past only | 36 | 28 | 18 | 17 | 16 | 28 | 17 | 11 | 10 | 28 | 16 | 19 | 17 | 31 | 29 |
| | Current <6 per week | 80 | 18 | 14 | 13 | 11 | 14 | 13 | 6 | 6 | 18 | 15 | 18 | 16 | 43 | 39 |
| | Current | 15 | 33 | 33 | 33 | 33 | 27 | 20 | 13 | 13 | 20 | 13 | 13 | 13 | 33 | 33 |
| | Current >10 per week | 17 | 41 | 24 | 29 | 24 | 35 | 35 | 24 | 24 | 24 | 24 | 24 | 24 | 47 | 47 |
| Bagging flock | Never | 88 | 15 | 9 | 6** | 5** | 14 | 8** | 7 | 5 | 9** | 5** | 9 | 8* | 32 | 24 |
| | Past only | 19 | 26 | 16 | 16 | 16 | 32 | 21 | 16 | 11 | 16 | 11 | 16 | 16 | 32 | 40 |
| | Current | 112 | 24 | 18 | 19 | 16 | 21 | 19 | 9 | 9 | 23 | 18 | 19 | 17 | 43 | 28 |
| Current respirable dust exposure (mg/m$^3$) | Low <0.04 | 76 | 13* | 7** | 5* | 3** | 12* | 7** | 3** | 1** | 17 | 9 | 11 | 8 | 29 | 23 |
| | Medium | 61 | 25 | 18 | 20 | 18 | 21 | 18 | 11 | 10 | 18 | 13 | 16 | 16 | 43 | 39 |
| | High ≥0.09 | 82 | 24 | 18 | 16 | 15 | 23 | 20 | 12 | 11 | 16 | 13 | 17 | 16 | 41 | 37 |
| Cumulative respirable dust exposure (mg-years/m$^3$) | Low <0.2 | 73 | 10** | 4** | 4** | 3** | 11 | 6** | 4 | 3 | 14 | 5** | 11 | 8 | 28 | 37 |
| | Medium | 55 | 31 | 22 | 22 | 16 | 25 | 20 | 16 | 13 | 15 | 11 | 25 | 24 | 35 | 40 |
| | High ≥0.4 | 91 | 23 | 18 | 15 | 16 | 21 | 19 | 8 | 8 | 21 | 18 | 11 | 11 | 34 | 36 |

$\chi^2$-test or Cochran–Mantel–Haenzel non-zero correlation test.
[a]Group sizes shown are for prevalence statistics. Incidence denominators are based on 217 rather than 219 participants.
*$P < 0.10$.
**$P < 0.05$.
***$P < 0.01$.

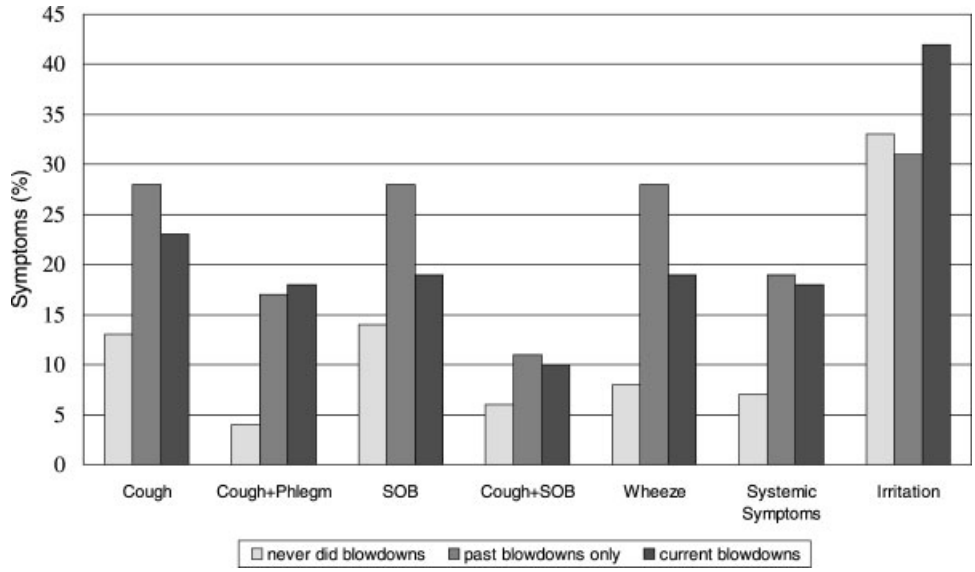


**FIGURE 2.** Symptom prevalence by never/past/current blowdowns among employees of five flock plants, New England.

cumulative exposure level. The most pronounced differences across the cumulative exposure groups occurred for cough ($P < 0.05$) and cough + phlegm ($P < 0.05$). An analysis of symptoms of chronic bronchitis (i.e., cough and phlegm for 3 or more consecutive months during the year) produced similar results to the symptom complex: cough + phlegm. Similar trends with dust exposure to those observed overall were noted within groups stratified by smoking (0, 0–20 pack-years and greater than 20 pack-years).

Table II also gives information on incident symptoms (i.e., symptoms developing post-employment in the flock industry) for the 217 participants for which data are available. The patterns of incident symptom occurrence were similar to those for prevalent symptoms in relation to smoking, blowdowns, bagging flock, and current and cumulative respirable dust exposures. For some incident symptoms, the statistical evidence for differences in the rates across exposure groups was greater than for the prevalent symptom data (e.g., cough + SOB, SOB, and wheeze).

Fiber counts using A- and B-rules of NIOSH method 7400 by phase contrast light microscopy revealed highly correlated results (Pearson correlation coefficient = 0.76). Current fiber exposures were highly correlated with current respirable dust exposures (Pearson correlation coefficient =

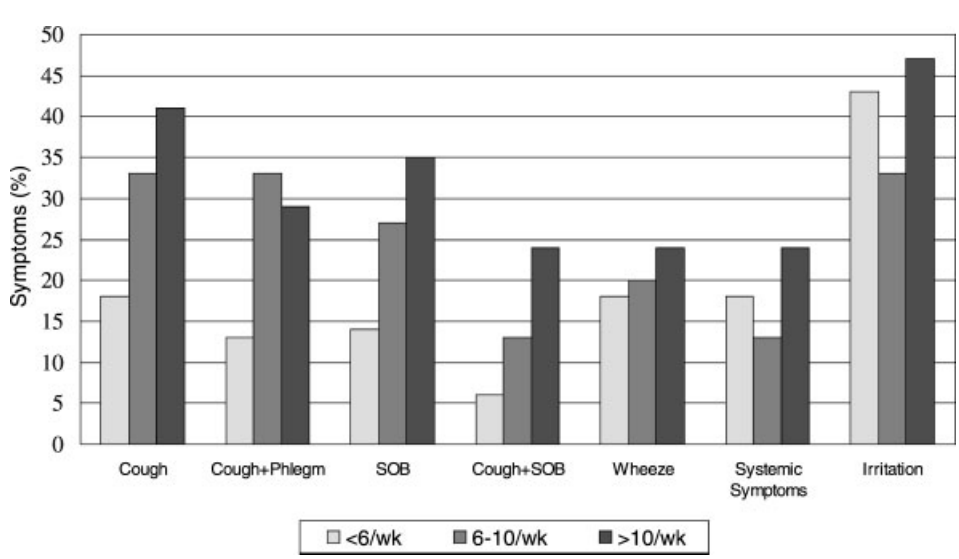


**FIGURE 3.** Symptom prevalence by frequency of current blowdowns among employees of five flock plants, New England.

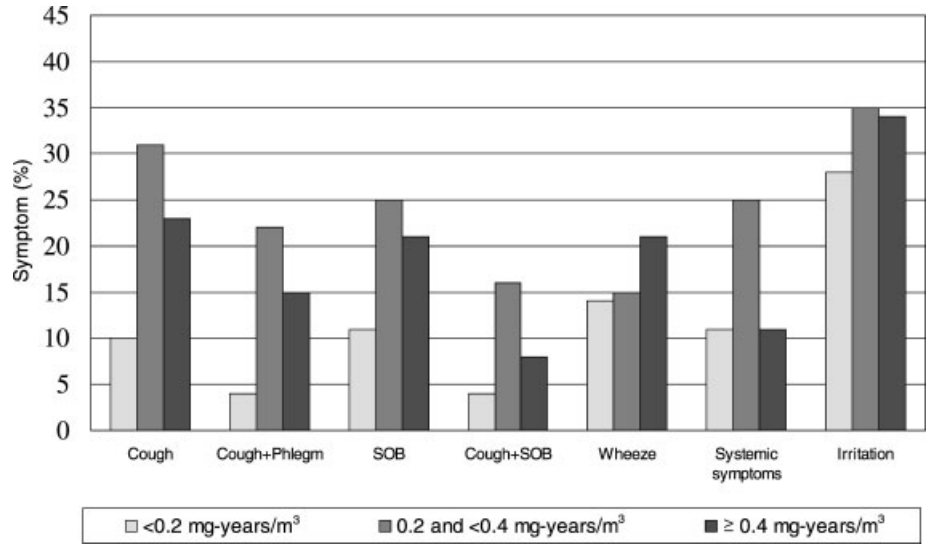


**FIGURE 4.** Symptom prevalence and cumulative respirable dust exposure, among employees of five flock plants, New England.

0.83), and cumulative fiber exposures with cumulative respirable dust exposures (correlation = 0.91). On this basis, it would be expected that the exposure–response findings for fiber exposures would be similar to those for respirable dust. This was found to be the case for both prevalent and incident symptoms (results not shown). Symptom rates for groups defined by both current and cumulative fiber exposure typically rose from the lowest exposure group to the intermediate group by a factor of 1.5–3 times, but then either leveled off or dropped in the highest exposure group. Statistical significance across exposure groups was, however, generally less for fiber concentrations than for respirable dust.

## Multivariate Analysis

The results from prevalence ratio modeling are presented in Table III for each symptom based on age, smoking, past asthma or hay fever, cumulative respirable dust exposure, and past and present blow-down experience. Although both cumulative exposure and current exposure were examined, the former was chosen for presentation because it showed somewhat stronger relationships to the symptom outcomes.

The findings in Table III indicate relationships of symptoms with exposure to flock dust, after adjustment for

**TABLE III.** Predicted Prevalence Ratios From Multivariate Models for Each Symptom Outcome Against Various Predictors[a] Among Employees in Five Flock Plants, New England

| | Cough | Cough + phlegm | SOB | Cough + SOB | Wheeze | Systemic symptoms | Irritation |
|---|---|---|---|---|---|---|---|
| **Smoking** | **2.3*** | **1.5** | **1.8** | **1.9** | **1.5** | **1.4** | **1.4** |
| Blow downs | | | | | | | |
| Past only | 1.6 | 2.7 | 1.7 | 1.9 | 3.6** | 2.9* | 0.8 |
| Current | | | | | | | |
| <6 per week | 1.1 | 2.0 | 0.9 | 1.0 | 2.7* | 2.2 | 1.1 |
| 6–10 per week | 1.9 | 5.0** | 1.7 | 2.4 | 2.9 | 1.8 | 0.8 |
| >10 per week | 2.7* | 4.7* | 2.4 | 4.7* | 3.8* | 3.5* | 2.0 |
| Cumulative respirable dust exposure | | | | | | | |
| Medium | 2.5* | 3.7* | 1.8 | 2.7 | 0.6 | 1.8 | 1.1 |
| High | 1.8 | 2.2 | 1.3 | 1.0 | 0.9 | 0.7 | 1.1 |

All blow-down groups are referenced to never blow-down category. Both cumulative exposure groups are referenced to the lowest category (low, <0.02 mg-years/m$^3$).
[a]Model based on age, smoking, past asthma or hay fever, blow-down categories, and cumulative exposure categories.
*$P < 0.10$.
**$P < 0.05$.

age, smoking, and presence of past asthma and hay fever. This pattern exists across symptoms, although not all coefficients show strong statistical significance. In comparison to those who never did blow-downs, prevalence ratios for all other blow-down categories were elevated for all symptoms except irritation, with current blow-downs >10 per week having the greatest prevalence ratios across symptoms. Among all symptoms, cough + phlegm had the greatest and most significant prevalence ratios (occurred for the top two levels of blow-down exposure). Medium cumulative respirable dust exposure also led to elevated prevalence ratios for most symptoms. The prevalence ratios for high cumulative dust exposure were sometimes elevated, but were lower than those for medium exposure. The addition of terms for never/past/current bagging to the models was not found to be useful.

## DISCUSSION

The five-plant evaluation showed substantial increases of chest symptoms and frequent flu-like illness in workers with higher workplace dust exposures, as reflected in conducting blow-downs and by cumulative respirable dust concentrations. Support for the view that chest symptoms are work-related is strengthened by the exposure–response relationships evident in these cross-sectional data: among workers who are currently conducting blow-downs, the frequency of blow-downs was associated with increased prevalence of chest symptoms; in multivariate analyses, cumulative dust exposure was related to symptom prevalence, adjusted for blow-down exposure and other factors. Finally, analyses restricted to symptoms with onset following employment in the flock industry strongly suggest work-relatedness in that high exposure groups had excess incident symptoms. In general, the effect of dust exposure was greater than that for smoking.

Work-related symptoms exist in these plants, despite their workforces having much lower dust exposures than those previously reported in the Rhode Island plant in which flock workers' interstitial lung disease was described [Burkhart et al., 1999; Washko et al., 2000]. The highest personal respirable dust concentration in the plants in the current study was 1.6 mg/m$^3$ during a blow-down in the flock room, whereas the highest of all area measurements in the flocking rooms at the Rhode Island plant was 39.9 mg/m$^3$. The average personal respirable dust exposure level in the Rhode Island plant was 2.2 mg/m$^3$, higher than all measurements in this study.

Workers in the two higher current respirable dust exposure groups in this study (0.04 to <0.09, and ≥0.09 mg/m$^3$) had similar symptom prevalences. This pattern could be consistent with a threshold exposure above which the same proportion of an exposed population develops symptoms regardless of the degree of exposure. However, the threshold exposure concept for symptoms seems implausible given the findings at the previously-studied Rhode Island plant where exposures were higher. Despite lack of strict comparability between symptom questions, the Rhode Island worker population appeared to have considerably higher prevalences of similar symptoms [Washko et al., 2000]. Among Rhode Island production workers, 35% reported SOB, compared to about 21%–23% of workers with exposure in production areas in these five plants; 32% had cough, compared to 24%–25% in the current study; 32% had cough with phlegm, compared to less than 20% in the current study; 28% had at least two attacks of SOB with wheeze in the preceding 2 years, compared to 15%–16% with wheeze in the current study; and 25% had frequent flu-like aches all over the body (and 29% reported at least two flu-like illnesses in the preceding year) at the Rhode Island plant, compared to 16%–17% with systemic symptoms in the five plants we studied. At the Rhode Island plant, 67% of production workers who had ever performed blow-downs reported at least one frequent respiratory or systemic symptom with onset after hire, in comparison to 41% of workers who had performed blow-downs in these five plants who reported at least one symptom with onset after hire (data not presented). In summary, taking the two studies into account together, the percentage of workers affected by respiratory and systemic symptoms does not appear to plateau at a threshold exposure level; rather, higher symptom prevalences appear to have occurred in the setting of higher plant-wide exposures. However, other differences existed between the two study populations, such as extensive overtime work at the Rhode Island plant but not at the five-plant population when we studied them.

An alternative and more likely explanation for the similar prevalences in the higher exposure groups is that symptomatic workers leave the plant, or transfer to lower exposure jobs, thereby contributing their symptoms to an exposure category with lower mean current exposure. Two consistent lines of evidence in this study suggest the presence of such a ''healthy worker'' effect in the high exposure jobs. First, the worker group with medium cumulative dust exposures had higher respiratory and systemic symptom prevalences (apart from wheeze) than the worker group with the highest cumulative exposure, suggesting that workers with either higher average exposure or longer tenure were more dust-tolerant. Second, workers who had left blow-down activity had a tendency for higher prevalences of cough, SOB, and wheeze than workers who were currently conducting blow-downs. Both of these observations indicate that workers staying in the higher exposed jobs are likely to be more tolerant of dust exposures, with those less tolerant or experiencing adverse outcomes moving to less dusty jobs or quitting work at the plant.

On the basis of the findings from this and the previous study of flock workers, we recommend environmental surveillance using respirable dust measurements, rather than

fiber counts, for ease, cost of measurement, and inclusion of nonfibrous particulate, which may be pertinent to biologic risk. In this investigation, fiber counts had a lower association with respiratory outcomes than did respirable dust, while job-specific respirable dust and fiber counts correlated closely. In settings with less correlation between measurements or a different proportion of fibers in respirable dust, fiber count data may be found to be more pertinent to health outcomes than respirable dust.

With work-related excess symptoms occurring at exposures in these five plants that were generally low compared to those in the Rhode Island plant, guidance for a respirable dust or fiber exposure level with no adverse effect on respiratory health remains difficult to articulate. The healthy worker effect apparent in these cross-sectional data creates uncertainty about an exposure guideline recommendation. However, we can recommend the institution of engineering controls (such as negative pressure enclosures, and external exhausting of process cyclones outside the plant) for bagging tasks, the elimination of compressed air cleaning (blow-downs), and the use of respiratory protection during high exposure tasks to reduce exposures, since task-related peak exposures (ranging to 1.6 $mg/m^3$) were associated with excess respiratory and flu-like illnesses. Ongoing work by researchers in the industry to investigate improved flock-cutting methods that minimize the production of respirable dust may also improve the work environment.

Our current and cumulative exposure indices likely underestimate exposure for those conducting blow-down activities, because they do not include the exposure contribution from the sporadic blow-down activity. This may result in an overestimate of risk for their measured exposures. However, if blow-down task exposures can be eliminated, our multivariate model still suggests that lowering exposure to respirable dust can further reduce the prevalence of SOB among workers. Striving to limit all exposures in flock plants to no more than the exposures of the internal comparison group (lowest exposure category), with mean respirable dust exposure level less than 0.04 $mg/m^3$, would be a worthy goal. Longitudinal follow-up of the studied flock plant workforces is recommended to demonstrate that interventions to lower respirable dust exposure have had their intended benefits to protect worker health. Such follow-up can also provide data to help guide the development of more definitive exposure limits to eliminate the occurrence of excess symptoms among flock workers.

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