NTP
National Toxicology Program
U.S. Department of Health and Human Services

NTP Toxicity Study Report on the Atmospheric Characterization, Particle Size, Chemical Composition, and Workplace Exposure Assessment of

Cellulose Insulation (CELLULOSEINS)

NTP TOX 74

AUGUST 2006

National Toxicology Program
Toxicity Report Series
Number 74

NTP Toxicity Study Report
on the Atmospheric Characterization,
Particle Size, Chemical Composition,
and Workplace Exposure Assessment of

Cellulose Insulation

(CELLULOSEINS)

August 2006

National Institutes of Health
Public Health Service
U.S. Department of Health and Human Services

FOREWORD

The National Toxicology Program (NTP) is an interagency program within the Public Health Service (PHS) of the Department of Health and Human Services (HHS) and is headquartered at the National Institute of Environmental Health Sciences of the National Institutes of Health (NIEHS/NIH). Three agencies contribute resources to the program: NIEHS/NIH, the National Institute for Occupational Safety and Health of the Centers for Disease Control and Prevention (NIOSH/CDC), and the National Center for Toxicological Research of the Food and Drug Administration (NCTR/FDA). Established in 1978, the NTP is charged with coordinating toxicological testing activities, strengthening the science base in toxicology, developing and validating improved testing methods, and providing information about potentially toxic substances to health regulatory and research agencies, scientific and medical communities, and the public.

NTP Toxicity Study Reports are indexed in the NIH/NLM PubMed database and are available free of charge electronically on the NTP website (*http://ntp.niehs.nih.gov*) or in hardcopy upon request from the NTP Central Data Management group at *cdm@niehs.nih.gov* or (919) 541-3419.

National Toxicology Program
Toxicity Report Series
Number 74

NTP Toxicity Study Report on the Atmospheric Characterization, Particle Size, Chemical Composition, and Workplace Exposure Assessment of

Cellulose Insulation

(CELLULOSEINS)

Daniel L. Morgan, Ph.D., Study Scientist

National Toxicology Program
P.O. Box 12233
Research Triangle Park, NC 27709

NIH Publication No. 06-5963

National Institutes of Health
Public Health Service
U.S. Department of Health and Human Services

CONTRIBUTORS

National Toxicology Program

Evaluated and interpreted results and reported findings

D.L. Morgan, Ph.D., Study Scientist
J.R. Bucher, Ph.D.
R.S. Chhabra, Ph.D.
J.R. Hailey, D.V.M.
J.K. Haseman, Ph.D.
R.R. Maronpot, D.V.M.
S.D. Peddada, Ph.D.
J.H. Roycroft, Ph.D.
C.S. Smith, Ph.D.
G.S. Travlos, D.V.M.

Battelle Pacific Northwest Laboratories

Conducted atmospheric characterization, particle size, and chemical composition studies

J.A. Dill, Ph.D.
R.B. Westerberg, Ph.D.
S. Yin-Fong, Ph.D.

Pathology Associates International

Evaluated slides and prepared pathology report on rats

J.C. Turnier, V.M.D.

National Institute of Occupational Safety and Health

Conducted workplace exposure assessment

J.E. Fernback
R.M. Hall, M.S.
R.E. McCleery, M.S.P.H.
J. McCullough, M.D.

Biotechnical Services, Inc.

Prepared Toxicity Study Report

S.R. Gunnels, M.A., Principal Investigator
M.P. Barker, B.A.
J.I. Powers, M.A.P.
R.E. Shaver, B.A.
R.A. Willis, B.A., B.S.
P.A. Yount, B.S.

PEER REVIEW

The draft report on the toxicity studies of cellulose insulation was evaluated by the reviewers listed below. These reviewers serve as independent scientists, not as representatives of any institution, company, or governmental agency. In this capacity, reviewers determine if the design and conditions of these NTP studies are appropriate and ensure that this Toxicity Study Report presents the experimental results and conclusions fully and clearly.

Richard B. Schlesinger, Ph.D.
Department of Biology and Health Sciences
Pace University
Pleasantville, NY

Maria T. Morandi, Ph.D., C.I.H.
School of Public Health
Houston Health Science Center
University of Texas
Houston, TX

CONTENTS

SUMMARY

Background
Cellulose insulation is produced mainly from recycled newspapers, which are shredded and treated with fire-retardant chemicals. The materials are installed by blowing, which creates a potential hazard to workers. We studied the physical and chemical properties of cellulose insulation aerosols and surveyed several workplace exposure conditions to determine if such a hazard exists.

Methods
We generated particles of cellulose insulation by the process used at work sites and separated them by size. We also investigated ten worksites in different parts of the country, examined the size of the dust particles or fibers, and surveyed the health of the workers.

Results
Of the cellulose insulation particles examined by the generator, less than 0.1% were of the size that were respirable by the lung. Similarly at the worksites, the amounts of respirable size dusts were typically low. While workers had occasional eye or mucous membrane irritation, there was little evidence of any lower respiratory health conditions.

Conclusions
We conclude that because almost all of the generated cellulose insulation particles are not respirable, additional studies of cellulose insulation in laboratory animals are not needed.

ABSTRACT

Cellulose Insulation

CELLULOSEINS

Synonym: CI

Cellulose insulation (CI) is a type of thermal insulation produced primarily from recycled newspapers. The newspapers are shredded, milled, and treated with fire-retardant chemicals. The blowing process for installing CI generates a significant quantity of airborne material that presents a potential inhalation hazard to workers. CI was selected for study based upon the high production volume, the potential for widespread human exposure, and a lack of toxicity data; insufficient information was available to determine whether inhalation studies in laboratory animals were technically feasible or necessary. Studies were conducted to characterize the chemical and physical properties of CI aerosols, to evaluate the potential acute pulmonary toxicity of CI, and to assess occupational exposure of CI installers. Workplace exposure assessments were conducted in collaboration with the National Institute for Occupational Safety and Health (NIOSH, 2001).

Evaluation of the Chemical Composition, Particle Size, and Pulmonary Toxicity of Cellulose Insulation

Chemical analyses were performed on samples of bulk CI from four major United States manufacturers. All samples of the bulk CI were found to contain primarily amorphous cellulose (60% to 65%) with a smaller crystalline component (35% to 40%). The crystalline phase was primarily native cellulose (75% to 85%) with a minor amount of cellulose nitrate (15% to 25%). Elemental analyses of acid digests of CI materials indicated that the major components (>0.1% by weight) included aluminum, boron, calcium, sodium, and sulfur. An acid-insoluble residue present in all four materials (3% to 5% of original sample weight) was found to consist primarily of aluminum silicate hydroxide (kaolinite; ~85%) with minor amounts (≤5% each) of magnesium silicate hydroxide (talc), potassium aluminum silicate hydroxide (muscovite), and titanium dioxide (rutile). Solvent extracts of the bulk materials were analyzed for organic components by gas chromatography with flame ionization detection. Analyses revealed a mass of poorly resolved peaks. Because of the very low concentrations, further quantitative and qualitative analyses were not performed.

An aerosol generation system was designed to separate CI particles based upon aerodynamic size and to simulate the process used during CI installation at work sites. Less than 0.1% of each of the CI samples was collected as the small respirable particle fraction. The mean equivalent diameter of respirable particles ranged from 0.6 to 0.7 µm. The numbers of fibers in the respirable fractions ranged from 9.7×10^3 to 1.4×10^6 fibers/g of CI. The respirable particle fractions did not contain cellulose material and consisted mainly of fire retardants and small quantities of clays.

The respirable fraction from one CI sample was administered by intratracheal instillation to male Fischer 344 rats at doses of 0, 0.625, 1.25, 2.5, 5, or 10 mg/kg body weight; the bronchoalveolar lavage (BAL) fluid cellularity was evaluated 3 days later. Based upon the relatively mild severity of the inflammatory response, a dose of 5 mg/kg body weight was selected for use in a subsequent 28-day study. Rats received CI, titanium dioxide (particle controls), or sterile saline (controls). BAL fluid was evaluated 1, 3, 7, 14, and 28 days after instillation, and lung histopathology was evaluated 14 and 28 days after treatment. CI caused a greater influx of inflammatory cells than titanium dioxide and caused significant increases in BAL fluid protein and lactate dehydrogenase. These CI-induced changes in BAL fluid parameters were transient and by day 14 were not significantly different than those observed in rats treated with titanium dioxide or phosphate-buffered saline. Unlike titanium dioxide, CI treatment caused a minimal to mild nonprogressive, minimally fibrosing granulomatous pneumonitis characterized by nodular foci of macrophages and giant cells.

These results indicated that few respirable particles or fibers are likely generated during the CI application and that the acute pulmonary toxicity is minimal.

Exposure Assessment of Cellulose Insulation Applicators

The CI exposure assessment was conducted with 10 contractors located across the United States. Air samples of total dust and respirable dust were collected for scanning electron microscopy (SEM) to characterize any fibers in the dust. Two SEM air samples for each day of CI activities were collected from the installer and hopper operator. Bulk CI samples were collected and analyzed for metal, boron, and sulfate content. Real-time and video exposure monitoring was conducted to further characterize the CI dust and workers' exposures. The exposure assessment also included a medical component.

Investigators collected 175 personal breathing zone (PBZ) total dust, 106 area total dust, and 90 area respirable dust air samples during CI-related activities at the 10 contractor sites. Twenty-six employees' total dust 8-hour time-weighted averages (TWAs) exceeded the Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) of 15 mg/m^3, and 42 exceeded the American Conference of Governmental Industrial Hygienists (ACGIH) threshold-limit value (TLV) of 10 mg/m^3. Respirable dust air sampling and real-time monitoring with particle size discrimination indicated low levels of respirable dust generation. The SEM analyses revealed that fibers were an average 28 µm in length and ranged from 5 µm to 150 µm. CI installers' PBZ total dust, area total dust, and area respirable dust air samples were all significantly higher during dry attic applications than wet attic applications ($P<0.01$). Conversely, the hopper operators' total dust exposures were significantly higher during wet wall and ceiling applications than dry wall and ceiling applications ($P=0.02$). Analyses of variance tests revealed that exposure concentrations in total dust air samples collected in the PBZ of all CI workers, including installers working in attics, installers during wall applications, hopper operators during attic applications, and hopper operators during wall and ceiling applications, varied significantly during dry applications ($P<0.01$). The respirable dust air samples collected in attic areas, hopper areas during attic applications, and hopper areas during wall and ceiling applications also differed significantly during dry applications ($P=0.03$).

Twenty-three workers participated in the medical phase of the investigation. The workers completed medical and work history questionnaires, performed serial peak flow tests, and completed multiple acute symptom surveys. The medical questionnaires indicated respiratory, nasal, and skin symptoms that employees attributed to CI exposure. The most common symptoms reported while working with CI included nasal symptoms (35%), eye symptoms (35%), and morning phlegm production (25%). There was a temporal association between CI exposure and eye symptoms, but there was little evidence of lower respiratory system health conditions associated with CI exposure.

CONCLUSIONS

Chemical analyses of the four bulk CI samples revealed only minor differences in additives. The major elemental components detected were aluminum, boron, calcium, sodium, and sulfur, but they were attributed to the fire retardants aluminum sulfate, boric acid, and sodium sulfate. For all four CI samples, less than 0.1% by weight was collected as the small respirable particle fraction. The fractions consisted mainly of fire retardants and smaller quantities of clays and did not contain cellulose material. Intratracheal instillation of the respirable fraction in rats produced minimal to mild inflammatory responses in the lungs with no increase in severity by 28 days after dosage. Although a significant increase in lung collagen was detected at day 28 in treated rats, microscopic evaluation revealed only a minimal to mild increase in collagen fibrils associated with granulomatous nodules.

The results of these studies indicated that few respirable particles or fibers are generated during the aerosolization of CI, and that even at very high doses of respirable CI particles, acute pulmonary toxicity is minimal.

These results are supported by the NIOSH workplace exposure assessment conducted on CI workers. Based on the air sample data collected from the 10 contractor site visits, there is a potential for overexposure to CI; however, respirable dust concentrations were typically low. There was increased potential for 8-hour TWAs exceeding the

OSHA PEL for total and respirable dust when employees were involved in CI application activities for longer periods of time. There was evidence of work-related eye and mucous membrane irritation among some workers, which were possibly caused by the additives present in CI, such as boric acid. There was little evidence of lower respiratory system health conditions associated with CI exposure.

Based upon the results of the CI chemical characterization studies, the pulmonary toxicity study, and the worksite exposure assessment, the NTP concluded that additional studies of CI in laboratory animals are not warranted at this time. However, the animal pulmonary toxicity studies and worker health surveys focused on acute CI exposures and do not preclude the possibility of toxicity resulting from chronic exposure. Although exposure concentrations of respirable CI particulate matter were low, additional information is needed on the biodurability and reactivity of CI particles and fibers in the respiratory tract. CI should continue to be regarded as a nuisance dust, and workers should continue to wear protective masks to prevent inhalation exposure to CI dusts.

INTRODUCTION

STUDY RATIONALE

Cellulose insulation (CI) was nominated to the National Toxicology Program (NTP) in 1994 for a comprehensive toxicologic evaluation including long-term inhalation bioassay. The nomination was based upon the potential for widespread human exposure, promotion of CI as a safe alternative to asbestos, and the lack of data on the potential carcinogenicity of CI. After reviewing the available data on CI, the NTP study design team identified two major data gaps that needed to be addressed in order to determine if chronic CI dust inhalation studies were technologically feasible and to determine if animal studies were warranted. Information was needed on the chemical and physical characteristics of CI and on the variability in composition between CI products. Because CI is a complex mixture containing a number of proprietary additives, the variability in chemical composition of CI from different manufacturers was unknown. In addition, little information was available concerning the physical characteristics of CI particulates. During an aerosol exposure, the dose, or amount of particulate reaching the lung, is dependent upon particle size. The greatest concern is for particles small enough to reach the deep lung (respirable particles). In addition, the shape of the particle (fibrous, nonfibrous) can influence deposition and toxicity. The amounts of respirable fibrous and nonfibrous particulates are different in CI from different manufacturers because of differences in production methods.

Although there is potential for widespread human exposure, CI applicators would receive the greatest exposure. Little information was available on the exposure concentrations or the chemical and physical characteristics of CI aerosol to which workers are exposed, and no information was available to indicate that there are adverse health effects for workers using CI.

The NTP study design team recommended that initial studies be conducted to obtain data on the chemical and physical characteristics of CI and to conduct an exposure assessment for CI applicators. These data were obtained through the collaborative efforts of the National Institute of Environmental Health Sciences (NIEHS) and the National Institute for Occupational Safety and Health (NIOSH), two member agencies of the NTP. Because of its extensive experience in conducting exposure assessments, NIOSH provided worksite exposure assessments, evaluated the chemical and physical characteristics of CI particulates in the workplace, and evaluated health information on CI workers. NIEHS developed and tested a CI aerosol generation system and evaluated the chemical and physical characteristics of bulk CI and CI aerosols from four major manufacturers. This work was conducted through NTP chemical support contracts. The collaborative efforts between NTP agencies resulted in a more comprehensive evaluation of the potential toxicity of CI.

Chemical and Physical Properties

CI is a type of thermal insulation produced primarily from recycled newspapers and sometimes from other uncoated paper products and wood chips. The newspapers are shredded and milled to obtain a homogeneous light-density material. Because paper is flammable, the material is treated with fire-retardant chemicals to about 20% to 25% loading. The composition of CI products varies depending on the chemicals the manufacturer selects to improve fire-retardant and settling properties. The primary fire retardants used are ammonium sulfate, boric acid, borax, and other borates. The fire-retardant chemicals are finely ground to more readily disperse into the CI and may be applied wet or dry. The finished product may also contain buffers (e.g., gypsum), residuals of the paper production process (e.g., sodium hydroxide, sodium sulfide, formaldehyde, chlorine, fluorine, lead, iron, sulfur compounds), and remnants of dyes, resins, gums, talc, printing inks, and various solvents (Davis, 1993; Lea, 1995). The chemical composition and the physical form of CI are significantly different from pure cellulose and other cellulose compounds. Pure cellulose is a white, solid polysaccharide and is a component of plant fiber (*Merck Index*, 1996). Cotton is the purest natural form, and rayon is regenerated cellulose.

Kelman *et al*. (1999) conducted a preliminary study of the chemical composition of several samples of insulation currently in use. Headspace air (90° C) and methylene chloride extracts of CI contained traces of aliphatic and aromatic hydrocarbons and higher aldehydes. No formaldehyde was detected. The CI was composed of approximately 98% paper fiber and 2% gelatinized starch with detectable levels of the fire retardants boron and sodium. By weight, approximately 0.01% of the CI was present as a fine dust of cellulose origin. About 13% of these small particles were fibers (aspect ratio $3:1). Most of these fibers were greater than 2 µm wide and 10 to 20 µm long.

Performance Standards

In 1978, to ensure the safety of CI, the Consumer Product Safety Commission (CPSC) issued performance standards that are mandatory for all manufacturers (Chrenka, 1980). These standards required that all CI produced after September 7, 1978, pass flammability and corrosiveness tests as specified in the General Services Administration standard HH-I-515-C, which mandates performance of CI products purchased by government agencies. There are also two standard specifications issued by the American Society for Testing and Materials (ASTM, 1991, 1997) pertaining to CI. Both ASTM standards address density, thermal resistance, smoldering combustion, fungal resistance, corrosion, moisture vapor absorption, and odor.

Production, Use, and Human Exposure

Production and Producers

CI is manufactured from cellulosic materials generally derived from recycled newspapers. Coated paper and fine paper are best avoided because coatings and smooth surface textures resist fire-retardant chemicals (Zicherman and

Fisher, 1978; Chrenka, 1980; Barton *et al*., 1981; McConnell, 1994). The recycled paper is processed to gain the proper consistency. Today, CI manufacturers use rotating disks (light density mill, AFT ringer, or Haybuster) to produce a light-density product of about 1.5 to 1.8 lbs/ft^3. This method does not crush the fibers and brings the paper back to the pulp state, unlike previous methods (Lea, 1995). In the 1970s, CI manufacturing used the hammer mill technology to produce insulation with a density of about 2 lbs/ft^3 or more. In a typical hammer mill operation, raw materials were first sorted then conveyed into mills that preshredded and pulverized the materials into a fibrous, reasonably homogeneous bulk material. In the shredder, which had either fixed or swinging rotary hammers, material was forced out through a mill screen with approximately 3-inch openings. The shredded paper was then pneumatically moved into an intermediate mill where it was forced through a smaller mill screen. After leaving the intermediate mill, the material was fed into a holding bin that was used to achieve a uniform feed rate to the next, and final, mill. In the final mill, the material was forced through a mill screen with about ¼-inch openings. Chemicals with fire-retardant properties, typically boric acid, borax, and aluminum trihydrate, were introduced simultaneously at 20% to 25%, loading with the ground paper to achieve flame retardancy. Prior to being added at this stage, the chemicals were blended, proportioned, and finely ground in order to disperse into the fiber more readily. In the final stage of the process, the finished product was conveyed to a bagging unit for packaging and then to a dust collector (Zicherman and Fisher, 1978; Chrenka, 1980; Lea, 1995).

Several leading brands of CI are manufactured primarily from recycled newspaper that has been treated with borax and boric acid (Sinanoglu, 1994). One United States company patented a method of making fire-resistant CI consisting of finely divided cellulose mixed with talc (5% to 25% by weight), the option of boron compounds (up to 10% by weight), and other additives (Bird *et al.*, 1980). According to the Cellulose Insulation Manufacturers Association (CIMA), talc is not currently used in the manufacture of CI (Lea, 1995).

Prior to the mid-1970s, there were roughly 100 firms manufacturing CI. Between 1975 and 1976, the demand for insulation heightened because of new energy efficiency awareness, and a surge of companies began producing CI. By the end of 1977, there were approximately 950 manufacturers. The number of CI manufacturers dropped to fewer than 450 firms in 1978, 200 in 1980, and 169 in 1983 (Anonymous, 1980a, 1984; Chrenka, 1980). In 1991, there were about 100 CI manufacturers (Anonymous, 1991). CIMA estimates that there are approximately 50 companies that presently manufacture CI (Lea, 1995).

Production levels are difficult to obtain because many of the CI producers are small enterprises and are not required to report production volumes. The estimated production capacity of cellulose loose-fill insulation was 2.4 million tons in 1980 (Neisel and Verschoor, 1981). According to an industry survey, CI manufacturing sales fell from $39.4 million in 1982 to $36.3 million in 1983 as production declined from 689,000 tons to 634,000 tons (Anonymous, 1984). The best available data indicate that CI production is presently between 270,000 and 420,000 tons per year (McConnell, 1994).

CI manufacturing accounted for 14% of waste newspaper consumption in 1977 and 24% in 1980 (Barton *et al.*, 1981). In 1979, CI manufacturers consumed an estimated 646,000 tons of old newspaper (Anonymous, 1980b). A report on the markets for waste newspaper in four South Atlantic states found that CI producers in Georgia consumed 78,200 tons of newspapers in 1980 compared with 14,700 tons in Florida and a combined 18,300 tons in North Carolina and South Carolina (Barton *et al.*, 1981).

CI accounted for 20% of the entire building insulation market in 1975, 20% to 25% in 1978, and 15% to 20% shortly afterwards. Relative demand for CI in 1975 was 10% for industrial equipment and pipes and 90% for building construction (10% for new residential construction, 75% for reinsulation and remodeling, and 5% for commercial/industrial construction) (ICF, Inc., 1977; Anonymous, 1981; Barton *et al.*, 1981). In 1979, CI manufactured by Diversified Insulation in the United Kingdom accounted for 40% of the United States insulation market (Anonymous, 1979). However, demand for CI has declined since the 1970s. CI accounted for only 10% of the insulation market for single-family residential homes in 1991 and 1993 (Anonymous, 1991).

Use and Human Exposure

Although patents for CI were issued in the 1800s, the product did not find a firm foundation in the marketplace until the 1950s. Since that time, it has been one of the principal thermal insulations used in retrofitting (i.e., adding thermal insulation) private homes, small, multiple-dwelling units, and, to a limited extent, new construction. The utility of CI is based on the ability of cellulose to trap air both between fibers and within fibers, creating its excellent insulating quality. ~~CI is more economical than other types of thermal insulation because it is more efficient. It can also reach more areas than other insulation materials because of its blown application process (Anonymous, 1977; Zicherman and Fisher, 1978; Chrenka, 1980; Sinanoglu, 1994).~~ See Erratum

The most common method of applying CI is blowing it into new or existing structures. It is normally applied in attics using an open blowing process and into sidewalls and retrofit situations using a closed blowing process. CI can also be applied by pouring it out of a bag between and over attic joists. Contractors install CI into existing exterior walls by drilling holes in siding materials between wall studs and blowing the insulation into the wall cavities (Anonymous, 1977; Zicherman and Fisher, 1978; Davis, 1993; McConnell, 1994). "Stabilized" CI can be applied with a spray gun. "Stabilized Cellulose" is a form of CI that is mixed with a water-based adhesive and a small amount of water, which stabilizes the applied depth of the CI. The water also assists in securing it between wall studs. Spray-applied CI has been used to cover and protect from existing asbestos-containing insulation (Cohn, 1981). It can also be installed on complex surfaces and substrates (e.g., barrel vaults, corrugated decks, concrete "T"s or pans, flat surfaces, wood, concrete, metal, sheetrock, plaster, etc.) and can be used in new construction and renovation. The thickness of the finished product can be altered to provide different levels of thermal or acoustical performance (Anonymous, 1990).

Between 1975 and 1980, one in eight homeowners insulated their homes with CI. During this same period, federally funded weatherization programs insulated homes of low-income families using CI almost exclusively (Chrenka, 1980). A survey by the CPSC in 1978 estimated that 3 million houses had CI installed between January 1976 and September 1978 (Levin and Purdom, 1983).

REGULATION

CI is considered a “nuisance dust” and is classified by the American Conference of Governmental Industrial Hygienists (ACGIH, 1991) as a particulate not otherwise classified (PNOC) and by the Occupational Safety and Health Administration (OSHA) as a particulate not otherwise regulated (PNOR). Nuisance dusts have been defined as dusts that have little adverse effect on the lungs and, when maintained under reasonable control, do not result in significant organic disease or toxic effect. However, in sufficient quantities, any dust will elicit some cellular response in the lung. The lung tissue reaction caused by the inhalation of PNOCs has the following characteristics: the architecture of the air spaces remains intact; collagen (scar tissue) is not synthesized to a significant extent; and the tissue reaction is potentially reversible.

Extreme concentrations of PNOCs in the workplace air may cause a serious reduction in visibility or unpleasant deposits in the eyes, ears, and nasal passages. PNOCs may also contribute to skin or mucous membrane injury by chemical or physical actions or by the rigorous skin cleansing procedures necessary for their removal.

The OSHA permissible exposure limit (PEL) for PNORs is 15 mg/m^3 for total dust and 5 mg/m^3 for respirable dust. Although a NIOSH recommended exposure limit (REL) for particulates has not been established, after reviewing available published literature, NIOSH provided comments to OSHA on August 1, 1988, regarding the “Proposed Rule on Air Contaminants” (29 CFR 1910). In these comments, NIOSH questioned whether the proposed OSHA PEL of an 8-hour time weighted average (TWA) of 10 mg/m^3 for PNORs (defined as total dust in this report) was adequate to protect workers from recognized health hazards.

ACGIH (2003) recommends a total dust 8-hour threshold limit value (TLV)-TWA of 10 mg/m^3 for inhalable PNOCs containing no asbestos and less than 1% crystalline silica and 3 mg/m^3 for respirable dust. For substances such as PNOCs without a short-term exposure limit (a 15 minute TWA, which cannot be exceeded at any time during the workday), ACGIH recommends an excursion limit. Excursions in worker exposure levels may exceed three times the TLV-TWA for no more than 30 minutes during an 8-hour workday. Excursions in worker exposure levels should never exceed 5 times the TLV-TWA.

TOXICITY AND CARCINOGENICITY

Experimental Animals

The toxicity of cellulose has been studied in animals using forms from pure microcrystalline cellulose (Adamson *et al.*, 1999) to wood (Tatrai *et al.*, 1995) and soft paper dust (Ericsson *et al.*, 1988; Järvholm *et al.*, 1988). Unfortunately, the toxicity of cellulose is highly dependent upon the form studied, so one cannot extrapolate from studies using other forms of cellulose. Only one animal inhalation study of CI has been reported. Hadley *et al.* (1992) exposed male and female Wistar rats by nose-only inhalation to 100, 500, or 2,000 mg/m^3 of Thermolite® CI for 6 hours per day, 5 days per week, for 21 exposures. Diffuse macrophage infiltration, microgranuloma formation, alveolitis, and epithelial hyperplasia were observed in the lungs of all treated rats. The severity of this effect increased with the exposure concentration. The authors stated that, because these effects were observed after short-term exposure to dust levels that were within an order of magnitude of reported work place exposures, human exposure to CI should be minimized. However, the CI exposures in this study were not representative of workplace exposures to CI. The Thermolite® CI was preprocessed in order to increase the amount of respirable material to between 38% and 47% rat respirable particles (mass median aerodynamic diameter ≤ 3 µm). Exposing animals to high concentrations of CI containing up to 47% respirable particles results in lung burdens that inhibit lung clearance mechanisms and cause an inflammatory response.

Adamson *et al.* (1999) compared the pulmonary effects of CI, bleached cellulose, and microcrystalline cotton cellulose following intratracheal instillation in male Fischer rats. Rats were given four consecutive daily instillations of presized particulate for total doses of 0, 0.25, 1.0, and 4.0 mg/animal. Animals were evaluated up to 90 days after treatment. Evidence of a transient pulmonary inflammation characterized by neutrophil and leukocyte infiltration was observed at the highest doses of CI, bleached cellulose, and microcrystalline cotton cellulose, with CI causing the greatest effect. The authors concluded that these cellulose materials behaved in a manner consistent with that of other poorly soluble particulates, and the inflammatory effects at the highest doses were likely confounded by impairment of clearance.

Humans

No epidemiological studies investigating the association of exposure to CI and respiratory disease in humans were identified in the published medical literature. One case report postulates that inhalation of CI may result in pulmonary alveolar proteinosis. McDonald *et al.* (2000) report the development of this disorder after exposure to household dust from a ventilation system. The dust contained cellulose fire-resistant fibrous insulation material. The affected individual showed symptomatic improvement once exposure to the insulation material ceased.

Two NIOSH investigations and a German study have documented occupational exposure to CI. A 1984 NIOSH investigation of health problems among personnel working with various insulating materials used for weatherization of homes found that concentrations of total particulate exceeded the ACGIH-recommended TLV and the OSHA PEL.

The bulk of the material composing the CI would be considered nuisance dust. The highest concentrations were present in personal samples collected while blowing cellulose into attic areas, with 8-hour TWAs of 20.8 and 34.5 mg/m^3 found at the two different sites monitored. Concentrations were significantly lower when blowing insulation in outside walls (5.2 mg/m^3) and when loading the hopper off the back of the weatherization truck (4.3 g/m^3). The respirable fraction and further characterization of the particulate were not measured. The NIOSH investigators noted that all personnel working at these activities were wearing Mine Safety and Health Association/NIOSH-approved respiratory protection, which, if properly used and fitted, should have greatly reduced the actual exposure (NIOSH, 1985).

A 1990 NIOSH evaluation of asbestos exposure during low-income housing weatherization procedures documented high levels of dusts and cellulose fibers associated with CI installation. These short term exposures included levels of 2.2 to 4.6 mg/m^3 for workers blowing insulation in holes in walls, 13.4 mg/m^3 for a worker feeding bags of CI into the hopper, and more than 40.8 mg/m^3 for a worker blowing insulation inside an attic. The respirable fraction was not measured and further characterization of the particulate was not conducted. The investigators noted that company policy required workers to wear a half-mask respirator with a combination high efficiency particulate arrestor (HEPA)/organic vapor cartridge when spraying CI or when entering an attic, a crawl space, or knee wall (NIOSH, 1990; Tharr, 1991). Therefore, workers adhering to the respirator policy should have minimal respiratory exposure to cellulose particulates.

A German study investigated fibrous dust emission from CI (Isofloc®) during installation and use. In all measurements, a large increase in fiber and dust exposure was noted with increasing time of exposure during installation. The tests were conducted primarily during the beginning of the installation phase and up to 2.5 hours into the installation phase. During insulation of a wooden floor, the German TLV for respirable dust of 6 mg/m^3 was exceeded. The investigators noted that the manufacturer of the insulation permits the installation of its products only by specialty firms and encourages them to use masks and respirators (Tiesler and Schnitteger, 1992). A response to the investigation further pointed out that the CI investigated in the study is used primarily in the interior of air-tight hollow spaces. In addition, the technical information and training provided to the installers of these air-tight layers further precludes any dust exposure to the occupants (Welteke, 1993).

Although direct effects of CI on human health have not been studied, cellulose particles from other sources have been associated with the formation of foreign body granulomas in humans. Zeltner *et al.* (1982) reported a fatal case of pulmonary granulomatosis in a male drug abuser caused by illicit intravenous injections of microscopic cellulose, a binding agent in pentazocine tablets. Brittan *et al.* (1984) described a case of cellulose granulomatous peritonitis in a woman that was ascribed to cellulose contamination during a previous surgery. Within the giant cells and necrotic debris, there were numerous hollow fibers of varying length with the characteristic morphological features of vegetable cellulose fibers.

Although there are no occupational health studies of CI workers, a Swedish team reported adverse health outcomes in a soft paper mill. The odds ratios for mortality from chronic obstructive pulmonary disease and from asthma among exposed workers were significantly elevated (Thoren *et al.*, 1989). A morbidity study found dose-related irritation of the upper respiratory tract. A decrease in vital capacity of the lung was associated with long-term exposure to dust (Järvholm *et al.*, 1988). Heederik *et al.* (1987) found lower FEV_1 in workers exposed to paper mill dust than in unexposed workers.

On two different occasions, NIOSH (1985, 1990) evaluated CI exposures of employees who weatherize homes. The first evaluation involved a weatherization company that applied CI in an attic and outside walls. The 8-hour TWAs were as follows: 20.6 and 34.5 mg/m^3 for the installers in the attic, 5.2 mg/m^3 for the installers at the outside walls, and 0.9 mg/m^3 and 4.3 mg/m^3 for the hopper operator. Employees wore NIOSH-approved half-mask respirators with cartridges for dusts, fumes, and mist while blowing CI into attics, and they wore disposable dust masks while loading CI into the hopper. The second evaluation was another weatherization program involved with reducing the energy consumption of low-income housing. Personal breathing zone air samples were collected for total dust during CI application activities and resulted in the following air sample concentrations: 4.6 mg/m^3 for the employee applying CI into walls, 13.8 g/m^3 for the employee trying to get the hopper running, 2.2 mg/m^3 for the other employee working on the hopper, 4.3 mg/m^3 for the hopper operator, and 40.8 mg/m^3 for the installer in the attic. All the employees wore half-mask respirators with HEPA/organic vapor cartridges.

EVALUATION OF THE CHEMICAL COMPOSITION, PARTICLE SIZE, AND PULMONARY TOXICITY OF CELLULOSE INSULATION

In order to conduct relevant inhalation studies of cellulose insulation (CI) in animals, the CI test material must be representative of that used in the workplace. However, insufficient data are available on the chemical composition and variability of CI from different manufacturers. NTP studies were conducted to characterize the fiber and particle size distribution in CI samples from four major United States manufacturers. CI samples were acquired with the assistance of the Cellulose Insulation Manufacturers Association (CIMA). These studies were designed to provide information about fibrous and nonfibrous particulates as well as how much of the CI is potentially respirable. In addition, chemical analyses were performed on these four CI samples to determine the chemical identity and relative concentration of major inorganic additives, the relative concentrations of inorganic trace element impurities, and the identity and relative concentrations of organic materials. These studies were designed to provide information on the presence of potentially toxic chemicals and to evaluate the variability between products from different manufacturers.

To measure acute pulmonary toxicity, the respirable fraction from one of the four samples was administered to Fischer 344 rats by intratracheal instillation. Toxicity endpoints were evaluated over 28 days and compared with the effects of the same dose of titanium dioxide, a relatively inert particle. This information is needed in order to determine the feasibility of conducting inhalation toxicity studies in animals at CI concentrations that are relevant to human exposures.

MATERIALS AND METHODS

CHEMICAL CHARACTERIZATION STUDIES

Chemicals

Bulk CI samples from four major United States manufacturers were obtained with the assistance of the CIMA. For proprietary reasons, the CI products were identified as Samples 1 to 4.

Inorganic Chemical Characterization

Elemental Analysis: Triplicate samples of each CI sample were weighed in Teflon® microwave digestion vessels and digested with nitric acid. The digests were diluted with water and centrifuged to remove insoluble residue. The clear supernatants were analyzed for inorganic elements by inductively coupled plasma-atomic emission spectroscopy (ICP-AES).

X-Ray Diffraction (XRD): The insoluble residue from each sample was dried and analyzed by XRD. XRD analysis was used to obtain qualitative and semiquantitative identification of crystalline phases in the four CI samples.

Organic Chemical Characterization

CI samples were extracted with methylene chloride. The extracts were analyzed using gas chromatography with flame ionization detection (GC-FID) and mass spectroscopy (GC-MS). The chromatographic profiles and relative responses of the total organic material from each of the test sample extracts were compared.

Fractionation of Particulates by Inertia in an Air Stream

A test system was built to generate an aerosol and to fractionate the bulk CI (Figure 1). The test system included a commercial insulation blower, a rough separator, a cyclone separator, a sampling chamber, and a membrane filter bag. The bulk CI was placed in the hopper of the blower where agitator paddles broke the material into small pieces. Agitator vanes at the bottom of the hopper pushed the small pieces into an airlock chamber where about 40 cfm of nitrogen was used to carry the test material through a static charge neutralizer into the rough separator. The rough separator was designed to collect at least 50% of particulates with aerodynamic diameters greater than or equal to 12 µm at a flow rate of 40 cfm. Particulates that passed through the rough separator entered the cyclone, which was designed to allow at least 75% of particulates with aerodynamic diameters less than 10 µm to pass into the sampling chamber. Neither the rough separator nor the cyclone removes fibers that are considered to have a high potential risk to human health.

Individual plastic collection bags at the ends of both the rough separator and the cyclone allowed weighing of collected material. The majority of particulates with aerodynamic diameters less than 10 µm penetrate the cyclone to the sampling chamber where filter samples (0.2 µm pore size) were taken for various analyses. Particulates in the aerosol leaving the sampling chamber were collected downstream in a filter bag. All collection bags were weighed before and after each experiment to determine the fraction in each size range. After weighing the filter bags, the collected materials were transferred to tared Teflon®-coated filters and weighed again. During each test run, filter samples were taken from the sampling chamber to determine aerosol concentration and estimate size distribution. The aerosol concentration was determined by collecting duplicate samples at known flow rates (8.9 L/minute) for the duration of each test run. Duplicate samples for size distribution analysis using scanning electron microscopy (SEM) were taken at 0.5 L/minute for 4 minutes.

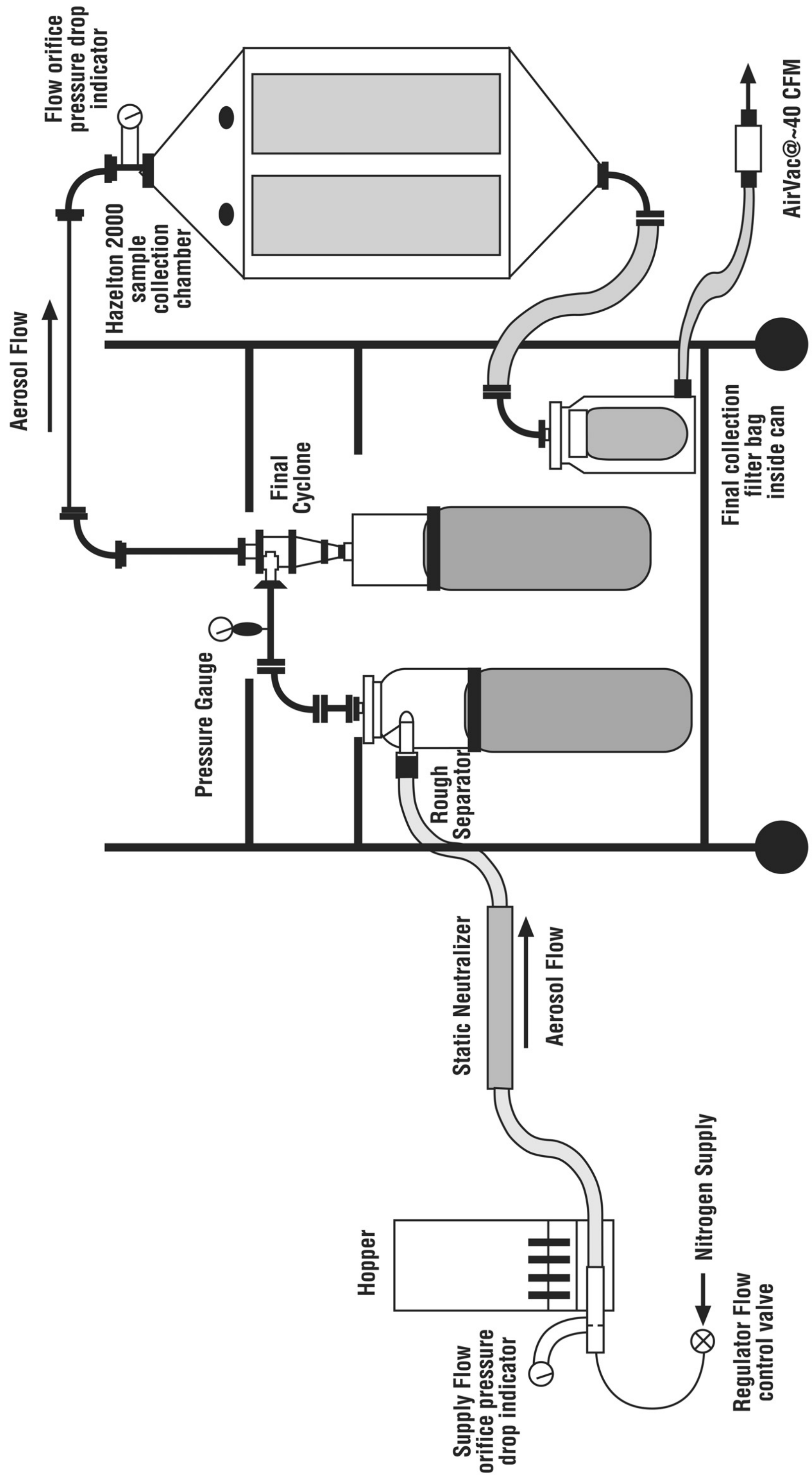


FIGURE 1
Cellulose Insulation Aerosol Generation and Particle Sampling System

Particulate Counting and Size Distribution Analysis

The size distribution of particulates collected in the cyclone collection bag was determined to evaluate the amount of respirable fibers that were collected in the cyclone separator. Samples were prepared for SEM by dispersing a small amount of this material onto a glass slide. Slides were turned upside down to remove large particles and clusters. Particle size distribution was analyzed by SEM using one slide from each test sample. Another filter sample from each test sample was taken from the sampling chamber and analyzed using SEM to determine number, concentration, and size distribution of the collected particles. Micrographs of 20 randomly selected fields per sample were digitized and saved as image files. Using commercial software, an image was randomly selected to determine number and size distribution of total particulates (both fibrous and nonfibrous particulates) for each sample. At least 100 particles per sample were measured.

Micrographs of filters were examined by electron microscopy to determine the number and size distribution of fibers in the sampling chamber. For Samples 1, 2, and 3, all 20 fields (2,000×) of each filter from the sample chamber were examined for size distribution of fibrous particulates. Because Sample 4 had a very low particle population, six fields were examined at 500× (equivalent to 96 fields at 2,000×). Micrographs of filters were examined using commercial software to determine the number and size distribution of fibers. This software requires manual identification of fibers and manual tracking of length and width. Only particulates with lengths greater than 5 µm, widths less than or equal to 3 µm, and aspect ratios (length to width) greater than or equal to 3 µm were counted as fibers. Additional counting rules stated in NIOSH Method 7400 were followed (NIOSH, 1994). For a fiber of 3 µm diameter to have an aerodynamic diameter of 12 µm, the length must be greater than 30 µm; for a 1 µm diameter fiber, the length would be much greater than 100 µm, assuming the specific gravity of the fiber is 1 (Baron, 1993).

The collection efficiencies of the rough separator and the cyclone separator were not experimentally validated because of the unavailability of monodisperse fibers of known sizes. In addition, the measurement protocol for fibers that penetrated the cyclone separator excluded fibers substantially larger (>>10 µm) than the design cutoff (about 12 µm). The fraction of small particles that deposited in the rough separator or cyclone separator instead of in the final filter was not determined. Therefore, the chamber concentration data were biased downward by the unknown number of small particles collected in the first two stages.

Animal Studies

Animals

Male Fischer 344 rats (Charles River Breeding Laboratory, Raleigh, NC) weighing 180 to 200 g (42 to 48 days old) were acclimated for 10 to 14 days after arrival. During acclimation, rats were randomized into treatment groups, five rats per group. Animals were provided NIH-07 diet and tap water *ad libitum* throughout the study.

Treatment

The respirable fraction of Sample 2 was administered by intratracheal instillation to lightly anesthetized (isoflurane) male Fischer 344 rats (8 weeks old). Only Sample 2 contained sufficient respirable material for the intratracheal instillation study. The CI was suspended in sterile saline, and the dosing volume was 0.15 mL/100 g body weight. An initial range-finding study was conducted by instilling saline containing 0, 0.625, 1.25, 2.5, 5, 10, or 20 mg CI/kg body weight. Bronchoalveolar lavage (BAL) fluids parameters were evaluated 3 days later. Based upon results of the range-finding study, 5 mg CI/kg body weight was selected as the dose to be used in the 28-day study.

In the 28-day study, rats were instilled with either saline (vehicle controls), 5 mg titanium dioxide/kg body weight suspended in saline (particle controls), or 5 mg CI/kg body weight suspended in saline (respirable fraction). Five rats per treatment group were euthanized (intraperitoneal Nembutal) 1, 3, 7, 14, and 28 days after instillation.

Histology

At 14 and 28 days after dosing, five rats per treatment group were weighed then euthanized. Lungs were weighed, then infused with 10% neutral-buffered formalin. Paraffin-embedded sections were stained with Masson's trichrome and evaluated by light microscopy. Wet weights were recorded for liver, kidney, and spleen.

Bronchoalveolar Lavage

At 1, 3, 7, 14, and 28 days after instillation, five rats per treatment group were euthanized, and their lungs were lavaged *in situ* three times with 10 mL cold calcium- and magnesium-free Hanks balanced salts solution. The BAL fluids were centrifuged (10 minutes, 2,000 rpm, 4° C), and the cell pellets were combined for total and differential cell counts. The cell-free supernatant of the first BAL fluid fraction was used for lactate dehydrogenase (LDH) and protein measurements.

BAL Fluid Cell Counts

The BAL fluid cell pellets were suspended in 5 mL of balanced salts solution, and the total number of white cells was determined using a Coulter counter. The cells were differentiated on cyto-centrifuge preparations fixed in methanol and stained with Diff-Quik. Differential counts were based on 300 cells per animal.

Biochemical Analyses

The first cell-free lavage fraction was analyzed for LDH activity and total protein (Bio-Rad) using an automated system (Monarch 2000, Laboratory Instrumentation, Lexington, MA). After collecting BAL fluid, lung tissue samples from all the rats were collected and analyzed for 4-hydroxyproline (Woessner, 1961).

Statistics

Data were analyzed for statistically significant differences by one-way analyses of variance and Duncan's multiple comparison test (Sokal and Rohlf, 1981).

RESULTS

CHEMICAL CHARACTERIZATION STUDIES

Inorganic Chemical Characterization

Elemental Analysis: Elements that were consistently present in all bulk samples of CI in quantities greater than about 0.1% by weight included aluminum, boron, calcium, sodium, and sulfur (Table 1). Samples 1 and 4 contained higher boron and sodium concentrations, and Samples 2 and 3 contained higher concentrations of aluminum and calcium. All four samples contained sulfur concentrations greater than 1%. Mean concentrations of beryllium, cadmium, cobalt, chromium, potassium, molybdenum, nickel, lead, antimony, and selenium were below the quantifiable limits in all four samples.

X-Ray Diffraction (XRD): XRD analyses indicated that the compositions of all four CI samples were similar. The compositions were primarily amorphous (60% to 65% by volume), with crystalline phases comprising the remaining fractions (35% to 40% by volume) (Table 2). The composition of the crystalline fraction was also very similar for all four CI samples (Table 3). The crystalline fraction was primarily composed of native cellulose (75% to 85% by weight), with a smaller amount of cellulose nitrate (15% to 25% by weight).

The composition of the insoluble residue that remained in the digested test material was determined for Samples 1 and 3 (Table 4). The relative amounts and compositions of the residue were remarkably similar in the two samples analyzed. The insoluble residue comprised approximately 3% to 5% of the original sample’s weight and was composed primarily of aluminum silicate hydroxide (kaolinite, ~85%), with smaller quantities (<5% each) of magnesium silicate hydroxide (talc), potassium aluminum silicate hydroxide (muscovite), and titanium dioxide (rutile).

Organic Chemical Characterization

In general, the organic material found in the extracts was represented as a mass of poorly resolved peaks with some prevalent compounds present as resolved peaks in the GC-FID chromatograms (data not shown). The summed area response for organic compounds was similar in all extracts with the exception of CI Sample 4, which contained approximately six times the total FID response exhibited by the other three samples. Because of the very low concentrations of organic compounds, identification and quantification of individual compounds in the extracts were not performed.

TABLE 1
Elemental Analysis of Bulk Cellulose Insulation

Element	Cellulose Insulation Samples[a] 1	2	3	4
Aluminum	0.49 ± 0.04	0.52 ± 0.04	0.8 ± 0.1	0.4 ± 0.01
Antimony	<0.004	<0.004	<0.004	<0.004
Arsenic	<0.007	0.007 ± 0.001	0.008 ± 0.002	0.007 ± 0.001
Beryllium	<0.00005	<0.00005	<0.00005	<0.00005
Boron	2.0 ± 0.1	0.52 ± 0.01	0.53 ± 0.005	1.37 ± 0.001
Cadmium	<0.0005	<0.0005	<0.0005	<0.0005
Calcium	0.23 ± 0.03	0.33 ± 0.02	0.24 ± 0.02	0.11 ± 0.01
Chromium	<0.001	<0.001	<0.001	<0.001
Cobalt	<0.001	<0.001	<0.001	<0.001
Copper	0.0028 ± 0.0001	0.0023 ± 0.00006	0.0025 ± 0.00009	0.0020 ± 0.0002
Iron	0.033 ± 0.002	0.027 ± 0.01	0.031 ± 0.002	0.017 ± 0.003
Lead	<0.005	<0.005	<0.005	<0.005
Magnesium	0.057 ± 0.001	0.027 ± 0.0006	0.022 ± 0.001	0.024 ± 0.0003
Manganese	0.0024 ± 0.0001	0.0032 ± 0.00003	0.0021 ± 0.00004	0.0029 ± 0.00003
Molybdenum	<0.001	<0.001	<0.001	<0.001
Nickel	<0.001	<0.001	<0.001	<0.001
Phosphorus	<0.01	0.167 ± 0.003	0.042 ± 0.002	<0.01
Potassium	<0.1	<0.1	<0.7	<0.1
Selenium	<0.006	<0.006	<0.006	<0.006
Silicon	0.03 ± 0.01	0.026 ± 0.001	0.032 ± 0.003	0.037 ± 0.007
Sodium	2.12 ± 0.05	0.082 ± 0.001	0.12 ± 0.01	1.47 ± 0.015
Sulfur	1.43 ± 0.02	2.47 ± 0.04	2.81 ± 0.06	3.60 ± 0.10
Titanium	0.0077 ± 0.0007	0.0063 ± 0.0005	0.009 ± 0.001	0.007 ± 0.002

[a] Values expressed as percent by weight; mean ± standard deviation; n=3; less than (<) values are below the quantifiable limit for the ARL-3410 ICP-AES.

TABLE 2
X-Ray Diffraction Results for Bulk Cellulose Insulation

Sample	Phase	% Composition (by volume)
1	Crystalline	~35
	Amorphous	~65
2	Crystalline	~35
	Amorphous	~65
3	Crystalline	~40
	Amorphous	~60
4	Crystalline	~35
	Amorphous	~65

Table 3
X-Ray Diffraction Results for Bulk Cellulose Insulation Crystalline Phase

Sample	Phase	% Crystalline Phase (by weight)
1	Native Cellulose	~80
	Cellulose Nitrate	~20
2	Native Cellulose	~80
	Cellulose Nitrate	~20
3	Native Cellulose	~75
	Cellulose Nitrate	~25
4	Native Cellulose	~85
	Cellulose Nitrate	~15

Table 4
Composition of Insoluble Residue in Cellulose Insulation Digests

Sample	Weight % Residue	Identity	
1	4.7 (n=1)	Aluminum silicate hydroxide (kaolinite)	(major; >85%)
		Magnesium silicate hydroxide (talc)	(minor; ~5%)
		Potassium aluminum silicate hydroxide (muscovite)	(minor; <5%
		Titanium dioxide (rutile)	(minor; ~5%)
3	3.4 ± 0.4 (n=3)	Aluminum silicate hydroxide (kaolinite)	(major; >85%)
		Magnesium silicate hydroxide (talc)	(minor; ~5%)
		Potassium aluminum silicate hydroxide (muscovite)	(minor; <5%)
		Titanium dioxide (rutile)	(minor; ~5%)

Fractionation of Particulates by Inertia in an Air Stream

The distribution of the aerosol particles in the test system is shown in Table 5. For all four bulk CI samples, approximately 99% of the total collected material was deposited in the rough separator collection bag, and approximately 1% was deposited in the cyclone collection bag. Less than 0.1% of the starting material was found in the sampling chamber filter bag (as determined gravimetrically) and represented the potentially respirable small particulate fraction. The amounts of materials transferred from the filter bags to filters were 1,126 mg (Sample 1), 395 mg (Sample 2), 292 mg (Sample 3), and 0.2 mg (Sample 4). Aerosol concentrations in the sampling chamber were derived from the total flow rate and the total mass of particles passing through the sampling chamber.

Table 5
Distribution of Cellulose Insulation in the Test System

	Amount Deposited in Collectors				
Sample	**Mass Processed (kg)**	**Rough Separator (%)[a]**	**Cyclone (%)[a]**	**Chamber Filter Bag (mg)**	**Chamber Aerosol Concentration[b] (mg/m^3)**
1	13.6	98.7	1.3	8.3×10^{-5}	48.3 ± 9.9
2	14.1	99.0	1.0	2.8×10^{-5}	22.9 ± 0.2
3	14.2	99.1	0.9	2.1×10^{-5}	15.4 ± 0.2
4	8.6	99.5	0.5	2.3×10^{-8}	0.3 ± 0.1

[a] Values expressed as percent by weight
[b] Estimated from air flow rate through chamber and amount of particulate collected on filters

Particulate Counting and Size Distribution Analysis

The size distributions of total particulates collected from the cyclone separator collection bag and the sampling chamber were determined. The mean equivalent diameters for particulates collected in the cyclone collection bag ranged from 3.5 to 11.4 µm (Table 6). Most of the material collected in the cyclone was in crumbs (several mm in diameter) and therefore not included in the size determination. The mean equivalent diameters for particulates collected in the sampling chamber ranged from 0.6 to 0.7 µm. These measurements demonstrated a difference in particle size distribution between samples collected from the cyclone and the sample chamber. Only one field from each sample (2,000×) was examined for particulate size distribution because there were more than 100 particulates on each field. The filter from the sampling chamber for Sample 4 had a very low particle population compared to the other test samples.

TABLE 6
Number and Size Distribution of Total Cellulose Insulation Particulates

Sample	Particle Count[b]	Equivalent Diameter (µm)[a] Mean	Standard Deviation	Min	Max
Cyclone Collector					
1	136	6.8	3.93	0.7	23.0
2	434	3.5	4.02	0.4	27.5
3	286	7.5	6.54	0.9	52.6
4	196	11.4	9.91	0.7	64.4
Sampling Chamber					
1	2,658	0.6	0.49	0.1	6.9
2	6,930	0.7	0.57	0.1	10.8
3	4,933	0.6	0.59	0.1	5.5
4	18	0.6	0.62	0.2	2.8

[a] The diameter of a circle having the same surface area as the target item
[b] Total particulates in one field at 2,000×

Fibers

Micrographs of filters were examined by electron microscopy to determine the number and size distribution of fibers in the sampling chamber (Plates 1 through 4). The observed fibers were curved or twisted, nonuniform in diameter, and had several branches, making it difficult to identify the endpoints of some fibers. Many fibers lay across the boundary of the SEM field, and an additional image at different magnification (500×) was required to determine the length of those fibers. All of these complications made it virtually impossible to automatically measure the size of the cellulose fibers by computerized image analysis; therefore, the reported fiber width is the average width visually estimated by the operator.

The size ranges of fibers found in the sampling chamber varied considerably; however, fibers from Sample 4 were generally shorter and narrower than the other three CI samples (Table 7). The total number of fibers identified in the examined fields ranged from 6 (Sample 4) to 172 (Sample 2) (Table 8). Based on these counts, the concentrations of fibers in the air of the sampling chambers were estimated to be 5 (Sample 4), 146 (Sample 1), 538 (Sample 3), and 847 (Sample 2) fibers/cc. The total number of fibers generated was estimated based on flow rate and sample times, and these data were used to calculate the total number of fibers per gram of insulation. Sample 4 generated considerably fewer fibers than the other samples.

TABLE 7
Size Ranges of Fibers Found in the Sampling Chamber

Sample Number	Length (µm)		Width (µm)		Aspect Ratio[a]	
	Max	Min	Max	Min	Max	Min
1	33.3	5.2	2.4	0.2	35.2	3.9
2	53.5	5.0	2.9	0.2	56.3	3.3
3	29.1	5.0	2.9	0.2	91.1	4.3
4	18.5	7.7	1.2	0.6	18.2	11.7

[a] Ratio of length:width

TABLE 8
Number of Fibers in Samples from the Chamber

Sample Number	Number of Fibers[a]	Fibers/Filter	Fibers/cc Air	Total Fibers[b]	Fibers/g Insulation
1	30	2.4×10^5	146	5.6×10^9	4.1×10^5
2	172	1.4×10^6	847	1.9×10^{10}	1.4×10^6
3	109	9.0×10^5	538	1.2×10^{10}	8.6×10^5
4	6[c]	1.1×10^4	5	8.4×10^7	9.7×10^3

[a] Total fiber counts in 20 fields at 2,000×
[b] Total number of fibers generated from cellulose insulation; estimated based on flow rate and sample time
[c] Total fiber counts in six fields at 500× (equivalent to 96 fields at 2,000×)

Chemical Analysis of Respirable Particle Fractions

XRD analysis of the respirable particle fractions from CI Samples 1, 2, and 3 did not indicate the presence of any cellulose material. These fractions consisted primarily of the fire retardants boric acid and sodium (ammonium sulfate) with smaller quantities of clays such as kaolinite and muscovite (Table 9).

Nitric acid digests of the respirable particle fractions are shown in Table 10. Boron concentrations were relatively high in the respirable fraction from Sample 1 but were low in Samples 2 and 3. The material from Sample 1 also contained significantly more sodium than the other two samples. Sulfur concentrations were comparable in all three samples. Concentrations of the toxic elements lead, cadmium, chromium, arsenic, and selenium were very low in all of the CI samples tested.

Table 9
X-Ray Diffraction Analysis of Nitric Acid Digests of Respirable Fractions

Sample Number	Composition Phase	% by Weight
1	Sassolite, $B(OH)_3$	~65
	Thenardite, (Na_2SO_4)	~20
	Sodium sulfate, Na_2SO_4	~15
	Kaolinite, $Al_2Si_2O_5\ (OH)_4$	< 5
2	Mascagnite (Na_2SO_4)	~55
	Kaolinite, $Al_2Si_2O_5\ (OH)_4$	~15
	Muscovite $KAl_2(Si_3Al)O_{10}(OH,F)_2$	~10
	Unidentified (11 peaks)	~20
3	Mascagnite (Na_2SO_4)	~45
	Kaolinite, $Al_2Si_2O_5(OH)_4$	~25
	Muscovite $KAl_2(Si_3Al)O_{10}(OH,F)_2$	~10
	Unidentified (11 peaks)	~20

The respirable fractions consisted primarily of fire retardants (boric acid and sodium or ammonium sulfate) together with smaller amounts of clays such as kaolinite and muscovite. Cellulose material was not detected. Sample 4 did not contain sufficient respirable material for analysis.

Table 10
Elemental Analysis of Respirable Fraction of Cellulose Insulation Samples

	Cellulose Insulation Samples[a]		
Element	1	2	3
Aluminum	1.61 ± 0.08	3.5 ± 0.03	5.6 ± 0.4
Arsenic	<0.02	0.029 ± 0.003	0.048 ± 0.003
Beryllium	<0.0002	<0.0002	<0.0002
Boron	7.4 ± 0.3	0.024 ± 0.0005	0.019 ± 0.0005
Cadmium	<0.003	<0.003	<0.003
Calcium	1.04 ± 0.04	3.24 ± 0.08	1.9 ± 0.1
Chromium	<0.005	<0.005	<0.005
Cobalt	<0.004	<0.004	<0.004
Copper	0.0095 ± 0.0002	0.0135 ± 0.0003	0.0186 ± 0.0007
Iron	0.89 ± 0.005	0.17 ± 0.01	0.042 ± 0.01
Lead	<0.02	<0.02	<0.02
Magnesium	0.116 ± 0.005	0.120 ± 0.005	0.132 ± 0.0008
Manganese	0.0024 ± 0.0002	0.0097 ± 0.0004	0.0069 ± 0.0003
Molybdenum	<0.005	<0.005	<0.005
Nickel	<0.005	<0.005	<0.005
Phosphorus	<0.04	0.50 ± 0.03	0.209 ± 0.0008
Potassium	<0.07	0.097 ± 0.002	0.115 ± 0.009
Selenium	<0.02	<0.02	<0.02
Silicon	0.4 ± 0.4	0.2 ± 0.1	0.4 ± 0.5
Sodium	5.8 ± 0.3	0.3 ± 0.02	0.3 ± 0.02
Sulfur	4.7 ± 0.2	6.3 ± 0.1	4.0 ± 0.1
Titanium	0.025 ± 0.001	0.027 ± 0.002	0.035 ± 0.002

[a] Values expressed as percent by weight; mean ± standard deviation; n=3; less than (<) values are below the quantifiable limit for the ARL-3410 ICP-AES.

A gray residue remained after the acid digestion of the three respirable fractions from the three samples. The insoluble residue comprised about 5% to 18% by weight of the respirable particle fraction (Table 11). The digestion residue from Samples 2 and 3 was composed mainly of kaolinite, with smaller quantities of titanium dioxide (rutile and anatase), quartz, and talc. Conversely, the residue in the small particle fraction of insulation from Sample 1 consisted primarily of talc, with smaller quantities of kaolinite, titanium dioxide, and quartz. The sodium nitrate and calcium carbonate component in this material is possibly an artifact of the nitric acid digestion.

TABLE 11
X-Ray Diffraction of Undissolved Residue in Nitric Acid Digests of Cellulose Insulation Respirable Fractions

Sample Number	Weight % Residue[a]	Identity	% by Weight
1	5.4 ± 0.7	Talc, $Mg_3Si_4O_{10}(OH)_2$	~40
		Kaolinite, $Al_2Si_2O_5(OH)_4$	10-15
		Anatase, TiO_2	10-15
		Rutile, TiO_2	~10
		Quartz, SiO_2[b]	~10
		Nitratine, $NaNO_3$ and or calcite $CaCO_3$[b]	~10
		Unidentified (1 peak)	~ 5
2	11.9 ± 0.8	Talc, $Mg_3Si_4O_{10}(OH)_2$	< 5
		Kaolinite, $Al_2Si_2O_5(OH)_4$	~50
		Anatase, TiO_2	~25
		Rutile, TiO_2	~15
		Quartz, SiO_2	~5-10
3	18.3 ± 3.2	Talc, $Mg_3Si_4O_{10}(OH)_2$	< 5
		Kaolinite, $Al_2Si_2O_5(OH)_4$	~65
		Anatase, TiO_2	15-20
		Rutile, TiO_2	~10
		Quartz, SiO_2[b]	~ 5

The digestion residue of the insoluble materials consisted primarily (>85%) of kaolinite (aluminum silicate hydroxide) with smaller amounts (<5% each) of talc (magnesium silicate hydroxide), muscovite (potassium aluminum silicate hydroxide), and rutile (titanium dioxide).

a Gravimetric analysis, % by weight of respirable fraction samples; values are represented as mean ± standard deviation, n=3.

b Tentative identification only

Animal Studies

Range-finding Study

Animals were instilled with CI (0.625 to 20 mg/kg body weight), and BAL fluid cell differentials were evaluated 3 days later. Control animals received sterile saline. Because mortality was observed at doses greater than 5 mg CI/kg body weight, these high doses were not considered for use in the 28-day study. A dose-related increase in polymorphonuclear leukocytes (PMNs) was observed in rats receiving up to 5 mg CI/kg body weight (Figure 2); however, even at 5 mg/kg body weight, the inflammatory response was mild to moderate. Based upon these results, the 28-day time course study was conducted using a single dose of 5 mg/kg body weight.

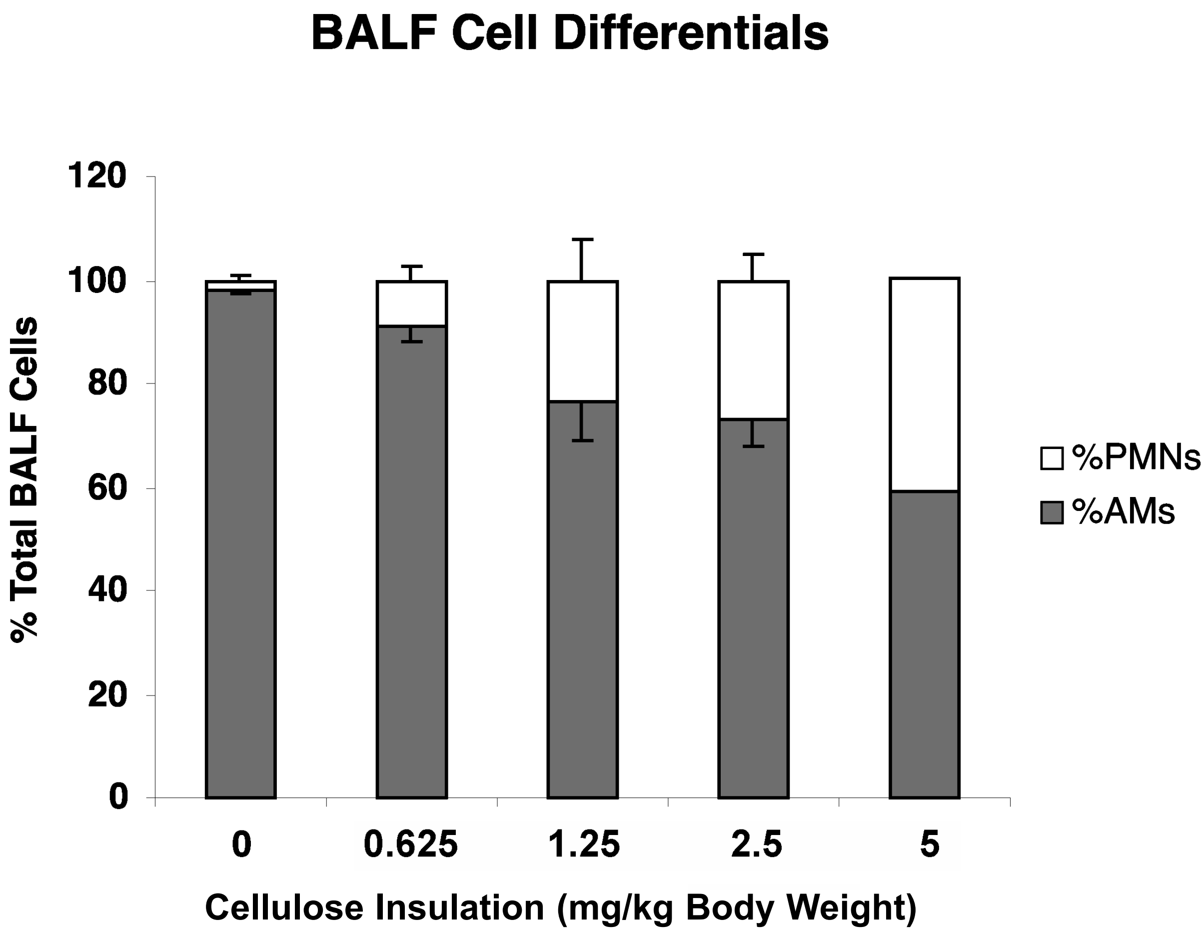


Figure 2
Bronchoalveolar Lavage Fluid (BALF) Cell Differentials from Rats 3 Days After Intratracheal Instillation of the Respirable Fraction of Cellulose Insulation Sample One
Values represent means ± standard deviation; n=5. PMN=polymorphonuclear leukocytes; AM=alveolar macrophages.

28-Day Time Course Study

BAL Fluid Cellularity: Animals were instilled with either sterile saline (controls), CI (5 mg/kg body weight), or titanium dioxide (5 mg/kg body weight), and the number of cells in BAL fluid was evaluated 1, 3, 7, 14, and 28 days after instillation (Figure 3). Relative to controls, CI caused a significant increase ($P<0.05$) in total BAL fluid cell numbers only on day 1. BAL fluid cell numbers in titanium dioxide-treated rats were greater than in the saline controls only on day 7. The increase in BAL fluid cell numbers was caused primiarily by an influx of PMNs in both CI- and titanium dioxide-treated rats (Figure 4). Saline instillation caused a slight (~5%) increase in PMNs that was present only on day 1. This minor, transient effect is often observed after saline instillation (Morgan *et al.*, 1997). CI instillation caused a significant influx of PMNs into the lung. This inflammatory response was greatest the day after instillation and was significantly greater than the effect in titanium dioxide-treated rats. Numbers of PMNs in BAL fluids from CI-treated rats gradually decreased through day 7 and returned to control levels by day 14. Titanium dioxide instillation caused a significant ($P<0.05$) influx of PMNs. PMN numbers remained elevated 1 and 3 days after instillation and returned to control levels by 7 days after treatment.

BAL Fluid Protein: Protein in BAL fluid is an indication of vascular leakage caused by treatment. Total protein was significantly increased ($P<0.05$) in the acellular BAL fluid at 1, 3, and 7 days after CI treatment (Table 12). This mild effect was transient and was not present when evaluated 14 and 28 days after instillation. Titanium dioxide had no significant effect on BAL fluid protein levels.

BAL Fluid LDH: CI also caused significant increases in BAL fluid levels of LDH that were only present on the day after instillation (Table 12). LDH is a cytoplasmic enzyme, and its presence in BAL fluid is an indication of cell injury. Titanium dioxide had no effect on LDH levels in BAL fluid.

Lung Hydroxyproline: 4-Hydroxyproline is an amino acid that is present primarily in collagen; its measurement is used to monitor collagen production and fibrosis. 4-Hydroxyproline was measured in lungs of saline-, CI-, and titanium dioxide-treated rats 7, 14, and 28 days after instillation. Only CI caused a significant increase ($P<0.05$) in 4-hydroxyproline that was present on day 28 (Table 12).

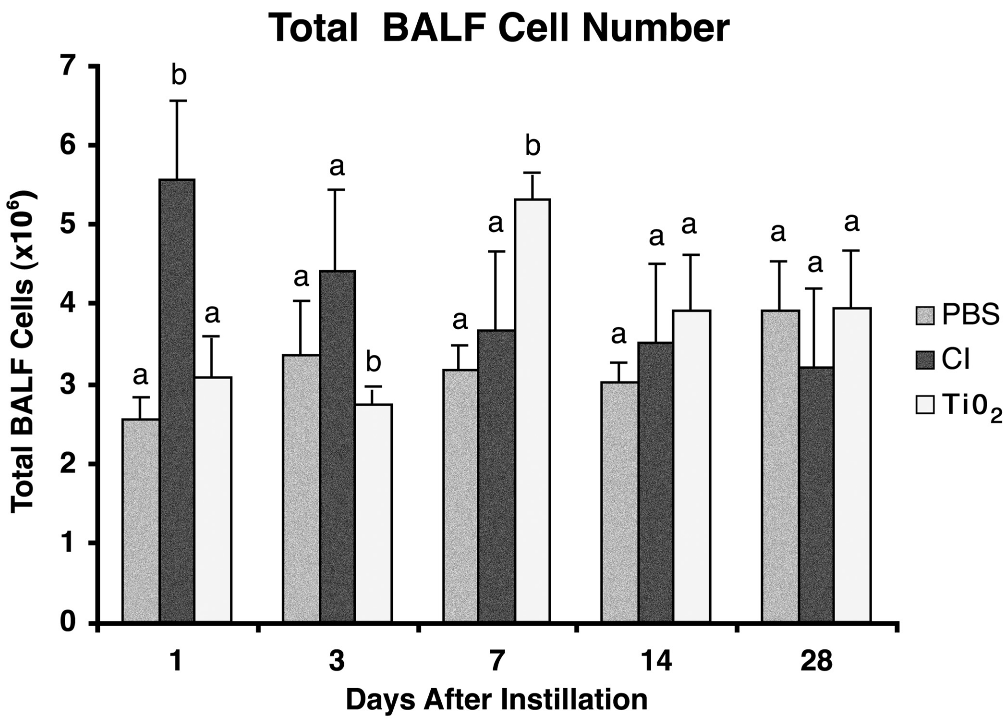


FIGURE 3
Total Bronchoalveolar Lavage Fluid (BALF) Cell Differentials at 1, 3, 7, 14, and 28 Days After a Single Intratracheal Instillation of Respirable Cellulose Insulation (CI) or Titanium Dioxide (TiO_2) Particles (5 mg/kg Body Weight)

Controls received phosphate buffered saline (PBS). Values represent means ± standard deviation; n=5. For each time point, values with different letters are significantly different ($P<0.05$).

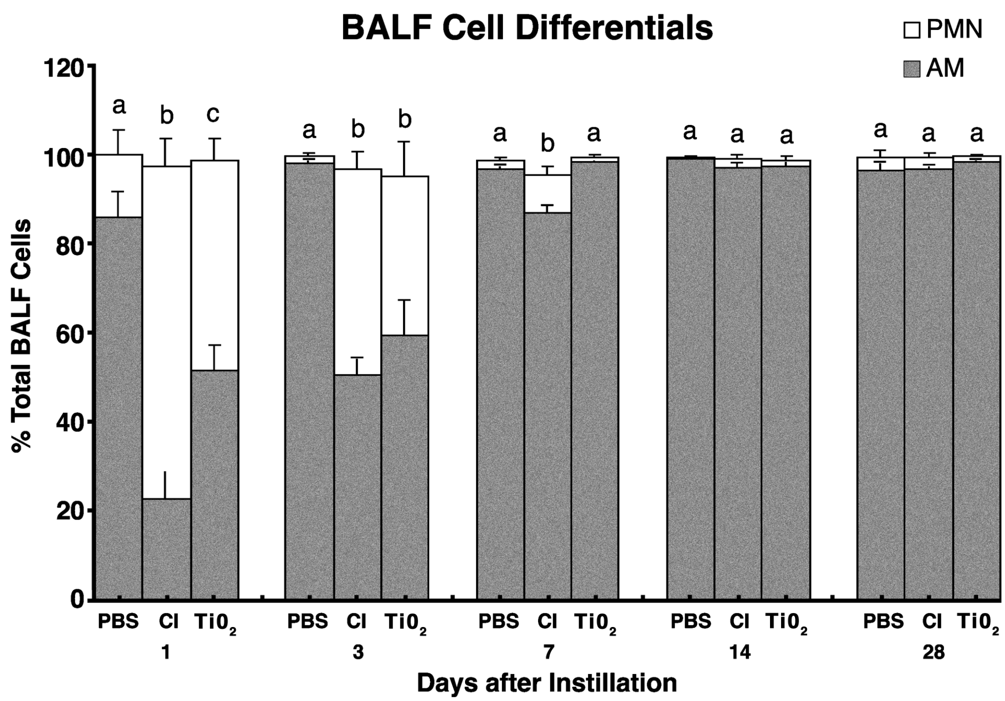


FIGURE 4
Bronchoalveolar Lavage Fluid (BALF) Cell Differentials at 1, 3, 7, 14, and 28 Days After a Single Intratracheal Instillation (5 mg/kg Body Weight) with Cellulose Insulation (CI) or Titanium Dioxide (TiO_2) Particles

Controls received phosphate buffered saline (PBS). Values represent means ± standard deviation; n=5. For each time point, values with different letters are significantly different (P<0.05). PMN=polymorphonuclear leukocytes; AM=alveolar macrophages.

TABLE 12
Pulmonary Toxicity of Intratracheally Instilled Cellulose Insulation and Titanium Dioxide Particulates[a]

	Days After Intratracheal Instillation				
	1	3	7	14	28
BAL Fluid Protein[b]					
Saline	0.19 ± 0.04	0.22 ± 0.05	0.11 ± 0.01	0.15 ± 0.02	0.19 ± 0.09
Titanium dioxide	0.29 ± 0.04	0.24 ± 0.04	0.13 ± 0.02	0.19 ± 0.03	0.09 ± 0.01
Cellulose insulation	0.46 ± 0.05*	0.38 ± 0.05*	0.19 ± 0.02*	0.21 ± 0.02	0.09 ± 0.01
BAL Fluid LDH[c]					
Saline	11 ± 5	48 ± 20	12 ± 1	8 ± 3	3 ± 0.7
Titanium dioxide	50 ± 22	32 ± 9	10 ± 2	16 ± 5	3 ± 0.3
Cellulose insulation	164 ± 21*	52 ± 16	6 ± 3	2 ± 4	2 ± 0.4
Lung 4-hydroxyproline[d]					
Saline	—[e]	—	23 ± 2	36 ± 12	7 ± 0.4
Titanium dioxide	—	—	45 ± 9	34 ± 19	38 ± 10
Cellulose insulation	—	—	24 ± 3	24 ± 4	811 ± 15*

* Significantly different from saline controls (P<0.05)
[a] Values are represented as mean ± standard deviation, n=5.
[b] mg protein/mL BAL fluid
[c] IU lactate dehydrogenase/L BAL fluid
[d] mg/lung
[e] Not determined

Histopathological Evaluation of Lungs

Lungs of saline-, CI-, and titanium dioxide-treated rats were collected for histopathological evaluation 14 and 28 days after instillation. Lungs from saline-treated rats were normal in appearance when evaluated microscopically on day 28 (Plate 5). CI-exposed lungs had scattered foci of minimal to mild granulomatous pneumonitis characterized by focal alveolar thickening (comprised primarily of macrophages) and discrete nodular foci of macrophages and giant cells often located adjacent to terminal bronchioles and alveolar ducts (Plate 6). Nodular foci occasionally contained greenish spicular material and/or granular punctate dark pigment or material (Plate 8). Wisps of blue staining collagen fibers (Masson's trichrome stain) were present (minimal increased collagen) within these nodular foci (Plate 6). There were no significant differences between animals and therefore no appreciable progression in the severity or distribution of lesions from day 14 to day 28 (Table 13). Epithelial changes were not present. One lymph node had mild hemorrhage, and another lymph node had minimal lymphoid hyperplasia. Minimal to mild granulomatous pneumonitis and collagen staining were present in all 10 CI-treated rats (Table 13).

Titanium dioxide-exposed lungs were characterized by scattered minimal intra-alveolar histiocytic macrophages laden with black pigment in nine of 10 rats (Table 13). There were no appreciable increases in blue staining collagen (Masson's trichrome stain) (Plates 7 and 9). Epithelial changes were not present. There were no significant differences between animals and therefore no appreciable progression in the severity or distribution of lesions from day 14 to day 28 (Table 13). Two bronchial lymph node sections contained pigment or pigment-laden macrophages. One lymph node had a moderate hemorrhage.

TABLE 13
Incidence and Severity of Histopathologic Lesions in the Lung in the 28-Day Study

	Saline Controls		Cellulose Insulation (5 mg/kg body weight)		Titanium Dioxide (5 mg/kg body weight)	
	Day 14	**Day 28**	**Day 14**	**Day 28**	**Day 14**	**Day 28**
Hemorrhage	2/5[a] (0.4)[b]	2/5 (0.4)	3/5 (0.6)	1/5 (0.2)	3/5 (0.6)	3/5 (0.6)
Alveolar histiocytosis	0/5	0/5	0/5	0/5	0/5	1/5 (0.1)
Granulomatous pneumonitis	0/5	0/5	5/5 (1.8)	5/5 (1.8)	0/5	0/5
Pigmented histiocytes	0/5	0/5	0/5	0/5	4/5 (0.8)	5/5 (1.0)
Collagen staining	0/5	0/5	5/5 (1.0)	5/5 (1.2)	0/5	0/5

[a] Number of animals with lesion/total animals examined
[b] Mean lesion severity grade based on a scale of 1 to 4 where 1=minimal, 2=mild, 3=moderate, and 4=severe.

DISCUSSION

Cellulose insulation is a complex mixture of fibrous and nonfibrous particulates, fire retardants, and other proprietary additives. Toxicity studies have been conducted on many different forms of cellulose from soft paper dusts and wood (Järvholm *et al.*, 1988; Tatrai *et al.*, 1995) to pure microcrystalline cellulose (Adamson *et al.*, 1999); however, little toxicological information is available for CI. Because the toxicity of cellulose is highly dependent upon the physical and chemical form, the potential toxicity of CI cannot be extrapolated from the toxicity data for other forms of cellulose. Cellulose insulation products can differ in chemical composition and in the amounts and size fractions of fibrous and nonfibrous particles, depending on the paper source and the methods used to process the paper. These studies were conducted to evaluate the variability in the chemical and physical composition of CI products from four major United States manufacturers.

Chemical analyses of the four CI products revealed only minor differences in inorganic additives. Organic components were present in low concentrations; therefore, no qualitative analyses were performed. Known toxic chemicals such as beryllium, cadmium, cobalt, chromium, potassium, molybdenum, nickel, lead, antimony, and selenium were below quantifiable concentrations in all four CI samples tested. The major elemental components detected were aluminum, boron, calcium, sodium, and sulfur. The presence of these chemicals is primarily due to the fire retardants aluminum sulfate, boric acid, and sodium sulfate. Samples 1 and 4 contained significantly more sodium than the other two samples. This difference was attributed to the use of sodium sulfate as the fire retardant in Samples 1 and 4, whereas ammonium sulfate was used in Samples 2 and 3. Sulfur concentrations were similar in all four samples.

Boric acid was added as a fire retardant to all four samples and was detected at relatively high concentrations in the bulk CI samples. However, only Sample 1 contained boric acid in the small respirable particle fraction. It is possible that boric acid may have been added as a solid particulate to Sample 1, whereas it was added as a solution and absorbed into the cellulose fibers in the other samples. Absorption of boric acid into the cellulose may have resulted in its deposition in the cyclone or rough separator along with the larger particles and fibers during particle classification, which would prevent it from being segregated with the small respirable particle fraction. Alternatively, boric acid may have been added to Samples 2, 3, and 4 as a solid consisting of large particles. Collections of these large particles in the rough separator or cyclone during the particle separation process would account for the absence of boron in these samples.

The physical composition of bulk CI from the different manufacturers was similar, composed primarily of large crumbs or particles. The composition of the four CI samples was determined by generating an aerosol of the bulk materials and evaluating the particle and fiber size distributions. The aerosol generation/separation system simulated the process used during installation of CI at work sites and separated the CI particles based on aerodynamic size. For all four products, less than 0.1% of the CI was collected as the small respirable particle fraction. The concentrations of respirable particles in the sampling chamber were less than 60 mg/m^3, or 2% of the TLV of 3,000 mg/m^3 for respirable nuisance particles. These data indicated that the exposure of CI applicators to significant levels of respirable particles is not likely. Sample 4 had significantly fewer respirable particles than the other samples. It was not apparent whether this reduced level was caused by a difference in stock material or manufacturing method. A manufacturing method that reduces the number of respirable products would be important for improving the safety of CI products.

The potential presence of respirable fibrous particles in the CI was a concern because of the known toxicity of asbestos and glass fibers. The numbers of respirable CI fibers generated from the four samples ranged from 9.7×10^3 to 1.4×10^6 fibers/gram test material in the sampling chamber. Although the numbers of CI fibers were very low, these fiber concentrations exceeded the stated limits for cited toxic and carcinogenic glass and mineral fibers. Concentration limits for various highly regulated fibers set by regulatory agencies are 0.1 asbestos fibers/cc 8-hour TWA; 1 asbestos fiber/cc per 30 minute excursion; 1 glass fiber/cc; 0.2 crocidolite, 0.5 amosite, 2 chrysotile, and other asbestos/cc (29 CFR 1910; ACGIH, 2003). Although numbers of cellulose fibers exceeded the acceptable levels of asbestos and glass fibers, CI is not considered to be as reactive or toxic as asbestos or glass fibers.

Although the number of fibers generated from cellulose insulation was very low, further characterization of these fibers may be warranted to evaluate solubility and durability in lung fluid and potential toxicity. Muhle *et al*. (1997) investigated the biodurability of cellulose fibers isolated from Isofloc® thermal insulation. The Isofloc® was processed to a median fiber length of 7.6 mm and a median fiber diameter of 0.50 mm. One year after intratracheal instillation of 2 mg of fibers in rats, fibers were still present in the lungs. Although fiber number and diameter could not be determined because of the splitting of fibers, the presence of fibers in the lung after 1 year indicates that Isofloc® fibers are highly durable and can persist in the lung.

Toxicity studies of CI were limited to an intratracheal instillation study because of the small amount of respirable CI particulate available. The potential pulmonary toxicity of the respirable CI particles was evaluated for up to 4 weeks after a single intratracheal instillation in rats. Intratracheal instillation of a high dose of respirable CI particles caused a mild, transient, pulmonary inflammatory reaction similar to that caused by an equivalent dose of titanium dioxide, a relatively inert particle. Microscopic examination of lungs from CI-treated rats 2 and 4 weeks after treatment revealed a minimal to mild granulomatous pneumonitis. Although the histological appearance and the severity of the lesions did not increase between weeks 2 and 4, biochemical analyses detected a significant increase in lung collagen during this time. Light microscopic evaluation of lung sections stained with Masson's trichrome stain for collagen demonstrated a slight increase in collagen fibrils associated with the granulomatous nodules. It could not be determined from this study if this lesion was the result of a high bolus dose of particulate or if the slight increase in collagen associated with granulomatous nodules could progress to focal pulmonary fibrosis.

The instilled respirable CI particles were primarily composed of fire retardant chemicals. Of these chemicals, boron has the most significant toxicological properties at low doses. Little information is available concerning the absorption and distribution of inhaled borates. Significant concentrations of boron were found in the kidney and liver of mice exposed to high concentrations of amorphous boron (72.8 mg/m^3) for 7 hours per day, 5 days per week, for 30 days (Stokinger and Speigel, 1953), indicating that pulmonary absorption and systemic exposure can result from inhalation exposure. Inhalation exposure of rats to boron oxide aerosol (77 mg/m^3 for 6 hours per day, 5 days per week, for 6 weeks) resulted in significant levels of boron in the urine, providing evidence that boron oxide is absorbed from the lungs (Wilding *et al.*, 1959). In humans, inhalation of borax in the range of 3.3 to 18 mg/m^3 resulted in measurable levels of boron in the urine and blood (Culver *et al.*, 1994). Oral administration of boron has been shown to result in reproductive (NTP, 1990; Fail *et al.*, 1990, 1991; Treinen and Chapin, 1991; Ku *et al.*, 1993) and developmental (NTP, 1989; Heindel *et al.*, 1992; Price *et al.*, 1996) toxicity in laboratory animals. Subchronic inhalation exposure of lab animals to boron trifluoride (2 to 18 mg/m^3) caused reduced body weight gains, decreased organ weights, and pneumonitis (Torkelson *et al.*, 1961; Rusch *et al.*, 1986). However, based on the small quantities of boron present in the respirable fraction, it is unlikely that inhalation of CI by applicators would result in significant systemic exposure.

Chemical characterization studies indicate that it is not technically feasible to obtain the amount of respirable particulate needed for an inhalation study from commercially available CI. These studies also determined that the small amount of respirable particulate obtained from CI aerosols was composed primarily of fire retardant chemicals and not cellulose. Although the bulk CI could be mechanically processed to reduce the particle size, the processed CI particles would not have the same chemical and physical properties as the CI particulates to which workers are exposed. Toxicity studies of the respirable particulate were limited to a short-term intratracheal instillation study because of the small amount of respirable particulate available. The respirable particles caused a mild, transient pulmonary inflammatory reaction similar to that caused by an equivalent dose of titanium dioxide, a relatively inert particle. CI particulates also caused a minimal to mild granulomatous pneumonitis with a slight increase in collagen fibrils associated with granulomatous nodules. It could not be determined from this study whether this lesion could progress to focal pulmonary fibrosis. More information is needed on the potential pulmonary toxicity of the fire retardant particulates present in CI.

EXPOSURE ASSESSMENT OF CELLULOSE INSULATION APPLICATORS

Cellulose insulation (CI) was nominated to the NTP for a comprehensive toxicological evaluation. As part of this evaluation, the Hazard Evaluations and Technical Assistance Branch of NIOSH worked in collaboration with NIEHS to conduct an exposure assessment. The study was performed on United States contractors installing CI in residential and commercial buildings.

Although CI has been used for over 50 years, no adequate assessments of CI exposure have been conducted. The CI industry is composed of many small companies with small workforces, and little information has been collected on worker exposure levels. Because there is no evidence that CI dust poses a health risk to workers, there was some question as to whether animal studies of CI were warranted. For this reason, a workplace exposure assessment was conducted to characterize the CI particulates to which workers are exposed and to determine whether or not a potential health risk for workers exists. This study has been reported separately (NIOSH, 2001).

CI application in attics begins with attic preparation. Attic preparation may be performed by a separate crew or by the same crew that conducts the CI application. Fiberglass batting is laid over pipes and recessed lights; barriers are installed in the attic soffit areas to prevent CI from passing to the outside; and other activities are performed as needed. An application hose is brought up to the attic through an attic access panel. CI is then applied at the specified depth to achieve the desired R-value (resistance to heat flow) (16 CFR 460). CI can be applied wet or dry. In wet applications, there is an in-line misting device in the application hose close to the hopper area. Dry application for existing walls begins with drilling holes in the inside or outside wall between the studs. CI is then applied through a hose that is smaller in diameter (1 to 2 inches) than hoses used with the other methods. The hose is pulled out of the wall as pressure builds so that the wallboard does not release from the wall. The drilled hole is then plugged. Plugs are made from many different types of materials.

During wet application for newly constructed walls, a misting device is placed at the end of the application hose. As the CI passes through the hose, the water moistens the CI and the wall surface to gain adherence. Excess material protruding between the wall studs is removed with an electric roller. The excess material is then vacuumed directly into the hopper or shoveled into trash bags and manually put into the hopper for reuse. In some cases, polyethylene sheeting is stapled to exterior wall studs to serve as a vapor barrier and to keep the CI in the wall space. For interior walls with no wallboard backing material, contractors staple white cloth material to the wall studs. CI is then applied to that surface, and the process proceeds as described previously. After installation, some contractors will staple a wire mesh to the wall studs to keep the CI in place.

CI hoppers come in various forms. Two basic types were observed during this project, those with built-in recycling capability and those without. Hoppers with built-in recycling capability are larger and have more advanced operation controls (i.e., setting units measured in rpm and psi). Hoppers without built-in recycling capability are smaller, use control plates to set the amount of material being fed to the hose, and have a dial to control the amount of air being sent through the hose. Attic applications are typically set to full air and do not use control plates. Existing wall applications use less air and fewer plates to reduce the amount of material.

After contacting various contractors, discussing the nature of the research project, and receiving support by contractor management, a CI exposure assessment was conducted with 10 contractors from across the United States. An initial environmental protocol development investigation was conducted in Colorado in January of 1998. Based upon the initial findings, the investigators determined the sampling methods needed to characterize CI applicators' exposure to generated CI dust. This section summarizes the worksite evaluation and provides recommendations for improving occupational health and safety of CI applicators.

Materials and Methods

Field Studies

Site Selection

Site selection and the number of site visits were based on: (1) having at least one contractor from each section of the country (i.e., Northwest, Midwest, Southeast, etc.), (2) the number of consenting contractors, (3) the ability to provide wall and attic CI application sites during the survey time period, and (4) the appropriate sample size for various statistical comparisons. Before NIOSH personnel arrived for the survey, each contractor was contacted to obtain their consent and a mutually agreeable date of the survey and to discuss the planned sampling efforts and details of their operation. After each site visit, the contractor received a report, which included discussions of job sites sampled, sections on sampling methods, air sample results, conclusions, and recommendations.

Sampling Protocol Development

The first contractor survey was conducted over a 3-day period to develop a sampling protocol for the rest of the project. The survey involved personal breathing zone (PBZ) and area air sampling, real-time monitoring using a portable dust monitor, and video exposure monitoring (VEM) during application activities. The survey objectives were to observe the CI application process, work with the various sampling methods, determine the most effective setup, and facilitate discussion about the process among the employees conducting the application.

Sample Collection

Samples were collected from two main areas of each application site, around the installer and around the employee dumping bags of CI into the hopper. Area and PBZ air samples for total and respirable dust were collected in both areas and subsequently analyzed gravimetrically; they were also analyzed for boron and sulfate content. Two PBZ scanning electron microscopy (SEM) samples were collected from each of the two areas. The sampling time depended on the extent of material loading on the filters. Real-time monitoring of total and respirable dust was also conducted during CI applications when feasible.

Employee duties throughout the day were highly variable, and no specific task lasted a full 8 hours. Therefore, the air sampling protocol was designed to collect task-based (i.e., short term) samples for each worker involved with specific CI activities. Analytical results were used to calculate the total and respirable dust concentrations for each task-based sample and the 8-hour time-weighted average (TWA) exposures for each worker. The 8-hour TWAs included all task-based samples for each worker's entire shift. Area 8-hour TWAs were based on the compiled exposure results from each area during the entire task period. Calculated area 8-hour TWA exposures were intended to represent potential exposure. Time periods of noninvolvement with CI-related activities were not sampled and were considered to be a zero exposure.

In-depth Surveys

Four in-depth surveys were conducted. Two of these surveys used VEM along with air sampling, portable dust monitor measurements, and medical evaluations. During CI applications, VEM was conducted inside the attic with the installer and inside the truck with the hopper operator. The other two surveys involved return visits because of CI application changes. One contractor changed from a dry application system to a wet application system. Another contractor changed back to the company's usual wet application system, which was not used during the initial visit.

Total and Respirable Dust

Area and PBZ air samples for total dust were collected on tared 37 mm diameter, 5 µm pore size polyvinyl chloride (PVC) filters at a calibrated flow rate of 1.0 L/min. The filters were gravimetrically analyzed according to NIOSH Method 0500 (NIOSH, 1994). Area air samples for respirable dust were collected with tared 37 mm diameter, 5 µm PVC filters in line with a 10 mm cyclone at a calibrated flow rate of 1.7 L/min. The filters were gravimetrically analyzed according to NIOSH Method 0600 (NIOSH, 1994). The analytical limits of detection for the total and respirable dust filters were 0.08 and 0.02 mg, respectively, which are equivalent to minimum detectable concentrations of 0.8 and 0.2 mg/m^3, respectively, assuming a sample volume of 100 L.

Scanning Electron Microscopy (SEM) Sample

PBZ air samples of the CI dust were collected using a modified version of NIOSH Method 7402 (NIOSH, 1994). Samples were collected using a 25 mm diameter cassette with an electrically conductive extension cowl and 0.8 µm pore size polycarbonate filters at a calibrated flow rate of 1.0 L/min. The filters were analyzed by SEM for fiber count, fiber size, and fiber characteristics (i.e., cellulose, fiberglass, and others).

The samples were first given a conductive carbon coat to minimize fiber charging and to improve the secondary electron images. The prepared samples were then placed in the instrument sample holder and were analyzed using a secondary electron detector adjusted to a magnification of 1,200×. The center of the filter was found using X-Y manipulators, and fields were examined at regular intervals along a traverse in one direction. Fibers were counted in each field using the "A" rules. Based upon morphology, cellulose and other fiber types were distinguished, and the relative proportion of fibrous to nonfibrous material in the field was recorded. A minimum of 40 fields were counted. If the edge of the filter was encountered before 40 fields were analyzed, a new traverse began from the center of the filter. The actual analysis was conducted on an image analyzer that had greater resolution than the SEM screen. At least two fields were captured and saved on disk for archival and presentation purposes. The fibers were sized by comparison to a calibrated, overlying micron bar.

Bulk Material Sampling

Bulk CI samples were collected from each contractor and analyzed by two methods. The first method was water extraction, which checked boron and sulfate content. The second method was NIOSH Method 7300 (NIOSH, 1994), which analyzed boron, sulfate, and other elemental constituents. These methods tested for aluminum, arsenic, barium, beryllium, calcium, cadmium, cobalt, chromium, copper, iron, lithium, magnesium, manganese, molybdenum, nickel, lead, phosphorus, platinum, selenium, silver, sodium, tellurium, thallium, titanium, vanadium, yttrium, zinc, and zirconium. Samples were analyzed with both methods using an inductively coupled plasma emission spectrometer.

Particle Count and Sizing

Real-time sampling was conducted to monitor the particulates generated by distinct events during CI application activities in the attics and around hoppers. The Grimm Model 1.105 Dust Monitor (Labortechnik GmbH and CoKG, Ainring, Germany) was used to collect the real-time data. This portable dust monitor is a light-scattering aerosol spectrometer designed for real-time particulate measurement with particle size discrimination. Eight channels collect count information for particle sizes 0.75, 1, 2, 3.5, 5, 7.5, 10, and 15 µm. For each operation, data were integrated for 1 minute and stored sequentially on the Grimm data card for the entire time period. Particle count and size information were then downloaded to a computer. Start and stop times for distinct events were also recorded.

The mass distribution of particles was reported as a concentration in micrograms of particulates per cubic meter of air. Particles are sized based on the amount of light scattered by individual particles. The monitor operates at a flow rate of 1.2 L/minute. Estimates were made of the mass median aerodynamic diameter (MMAD) and the associated geometric standard deviation (GSD) based on the integrated particle size discrimination provided by the instrument. The MMAD is the mid-point of the aerodynamic size distribution, the point where half the particles are larger and half are smaller. A CI density correction factor for the personal dust monitor was applied during data analyses. The density correction factor is the ratio of an integrated total dust sample to the indicated instrument total dust weight of the CI sampled. The conversion factors were used to adjust the instrument concentration values.

Video Exposure Monitoring (VEM)

Real-time particulate sampling was coupled with video recording and performed during two surveys to evaluate worker exposures. VEM was typically conducted concurrently during attic applications and hopper loading operations. The objective of VEM during CI-related activities was to observe the work practices and associated total dust exposures of the installer and hopper operator. The VEM may indicate certain work practices that can increase or reduce the concentration of dust in the air.

During application activities, a Handheld Aerosol Monitor (HAM) (PPM, Inc., Knoxville, TN) was used to measure PBZ relative air contaminant concentrations. The HAM operates by continuously drawing aerosols through an illuminated sensing volume and detecting the amount of light scattered by all the particles in that volume (NIOSH, 1992). The analog output of the HAM was recorded by a data logger. The information collected on the data logger was downloaded to a computer and converted into a spreadsheet for analysis. The HAM was operated on a 0 to 200 volt scale during monitored activities in the attic and around the hopper.

VEM was used to identify the source of air contaminants, evaluate how exposures vary among the components of a job, identify potential shortcomings of a control, and determine how quickly air contaminants decay once an operation has stopped (Gressel *et al.*, 1987, 1988). While the HAM measured air concentrations, workplace activities were recorded on videotape. The analog output from direct reading instruments can be overlaid on a video recording as a moving bar that has a height proportional to the air contaminant concentration. This technique shows how worker exposures are related to work activities, and it permits control recommendations that are focused upon actual exposure sources.

MEDICAL MONITORING

Health Assessment of Symptoms and Lung Function

Available CI workers were recruited at each work site. The workers were asked to complete self-administered questionnaires, perform serial peak flow tests, and complete a repeated acute symptoms survey.

Questionnaires

A modified version of the American Thoracic Society standardized questionnaire (Appendix B) was administered to all participants to obtain the prevalence of chronic respiratory, eye, nose, throat, and skin symptoms. Information concerning smoking history and work history was also solicited. The questionnaires took approximately 10 to 15 minutes to complete. Investigators also administered short acute symptoms surveys (Appendix C) before and after each work shift, twice during the work shift, and once at bedtime (self-administered) for a total of five data collection periods per day.

Peak Expiratory Flow Rate (PEFR)

Serial determinations of PEFR , the amount of air that can be blown through the flow meter in one sharp breath, were obtained using Wright portable flow meters. PEFR was measured (L/min) concurrently with the acute symptom surveys (five times per day for 1 to 4 days). The participants were taught how to use portable meters. Three exhalations were recorded each session, and the highest of the three was accepted as the PEFR. Participants were considered to have significant bronchial liability if their amplitude percent means of PEFR [(maximum – minimum)/mean] were greater than 20% (Higgens *et al.*, 1992).

Statistics

Individual air sample concentrations for total and respirable dust were compiled into a statistical analysis system (SAS) database. The data were arranged and grouped according to the type of sample (PBZ or area) and type of application. Concentration data were analyzed to compare CI dust concentrations during wet and dry applications. T-tests were used to accept or reject a null hypothesis of no significant difference in wet and dry concentrations. Statistical significance was set at $P \leq 0.05$. Additionally, all employee tasks and respective air sample concentrations during wet or dry applications were grouped separately and analyzed to compare exposure potential. Analysis of variance was used to accept or reject a null hypothesis of no significant difference in employee exposures. Statistical significance was set at $P \leq 0.05$.

Results

Personal Protective Equipment

Most of the evaluated contractors provided disposable particulate respirators to their employees. These respirators included North® full-face masks with HEPA filters, 3M® particulate facepieces, and Gerson® particulate facepieces. Approximately half of the contractors were familiar with the new OSHA Respiratory Protection Standard (29 CFR 1910) and the NIOSH respirator certification system (NIOSH, 1996) and had implemented them into each of their company's day-to-day operations. A few contractors had written respiratory protection programs established in their workplaces. One contractor's employees wore Tyvek™ suits during attic preparation and CI application.

Cellulose Insulation Statistical Analysis

The airborne CI concentration data were log-transformed to perform statistical analyses on normally distributed data (Table 14). Installers' exposures to total dust are significantly higher during dry attic applications than wet attic applications ($P<0.01$). Area air samples for total and respirable dust also revealed a significantly higher CI concentration during dry attic applications than wet attic applications ($P<0.01$). Conversely, hopper operators' exposures to total dust are significantly higher during wet wall and ceiling applications than dry wall and ceiling applications ($P=0.02$).

Table 15 displays the ANOVA analyses comparing employee area exposure concentrations during wet and dry applications. PBZ air samples for total dust varied significantly during dry applications ($P<0.01$). The area air samples for respirable dust also indicated a significant difference in concentration during dry applications ($P=0.03$).

Medical Evaluation

Twenty-three CI workers participated in the medical phase of the investigation. All of the workers present at the site visits agreed to participate. Medical evaluations took place at seven sites. The average age at the time of the investigations was 36 years (range 21 to 62). The average time the workers were employed in the CI industry was 4 years. Almost all of the workers installed CI full-time and year round.

Medical History Questionnaire

On the questionnaires, workers reported suffering from several symptoms while working with CI. Six workers (26%) reported that they had experienced some respiratory symptoms since working with CI. The only chronic respiratory symptom reported on the questionnaires was the production of phlegm in the morning; one worker reported having it always, two often, two sometimes, and one rarely. Of the workers who reported morning phlegm, four were current smokers, one was an ex-smoker, and one was a nonsmoker. Smokers were more likely to report phlegm production than nonsmokers, but the difference was not statistically significant.

Table 14
Concentrations of Airborne Cellulose Insulation During Dry or Wet Application[a]

Group	n	Range (mg/m^3)	Geometric Mean ± Standard Deviation	P Value[b]
Personal Breathing Zone, Total Dust				
Attic CI application, CI installer, dry	22	16.2 - 431	74.8 ± 2.33	
Attic CI application, CI installer, wet	29	1.27 - 97.3	18.7 ± 2.85	<0.01
Wall/ceiling CI application, CI installer, dry	9	3.86 - 78.7	20.2 ± 2.66	
Wall/ceiling CI application, CI installer, wet	27	4.34 - 80.6	26.2 ± 1.80	0.47
Attic CI application, hopper operator, dry	13	2.17 - 140	25.8 ± 3.09	
Attic CI application, hopper operator, wet	24	0.82 - 58.3	17.8 ± 2.56	0.29
Wall/ceiling CI application, hopper operator, dry	7	1.22 - 44.6	9.99 ± 2.98	
Wall/ceiling CI application, hopper operator, wet	30	2.08 - 61.3	22.2 ± 2.03	0.02
Area, Total Dust				
Attic CI application, dry	11	7.68 - 98.1	23.8 ± 2.32	
Attic CI application, wet	19	0.31 - 38.3	6.19 ± 4.09	<0.01
Hopper with attic CI application, dry	10	1.67 - 101	13.4 ± 3.32	
Hopper with attic CI application, wet	23	0.74 - 202	15.0 ± 3.82	0.82
Hopper with wall CI application, dry	5	0.73 - 61.1	5.46 ± 9.20	
Hopper with wall CI application, wet	22	1.3 - 61.3	11.5 ± 2.82	0.50
Area, Respirable Dust				
Attic CI application, dry	10	0.84 - 3.52	1.53 ± 1.62	
Attic CI application, wet	19	0.01 - 8.54	0.11 ± 12.8	<0.01
Hopper with attic CI application, dry	9	0.01 - 1.24	0.15 ± 8.10	
Hopper with attic CI application, wet	21	0.01 - 12.9	0.45 ± 5.38	0.15
Hopper with wall CI application, dry	5	0.01 - 8.70	0.36 ± 14.7	
Hopper with wall CI application, wet	12	0.01 - 2.43	0.28 ± 6.18	0.83

[a] CI=cellulose insulation
[b] Pairwise comparison between wet and dry CI applications by a t-test

Table 15
Area Exposure Concentrations of Cellulose Insulation During Dry or Wet Application[a]

Group	n	Range (mg/m³)	Geometric Mean ± Standard Deviation	P Value[b]
Personal Breathing Zone, Total Dust				
Attic CI application, CI installer, dry	22	16.2 - 431	74.8 ± 2.33	
Attic CI application, hopper operator, dry	13	2.17 - 140	25.8 ± 3.09	
Wall/ceiling CI application, CI installer, dry	9	3.86 - 78.7	20.2 ± 2.66	
Wall/ceiling CI application, hopper operator, dry	7	1.22 - 44.6	9.99 ± 2.98	<0.01
Attic CI application, CI installer, wet	29	1.27 - 97.3	18.7 ± 2.85	
Attic CI application, hopper operator, wet	24	0.82 - 58.3	17.8 ± 2.56	
Wall/ceiling CI application, CI installer, wet	27	4.34 - 80.6	26.2 ± 1.80	
Wall/ceiling CI application, hopper operator, wet	30	2.08 - 61.3	22.2 ± 2.03	0.33
Area, Total Dust				
Attic CI application, dry	11	7.68 - 98.1	23.8 ± 2.32	
Hopper with attic CI application, dry	10	1.67 - 101	13.4 ± 3.32	
Hopper with wall CI application, dry	5	0.73 - 61.1	5.46 ± 9.20	0.14
Attic CI application, wet	19	0.31 - 38.3	6.19 ± 4.09	
Hopper with attic CI application, wet	23	0.74 - 202	15.0 ± 3.82	
Hopper with wall CI application, wet	22	1.3 - 61.3	11.5 ± 2.82	0.08
Area, Respirable Dust				
Attic CI application, dry	10	0.84 - 3.52	1.53 ± 1.62	
Hopper with attic CI application, dry	9	0.01 - 1.24	0.15 ± 8.10	
Hopper with wall CI application, dry	5	0.01 - 8.70	0.36 ± 14.7	0.03
Attic CI application, wet	19	0.01 - 8.54	0.11 ± 12.8	
Hopper with attic CI application, wet	21	0.01 - 12.9	0.45 ± 5.38	
Hopper with wall CI application, wet	12	0.01 - 2.43	0.28 ± 6.18	0.09

[a] CI=cellulose insulation
[b] Trend test by ANOVA

Eight workers (35%) reported nasal symptoms, including stuffiness or drainage. However, none of these workers reported a temporal relationship between their nasal symptoms and CI exposure. Eight workers (35%) reported eye symptoms, having red, itchy, or watery eyes more than twice in the previous 12 months, and four of these (50%) reported a temporal association between their eye symptoms and work. Three workers (13%) reported skin symptoms, which included skin rash, dermatitis, hives, or eczema. Two of these three workers reported a workplace association with their skin symptoms.

Acute Symptoms Survey

Ten of the 23 workers (43%) reported at least one symptom during the survey. The most common symptom reported was coughing; five of the 23 workers reported being bothered by coughing on at least one occasion. Two workers reported wheezing. One of these workers reported wheezing on 25% of the symptoms survey responses; however, this worker noted that he had a respiratory tract infection at the time of the survey.

The next most common symptoms were nose symptoms and throat symptoms; four workers reported at least one nose symptom, and four reported at least one throat symptom. Only two workers reported eye symptoms, and each reported it only once during the site visit. Seven workers reported job-related ache or pain within the previous 12 months. The most common complaint was lower back pain (five workers), followed by shoulder pain (two workers).

Peak Expiratory Flow Rate (PEFR)

PEFR was measured on 22 workers five times per day. The median number of days that the workers were monitored was three (range 1 to 4). All monitoring was at work except the bedtime reading. No monitoring occurred on days the employees were away from work. The percent amplitude mean was less than 20% for all workers. The median percent amplitude mean was 7.8%. The highest was 16.9%. None of the three workers with percent amplitude means greater than 15% reported acute respiratory symptoms on the symptoms survey.

Individual Contractor Results

Appendix A presents the individual contractor data in tabular form for PBZ and area air samples, SEM air samples, bulk sample analyses, personal dust monitor, and VEM results, respectively. For the SEM analyses, the fiber lengths and averages are estimates and are probably understated because of the difficulty of accurately measuring the fibers. Each contractor received an individual copy of their evaluation after the site visit was completed.

DISCUSSION

Dry CI applications in attic areas generated significantly higher PBZ total dust air sample concentrations than wet attic applications ($P<0.01$). The installer in the attic environment has a considerable potential for an 8-hour TWA exceeding the OSHA permissible exposure limit (PEL) for total dust. This is especially true when the actual application time increases, the attic area is small, or when the installer is required to crawl into enclosed areas, such as cathedral ceilings. Because the settling of CI dust is relatively slow, as application time increases, the cloud of CI dust becomes denser, increasing the potential for higher exposure.

Also, when applying CI in existing walls, pressure is generated in the wall. When the application nozzle is taken out of the wall, the pressure forces CI out of the wall hole and creates a considerable cloud of dust. The dust is typically released into the PBZ of the installer. Some contractors, when involved with this type of application, hang polyethylene sheeting to reduce the amount of CI dust settling on furniture, pictures, etc. This creates an enclosed area where the generated dust can become denser, which also increases the exposure potential.

The area respirable dust concentrations varied significantly by work area during dry applications ($P=0.03$). Higher respirable concentrations were found in attic spaces than in other areas during CI application. Two possible reasons are the extensive amount of CI dust generated naturally contains a larger amount of respirable material, and the enclosed nature of attic spaces creates an environment with minimal air movement and lack of air exchange with the outdoors. Limited air movement will bias airborne concentrations to the respirable range as larger particulates settle out. Therefore, the attic space should see a gradual increase in airborne respirable CI over time.

A moistening system can reduce the dust concentrations during attic applications, resulting in less potential for installers to exceed the OSHA PEL for total dust. Proper operation of the system depends on the correct amount of water (per manufacturers' specifications) and sufficient hopper strength to force moistened CI from the truck into the attic. Problems with the system can increase exposure potential. High concentrations were found during this wet attic application that were not found during any other site visits with contractors who used misting systems.

During wet wall applications, installers, hopper operators, and recyclers could have 8-hour TWAs that exceed the OSHA PEL for total dust. When applying CI between wall studs, the force of the CI releasing from the application hose and hitting the wall generates a cloud of CI dust. Because this application requires all three types of employees to be close to the wall, they are close to the generated dust as well. After the CI has filled the space between the wall studs, workers use rollers to remove excess CI and provide a consistent depth. To roll off the material 8 to 10 feet high, workers must reach up to the top of the wall; this results in excess CI falling onto those employees and into their PBZs. Workers then use a vacuum connected to the hopper to recycle this excess material; it can also be collected by shovel and deposited back into the hopper. The close proximity of the recycling operation to the application area can lead to high airborne concentrations as well. During wet wall and ceiling applications, the hopper operators work with the hopper, the roller, and sometimes the recycling portion of the process; this increases the hopper operators' exposure potential. The hopper operators have total dust exposures significantly higher during wet wall and ceiling applications than dry (P=0.02).

Cellulose fibers were observed and characterized by SEM analysis, which indicated the length of the fibers averaged 28 mm and ranged from 5 to 150 mm. The fibers came in various shapes and sizes, were rarely linear, could be found attached to cellulose particles, and did not typically have a uniform diameter. The variable fiber diameter could not easily be measured because the fibers, especially the longer fibers, tended to curve and twist into shapes that were difficult to characterize (Plates 10 and 11). Many of the fibers did not lay flat on the filter, which then resulted in differential charging, making them less stable. This reduction in stability primarily affected the image quality.

The fibers' nonlinearity, along with their varying shapes, sizes, and diameters, complicates the issue of fiber respirability. Classifying respirability depends heavily on the diameter of the fiber, so not being able to measure the diameter makes it difficult to conclude whether or not a fiber is respirable.

The bulk CI samples were analyzed by water extraction and strong acid extraction. The water extraction indicated a boron and sulfate range of 4,700 to 25,000 mg/g of material and 25,000 to 97,000 mg/g of material, respectively. The strong acid extraction indicated a boron and sulfate range of 5,900 to 26,000 mg/g of material and 29,577 to 94,000 mg/g of material, respectively. Assuming that all detected boron and sulfate originated from the fire-retardant materials added, the amount of each was approximately 0.5% to 2.5% and 2.5% to 10% by weight of CI material, respectively. The boron levels were low in the bulk samples, and the potential for exposure to high concentrations of boron in individual air samples is extremely unlikely. Sulfate levels were higher than boron levels in the bulk samples. However, sulfates occur naturally in wood products, which probably added to the overall amount detected. Both extraction methods found a number of other metals in their analyses. The metals consistently detected included aluminum, calcium, copper, iron, lithium, magnesium, manganese, sodium, titanium, and zinc.

Real-time monitoring with a personal dust monitor assisted in characterizing the particulate size of the generated CI dust. Monitoring results from various activities revealed MMADs typically greater than 10 µm with GSDs between 2.0 and 3.0 (Table A5). These data indicated that the particle size distribution was biased towards particle sizes out of the respirable range of 10 µm and larger. A large amount of respirable material was not generated during CI application. The respirable material was typically less than 11%, which coincided with calculations from the personal dust monitor data. However, the personal dust monitor and respirable dust samples were area samples, not PBZ samples. A higher concentration of dust, as seen in attics during dry application, may result in a larger amount of respirable material and increased exposure potential for employees, which are not indicated by area sampling.

The personal dust monitor has a maximum concentration that it can measure. At or above this maximum concentration, the instrument is unable to classify the particles into the eight size ranges. Two contractors (7 and 8) had real-time monitoring events where the calculated respirable mass fraction was at or slightly above 0%. The instrument indicated that each size range had the same amount of mass. Therefore, when the respirable mass fraction was calculated from the data provided by the instrument and that data had concentration readings above the maximum, the percentage was lower.

The VEM explained the relationship between CI-related activities and total dust concentrations (Figures A1 and A2). A qualitative assessment of the concentrations measured with the HAM during VEM indicated that installers were exposed to the highest particulate concentrations when working in "tight areas," such as the corners or edges of an attic, or when applying insulation near the body. Hopper operators are exposed to the highest particulate concentrations when dumping bags of CI into the hopper. The initial positioning of the CI block in the hopper creates a large cloud of dust, producing a higher concentration as well.

Engineering controls in the hopper area can assist in controlling CI dust (Figures 5 and 6). The figures show an exhaust fan and baffles around the sides of the hopper. The baffles keep the CI dust in a controlled area, and the fan blows the dust to the outside of the truck. (Note: Figure 5 - High winds could decrease the effectiveness of the exhaust fan). Implementing engineering controls in other CI applications is not a practical solution to controlling dust concentrations. Instead, because VEM indicated that employees had greater exposure potential when applying CI in corners and near the body, workers should minimize these practices when possible to reduce exposure potential. This may be accomplished by using a lightweight pole that extends approximately 4 feet from the end of the application hose. The extension has handles so the workers can manipulate the hose into tight areas without entering the areas themselves.

The wide range of dust concentrations measured during CI applications complicates the respirator selection process for the industry. The exposure data in this report indicate that workers were exposed to CI total dust concentrations above the OSHA PEL. Therefore, until engineering controls and work practices are developed to reduce exposures to safe levels, the OSHA Respiratory Protection Standard (29 CFR 1910) requires that employers provide respirators to CI workers and establish and maintain respiratory protection programs in accordance with the standard's requirements.

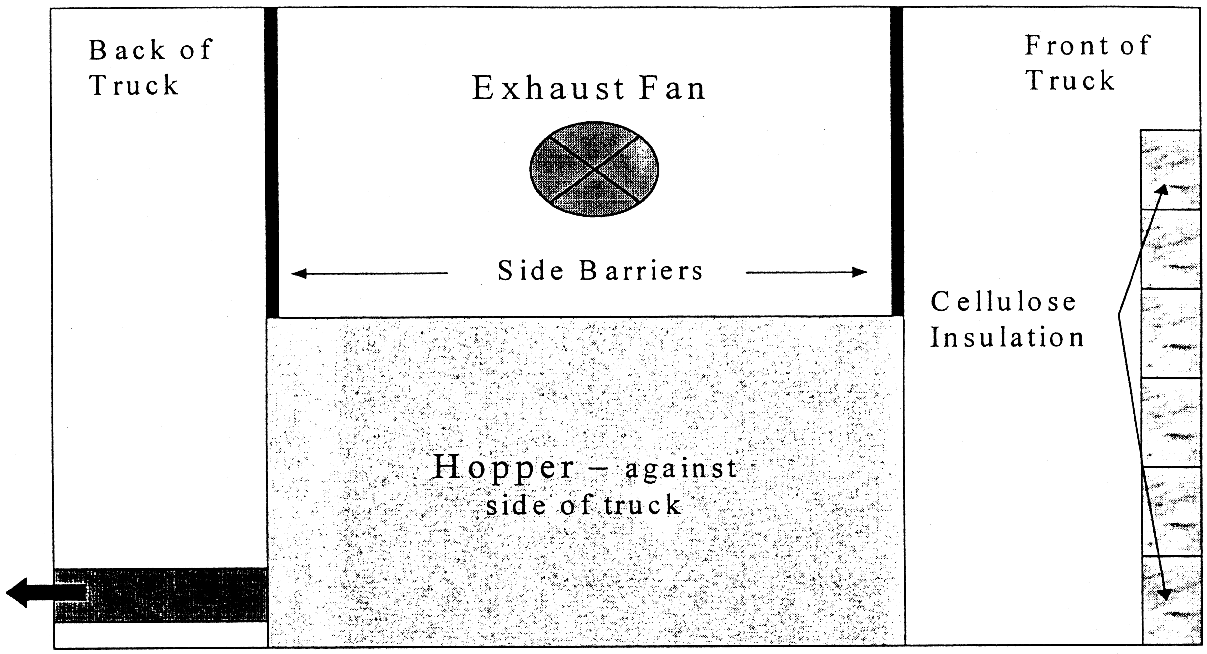


FIGURE 5
Proposed Engineering Control for Hopper Area

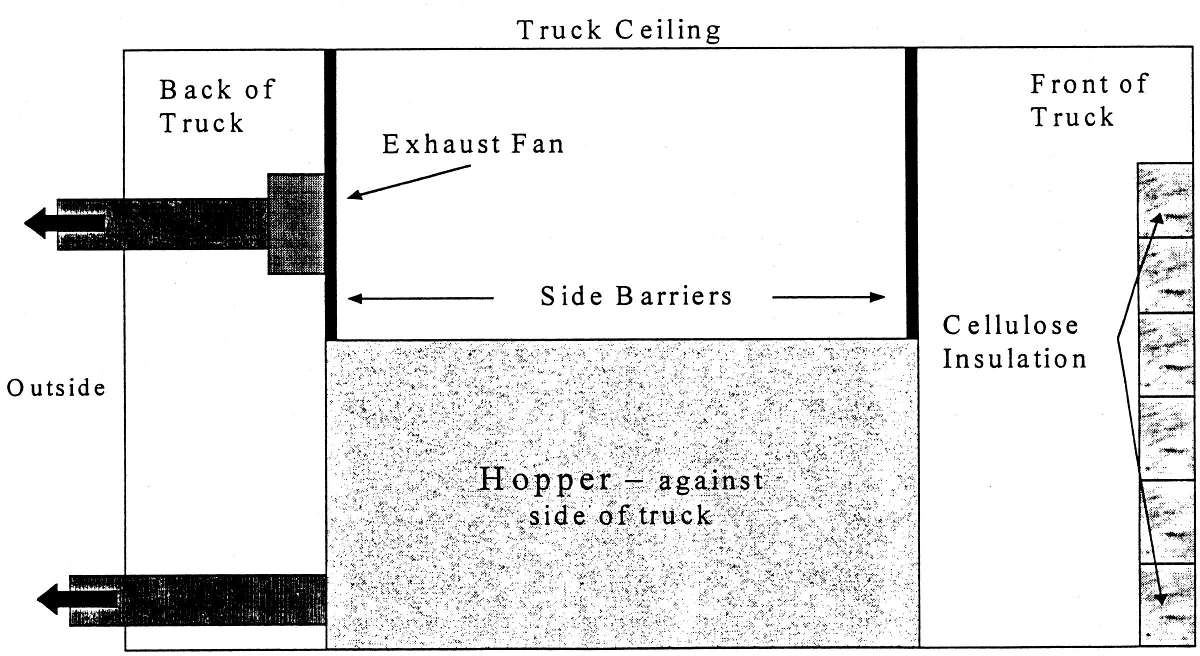


FIGURE 6
Proposed Engineering Control (#2) for Hopper Area

Respirators typically have an assigned protection factor (APF), which describes the level of respiratory protection that should be expected when an employee has been fit tested and has received appropriate training. Based on the OSHA PEL for total dust, the APF for each respirator, and the variations in CI total dust concentrations, employees in all CI-related activities (installers, hopper operators, and recyclers) should wear at minimum a disposable half-mask particulate-filtering respirator. Respirators should be quantitatively fit-tested and NIOSH-approved with an N95 designation (NIOSH, 1996). The N95 designation indicates that the filter material has been shown to remove 95% of particles greater than or equal to 0.3 mm. Although there is no APF for disposable respirators, a NIOSH (1997) document on histoplasmosis suggests an APF of 5 to 10. NIOSH is currently studying disposable respirators to determine an official APF.

The exposure data indicate that there are instances, such as dry attic applications, where a more protective respirator should be used. Elastomeric half-face air-purifying respirators with N95 filters have an APF of 10 and are acceptable for dust concentrations 10 times the OSHA PEL (150 mg/m^3). Elastomeric full-face air-purifying respirators have an APF 50 times the PEL (750 mg/m^3) with the added benefit of eye protection. Employers should review the exposure data and choose the most appropriate respiratory protection for their workers.

Twenty-three workers were studied for possible health effects associated with CI exposure. These workers reported a variety of symptoms that may or may not be associated with their workplace exposure to CI. The most common chronic respiratory symptom reported was morning phlegm production. However, most of the workers who reported the symptom were current smokers, which could also explain their symptoms.

Eye irritation was the most common symptom related to CI exposure that was reported on the questionnaire. Thirty-five percent of the workers reported having eye symptoms that were worse during CI exposure. These symptoms may be caused by dust or by additives, such as boric acid. Most workers did not wear eye protection and reported that their eye symptoms improved once exposure ended. Cough and nasal symptoms were also reported relatively frequently, but they were not temporally related to CI exposure.

None of the workers had evidence of bronchial hyperreactivity (percent amplitude means of greater than 20%), an indication of occupational asthma. However, studying such a small number of workers decreased the likelihood of finding bronchial hyperreactivity (Bernstein and Bernstein, 1997). Also, PEFR was measured mostly at work, which limits the ability to detect the maximum change in PEFR that may have occurred. Measuring PEFR on workdays only and not on weekends or extended times away from work reduces the likelihood of seeing work-related patterns or delayed effects. A few workers reported lower respiratory tract symptoms, but these symptoms were classified as mild and infrequent and did not worsen with continued exposure.

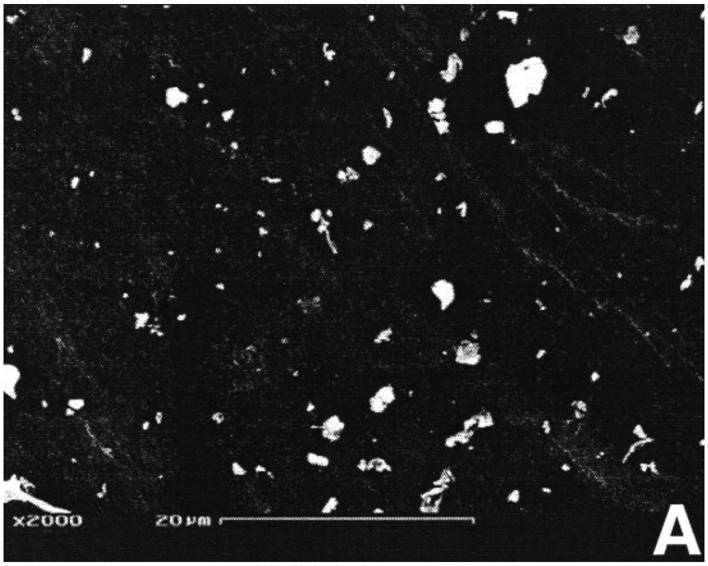


Plate 1
Scanning electron micrograph (SEM) of respirable particles collected on filters from the sampling chamber. Cellulose insulation (CI) sample 1.

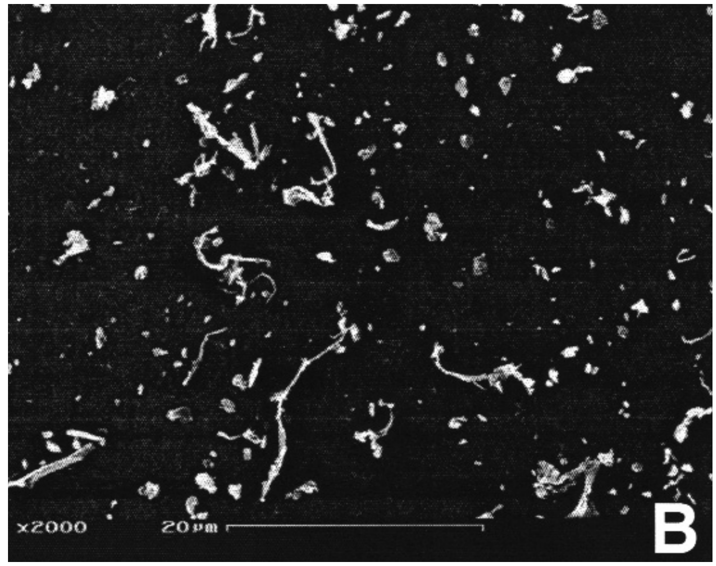


Plate 2
SEM of respirable particles collected on filters from the sampling chamber. CI sample 2.

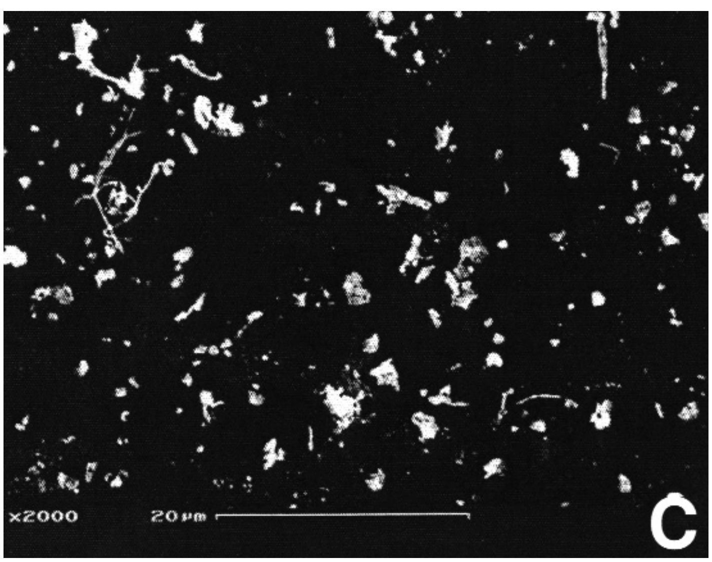


Plate 3
SEM of respirable particles collected on filters from the sampling chamber. CI sample 3.

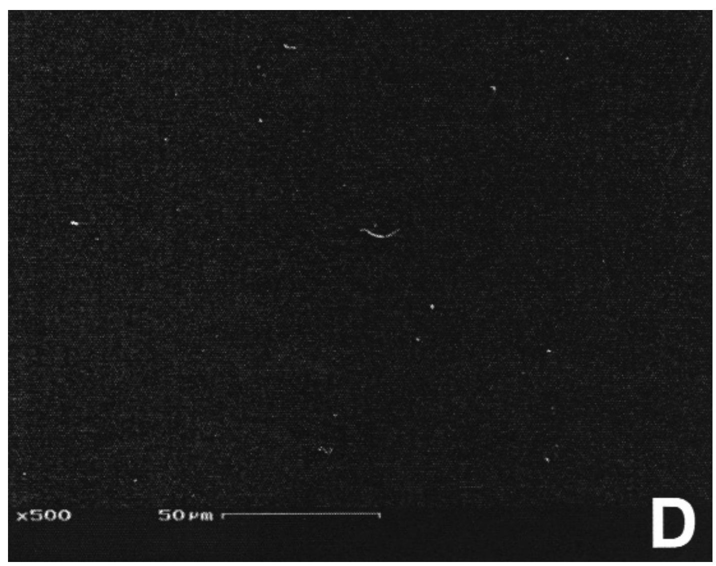


Plate 4
SEM of respirable particles collected on filters from the sampling chamber. CI sample 4.

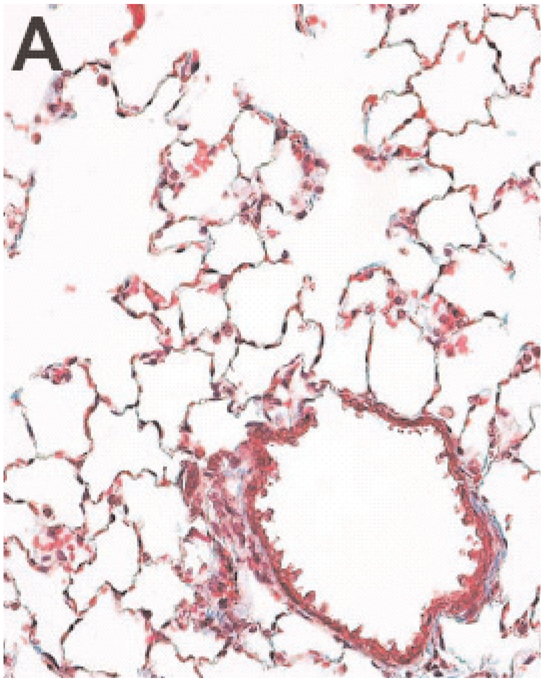


Plate 5
Rat lung 28 days after intratracheal instillation of phosphate buffered saline (controls). Tissue sections were stained with Masson's trichrome stain for collagen (blue fibrils); 20× magnification.

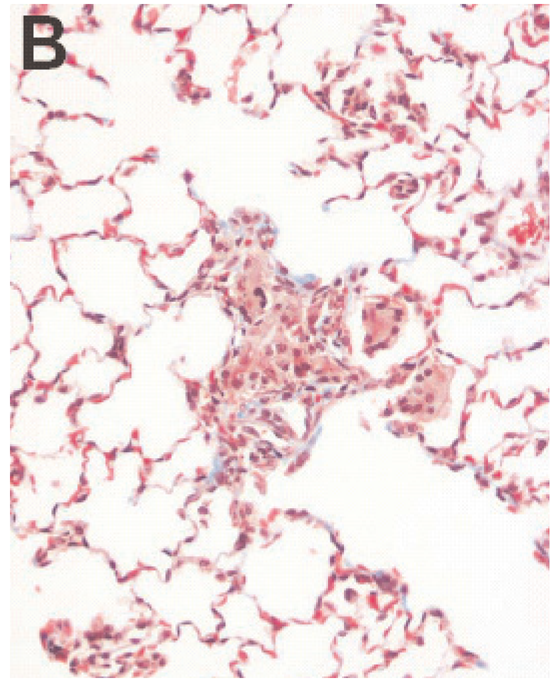


Plate 6
Rat lung 28 days after intratracheal instillation (5 mg/kg) of CI. Tissue sections were stained with Masson's trichrome stain for collagen (blue fibrils); 20× magnification.

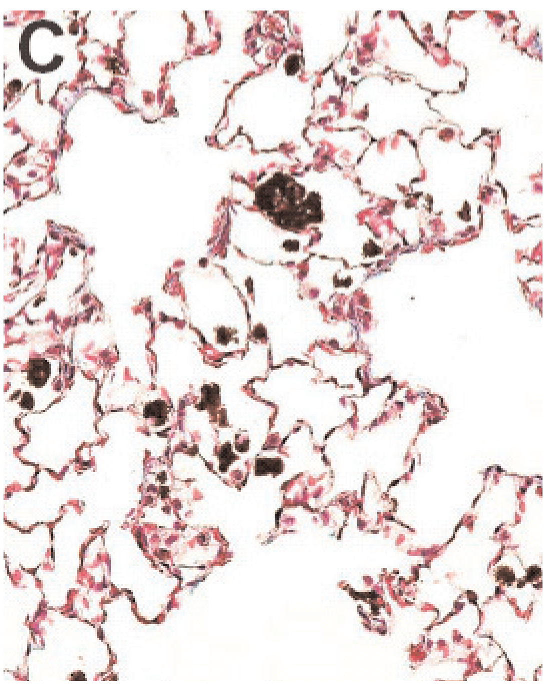


Plate 7
Rat lung 28 days after intratracheal instillation (5 mg/kg) of titanium dioxide (TiO_2). Tissue sections were stained with Masson's trichrome stain for collagen (blue fibrils); 20× magnification.

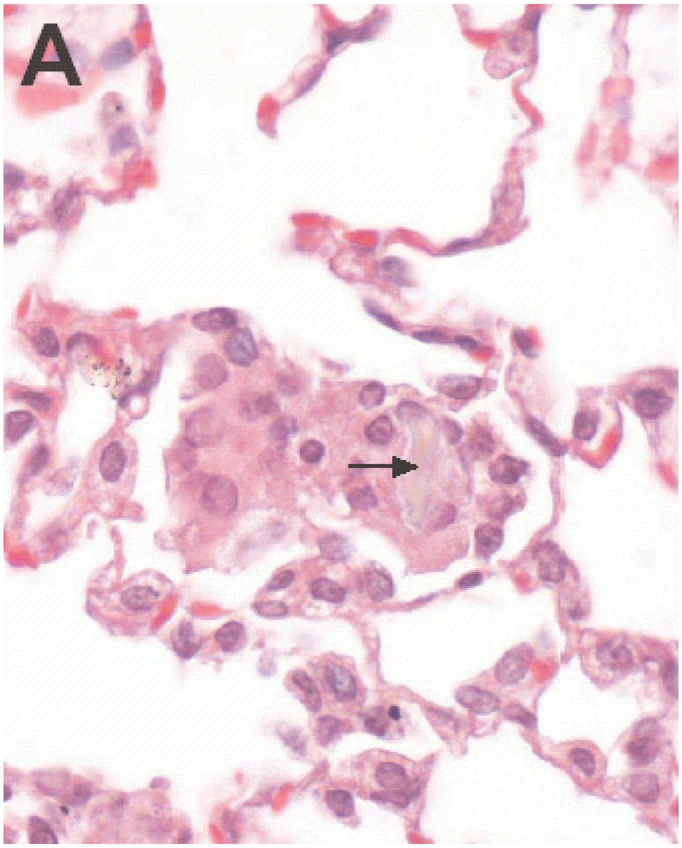


Plate 8
Rat lung 28 days after intratracheal instillation (5 mg/kg) of CI. Tissue sections were stained with hematoxylin and eosin; 60× magnification. A green, spicular material was occasionally present within nodular foci in CI-treated lungs (arrow).

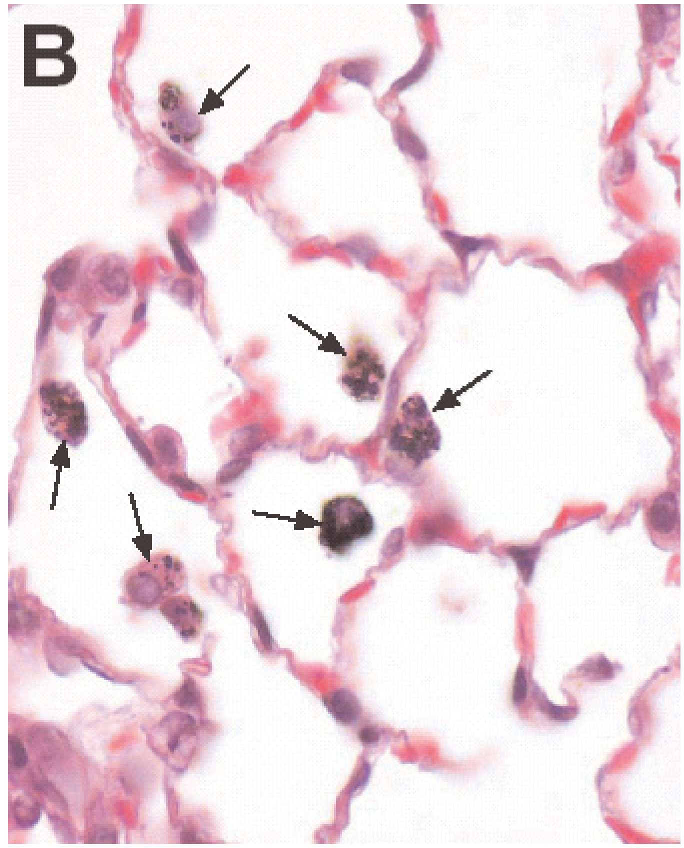


Plate 9
Rat lung 28 days after intratracheal instillation (5 mg/kg) of TiO_2. Tissue sections were stained with hematoxylin and eosin; 60× magnification. Black particle-laden alveolar macrophages are present in TiO_2-treated lungs (arrows).

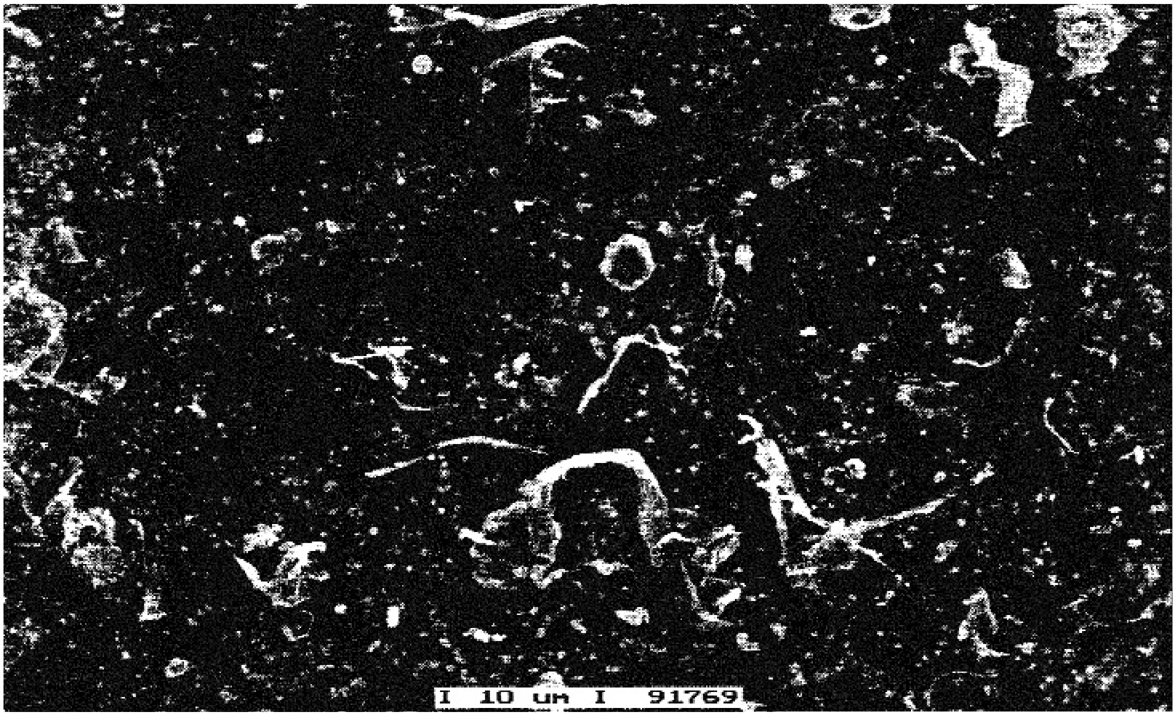


Plate 10
Example of a group of CI fibers from SEM analysis.

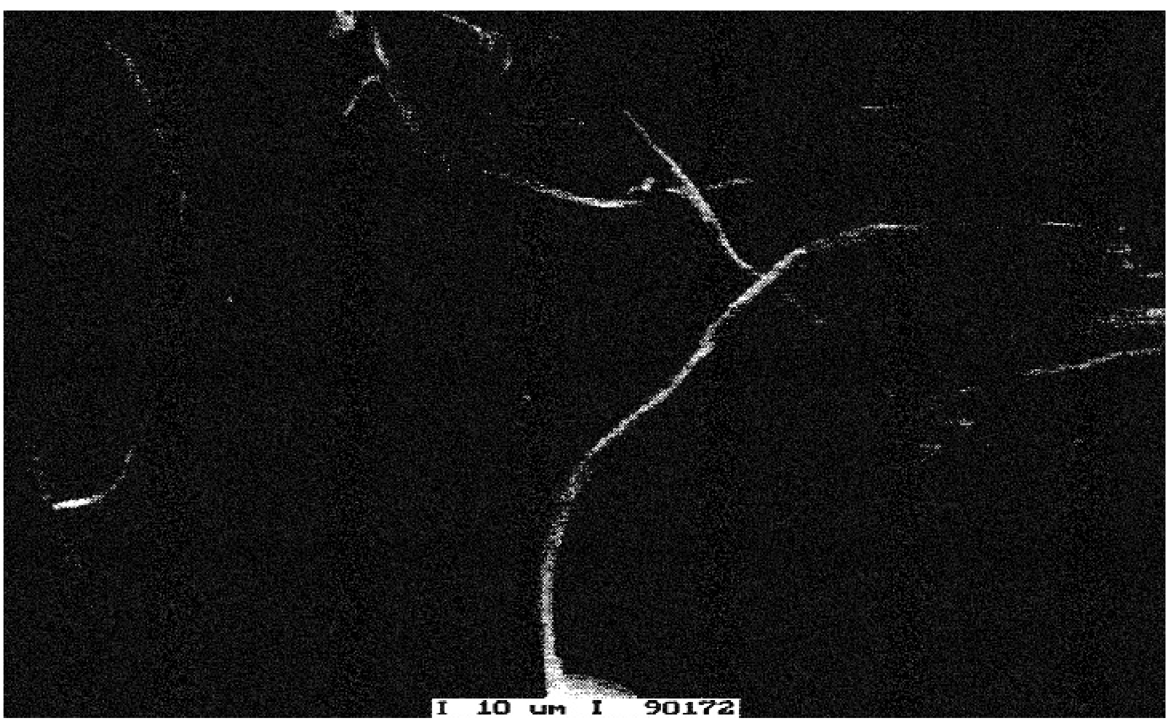


Plate 11
Example of CI fiber. Note the variation in fiber diameter.

REFERENCES

Adamson, G.M., Muhle, H., Creutzenberg, O., Bellmann, B., and Dasenbrock, C. (1999). Effects of different cellulose-containing respirable samples in the lung of Fischer 344 rats [Abstract]. *Toxicologist* **53**, 552.

American Conference of Governmental Industrial Hygienists (ACGIH) (1991). *Particulates not otherwise classified (PNOC). Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*. Cincinnati, OH.

American Conference of Governmental Industrial Hygienists (ACGIH) (2003). *2003 TLVs® and BEIs®. Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*. Cincinnati, OH.

American Society for Testing and Materials (ASTM) (1991). Standard specification for cellulosic fiber (wood base) loose-fill thermal insulation (ASTM C1149-93), Philadelphia, PA.

American Society for Testing and Materials (ASTM) (1997). Standard specification for self-supported spray applied cellulosic thermal insulation (ASTM C1149-97), Philadelphia, PA.

Anonymous (1977). Paper being recycled for use in insulation. *Timber Producer* **10**, 38.

Anonymous (1979). The production and laboratory testing of cellulose fibre. *Insulation* **July/August**, 5-8.

Anonymous (1980a). Cellulose insulation reviving. *Pulp & Paper* **January**, 23.

Anonymous (1980b). Layer former aids production of Cellcem board. *Pulp & Paper* **January**, 27.

Anonymous (1981). Insulation is thriving, but glass fiber's share lags. *Chemical Week* **March 11**, 321.

Anonymous (1984). Building insulation sales. *Construction Review* **30**, 2-3.

Anonymous (1990). Tapping into new markets with sprayed cellulose. *Roofing Siding Insulation* **November**, 24-26.

Anonymous (1991). Business turns recycled newspapers into insulation. Cell-Pak: Makes home insulation out of recycled newspapers. *Birmingham News* **February 24**, D1, D4.

Baron, P.A. (1993). Measurement of asbestos and other fibers. In *Aerosol Measurement* (K. Willeke and P.A. Baron, Eds.), pp. 564-565. Van Nostrand Reinhold, New York.

Barton, D.R., Friedman, D.B., Post, H.A., and Williams, F.E. (1981). Marketing Information Report: Waste Newspapers in Four South Atlantic States 1980 (NBS-GCR 82-371; US NTIS PB82-170382), Bureau of Industrial Economics, U.S. Department of Commerce, Washington, DC.

Bernstein, J.A., and Bernstein, I.L. (1997). Occupationally induced asthma. In *Allergy,* 2nd ed. (A.P. Kaplan, Ed.), pp. 511-524. W.B. Saunders Company, Philadelphia, PA.

Bird, T.O., White, J., and Bird, C.H. (1980). Fire-retardant cellulose insulation and process for making same. Assignee: White-Bird Enterprises, Inc. (Patent No. US 4,230,585).

Brittan, R.F., Studley, J.G., Parkin, J.V., Rowles, P.M., and Le Quesne, L.P. (1984). Cellulose granulomatous peritonitis. *Br. J. Surg.* **71**, 452-453.

Chrenka, G.A. (1980). Use of secondary fiber for insulation. In *Proceedings of the Technical Association of the Pulp and Paper Industry*, 1980 Pulping Conference, pp. 141-143. Technical Association of the Pulp and Paper Industry, Atlanta, GA.

Cohn, L. (1981). Cellulose insulation industry plans certification program. *Energy User News* **6**, 1, 11.

Code of Federal Regulations (CFR) **16**, Part 460.

Code of Federal Regulations (CFR) **29**, Parts 1910, 1915, and 1926.

Culver, B.D., Shen, P.T., Taylor, T.H., Lee-Feldstein, A., Anton-Culver, H., and Strong, P.L. (1994). The relationship of blood- and urine-boron to boron exposure in borax-workers and the usefulness of urine-boron as an exposure marker. *Environ. Health Perspect*. **102** (Suppl. 7), 133-137.

Davis, J. (1993). The need for standardised testing procedures for all products capable of liberating respirable fibres; the example of materials based on cellulose. *Br. J. Ind. Med*. **50**, 187-190.

Ericsson, J., Järvholm, B., and Norin, F. (1988). Respiratory symptoms and lung function following exposure in workers exposed to soft paper tissue dust. *Int. Arch. Occup. Environ. Health* **60**, 341-345.

Fail, P.A., George, J.D, Grizzle, T.B., Heindel, J.J., and Chapin, R.E. (1990). Final report on the repoductive toxicity of boric acid (CAS No. 10043-35-3) in Swiss (CD-1) mice. United States Department of Health and Human Services, National Toxicology Program (NTP Report No. 90-105). Research Triangle Park, NC.

Fail, P.A., George, J.D., Seely, J.C., Grizzle, T.B., and Heindel, J.J. (1991). Reproductive toxicity of boric acid in Swiss (CD-1) mice: Assessment using the continuous breeding protocol. *Fundam. Appl. Toxicol*. **E17**, 225-239.

Gressel, M.G., Heitbrink, W.A., McGlothlin, J.D., and Fischback, T.J. (1987). Real-time, integrated, and ergonomic analysis of dust exposure during manual materials handling. *Appl. Ind. Hyg.* **2**, 108-113.

Gressel, M.G., Heitbrink, W.A., McGlothlin, J.D., and Fischback, T.J. (1988). Advantages of real-time data acquisition for exposure assessment. *Appl. Ind. Hyg.* **3**, 316-320.

Hadley, J.G., Kotlin, P., and Bernstein, D.M. (1992). Subacute (28 days) repeated dose inhalation toxicity of cellulose building insulation in the rat. *Toxicologist* **12**, 225.

Heederik, D., Burdorf, L., Boleij, J., Willems, H., and van Bilsen, J. (1987). Pulmonary function and intradermal tests in workers exposed to soft-paper dust. *Am. J. Ind. Med.* **11**, 637-645.

Heindel, J.J., Price, C.J., Field, E.A., Marr, M.C., Myers, C.B., Morrissey, R.E., and Schwetz, B.A. (1992). Developmental toxicity of boric acid in mice and rats. *Fundam. Appl. Toxicol*. **18**, 266-277.

Higgins, B.G., Britton, J.R., Chinn, S., Cooper, S., Burney, P.G., and Tattersfield, A.E. (1992). Comparison of bronchial reactivity and peak expiratory flow variability measurements for epidemiologic studies. *Am. Rev. Respir. Dis.* **145**, 588-593.

ICF, Inc. (1977). Supply Response to Residential Retrofit Demand (Federal Energy Administration Report No. FEA/B-77/303; NTIS PB-27- 445).

Järvholm, B., Thoren, K., Brolin, I., Ericsson, J., Morgan, U., Tylen, U., and Bake, B. (1988). Lung function in workers exposed to soft paper dust. *Am. J. Ind. Med.* **14**, 457-464.

Kelman, B.J., Swenson, L.J., Uppala, L.V., Cohen, J.M., Millette, J.R., and Mueller, W.F. (1999). Chemical components of shredded paper insulation: A preliminary study. *Appl. Occup. Environ. Hyg.* **14**, 192-197.

Ku, W.W., Chapin. R.E., Wine, R.N., and Gladen, B.C. (1993). Testicular toxicity of boric acid (BA): Relationship of dose to lesion development and recovery in the F344 rat. *Reprod. Toxicol*. **7**, 305-319.

Lea, D. (1995). Personal communication by telephone to Maureen King, Technical Resources International, Inc., from Daniel Lea, Cellulose Insulation Manufacturers Association, 5/11/95. Prepared for NTP by Technical Resources International, Inc., under NCI Contract No. N01-CP-56019 (6/95) 23, Cellulose Insulation.

Levin, L., and Purdom, P.W. (1983). A review of the health effects of energy conserving materials. *Am. J. Public Health* **73**, 683-690.

McConnell, E.E. (1994). Personal communication [letter, July 22] from Ernest McConnell, Consultant in Toxicology and Pathology, Raleigh, NC, to Errol Zeiger, National Toxicology Program, Research Triangle Park, NC.

McDonald, J.W., Alvarez, F., and Keller, C.A. (2000). Pulmonary alveolar proteinosis in association with household exposure to fibrous insulation material. *Chest* **117**, 1813-1817.

The Merck Index (1996). 12th ed. (S. Budavari, Ed.), p. 1365. Merck and Company, Rahway, NJ.

Morgan, D.L., Shines, C.J., Jeter, S.P., Blazka, M.E., Elwell, M.R., Wilson, R.E., Ward, S.M., Price, H.C., and Moskowitz, P.D. (1997). Comparative pulmonary absorption, distribution, and toxicity of copper gallium diselenide, copper indium diselenide, and cadmium telluride in Sprague-Dawley rats. *Toxicol. Appl. Pharmacol.* **147**, 399-410.

Muhle, H., Ernst, H., and Bellmann, B. (1997). Investigation of the durability of cellulose fibres in rat lungs. *Ann. Occup. Hyg.* **41** (Suppl. 1), 184-188.

National Institute for Occupational Safety and Health (NIOSH) (1985). Duluth Community Action Program, Duluth, MN. HETA 84-213, 391-1619. NIOSH, Cincinnati, OH.

National Institute for Occupational Safety and Health (NIOSH) (1990). Westside Energy Co-op, Denver, CO. HETA 90-151-L2067 (NTIS PB91- 152025). NIOSH, Cincinnati, OH.

National Institute for Occupational Safety and Health (NIOSH) (1992). Analyzing Workplace Exposures Using Direct Reading Instruments and Video Exposure Monitoring Techniques (Publication No. 92-104). NIOSH, Cincinnati, OH.

National Institute for Occupational Safety and Health (NIOSH) (1994). NIOSH Manual of Analytical Methods, 4th ed. (Publication No. 94-113). NIOSH, Cincinnati, OH.

National Institute for Occupational Safety and Health (NIOSH) (1996). NIOSH Guide to the Selection and Use of Particulate Respirators Certified under 42 CFR 84 (Publication No. 96-101). NIOSH, Cincinnati, OH.

National Institute for Occupational Safety and Health (NIOSH) (1997). Histoplasmosis-Protecting Workers at Risk. (Publication No. 97-146). NIOSH, Cincinnati, OH.

National Institute for Occupational Safety and Health (NIOSH) (2001). NIOSH Exposure Assessment of Cellulose Insulation Applicators. Health Hazard Evaluation Report, HETA 2000-0322-2827. NIOSH, Cincinnati, OH.

National Toxicology Program (NTP) (1989). Final Report on the Developmental Toxicity of Boric Acid (CAS No. 10043-35-3) in CD-1 Swiss mice (NTP Report No. 89-250). U.S. Department of Health and Human Services, National Toxicology Program, Research Triangle Park, NC.

National Toxicology Program (NTP) (1990). Final Report on the Reproductive Toxicity of Boric Acid (CAS No. 10043-35-3) in CD-1 Swiss Mice (NTP Report No. 90-105). U.S. Department of Health and Human Services, National Toxicology Program, Research Triangle Park, NC.

Neisel, R.H., and Verschoor, J.D. (1981). Insulation, thermal. In *Kirk-Othmer Encyclopedia of Chemical Technology*, 3rd ed. (M. Grayson and D. Eckroth, Eds.), Vol. 13, pp. 600-601. John Wiley and Sons, Inc., New York.

Price, C.J., Marr, M.C., Myers, C.B., Seely, J.C., Heindel, J.J., and Schwetz, B.A. (1996). The developmental toxicity of boric acid in rabbits. *Fundam. Appl. Toxicol*. **34**, 176-187.

Rusch, G.M., Hoffman, G.M., McConnell, R.F., and Rinehart, W.E. (1986). Inhalation toxicity studies with boron trifluoride. *Toxicol. Appl. Pharmacol*. **83**, 69-78.

Sinanoglu, E. (1994). Pass on the pink stuff when you pick insulation. *Money* **23**, 182.

Sokal, R.R., and Rohlf, F.J. (1981). *Biometry: The Principles and Practice of Statistics in Biological Research*, 2nd ed. W.H. Freeman and Company, San Francisco.

Stokinger, H.E., and Speigel, C.J. (1953). Special materials, Part A: Inhalation toxicity studies of boron halides and certain fluorinated hydrocarbons. In *Pharmacology and Toxicology of Uranium Compounds: Chronic Inhalation and Other Studies* (C. Voegtlin and H.C. Hodge, Eds.) pp. 2291-2321. McGraw-Hill, New York.

Tatrai, E., Adamis, Z., Bohm, U., Meretey, K., and Ungvary, G. (1995). Role of cellulose in wood dust-induced fibrosing alveo-bronchiolitis in rat. *J. Appl. Toxicol.* **15**, 45-48.

Tharr, D. (1991). Asbestos exposure during low-income housing weatherization. *Appl. Occup. Environ. Hyg*. **6**, 347-348.

Thoren, K., Järvholm, B., and Morgan, U. (1989). Mortality from asthma and chronic obstructive pulmonary disease among workers in a soft paper mill: A case-referent study. *Br. J. Ind. Med.* **46**, 192-195.

Tiesler, H., and Schnitteger, J. (1992). Investigation of fibrous dust emission from cellulose insulating materials during installation (Ger.). *Zentralbl. Arbeitsmed. Arbeitsshutz. Prophyl. Ergon.* **42**, 278-285.

Torkelson, T.R., Sadek, S.E., and Rowe, V.K. (1961). The toxicity of boron trifluoride when inhaled by laboratory animals. *Am. Ind. Hyg. Assoc. J*. **22**, 263-270.

Treinen, K.A., and Chapin, R.E. (1991). Development of testicular lesions in F344 rats after treatment with boric acid. *Toxicol. Appl. Pharmacol*. **107**, 325-335.

Welteke, U. (1993). Comments on investigation of fibrous dust (Ger.). *Zentralbl. Arbeitsmed. Arbeitsshutz. Prophyl. Ergon.* **43**, 50-51.

Wilding, J.L., Smith, W.J., Yevich, P., Sicks, M.E., Ryan, S.G., and Punte, C.L. (1959). The toxicity of boron oxide. *Am. Ind. Hyg. Assoc. J*. **20**, 284-289.

Woessner, J.F., Jr. (1961). The determination of hydroxyproline in tissue and protein samples containing small proportions of this amino acid. *Arch. Biochem. Biophys*. **93**, 440-447.

Zeltner, T.B., Nussbaumer, U., Rudin, O., and Zimmerman, A. (1982). Unusual pulmonary vascular lesions after intravenous injections of microcrystalline cellulose. A complication of pentazocine tablet abuse. *Virchows Arch. A. Pathol. Anat. Histol.* **395**, 207-216.

Zicherman, J.B., and Fisher, F.L. (1978). Fire Protection Problems Associated with Cellulose Based Insulation Products (Technical Report No. SFPE-TR-78-7). Society of Fire Protection Engineering, Boston, MA.

APPENDIX A
CELLULOSE INSULATION APPLICATION AND FIELD STUDIES RESULTS

TABLE A1
Total and Respirable Dust Sampling Results[a]

Contractor 1

Location	Sample Time (military)	Sample Volume (liters)	Sample Concentration (mg/m^3)	8–hour TWA (mg/m^3)
Results of January 13, 1998, area and PBZ air sampling during an existing residential attic CI application.				
Area (total) – Inside truck – near hopper	1000 – 1047	90	100.9	9.88
Area (total) – Inside attic, on rafter, middle of attic	1009 – 1052	85.4	52.31	4.69
PBZ (total) – Hopper operator sample	1000 – 1045	88.5	100.4	9.41
PBZ (total) – CI installer sample	1006 – 1046	78.8	109.3	9.11
Area (respirable) – Inside truck – near hopper	1000 – 1047	79.3	0.57	0.06
Area (respirable) – Inside attic, on rafter, middle of attic	1009 – 1052	71.8	2.65	0.24
Results of January 13, 1998, area and PBZ air sampling during an existing residential wall CI application.				
Area (total) – In truck on hose holder	1410 – 1438	27.6	0.725	0.04
PBZ (total) – Wall CI installer – upstairs and basement	1354 – 1437	84.7	8.74	0.78
PBZ (total) – Hopper operator – using HAM instrument	1404 – 1445	82	1.22	0.10
Area (respirable) – In truck on hose holder	1410 – 1438	47.2	0.636	0.04
Results of January 14, 1998, area and PBZ air sampling during an existing residential attic CI application.				
Area (total) – In truck above hopper	1328 – 1352	24.8	29.44	
Area (total) – 2nd sample – in truck – hopper	1352 – 1500	70.2	31.77	5.97
Area (total) – west side of house – close to attic entrance	1333 – 1444	64.9	8.48	1.25
PBZ (total) – Hopper operator sample	1326 – 1357	31.4	8.92	
PBZ (total) – 2nd Hopper operator sample	1357 – 1457	60.8	10.69	
PBZ (total) – 3rd Hopper operator sample – using HAM instrument	1421 – 1457	72	6.81	2.42
PBZ (total) – CI installer sample	1427 – 1442	14.7	68.71	
PBZ (total) – 2nd CI installer sample – using HAM instrument	1339 – 1356	34	27.94	3.14
Area (respirable) – west side of house – close to attic entrance	1333 – 1444	108.8	1.38	0.20
Area (respirable) – In truck above hopper	1328 – 1500	153	1.24	0.24

Table A1
Total and Respirable Dust Sampling Results

Contractor 2

Location	Sample Time (military)	Sample Volume (liters)	Sample Concentration (mg/m³)	8–hour TWA (mg/m³)
Results of April 27, 1998, area and PBZ air sampling during a new residential attic CI application.				
Area (total) – Indoor background	0941 – 1243	190	0.58	
Area (total) – Attic sample – near attic entrance	1031 – 1150	80.1	98.1	16.2
Area (total) – Hopper sample – to rt. of hopper	1028 – 1244	140	5.08	1.44
PBZ (total) – CI installer	1027 – 1051	25.7	220	
PBZ (total) – 2nd attic sample – CI installer	1051 – 1135	47.2	199	
PBZ (total) – 3rd attic sample – CI installer	1135 – 1146	11.8	431	39.0
PBZ (total) – Hopper operator	1029 – 1244	138	18.1	5.08
Area (respirable) – Indoor background	0941 – 1243	319	ND	
Area (respirable) – Attic sample – near attic entrance	1031 – 1150	138	1.38	0.23
Area (respirable) – Hopper sample – to rt. of hopper	1028 – 1245	237	0.29	0.08
Results of April 28, 1998, area and PBZ air sampling during an existing residential garage ceiling CI application.				
Area (total) – Garage sample – middle steel support	1029 – 1107	38.4	ND	
Area (total) – 2nd garage sample – middle steel support	1334 – 1622	170	4.06	1.42
Area (total) – Hopper sample – to rt. of hopper	1035 – 1110 1338 – 1627	207	1.70	0.72
PBZ (total) – Garage ceiling – drilling drywall	0939 – 1009	30.3	32.3	
PBZ (total) – Garage ceiling – CI application	1028 – 1106 1334 – 1621	207	21.9	11.4
PBZ (total) – Hopper operator	1037 – 1107 1337 – 1627	202	12.9	5.41
Area (respirable) – Garage sample – middle steel support	1029 – 1107 1334 – 1622	353	0.11	0.05
Area (respirable) – Hopper sample – to rt. of hopper	1035 – 1110 1338 – 1627	345	0.06	0.03

TABLE A1
Total and Respirable Dust Sampling Results

Contractor 2
(continued)

Location	Sample Time (military)	Sample Volume (liters)	Sample Concentration (mg/m³)	8–hour TWA (mg/m³)
Results of April 29, 1998, area and PBZ air sampling during an existing residential attic CI application.				
Area (total) – Attic above garage – driveway side – on rafter	1143 – 1303 1349 – 1420	117	23.1	5.34
Area (total) – Hopper sample – to rt. of hopper	1205 – 1306 1349 – 1428	102	1.67	0.35
PBZ (total) – CI installer sample	1143 – 1237	54.1	54.2	
PBZ (total) – 2nd CI installer sample	1237 – 1302 1349 – 1434	70.1	105	21.4
PBZ (total) – Hopper operator sample	1135 – 1302	88.3	20.4	
PBZ (total) – 2nd Hopper operator sample	1353 – 1428	35.5	94.4	10.6
Area (respirable) – Attic above garage – driveway side – on rafter	1143 – 1303 1349 – 1420	192	0.84	0.19
Area (respirable) – Hopper sample – to rt. of hopper	1205 – 1306 1349 – 1428	171	ND	ND
Results of April 30, 1998, area and PBZ air sampling during an existing residential attic CI application.				
Area (total) – Attic prep. – near attic entrance	1023 – 1212	107	5.12	
Area (total) – CI application – near attic entrance	1307 – 1354	46.3	38.2	4.91
Area (total) – Hopper sample – rt. of hopper	1308 – 1446	99.5	5.33	1.09
PBZ (total) – attic preparation – using fiberglass	1027 – 1209	99.1	41.5	
PBZ (total) – CI installer sample	1306 – 1331	24.3	164	
PBZ (total) – 2nd CI installer sample	1331 – 1350	18.5	50.3	18.8
PBZ (total) – Hopper operator sample	1310 – 1446	99.1	32.8	6.56
Area (respirable) – Attic prep. – near attic entrance	1032 – 1212	169	0.65	
Area (respirable) – CI application – near attic entrance	1307 – 1354	79.6	3.52	0.48
Area (respirable) – Hopper sample – rt. of hopper	1308 – 1446	169	0.47	0.10

Table A1
Total and Respirable Dust Sampling Results

Contractor 3

Location	Sample Time (military)	Sample Volume (liters)	Sample Concentration (mg/m^3)	8–hour TWA (mg/m^3)
Results of July 7, 1998, area and PBZ air sampling during an existing residential wall CI application.				
Area (total) – Indoor background	0920 – 1148	150	0.67	
Area (total) – Hopper sample – to rt. of hopper	0917 – 1145	151	1.06	0.33
PBZ (total) – CI installer sample	0926 – 1001	34.8	78.7	
PBZ (total) – 2nd CI installer sample	1001 – 1038	36.8	43.7	
PBZ (total) – 3rd CI installer sample	1107 – 1145	37.8	51.8	13.2
PBZ (total) – Wall hole driller	0925 – 1038	73.7	14.7	
PBZ (total) – 2nd wall hole driller sample	1056 – 1147	51.5	13.6	3.68
PBZ (total) – Hopper operator sample	0920 – 1040	78.1	8.58	
PBZ (total) – 2nd Hopper operator sample	1057 – 1149	50.7	10.1	2.52
Area (respirable) – Indoor background	0920 – 1148	246	ND	
Area (respirable) – Hopper sample – to rt. of hopper	0915 – 1145	251	ND	ND
Results of July 8, 1998, area and PBZ air sampling during a new residential attic CI application.				
Area (total) – 1st attic – near entrance	0938 – 1000	22.2	58.2	
Area (total) – 2nd attic – near entrance	1045 – 1103	18.1	29.8	3.78
Area (total) – Hopper sample – 1st attic install	0937 – 1011	34.8	6.03	
Area (total) – Hopper sample – 2nd attic install	1045 – 1108	23.6	12.3	1.02
Area (total) – Background sample – in house	0903 – 1130	151	0.53	
PBZ (total) – CI installer sample – 1st attic	0938 – 0951	13.2	141	
PBZ (total) – 2nd CI installer sample – 1st attic	0951 – 1000	9.11	111	
PBZ (total) – 3rd CI installer sample – 2nd attic	1045 – 1055	10.1	70.2	
PBZ (total) – 4th CI installer sample – 2nd attic	1055 – 1110	15.2	89.6	10.2
PBZ (total) – Hopper operator sample – 1st attic	0936 – 1005	28.2	20.2	
PBZ (total) – 2nd Hopper operator sample – 2nd attic	1041 – 1102	20.4	21.1	
PBZ (total) – 3rd Hopper operator sample – 2nd attic	1102 – 1108	5.83	17.2	2.36
Area (respirable) – 1st attic – near entrance	0938 – 1000	38.6	2.59	
Area (respirable) – 2nd attic – near entrance	1045 – 1103	31.6	1.58	0.18
Area (respirable) – Hopper sample – 1st attic install	0937 – 1011	60.0	ND	
Area (respirable) – Hopper sample – 2nd attic install	1045 – 1108	40.6	ND	ND
Area (respirable) – Background sample – in house	0903 – 1130	249	ND	

TABLE A1
Total and Respirable Dust Sampling Results

Contractor 3
(continued)

Location	Sample Time (military)	Sample Volume (liters)	Sample Concentration (mg/m^3)	8–hour TWA (mg/m^3)
Results of July 9, 1998, area and PBZ air sampling during two existing residential attic CI applications.				
Area (total) – 1st attic – near entrance	0957 – 1041	44.5	19.1	
Area (total) – 2nd attic – near entrance	1305 – 1325	20.2	10.9	2.21
Area (total) – Hopper sample – 1st and 2nd attic	1001 – 1057 1310 – 1329	76.9	22.8	3.56
PBZ (total) – Prep. work – 2 unit attic – worker #1	0840 – 0925	45.9	2.17	
PBZ (total) – Prep. work – 2 unit attic – worker #2	0841 – 0925	45.4	22.5	
PBZ (total) – CI installer sample – 1st attic	0954 – 1016	22.4	73.8	
PBZ (total) – 2nd CI installer sample – 1st attic	1016 – 1054	38.6	72.7	
PBZ (total) – 3rd CI installer sample – 2nd attic	1304 – 1318	14.2	16.2	
PBZ (total) – 4th CI installer sample – 2nd attic	1318 – 1333	15.3	21.0	10.3
PBZ (total) – Hopper operator sample – worker #1	0958 – 1021 1310 – 1329	42.3	34.8	3.25
PBZ (total) – Hopper operator sample – worker #2	1021 – 1057	36.2	18.5	3.45
Area (respirable) – 1st attic – near entrance	0957 – 1041	73.7	1.22	
Area (respirable) – 2nd attic – near entrance	1305 – 1325	33.5	0.89	0.15
Area (respirable) – Hopper sample – 1st and 2nd attic	1001 – 1057 1310 – 1329	130	0.93	0.15
Results of July 10, 1998, area and PBZ air sampling during an existing residential attic CI application.				
Area (total) – Attic application – near entrance	1328 – 1341	13.3	12.8	
Area (total) – Attic sample #2 – near entrance	1341 – 1355	14.3	7.68	0.57
Area (total) – Hopper sample	1335 – 1407	31.8	25.8	1.72
PBZ (total) – CI installer sample	1325 – 1344	18.9	22.1	
PBZ (total) – 2nd CI installer sample	1344 – 1403	18.9	32.1	2.15
PBZ (total) – Hopper operator sample	1336 – 1407	31.4	47.1	3.04
Area (respirable) – Attic application – near entrance	1328 – 1356	45.7	1.09	0.06
Area (respirable) – Hopper sample	1335 – 1407	54.8	0.55	0.04

TABLE A1
Total and Respirable Dust Sampling Results

Contractor 4

Location	Sample Time (military)	Sample Volume (liters)	Sample Concentration (mg/m³)	8–hour TWA (mg/m³)
Results of August 10, 1998, area and PBZ air sampling during a new commercial wall CI application.				
Area (total) – Indoor background	1117 – 1656	345	0.44	
Area (total) – Hopper sample – to rt. of hopper	0924 – 1104	102	11.5	
Area (total) – 2nd hopper sample	1104 – 1358	178	11.0	
Area (total) – 3rd hopper sample	1358 – 1705	191	17.8	13.4
PBZ (total) – CI installer sample	0925 – 1100	98.7	16.0	
PBZ (total) – 2nd CI installer sample	1138 – 1359	147	19.9	
PBZ (total) – 3rd CI installer sample	1359 – 1702	190	30.7	20.7
PBZ (total) – Hopper/roller operator sample	0927 – 1102	95.1	11.1	
PBZ (total) – 2nd Hopper/roller operator sample	1102 – 1400	178	10.2	
PBZ (total) – 3rd Hopper/roller operator sample	1400 – 1703	183	33.3	18.7
PBZ (total) – Worker with misc. tasks sample	1142 – 1401	141	32.3	
PBZ (total) – 2nd Worker with misc. tasks sample	1401 – 1703	184	19.5	16.7
Area (respirable) – Indoor background	1117 – 1656	597	0.07	
Area (respirable) – Hopper sample – to rt. of hopper	0924 – 1705	779	0.28	0.27
Results of August 11, 1998, area and PBZ air sampling during a new commercial wall CI application.				
Area (total) – Indoor background	0856 – 1401	327	0.65	
Area (total) – Hopper sample – to rt. of hopper	1043 – 1325	164	16.9	
Area (total) – 2nd Hopper sample	1325 – 1357	32.5	13.9	6.64
PBZ (total) – CI installer sample	1123 – 1329	126	27.9	
PBZ (total) – 2nd CI installer sample	1329 – 1351	22.0	14.2	7.97
PBZ (total) – Hopper/roller operator sample	1134 – 1328	113	9.39	
PBZ (total) – 2nd Hopper/roller operator sample	1328 – 1359	30.8	20.6	3.56
PBZ (total) – Worker with misc. tasks sample	0935 – 1051 1129 – 1149	96.7	3.43	0.69
Area (respirable) – Indoor background	0856 – 1401	522	0.64	
Area (respirable) – Hopper sample – to rt. of hopper	1043 – 1357	327	0.17	0.07

Table A1
Total and Respirable Dust Sampling Results

Contractor 4
(continued)

Location	Sample Time (military)	Sample Volume (liters)	Sample Concentration (mg/m^3)	8–hour TWA (mg/m^3)
Results of August 12, 1998, area and PBZ air sampling during two new residential attic CI applications.				
Area (total) – 1st attic – near entrance	0958 – 1035	38.5	0.31	
Area (total) – 2nd attic – near entrance	1210 – 1343	96.7	0.85	0.11
Area (total) – 1st attic hopper sample	0955 – 1042	47.8	6.74	
Area (total) – 2nd attic hopper sample	1207 – 1356	111	0.74	0.83
PBZ (total) – 1st attic CI installer sample	0954 – 1042	48.2	3.57	
PBZ (total) – 2nd attic CI installer sample	1209 – 1356	107	3.18	2.28
PBZ (total) – 1st attic hopper operator sample	0959 – 1043	45.0	9.82	
PBZ (total) – 2nd attic hopper operator sample	1206 – 1355	112	8.45	1.61
Area (respirable) – 1st attic – near entrance	0958 – 1035	62.9	1.18	
Area (respirable) – 2nd attic – near entrance	1210 – 1343	158	ND	0.09
Area (respirable) – 1st attic hopper sample	0955 – 1042	79.5	0.93	
Area (respirable) – 2nd attic hopper sample	1207 – 1356	184	0.35	0.17
Results of August 13, 1998, area and PBZ air sampling during a new residential attic CI application.				
Area (total) – Attic – near entrance	0845 – 1050	128	0.72	0.19
Area (total) – Hopper sample – rt. of hopper	0842 – 1052	133	2.73	0.74
PBZ (total) – CI installer sample	0843 – 0949	67.5	2.99	
PBZ (total) – 2nd CI installer sample	0949 – 1054	64.7	1.27	0.95
PBZ (total) – Hopper operator sample	0937 – 0947	9.95	0.82	
PBZ (total) – 2nd hopper operator sample	0950 – 1051	62.3	4.20	0.34
Area (respirable) – Attic – near attic entrance	0845 – 1050	217	ND	ND
Area (respirable) – Hopper sample – rt. of hopper	0842 – 1052	221	0.29	0.08

Table A1
Total and Respirable Dust Sampling Results

Contractor 5

Location	Sample Time (military)	Sample Volume (liters)	Sample Concentration (mg/m³)	8–hour TWA (mg/m³)
Results of September 29, 1998, area and PBZ air sampling during three new residential attic CI applications.				
Area (total) – Attic sample (1st attic)	0937 – 1029	52.9	2.08	
Area (total) – Attic sample (2nd attic)	1314 – 1358	44.8	5.13	
Area (total) – Attic sample (3rd attic)	1642 – 1658	16.3	9.82	1.02
Area (total) – Hopper sample (1st attic)	0931 – 1102	95.6	3.98	
Area (total) – Hopper sample (2nd attic)	1311 – 1455	109	60.9	
Area (total) – Hopper sample (3rd attic)	1639 – 1805	90.3	11.2	16.0
PBZ (total) – CI installer sample (1st attic)	0929 – 1059	88.4	18.6	
PBZ (total) – CI installer sample (2nd attic)	1312 – 1438	84.5	35.5	
PBZ (total) – 2nd CI installer sample (2nd attic)	1438 – 1454	15.7	24.8	
PBZ (total) – CI installer sample (3rd attic)	1635 – 1800	83.5	16.2	13.5
PBZ (total) – Hopper operator sample (1st attic)	0931 – 1059	89.3	19.4	
PBZ (total) – Hopper operator sample (2nd attic)	1311 – 1455	106	9.66	
PBZ (total) – Hopper operator sample (3rd attic)	1639 – 1805	87.3	16.9	8.68
Area (respirable) – Attic sample (1st attic)	0937 – 1029	89.4	ND	
Area (respirable) – Attic sample (2nd attic)	1314 – 1358	75.7	ND	
Area (respirable) – Attic sample (3rd attic)	1642 – 1658	27.5	ND	ND
Area (respirable) – Hopper sample (1st attic)	0931 – 1102	155	0.13	
Area (respirable) – Hopper sample (2nd attic)	1311 – 1455	177	0.17	
Area (respirable) – Hopper sample (3rd attic)	1639 – 1805	146	0.27	0.11

TABLE A1
Total and Respirable Dust Sampling Results

Contractor 5
(continued)

Location	Sample Time (military)	Sample Volume (liters)	Sample Concentration (mg/m^3)	8–hour TWA (mg/m^3)
Results of September 30, 1998, area and PBZ air sampling during two new residential attic CI applications.				
Area (total) – Attic sample (1st attic)	1247 – 1308	21.3	12.7	
Area (total) – Attic sample (2nd attic)	1545 – 1644	59.9	17.5	2.71
Area (total) – Hopper sample (1st attic)	1245 – 1324	39.5	11.6	
Area (total) – Hopper sample (2nd attic)	1540 – 1649	69.9	14.9	3.08
PBZ (total) – CI installer sample (1st attic)	1243 – 1325	42.6	13.2	
PBZ (total) – CI installer sample (2nd attic)	1540 – 1620	40.5	33.6	
PBZ (total) – 2nd CI installer sample (2nd attic)	1620 – 1649	29.4	11.6	4.66
PBZ (total) – Hopper operator	1245 – 1324	38.9	23.4	
PBZ (total) – Hopper operator (2nd attic)	1540 – 1649	68.7	34.8	6.90
Area (respirable) – Attic sample (1st attic)	1247 – 1308	35.7	0.56	
Area (respirable) – Attic sample (2nd attic)	1545 – 1644	100	0.40	0.07
Area (respirable) – Hopper sample (1st attic)	1245 – 1324	65.6	0.76	
Area (respirable) – Hopper sample (2nd attic)	1540 – 1649	116	0.26	0.10

TABLE A1
Total and Respirable Dust Sampling Results

Contractor 5
(continued)

Location	Sample Time (military)	Sample Volume (liters)	Sample Concentration (mg/m^3)	8–hour TWA (mg/m^3)
Results of October 1, 1998, area and PBZ air sampling during a new residential attic CI application.				
Area (total) – Attic sample	1009 – 1022	13.3	35.3	0.96
Area (total) – Hopper sample	1009 – 1027	18.1	34.8	1.31
PBZ (total) – CI installer sample	1008 – 1027	19.4	47.4	1.88
PBZ (total) – Hopper operator sample	1009 – 1027	18.4	41.9	1.57
Area (respirable) – Attic sample	1009 – 1022	22.2	0.90	0.02
Area (respirable) – Hopper sample	1009 – 1027	30.2	0.99	0.04
Results of October 2, 1998, area and PBZ air sampling during a new residential wall CI application.				
Area (total) – Hopper sample	0845 – 1322	277	3.59	2.07
PBZ (total) – CI installer sample	0843 – 0928	45.9	36.3	
PBZ (total) – 2nd CI installer sample	0928 – 1109	103	24.1	
PBZ (total) – 3rd CI installer sample	1109 – 1345	159	27.3	17.4
PBZ (total) – Hopper operator sample	0845 – 0939	55.2	16.1	
PBZ (total) – 2nd hopper operator sample	0939 – 1147	131	12.5	
PBZ (total) – 3rd hopper operator sample	1147 – 1345	121	15.4	8.93
Area (respirable) – Hopper sample	0845 – 1322	279	0.22	0.13

TABLE A1
Total and Respirable Dust Sampling Results

Contractor 6

Location	Sample Time (military)	Sample Volume (liters)	Sample Concentration (mg/m³)	8–hour TWA (mg/m³)
Results of December 15, 1998, area and PBZ air sampling during six new residential attic CI applications.				
Area (total) – 1st attic sample – near entrance	1148 – 1202 1252 – 1301 1358 – 1408 1419 – 1427	40.9	10.0	
Area (total) – 2nd attic sample – near entrance	1624 – 1635 1652 – 1702	20.9	5.26	1.08
Area (total) – 1st hopper sample – left of entrance	1029 – 1108	41.5	9.88	
Area (total) – 2nd hopper sample – left of entrance	1145 – 1203 1248 – 1303	35.1	42.7	
Area (total) – 3rd hopper sample – left of entrance	1356 – 1431	37.2	48.4	
Area (total) – 4th hopper sample – left of entrance	1620 – 1638 1649 – 1703	34.1	55.1	10.9
PBZ (total) – 1st CI installer sample	1032 – 1120	48.5	28.9	
PBZ (total) – 2nd CI installer sample	1138 – 1207 1247 – 1307 1355 – 1434	88.9	16.9	
PBZ (total) – 3rd CI installer sample	1619 – 1641 1649 – 1702	35.4	15.0	7.08
PBZ (total) – 1st hopper operator sample	1029 – 1118	52.0	19.8	
PBZ (total) – 2nd hopper operator sample	1139 – 1203 1242 – 1303	47.7	23.9	
PBZ (total) – 3rd hopper operator sample	1353 – 1430	39.3	41.7	
PBZ (total) – 4th hopper operator sample	1620 – 1640 1649 – 1702	35.0	22.0	8.99
Area (respirable) – 1st attic sample – near entrance	1148 – 1202 1252 – 1301 1358 – 1408 1419 – 1427	69.5	ND	
Area (respirable) – 2nd attic sample – near entrance	1624 – 1635 1652 – 1702	35.6	ND	ND
Area (respirable) – 1st hopper sample – left of entrance	1029 – 1108	41.5	0.61	
Area (respirable) – 2nd hopper sample – left of entrance	1145 – 1203 1248 – 1303	35.1	1.08	
Area (respirable) – 3rd hopper sample – left of entrance	1356 – 1431	37.2	1.36	
Area (respirable) – 4th hopper sample – left of entrance	1620 – 1638 1649 – 1703	34.1	ND	0.22

Table A1
Total and Respirable Dust Sampling Results

Contractor 6
(continued)

Location	Sample Time (military)	Sample Volume (liters)	Sample Concentration (mg/m³)	8–hour TWA (mg/m³)
Results of December 16, 1998, area and PBZ air sampling during a new residential wall CI application.				
Area (total) – Indoor background	1001 – 1516	263	0.72	
Area (total) – 1st hopper sample – ceiling of truck	1004 – 1149	112	22.4	
Area (total) – 2nd hopper sample – ceiling of truck	1149 – 1235	48.9	17.8	
Area (total) – 3rd hopper sample – ceiling of truck	1235 – 1325 1348 – 1520	151	25.2	14.1
PBZ (total) – 1st CI installer sample	1000 – 1117	79.8	10.7	
PBZ (total) – 2nd CI installer sample	1117 – 1323 1348 – 1520	226	21.0	11.3
PBZ (total) – 1st hopper/roller operator sample	1013 – 1144	96.2	14.0	
PBZ (total) – 2nd hopper/roller operator sample	1144 – 1323 1348 – 1519	201	14.0	8.20
Area (respirable) – Indoor background	1001 – 1516	255	ND	
Area (respirable) – Hopper sample – ceiling of truck	1004 – 1325 1348 – 1520	507	2.41	1.01

TABLE A1
Total and Respirable Dust Sampling Results

Contractor 6
(continued)

Location	Sample Time (military)	Sample Volume (liters)	Sample Concentration (mg/m³)	8–hour TWA (mg/m³)
Results of December 17, 1998, area and PBZ air sampling during three new and one existing residential attic CI applications.				
Area (total) – Attic sample – near entrance	0923 – 0928 1030 – 1045 1453 – 1505	35.5	3.10	0.21
Area (total) – Hopper sample – left of entrance	0917 – 0934 1020 – 1044 1450 – 1509 1526 – 1540	74.7	43.0	6.63
PBZ (total) – CI installer sample	0915 – 0935 1015 – 1050 1449 – 1511 1525 – 1542	95.6	7.74	1.52
PBZ (total) – Hopper operator sample	0914 – 0935 1020 – 1047 1451 – 1512 1525 – 1540	87.6	37.0	6.48
Area (respirable) – Attic sample – near entrance	0923 – 0928 1030 – 1045 1453 – 1505	57.2	ND	ND
Area (respirable) – Hopper sample – left of entrance	0917 – 0934 1020 – 1044 1450 – 1509 1526 – 1540	125	0.88	0.14
Results of December 18, 1998, area and PBZ air sampling during a new residential attic CI application.				
Area (total) – Background	1418 – 1732	126	4.13	
Area (total) – 1st hopper sample – ceiling of truck	1415 – 1623	139	34.2	
Area (total) – 2nd hopper sample – ceiling of truck	1623 – 1733	76.0	61.3	18.1
PBZ (total) – 1st CI installer sample – prep. work	0845 – 1304	263	4.34	
PBZ (total) – 2nd CI installer sample	1417 – 1621	126	28.3	
PBZ (total) – 3rd CI installer sample	1621 – 1735	75.0	19.6	12.7
PBZ (total) – 1st hopper operator sample – prep.	0849 – 1306	260	2.08	
PBZ (total) – 2nd hopper operator sample	1417 – 1620	125	28.8	
PBZ (total) – 3rd hopper operator sample	1620 – 1733	74.0	32.2	13.4
Area (respirable) – Background	1418 – 1732	336	ND	
Area (respirable) – Hopper sample – ceiling of truck	1415 – 1733	334	2.43	1.00

TABLE A1
Total and Respirable Dust Sampling Results

Contractor 7

Location	Sample Time (military)	Sample Volume (liters)	Sample Concentration (mg/m^3)	8–hour TWA (mg/m^3)
Results of February 24, 1999, area and PBZ air sampling during an existing residential attic CI application.				
Area (total) – Attic sample	1102 – 1222	83.4	36.8	6.13
Area (total) – Hopper sample	1054 – 1237	109	202	See Hopper #1 below
PBZ (total) – 1st CI installer sample – HAM	1052 – 1143	104	39.7	
PBZ (total) – 2nd CI installer sample – HAM	1204 – 1236	64.9	53.3	7.77
PBZ (total) – Hopper operator – attic preparation	0948 – 1041	54.5	26.2	
PBZ (total) – Hopper operator sample	1055 – 1234	102	58.3	See H.O. #1 below
Area (respirable) – Attic sample	1102 – 1222	137	8.54	1.42
Area (respirable) – Hopper sample	1054 – 1237	175	7.14	See Hopper #1 below
Results of February 24, 1999, area and PBZ air sampling during an existing residential wall CI application.				
Area (total) – Hopper #1 sample	1329 – 1451	87.1	60.3	53.7
Area (total) – Hopper #2 sample	1329 – 1451	88.5	61.1	10.8
PBZ (total) – CI installer #1 sample	1328 – 1452	86.8	10.4	1.82
PBZ (total) – CI installer #2 sample	1326 – 1453	90.7	3.86	0.70
PBZ (total) – Hopper operator #1 sample	1326 – 1452	88.5	18.4	18.2
PBZ (total) – Hopper operator #2 sample	327 – 1452	85.9	44.6	7.90
Area (respirable) – Hopper #1 sample	1328 – 1453	140	1.71	1.82
Area (respirable) – Hopper #2 sample	1328 – 1453	146	8.70	1.54

Table A1
Total and Respirable Dust Sampling Results

Contractor 7
(continued)

Location	Sample Time (military)	Sample Volume (liters)	Sample Concentration (mg/m^3)	8–hour TWA (mg/m^3)
Results of February 26, 1999, area and PBZ air sampling during an existing residential attic CI application.				
Area (total) – Attic sample	1254 – 1400	69.9	36.9	5.07
Area (total) – Hopper sample	1242 – 1404	84.8	187	32.0
PBZ (total) – Attic preparation worker	0912 – 1041	94.3	3.82	0.71
PBZ (total) – 1st CI installer sample – HAM	1245 – 1320	70.8	34.6	
PBZ (total) – 2nd CI installer sample	1343 – 1405	22.7	171	10.4
PBZ (total) – Hopper operator – preparation work	0911 – 1041	92.8	14.4	
PBZ (total) – 1st Hopper operator sample	1246 – 1334	49.5	46.7	
PBZ (total) – 2nd Hopper operator sample – HAM	1343 – 1405	44.5	140	13.8
Area (respirable) – Attic sample	1254 – 1400	113	6.55	0.90
Area (respirable) – Hopper sample	1242 – 1404	140	12.9	2.20

TABLE A1
Total and Respirable Dust Sampling Results

Contractor 8

Location	Sample Time (military)	Sample Volume (liters)	Sample Concentration (mg/m³)	8–hour TWA (mg/m³)
Results of March 23, 1999, area and PBZ air sampling during a new residential wall CI application.				
Area (total) – Background sample	0815 – 1147	222	1.26	
Area (total) – Hopper sample	0824 – 1144	205	9.46	3.94
PBZ (total) – CI installer #1sample	0817 – 1150	217	22.1	9.81
PBZ (total) – Hopper–roller/recycle operator #2 sample	0821 – 1155	215	61.3	27.3
PBZ (total) – Hopper–roller/recycle operator #3 sample	0820 – 1150	219	34.2	15.0
Area (respirable) – Background sample	0815 – 1147	366	ND	
Area (respirable) – Hopper sample	0824 – 1144	345	0.26	0.11
Results of March 24, 1999, area and PBZ air sampling during a new residential wall CI application.*				
Area (total) – Background sample	0800 – 1230	286	2.03	
Area (total) – Hopper sample	0757 – 1230	286	2.87	1.63
PBZ (total) – 1st CI installer #1 sample	0759 – 0951	115	29.3	
PBZ (total) – 2nd CI installer #1 sample	0952 – 1237	170	20.6	13.9
PBZ (total) – 1st Hopper–roller/recycle operator #2 sample	0800 – 0953	116	45.7	
PBZ (total) – 2nd Hopper–roller/recycle operator #2 sample	0953 – 1239	170	23.4	18.9
PBZ (total) – 1st Hopper–roller/recycle operator #3 sample	0800 – 0952	114	33.8	
PBZ (total) – 2nd Hopper–roller/recycle operator #3 sample	0952 – 1239	171	12.9	12.4
Area (respirable) – Background sample	0800 – 1230	467	0.17	
Area (respirable) – Hopper sample	0757 – 1230	472	0.17	0.10

TABLE A1
Total and Respirable Dust Sampling Results

Contractor 8
(continued)

Location	Sample Time (military)	Sample Volume (liters)	Sample Concentration (mg/m^3)	8–hour TWA (mg/m^3)
Results of March 25, 1999, area and PBZ air sampling during a new residential attic and wall CI application.				
Area (total) – Attic sample	0837 – 1157	209	12.3	5.13
Area (total) – Hopper sample (attic CI install)	0830 – 1228	242	5.91	
Area (total) – Hopper sample (wall CI install)	1350 – 1810	275	10.8	8.78
PBZ (total) – 1st CI installer #2 sample – attic	0824 – 1013	112	84.9	
PBZ (total) – 2nd CI installer #2 sample – attic	1013 – 1229	139	90.7	
PBZ (total) – Hopper–roller/recycle operator #2 sample	1352 – 1808	263	37.2	64.8
PBZ (total) – 1st CI installer helper #3 sample – attic	0822 – 1013	114	23.3	
PBZ (total) – 2nd CI installer helper #3 sample – attic	1013 – 1229	140	37.5	
PBZ (total) – roller/recycle operator #3 sample – wall install & CI installer of ceiling	1352 – 1808	268	80.6	59.0
PBZ (total) – Hopper operator #1 sample – attic	0830 – 1230	254	16.3	
PBZ (total) – CI installer #1 sample – wall	1351 – 1808	261	31.8	25.2
Area (respirable) – Attic sample	0837 – 1157	346	0.09	0.04
Area (respirable) – Hopper sample (attic CI install)	no sample		bad filter	
Area (respirable) – Hopper sample (wall CI install)	1350 – 1810	450	0.40	0.40

Table A1
Total and Respirable Dust Sampling Results

Contractor 8
(continued)

Location	Sample Time (military)	Sample Volume (liters)	Sample Concentration (mg/m^3)	8–hour TWA (mg/m^3)
Results of March 26, 1999, area and PBZ air sampling during a new residential attic and wall CI application.				
Area (total) – Background sample – wall CI install	0732 – 1020	176	21.7	
Area (total) – Hopper sample – wall CI install	0731 – 1027	181	21.9	
Area (total) – Hopper sample	1027 – 1240	137	6.20	9.75
Area (total) – Attic sample	1050 – 1235	110	38.3	8.38
PBZ (total) – CI installer #1 sample – wall	0728 – 1027	190	41.1	
PBZ (total) – Hopper operator #1 sample – attic	1027 – 1243	144	20.2	21.1
PBZ (total) – Hopper–roller/recycle operator #2 sample	0730 – 1027	181	48.9	
PBZ (total) – CI installer #2 sample – attic	1027 – 1244	140	97.3	45.8
PBZ (total) – Hopper–roller/recycle operator #3 sample	0730 – 1025	186	48.5	
PBZ (total) – CI installer helper #3 sample – attic	1025 – 1247	151	20.2	23.7
Area (respirable) – Background sample – wall CI install	0732 – 1020	291	1.79	
Area (respirable) – Hopper sample – wall CI install	0731 – 1027	305	1.08	
Area (respirable) – Hopper sample	1027 – 1240	182	0.91	0.65
Area (respirable) – Attic sample	1050 – 1235	230	4.51	0.99

TABLE A1
Total and Respirable Dust Sampling Results

Contractor 9

Location	Sample Time (military)	Sample Volume (liters)	Sample Concentration (mg/m^3)	8–hour TWA (mg/m^3)
Results of September 27, 1999, area and PBZ air sampling during a new residential wall CI application.				
Area (total) – Background sample	1122 – 1652	340	4.32	
Area (total) – Hopper sample	1128 – 1655	330	1.30	0.89
PBZ (total) – 1st CI installer sample	1120 – 1235	74.3	46.2	
PBZ (total) – 2nd CI installer sample	1343 – 1650	185	58.9	30.2
PBZ (total) – 1st Hopper operator sample	1138 – 1244	66	14.4	
PBZ (total) – 2nd Hopper operator sample	1343 – 1653	197	13.7	7.40
PBZ (total) – Worker picking–up CI sample	1217 – 1235 1343 – 1650	203	17.2	7.35
Area (respirable) – Background sample	1122 – 1652	566	ND	
Area (respirable) – Hopper sample	1128 – 1655	578	ND	
Results of September 28, 1999, area and PBZ air sampling during new residential attic CI applications.				
Area (total) – Attic sample	1058 – 1400 1415 – 1607	307	5.21	3.19
Area (total) – Hopper sample	1103 – 1618	333	5.83	3.83
PBZ (total) – 1st CI installer sample	1056 – 1236	103	39.2	
PBZ (total) – 2nd CI installer sample	1236 – 1611	222	11.9	13.5
PBZ (total) – 1st Hopper operator sample	1102 – 1155	54.0	12.6	
PBZ (total) – 2nd Hopper operator sample	1201 – 1331 1407 – 1611	218	40.9	19.6
PBZ (total) – Attic helper sample	1212 – 1616	248	10.1	5.13
Area (respirable) – Attic sample	1058 – 1400 1415 – 1607	513	ND	
Area (respirable) – Hopper sample	1103 – 1618	546	0.20	0.13

TABLE A1
Total and Respirable Dust Sampling Results

Contractor 9
(continued)

Location	Sample Time (military)	Sample Volume (liters)	Sample Concentration (mg/m³)	8–hour TWA (mg/m³)
Results of September 29, 1999, area and PBZ air sampling during a new residential attic CI application.				
Area (total) – Attic sample	1012 – 1134	82.0	2.07	0.35
Area (total) – Hopper sample	1020 – 1202	104	8.46	1.80
PBZ (total) – CI installer sample	1011 – 1155	105	16.5	3.58
PBZ (total) – Hopper operator sample	1019 – 1200	102	51.3	10.8
Area (respirable) – Attic sample	1012 – 1134	139	0.29	0.05
Area (respirable) – Hopper sample	1020 – 1202	178	ND	
Results of September 30, 1999, area and PBZ air sampling during an existing residential wall CI application.				
Area (total) – Hopper sample	1010 – 1549	348	1.44	1.02
PBZ (total) – CI installer sample	1011 – 1230 1345 – 1550	273	12.6	6.93
PBZ (total) – Hopper operator/drilling holes in wall sample	1009 – 1231 1348 – 1552	266	8.87	4.92
Area (respirable) – Hopper sample	1010 – 1549	586	ND	

TABLE A1
Total and Respirable Dust Sampling Results

Contractor 10

Location	Sample Time (military)	Sample Volume (liters)	Sample Concentration (mg/m³)	8–hour TWA (mg/m³)
Results of April 5, 2000, area and PBZ air sampling during new residential attic CI applications.				
Area (total) – Attic sample	1405 – 1416 1733 – 1745 1425 – 1445 1753 – 1815 1511 – 1523 1842 – 1912 1545 – 1603 1952 – 2010 1714 – 1724	160	6.25	2.01
Area (total) – 1st Hopper sample	1357 – 1705	193	5.75	
Area (total) – 2nd Hopper sample	1705 – 1832	89.4	16.0	
Area (total) – 3rd Hopper sample	1832 – 2022	113	16.9	9.03
PBZ (total) – 1st CI installer sample	1403 – 1705	184	9.89	
PBZ (total) – 2nd CI installer sample	1705 – 2026	203	18.5	11.5
PBZ (total) – 1st Hopper operator sample	1353 – 1705	200	10.5	
PBZ (total) – 2nd Hopper operator sample	1705 – 1826	84	12.1	
PBZ (total) – 3rd Hopper operator sample	1848 – 2027	103	14.4	9.21
Area (respirable) – Attic sample	1405 – 1416 1733 – 1745 1425 – 1445 1753 – 1815 1511 – 1523 1842 – 1912 1545 – 1603 1952 – 2010 1714 – 1724	263	0.19	0.06
Area (respirable) – Hopper sample	1357 – 2023	661	0.59	0.48

TABLE A1
Total and Respirable Dust Sampling Results

Contractor 10
(continued)

Location	Sample Time (military)	Sample Volume (liters)	Sample Concentration (mg/m³)	8–hour TWA (mg/m³)
Results of April 6, 2000, area and PBZ air sampling during new residential wall CI applications.				
Area (total) – 1st General house area sample	0743 – 0850	67.9	1.33	
Area (total) – 2nd General house area sample	1149 – 1325	97.3	3.19	
Area (total) – 3rd General house area sample	1352 – 1717	208	6.39	3.55
Area (total) – 1st Hopper sample	0735 – 0833	60.6	14.4	
Area (total) – 2nd Hopper sample	1147 – 1307	83.6	2.51	
Area (total) – 3rd Hopper sample	1354 – 1703	198	23.9	11.6
PBZ (total) – 1st CI installer sample	0734 – 0838	67.5	16.9	
PBZ (total) – 2nd CI installer sample	1149 – 1322	98.1	31.8	
PBZ (total) – 3rd CI installer sample	1354 – 1726	224	68.7	38.8
PBZ (total) – 1st Hopper–roller/recycle operator sample	0733 – 0842	71.2	35.5	
PBZ (total) – 2nd Hopper–roller/recycle operator sample	1145 – 1323	101	39.2	
PBZ (total) – 3rd Hopper–roller/recycle operator sample	1351 – 1724	220	48.1	34.5
PBZ (total) – 1st Roller/recycle operator sample	0731 – 0838	69.3	18.3	
PBZ (total) – 2nd Roller/recycle operator sample	1148 – 1323	98.2	20.2	
PBZ (total) – 3rd Roller/recycle operator sample	1351 – 1724	220	29.1	19.5
Area (respirable) – General house area sample	0740 – 0850 1149 – 1325 1352 – 1717	643	0.42	0.42
Area (respirable) – Hopper sample	0735 – 0833 1147 – 1307 1354 – 1703	562	0.94	0.64

TABLE A1
Total and Respirable Dust Sampling Results

Contractor 10
(continued)

Location	Sample Time (military)	Sample Volume (liters)	Sample Concentration (mg/m³)	8–hour TWA (mg/m³)
Results of April 7, 2000, area and PBZ air sampling during new residential wall CI applications.				
Area (total) – 1st General house area sample	1131 – 1308	105	4.95	
Area (total) – 2nd General house area sample	1308 – 1450	110	5.18	2.10
Area (total) – 1st Hopper sample	1121 – 1240	80.1	14.9	
Area (total) – 2nd Hopper sample	1308 – 1425	78.1	33.9	7.89
PBZ (total) – 1st CI installer sample	1125 – 1308	107	22.1	
PBZ (total) – 2nd CI installer sample	1310 – 1450	104	41.5	13.4
PBZ (total) – 1st Hopper–roller/recycle operator sample	1120 – 1308	113	30.1	
PBZ (total) – 2nd Hopper–roller/recycle operator sample	1308 – 1450	106	41.2	15.5
PBZ (total) – 1st Roller/recycle operator sample	1122 – 1308	110	13.1	
PBZ (total) – 2nd Roller/recycle operator sample	1310 – 1449	103	15.9	6.17
Area (respirable) – General house area sample	1131 – 1308 1308 – 1450	347	0.40	0.17
Area (respirable) – Hopper sample	1121 – 1240 1308 – 1425	267	0.82	0.27

[a] PBZ=personal breathing zone; TWA=time-weighted averages; ND=not detected; CI=cellulose insulation

TABLE A2
Fiber Characterization of Cellulose Insulation Application in Air Samples by Scanning Electron Microscopy[a]

Location	Sample Time (minutes)	CI Fiber Concentration (fibers/mm^2)	Fibrous/ Nonfibrous Ratio	Average Fiber Length (µm)	Size Range (µm)
Contractor 2					
New Residential Attic					
CI installer sample 1	8	66	40/60	33	6 - 90+
CI installer sample 2	3	73	35/65	39	6 - 90+
Hopper operator sample 1	3	15	35/65	31	7 - 80+
Hopper operator sample 2	5	13	35/65	24	8 - 55
Existing Residential Garage Ceiling					
CI installer sample 1	56	65	35/65	34	5 - 100+
CI installer sample 2	33	42	45/55	27	5 - 100+
Hopper operator sample 1	6	68	35/65	40	5 - 85+
Hopper operator sample 2	5	2	25/75	55	50 - 60+
Existing Residential Attic					
CI installer sample 1	16	24	35/65	35	5 - 100+
CI installer sample 2	13	48	35/65	37	8 - 75+
Hopper operator sample 1	5	66	35/65	40	7 - 100+
Hopper operator sample 2	4	9	35/65	49	7 - 100+
CI installer sample 1	4	71	40/60	42	8 - 90+
CI installer sample 2	11	—[b]			
Hopper operator sample 1	6	41	40/60	31	7 - 120+
Hopper operator sample 2	3	16	35/65	36	8 - 150+
Contractor 3					
Existing Residential Wall					
CI installer sample	8	110	35/65	47	5 - 58+
Hopper operator sample	2	5	35/65	27	9 - 75+
New Residential Attic					
CI installer sample	3	60	40/60	34	7 - 90+
Hopper operator sample	7	32	35/65	27	6 - 90+
Two Existing Residential Attics					
CI installer sample	6	22	30/70	31	5 - 90+
Hopper operator sample	3	34	35/65	32	5 - 80+
Existing Residential Attic					
CI installer sample	3	43	40/60	30	7 - 90+
Hopper operator sample	5	42	40/60	35	8 - 90+

Table A2
Fiber Characterization of Cellulose Insulation Application in Air Samples by Scanning Electron Microscopy

Location	Sample Time (minutes)	CI Fiber Concentration (fibers/mm^2)	Fibrous/ Nonfibrous Ratio	Average Fiber Length (µm)	Size Range (µm)
Contractor 4					
New Commercial Wall					
CI installer sample	14	38	40/60	31	5 - 90+
Hopper operator sample	12	47	35/65	29	5 - 80+
New Commercial Wall					
CI installer sample	16	14	40/60	42	6 - 90+
Hopper operator sample	9	10	40/60	39	5 - 80+
Two New Residential Attics					
CI installer sample	7	5	35/65	19	7 - 50+
Hopper operator sample	3	28	35/65	30	5 - 85+
New Residential Attic					
CI installer sample	7	6	40/60	35	5 - 90+
Hopper operator sample	5	26	35/65	22	5 - 80+
Contractor 5					
Three New Residential Attics					
CI installer sample	5	32	35/65	25	5 - 90+
Hopper operator sample	5	3	35/65	42	5 - 85+
Two New Residential Attics					
CI installer sample	3	50	40/60	31	5 - 90+
Hopper operator sample	6	13	40/60	32	5 - 80+
New Residential Wall					
CI installer sample	11	23	40/60	39	6 - 85+
Hopper operator sample	12	16	35/65	36	7 - 90+
Contractor 6					
Six New Residential Attics					
CI installer sample	12	6	40/60	22	6 - 75+
Hopper operator sample	18	18	35/65	23	5 - 80+
New Residential Wall					
CI installer sample	2	4	35/65	21	5 - 65+
Hopper operator sample	6	6	40/60	25	5 - 80+
One Existing and Three New Residential Attics					
CI installer sample	8	5	35/65	19	5 - 70+
Hopper operator sample	7	9	35/65	16	5 - 60+
New Residential Attic					
CI installer sample	4	6	35/65	37	7 - 80+
Hopper operator sample	7	5	40/60	29	6 - 85+

Table A2
Fiber Characterization of Cellulose Insulation Application in Air Samples by Scanning Electron Microscopy

Location	Sample Time (minutes)	CI Fiber Concentration (fibers/mm²)	Fibrous/ Nonfibrous Ratio	Average Fiber Length (µm)	Size Range (µm)
Contractor 7					
Existing Residential Wall					
CI installer sample	12	11	35/65	18	5 - 55+
Hopper operator sample	6	42	35/65	19	5 - 65+
Existing Residential Attic					
CI installer sample	4	15	30/70	20	6 - 85+
Hopper operator sample	6	22	35/65	19	5 - 65+
Contractor 8					
New Residential Wall					
CI installer sample	6	4	40/60	33	6 - 85+
Hopper operator sample	11	5	35/65	35	6 - 90+
New Residential Wall					
CI installer sample	24	17	35/65	30	5 - 75+
Hopper operator sample	7	75	30/70	31	5 - 75+
New Residential Attic and Wall					
CI installer sample	25	28	30/70	20	5 - 80+
Hopper operator sample	14	15	35/65	21	5 - 100+
New Residential Attic and Wall					
CI installer sample	7	26	45/55	31	6 - 80+
Hopper operator sample	9	30	40/60	27	5 - 80+
Contractor 9					
New Residential Wall					
CI installer sample	7	21	35/65	29	5 - 80+
Hopper operator sample	8	12	35/65	21	7 - 80+
New Residential Wall					
CI installer sample	12	43	40/60	29	5 - 80+
Hopper operator sample	7	18	35/65	32	5 - 100+
New Residential Attic and Wall					
CI installer sample	17	33	40/60	31	5 - 90+
Hopper operator sample	13	25	40/60	26	5 - 100+
New Residential Attic and Wall					
CI installer sample	19	9	35/65	41	6 - 90+
Hopper operator sample	26	5	40/60	33	10 - 90+

Table A2
Fiber Characterization of Cellulose Insulation Application in Air Samples by Scanning Electron Microscopy

Location	Sample Time (minutes)	CI Fiber Concentration (fibers/mm^2)	Fibrous/ Nonfibrous Ratio	Average Fiber Length (µm)	Size Range (µm)
Contractor 10					
New Residential Attic					
CI installer sample	4	4	35/65	23	6 - 80+
Hopper operator sample	4	4	35/65	18	6 - 45+
New Residential Wall					
CI installer sample	7	11	40/60	21	5 - 85+
Hopper operator sample	3	16	40/60	36	5 - 90+
New Residential Wall					
CI installer sample	4	20	35/65	25	5 - 80+
Hopper operator sample	2	ND[c]			

[a] CI=cellulose insulation
[b] Overloaded
[c] ND=not detected

Table A3
Chemical Elements in Bulk Samples of Cellulose Insulation – Water Extraction[a]

Contractor	Al	As	Ba	Be	B	$[SO_4]^{-2}$	Ca	Cd	Co	Cr	Cu	Fe	Li	Mg	Mn
1a	ND[b]	ND	Trace	ND	16,580	41,074	1,122	ND	ND	ND	Trace	ND	0.86	65.6	8.26
1b	Trace	ND	2.63	ND	19,353	48,207	1,777	ND	ND	ND	Trace	ND	1.07	79.2	11.7
2a	ND	ND	Trace	ND	10,000	78,000	1,900	ND	Trace	ND	ND	ND	Trace	75	8.8
2b	43	Trace	3.9	ND	5,700	83,000	320	ND	ND	ND	ND	ND	0.84	45	14
3	ND	ND	3.3	ND	13,000	95,000	3,100	ND	ND	ND	Trace	ND	Trace	1,400	13
4a	49	ND	Trace	ND	5,100	42,000	980	ND	ND	ND	ND	ND	0.92	54	15
4b	91	Trace	Trace	ND	7,100	48,000	1,700	ND	Trace	ND	ND	Trace	0.86	77	14
5	110	ND	ND	ND	4,700	36,000	320	ND	ND	ND	ND	ND	ND	42	20
6a	ND	Trace	3.9	ND	7,700	45,000	3,600	ND	Trace	ND	ND	ND	ND	89	14
6b	ND	ND	5.5	ND	9,800	55,000	4,600	ND	ND	ND	ND	ND	ND	98	17
6c	180	Trace	2.2	Trace	6,200	57,000	4,600	ND	ND	ND	ND	58	ND	110	27
7a	39	ND	No data	ND	21,000	36,000	6,300	ND	ND	ND	Trace	ND	Trace	160	9.5
7b	54	ND	No data	ND	20,000	31,000	4,400	ND	Trace	ND	ND	ND	ND	110	9.0
8a	120	Trace	No data	ND	5,900	32,000	2,600	ND	ND	ND	Trace	ND	Trace	100	3.7
8b	45	Trace	No data	ND	7,500	25,000	2,500	ND	ND	ND	ND	ND	Trace	110	4.2
9a	Trace	ND	No data	ND	25,000	47,000	2,300	Trace	ND	ND	ND	ND	2.1	120	12
9b	ND	ND	No data	ND	13,000	97,000	3,500	ND	ND	ND	ND	ND	Trace	110	20
10a	ND	ND	No data	Trace	6,400	31,000	5,400	ND	ND	ND	ND	ND	ND	170	18
10b	Trace	ND	No data	Trace	5,400	32,000	2,900	ND	ND	ND	ND	ND	ND	130	15

1a	ND	ND	ND	Trace	ND	ND	ND	18,577	ND	ND	ND	ND	12.2	ND	Trace
1b	ND	ND	ND	Trace	ND	ND	ND	21,963	ND	ND	ND	ND	13.1	ND	Trace
2a	Trace	ND	ND	Trace	ND	ND	ND	11,000	ND	ND	ND	ND	ND	ND	ND
2b	ND	ND	Trace	Trace	ND	ND	ND	6,700	ND	ND	ND	ND	ND	Trace	ND
3	ND	ND	ND	ND	ND	ND	ND	14,000	ND	ND	ND	ND	ND	ND	ND
4a	ND	ND	ND	2,100	ND	ND	ND	760	Trace	ND	ND	Trace	ND	ND	ND
4b	ND	Trace	ND	2,700	ND	ND	ND	1,100	ND	ND	ND	Trace	ND	Trace	ND
5	ND	ND	ND	3,800	ND	ND	ND	1,200	ND	ND	ND	Trace	ND	ND	ND
6a	ND	ND	ND	ND	ND	Trace	ND	540	ND	ND	ND	Trace	ND	Trace	ND
6b	ND	ND	ND	ND	ND	ND	ND	680	ND	ND	ND	ND	ND	Trace	ND
6c	ND	ND	ND	4,200	ND	Trace	ND	1,100	ND	Trace	Trace	Trace	ND	23	ND
7a	ND	ND	ND	ND	Trace	ND	ND	21,000	ND	ND	ND	Trace	ND	ND	ND
7b	ND	ND	ND	ND	Trace	Trace	ND	19,000	ND	ND	ND	ND	ND	Trace	ND
8a	ND	ND	ND	250	Trace	ND	Trace	670	ND	ND	8.2	Trace	ND	Trace	ND
8b	Trace	ND	ND	260	ND	ND	Trace	870	ND	ND	ND	Trace	ND	Trace	ND
9a	ND	ND	ND	ND	ND	ND	Trace	22,000	ND	ND	ND	ND	Trace	ND	ND
9b	Trace	ND	ND	ND	ND	ND	ND	12,000	ND	ND	ND	ND	ND	Trace	ND
10a	ND	ND	ND	2,200	ND	ND	ND	720	ND	ND	ND	ND	ND	79	ND
10b	ND	ND	ND	1,800	Trace	ND	Trace	620	ND	ND	ND	Trace	Trace	67	ND

[a] Results reported in µg/g; Al=aluminum, As=arsenic, Ba=barium, Be=beryllium, B=boron, $[SO_4]^{-2}$=sulfate, Ca=calcium, Cd=cadmium, Co=cobalt, Cr=chromium, Cu=copper, Fe=iron, Li=lithium, Mg=magnesium, Mn=manganese, Mo=molybdenum, Ni=nickel, Pb=lead, P=phosphorus, Pt=platinum, Se=selenium, Ag=silver, Na=sodium, Te=tellurium, Tl=thallium, Ti=titanium, V=vanadium, Y=yttrium, Zn=zinc, Zr=zirconium

[b] ND=not detected

TABLE A4
Chemical Elements in Bulk Samples of Cellulose Insulation – Strong Acid Extraction[a]

Contractor	Al	As	Ba	Be	B	$[SO_4]^{-2}$	Ca	Cd	Co	Cr	Cu	Fe	Li	Mg	Mn
1a	2,003	ND[b]	13.4	ND	9,243	29,577	3,334	ND	ND	ND	27.5	93.7	3.22	176	23.1
1b	1,690	ND	12.0	ND	12,365	35,695	2,831	ND	ND	ND	21.9	99.3	3.22	168	25.6
2a	2,800	ND	14	ND	11,000	No data	5,100	ND	ND	ND	27	150	3.8	200	23
2b	1,700	ND	15	ND	5,900	No data	530	ND	ND	ND	8.1	71	Trace	97	20
3	1,400	ND	9.2	ND	No data	94,000	3,700	ND	ND	ND	21	61	1.5	1,400	23
4a	820	Trace	12	ND	7,100	52,000	2,500	Trace	ND	Trace	25	83	1.1	140	35
4b	600	Trace	9.8	ND	6,400	46,000	1,900	Trace	Trace	7.7	24	95	0.98	130	37
5	2,800	Trace	12	0.33	6,600	41,000	1,200	ND	ND	7.6	17	210	2.4	160	80
6a	2,600	Trace	14	ND	8,600	No data	5,600	ND	ND	ND	25	250	2.2	190	200
6b	2,600	Trace	15	ND	9,800	No data	5,200	ND	ND	ND	24	120	3.1	170	32
6c	3,100	Trace	17	Trace	6,300	No data	6,200	ND	ND	Trace	32	460	2.7	230	36
7a	640	ND	No data	ND	18,000	No data	6,900	ND	ND	ND	26	79	1.6	190	17
7b	1,200	ND	No data	ND	15,000	No data	7,300	ND	ND	ND	26	150	1.7	200	15
8a	1,700	Trace	No data	ND	9,000	No data	8,200	ND	ND	Trace	31	180	0.78	240	19
8b	1,600	Trace	No data	ND	8,500	No data	7,900	ND	ND	Trace	29	160	0.78	220	17
9a	2,300	ND	No data	ND	26,000	No data	5,800	ND	ND	Trace	22	210	3.0	280	30
9b	2,200	ND	No data	ND	14,000	No data	4,000	ND	ND	Trace	26	140	2.9	210	32
10a	3,500	ND	No data	0.11	8,100	No data	7,500	Trace	ND	Trace	22	520	2.2	370	33
10b	1,900	ND	No data	Trace	6,400	No data	4,100	Trace	ND	Trace	18	340	1.6	210	27

1a	ND	ND	Trace	Trace	ND	ND	ND	15,812	ND	ND	10.3	ND	30.2	Trace	ND
1b	ND	ND	Trace	Trace	ND	ND	ND	19,093	ND	ND	Trace	ND	19.9	Trace	ND
2a	ND	ND	ND	Trace	ND	ND	ND	11,000	ND	ND	52	ND	Trace	35	Trace
2b	ND	ND	ND	ND	ND	ND	ND	6,400	ND	ND	40	ND	ND	Trace	ND
3	Trace	Trace	Trace	24	ND	ND	ND	17,000	ND	ND	4.1	1.4	ND	26	Trace
4a	ND	ND	ND	3,200	ND	Trace	Trace	1,100	Trace	ND	11	2.8	0.28	40	1.2
4b	ND	ND	ND	2,800	ND	ND	ND	970	ND	ND	8.6	2.6	0.24	29	1.2
5	ND	ND	ND	5,100	ND	ND	Trace	1,500	ND	ND	51	3.8	1.1	27	2.4
6a	ND	ND	ND	500	Trace	ND	ND	1,400	ND	ND	49	ND	ND	51	ND
6b	ND	ND	ND	Trace	ND	ND	ND	800	ND	ND	34	Trace	ND	47	ND
6c	ND	ND	ND	4,700	ND	ND	ND	1,500	ND	ND	60	6.7	ND	55	Trace
7a	ND	ND	ND	68	ND	ND	ND	18,000	ND	ND	6.8	Trace	Trace	21	2.1
7b	ND	ND	ND	54	ND	ND	ND	15,000	ND	ND	7.1	1.0	Trace	42	1.8
8a	Trace	ND	ND	680	Trace	ND	13	950	ND	ND	14	3.9	0.59	46	5.2
8b	ND	Trace	ND	640	ND	ND	ND	890	ND	ND	18	3.9	0.63	42	6.8
9a	Trace	Trace	ND	Trace	ND	ND	Trace	21,000	Trace	ND	48	ND	Trace	19	ND
9b	ND	ND	ND	Trace	ND	ND	ND	12,000	Trace	Trace	17	ND	Trace	19	2.8
10a	ND	Trace	Trace	4,600	ND	ND	ND	720	ND	ND	26	6.0	2.3	360	4.8
10b	ND	ND	ND	2,500	ND	ND	ND	740	ND	ND	20	3.4	1.4	140	6.8

[a] Results reported in µg/g; Al=aluminum, As=arsenic, Ba=barium, Be=beryllium, B=boron, $[SO_4]^{-2}$=sulfate, Ca=calcium, Cd=cadmium, Co=cobalt, Cr=chromium, Cu=copper, Fe=iron, Li=lithium, Mg=magnesium, Mn=manganese, Mo=molybdenum, Ni=nickel, Pb=lead, P=phosphorus, Pt=platinum, Se=selenium, Ag=silver, Na=sodium, Te=tellurium, Tl=thallium, Ti=titanium, V=vanadium, Y=yttrium, Zn=zinc, Zr=zirconium

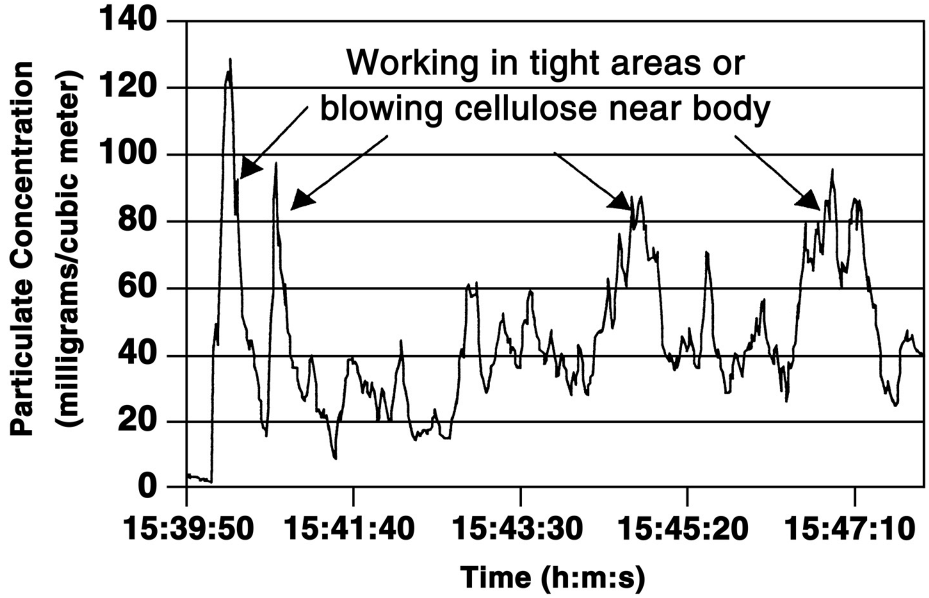
[b] ND=not detected

Table A5
Estimated Particle Size Data from Real-Time Particulate Measurements[a]

Location	Activity	Respirable Fraction (%)	MMAD[b] (µm)	Geometric Standard Deviation
Contractor 1 (Colorado)				
Existing Residential Attic				
13 January 1998	Preparation	20	7.9	1.9
	CI application	10	15	2.5
	CI application, hopper area	5	18	2.2
14 January 1998	CI activities	2	28	2.4
	CI application, hopper area	1	58	2.8
Contractor 2 (Missouri)				
Existing Residential Garage Ceiling				
28 April 1998	CI application, hopper area	11	11	1.9
Existing Residential Attic				
29 April 1998	CI application, truck	9	13	2.1
30 April 1998	CI application	7	20	2.5
Contractor 4 (Wisconsin)				
New Commercial Wall				
11 August 1998	CI application, hopper area	11	16	2.9
New Residential Attic				
12 August 1998	CI application	28	8.2	3.2
13 August 1998	CI application	32	8.5	4.2
Contractor 5 (Michigan)				
New Residential Attic				
29 September 1998	CI application	8	15	2.4
Contractor 7 (Colorado)				
Existing Residential Attic				
24 February 1999	CI application, hopper area	2.5	29	2.5
	CI activities, hopper area	2.5	20	2.3
26 February 1999	CI application	0	64	2.5
	CI activities, hopper area	1.0	55	2.8
Contractor 8 (Arizona)				
New Residential Attic and Wall				
25 March 1999	CI application	0	115	3.4
26 March 1999	CI application, hopper area	11	13	2.4
Contractor 10 (Colorado)				
New Residential Attic or Wall				
5 April 2000	CI application, hopper area	7	17	2.3
6 April 2000	CI application, hopper area	11	13	2.4
7 April 2000	CI application, hopper area	7	18	2.5

[a] CI=cellulose insulation
[b] Mass median aerodynamic diameter

Contractor 1



Contractor 7

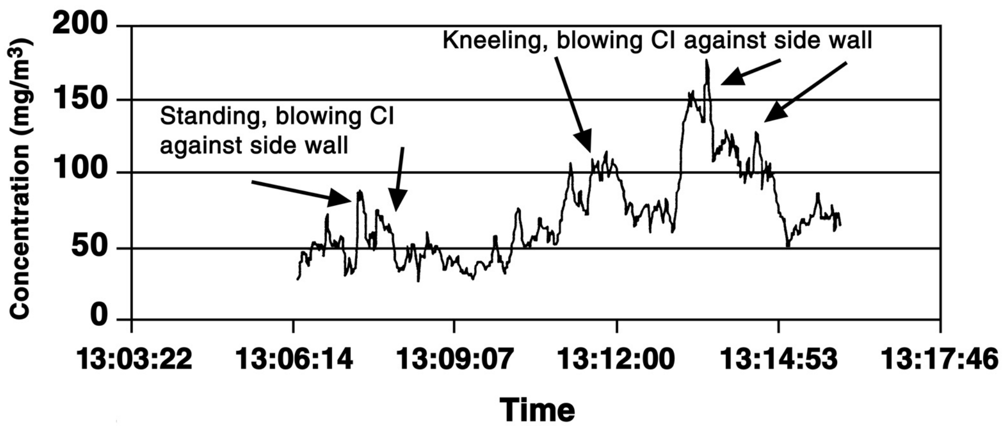
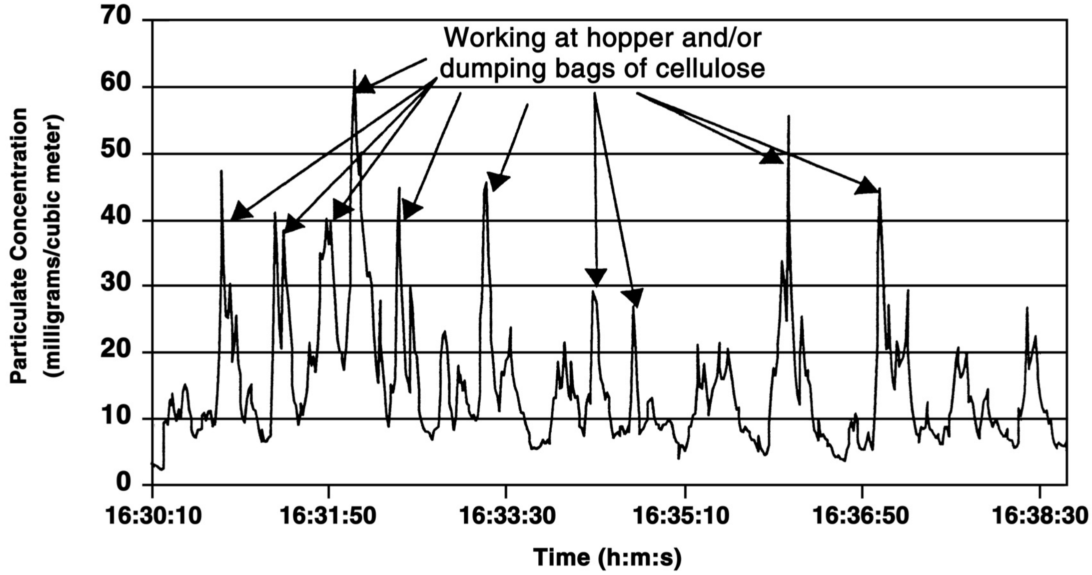


FIGURE A1
Video Exposure Monitoring of Cellulose Installation Activities in the Attic

Contractor 1



Contractor 7

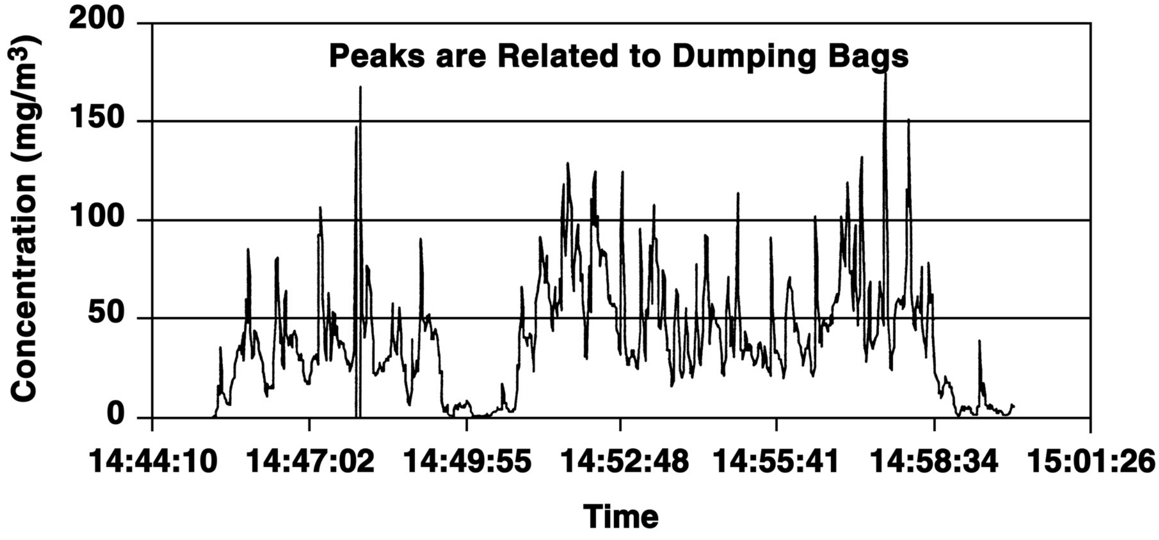


FIGURE A2

Video Exposure Monitoring of Cellulose Installation Activities in the Truck

APPENDIX B
MEDICAL HISTORY QUESTIONNAIRE

TABLE B1
Health Questionnaire: Cellulose Insulation Study

Medical History Questionnaire

ID#______

Health Questionnaire: Cellulose Insulation Study

IDENTIFYING INFORMATION

Complete the entire form. ***DO NOT LEAVE ANY BLANKS.***

Last Name:______________________	First Name:______________________

Street Address:	City/Town:
State:	Zip Code:
Home Phone Number: (_____) ______________	Work Phone Number: (_____) ______________

Sex: 1. M ☐ 2. F ☐

Date of birth: ________ (MM/DD/YY) Age: _____

Height: ____ feet _____ inches

Weight: _____ pounds

WORK HISTORY

1. In What Year Did You First Begin Working in Cellulose Insulation? 19_____
2. What Term Best Describes Your Current Job Title?

   ____

3. How Long Have You Worked at Your Current Job Title? ______ (Weeks / months / years) (Circle One)
4. How Many Weeks per Year Do You Perform Cellulose Insulation? ______
5. On Average, for the Weeks That You Perform Insulation Work, How Many Hours Do You Work Each Week? ________ Hrs.

TABLE B1
Health Questionnaire: Cellulose Insulation Study
(continued)

Complete the entire form. DO NOT LEAVE ANY BLANKS

Indicate how often in the **LAST 10 DAYS** you have experienced each of the following symptoms.

Check only ONE column for each symptom.

SYMPTOMS	Never in last 10 days (1)	Rarely (2)	Some-times (3)	Often (4)	Always (5)
chest pain					
difficulty breathing					
bringing up phlegm in the morning					
awakening at night short of breath					
chest tightness					
wheezing or whistling in chest					
awakening at night with an attack of wheezing					
shortness of breath					

1. Do you usually **cough** first thing in the **morning**?
   1. Yes ☐ 2. No ☐ {5}

   Count a cough with the first cigarette or on first going out of doors.
   Exclude clearing the throat or a single cough.
   "Usually" means 4 or more days per week.

2. Do you usually **cough** during the **day**?
   1. Yes ☐ 2. No ☐ {6}

   Ignore an occasional cough.
   "Usually" means 4 or more days per week.

(If "NO" to BOTH questions #1 and #2, go to Question #3 below.)
(If "YES" to either #1 or #2 answer questions in the box below and continue.)

2a. Do you cough like this on most days for as much as three months during the year?
1. Yes ☐ 2. No ☐

2b. If yes, how many years have you coughed like this? # years.

PHLEGM

3. Do you usually bring up any **phlegm** from your chest on **getting up**, or **first thing in the morning**?

   1. Yes ☐ 2. No ☐

   Count phlegm with first cigarette or on first going out of doors.
   Exclude phlegm from the nose.
   Count swallowed phlegm.
   "Usually" means 4 or more days per week.

TABLE B1
Health Questionnaire: Cellulose Insulation Study
(continued)

4. Do you usually bring up **phlegm** from your chest **during the day**?

1. Yes ☐ 2. No ☐

"Usually" means 4 or more days per week.
Answer "YES" if it occurs twice or more.

(If "NO" to BOTH questions #3 and #4, go to question #5.)
(If "YES" to either #3 or #4, answer questions in the box below and continue.)

4a. Do you bring up phlegm like this on most days for as much as three months during the year?
1. Yes ☐ 2. No ☐

4b. If yes, how many years have you brought up phlegm like this? ________# years

RESPIRATORY

5. Are you troubled by **shortness of breath** when hurrying on level ground or walking up a slight hill?

1. Yes ☐ 2. No ☐

(If "YES" to #5, answer questions in the box below. If "NO", go to question #6.)

5a. Do you get short of breath walking with other people of your own age on level ground?
1. Yes ☐ 2. No ☐

5b. Do you have to stop for breath when walking at a normal pace at level ground?
1. Yes ☐ 2. No ☐

6. Does your chest ever **feel tight** or your **breathing become difficult**?

1. Yes ☐ 2. No ☐

(If "YES" to #6, continue with questions in the box below. If "NO", skip to question #7)

6a. What time of day? (choose one)
☐ 1. No set pattern
☐ 2. Before entering the work site?
☐ 3. After entering the work site?
☐ 4. Shortly after leaving the work site (1-3 hours)?
☐ 5. Some hours after leaving the work site (3-8 hours)?

6b. Are/were the attacks of **chest tightness** accompanied by either **fever** or **shivering**?
1. Yes ☐ 2. No ☐

6c. Are/were the attacks accompanied by **headache**?
1. Yes ☐ 2. No ☐

6d. Are/were the attacks accompanied by **muscle ache**?
1. Yes ☐ 2. No ☐

6e. Does your chest tightness or your breathing difficulty occur on any particular day of the week?
1. Yes ☐ 2. No

(If "YES" to #6e answer questions in the following box. If "NO", go to question #7)

TABLE B1
Health Questionnaire: Cellulose Insulation Study
(continued)

6e-1. Which day? (choose one)

1. ☐ Monday
2. ☐ Tuesday
3. ☐ Wednesday
4. ☐ Thursday
5. ☐ Friday
6. ☐ Saturday
7. ☐ Sunday

6e-2. Is the day you checked the first day of your work week?
1. Yes ☐ 2. No ☐

7. Do you ever have **wheezing** or **whistling noises** in your chest?
1. Yes ☐ 2. No ☐

(If "YES" to # 7 answer question in box below. If "NO", go to question #8)

7a. Does this happen as often as once per week?
1. Yes ☐ 2. No ☐

8. Have you ever had attacks of **shortness of breath** with wheezing?
1. Yes ☐ 2. No ☐

(If "YES" to #8 answer questions in box below. If "NO", go to question #9)

8a. Was your breathing absolutely normal between attacks?
1. Yes ☐ 2. No ☐

8b. How many **attacks** like this have you had in the **past three years**? ___# attacks

8c. How many **years** have you had attacks like this? # years

9 Since childhood, have you ever had:

Hay fever	1. Yes ☐	2. No ☐
Emphysema	1. Yes ☐	2. No ☐
Tuberculosis	1. Yes ☐	2. No ☐
Bronchitis	1. Yes ☐	2. No ☐
Pneumonia	1. Yes ☐	2. No ☐

10. Have you ever had **asthma**? (check the number for the best answer)
☐1. No, I have never had asthma.
☐2. Yes, I had asthma as a child and it has continued as an adult.
☐3. Yes, I had asthma as a child, the symptoms went away, but started again.
☐4. Yes, I had asthma as a child, but it went away and has not returned.
☐5. Yes, I have asthma as an adult, but I never had it when I was a child.

"YES" to #10 answer questions in box below. If "NO", go to question #11

10a. If you have had asthma has it ever been **confirmed by a physician**?
1. ☐ Yes 2. ☐ No

10b. Have you developed asthma or has your asthma gotten worse since starting work on a CI crew?
1. ☐ Yes 2. ☐ No

10c. Have you ever taken a **prescription medication** for asthma?
1. ☐ Yes 2. ☐ No

TABLE B1
Health Questionnaire: Cellulose Insulation Study
(continued)

SINUS/NASAL

11. Do you usually have a stuffy nose, or drainage at the back of your nose?

1. Yes ☐ 2. No ☐

12. During the **past 12 months**, have you had two or more episodes of blocked, itchy, or runny nose?

1. Yes ☐ 2. No ☐

*(If "YES" to #11 **or** #12, answer questions in the box below. If "NO" to **BOTH** #11 and #12, go to question #13)*

12a. Do you usually have these nose symptoms at any **particular time of year**?
1. Yes ☐ 2. No ☐

If "Yes", which is the worst season? (choose one)
1. ☐ Winter
2. ☐ Spring
3. ☐ Summer
4. ☐ Fall

12b. When you have nose symptoms, do you usually have fever, headache, or general body ache?
1. Yes ☐ 2. No ☐

12c. Were these nose symptoms mainly due to one of the following? (choose one)
1. ☐ cold or flu
2. ☐ hay fever
3. ☐ other allergies
4. ☐ something else
(specify:_______________________________________)

12d. Do the nose symptoms seem better or worse when you are away from work, such as on weekends, vacation, sick leave, or lay-off? (choose one)
1. ☐ neither better nor worse away from work
2. ☐ better away from work
3. ☐ worse away from work

Table B1
Health Questionnaire: Cellulose Insulation Study
(continued)

EYES

13. During the **past 12 months**, have your eyes been red, itchy, or watery more than twice?

1. Yes ☐ 2. No ☐

(If "YES" to #13, answer questions in the box below. If "NO", go to question #14)

13a. Over the past year, about how often have you noticed these eye symptoms? (choose one)
1. ☐ less than 1-2 days altogether
2. ☐ less than 7 days
3. ☐ less than 30 days
4. ☐ more than 30 days

13b. Do you usually have these **eye symptoms** at any particular time of the year?
1. Yes ☐ 2. No ☐

If "Yes" which is the worst season? (choose one)
1. ☐ Winter
2. ☐ Spring
3. ☐ Summer
4. ☐ Fall

13c. When you have **eye symptoms**, do you usually have fever, headache, or general body ache?
1. Yes ☐ 2. No ☐

13d. Were these **eye symptoms** mainly due to one of the following? (choose one)
1. ☐ contact lenses
2. ☐ cold or flu
3. ☐ hay fever
4. ☐ other allergies
5. ☐ something else
(specify ______________________________)

13e. Did/do the **eye symptoms** seem better or worse when you were away from work, such as on weekends, vacation, sick leave, or lay-off? (choose one)
1. ☐ stayed the same
2. ☐ got better
3. ☐ got worse

TABLE B1
Health Questionnaire: Cellulose Insulation Study
(continued)

SKIN

14. During the **last 12 months** have you had a **skin rash, dermatitis, hives,** or **eczema**?
1. Yes ☐ 2. No ☐

(If "YES" to #14, answer questions in box below. If "NO", go to question #15)

14a. Is/was this rash related to anything you do at work?
1. ☐ Yes 2. ☐ No

If "YES" to #18a what is this rash related to? ____________________)

14b. What parts of your body were affected?

Scalp	1. ☐ Yes	2. ☐ No
Face	1. ☐ Yes	2. ☐ No
Hand or arm	1. ☐ Yes	2. ☐ No
Trunk	1. ☐ Yes	2. ☐ No
Groin or private parts	1. ☐ Yes	2. ☐ No
Feet or legs	1. ☐ Yes	2. ☐ No
Other	1. ☐ Yes	2. ☐ No

(Specify: ________________________________)

14c. Did/does your skin seem better or worse when you were away from work such as weekends, vacation, sick leave, or lay-off? (choose one)
1. ☐ stayed the same
2. ☐ got better
3. ☐ got worse

15. Have you seen a doctor for **any** problem in the **last year**?
1. Yes ☐ 2. No ☐
If "Yes", please specify: ________________________________

16. Do you presently take **any** medications, including non-prescription medicine, for **any** reason?
1. Yes ☐ 2. No ☐
If "Yes", please specify: ________________________________

SMOKING HISTORY

17. Have you smoked, altogether, as many as 5 packs of cigarettes during your entire life?
1. Yes ☐ 2. No ☐ 3. Never smoked ☐

(If "YES" to #17, answer questions in box below. If "NO", go to "Musuloskeletal" section top of page 11)

17a. Over the years that you smoked, on average how many cigarettes do (did) you smoke?
☐ 1. less than ½ pack per day
☐ 2. more than 1/2 to one pack per day
☐ 3. 1-2 packs per day
☐ 4. more than two packs per day

17b. How old were you when you started smoking? _______ years old

17c. If you have stopped smoking, how old were you when you stopped?
______ years old

17d. During the years that you smoked, did you ever quit for a year or more?
1. Yes ☐ 2. No ☐

IF "YES", ADDING ALL THE NON-SMOKING PERIODS TOGETHER FOR HOW MANY TOTAL YEARS WERE YOU NOT SMOKING? # years.

18. Do you regularly smoke **during work**?
Yes ☐ 2. No ☐

TABLE B1
Health Questionnaire: Cellulose Insulation Study
(continued)

MUSCULOSKELETAL

1. ARE YOU:

   RIGHT-HANDED_____ LEFT-HANDED______ USE BOTH HANDS EQUALLY_______

2. WHICH HAND DO YOU MOST OFTEN USE AT WORK?

   RIGHT______ LEFT_______ USE BOTH HANDS EQUALLY_______

3. Next, we have a few questions about physical symptoms you could experience from working on a road crew.

During the last 12 months have you had a job-related ache, pain, discomfort, etc. in your:				During the last 12 months have you been prevented from doing your day's work due to this condition?			During the last 12 months have you seen a physician for this condition?	
NECK	___No	___Yes	→	___No	___Yes	→	___No	___Yes
UPPER BACK	___No	___Yes	→	___No	___Yes	→	___No	___Yes
LOW BACK	___No	___Yes	→	___No	___Yes	→	___No	___Yes
SHOULDERS	___No	___Yes	→	___No	___Yes	→	___No	___Yes
ELBOWS	___No	___Yes	→	___No	___Yes	→	___No	___Yes
WRISTS/HANDS	___No	___Yes	→	___No	___Yes	→	___No	___Yes
HIPS/THIGHS	___No	___Yes	→	___No	___Yes	→	___No	___Yes
KNEES	___No	___Yes	→	___No	___Yes	→	___No	___Yes
ANKLES/FEET	___No	___Yes	→	___No	___Yes	→	___No	___Yes

That is all the questions we have.
Thank you so much for your cooperation!

Interviewer Name:

Interviewer Comments:

APPENDIX C
ACUTE SYMPTOMS SURVEY

Table C1
Acute Symptoms Survey: Cellulose Insulation Study

LAST:__________ FIRST: __________ DATE: / /

TIME (nearest qtr hour)	PEAK FLOW TESTS
1) ______ (am / pm) pre-shift	1) Peak Flow 1: ____ Peak Flow 2: ____ Peak Flow 3: ____
2) ______ (am / pm)	2) Peak Flow 1: ____ Peak Flow 2: ____ Peak Flow 3: ____
3) ______ (am / pm)	3) Peak Flow 1: ____ Peak Flow 2: ____ Peak Flow 3: ____
4) ______ (am / pm)	4) Peak Flow 1: ____ Peak Flow 2: ____ Peak Flow 3: ____
5) ______ (am / pm)	5) Peak Flow 1: ____ Peak Flow 2: ____ Peak Flow 3: ____

MAJOR ACTIVITIES (approx. duration)	Duration cellulose exp. since last ques. (nearest qtr. hr.)
1) pre-shift: __________	1) ______ (pre-shift)
2) __________	2) ______
3) __________	3) ______
4) __________	4) ______
5) __________	5) ______

How many cigarettes / cigars have you smoked since getting up today OR since the last questionnaire?	1) None __ ≤5 __ 6-10 __ 11-20 __ >20 __ last smoke time: ____ 2) None __ ≤5 __ 6-10 __ 11-20 __ >20 __ last smoke time: ____ 3) None __ ≤5 __ 6-10 __ 11-20 __ >20 __ last smoke time: ____ 4) None __ ≤5 __ 6-10 __ 11-20 __ >20 __ last smoke time: ____ 5) None __ ≤5 __ 6-10 __ 11-20 __ >20 __ last smoke time: ____
Have your EYES been burning, itchy, painful, or irritated since getting up today OR since the last questionnaire?	1) NO__ Mild__ Mod__ Severe__ Still have Sxs : Y / N If no, dur. Sxs __ (qtr hr) 2) NO__ Mild__ Mod__ Severe__ Still have Sxs : Y / N If no, dur. Sxs ___ 3) NO__ Mild__ Mod__ Severe__ Still have Sxs : Y / N If no, dur. Sxs ___ 4) NO__ Mild__ Mod__ Severe__ Still have Sxs : Y / N If no, dur. Sxs ___ 5) NO__ Mild__ Mod__ Severe__ Still have Sxs : Y / N If no, dur. Sxs ___
Has your NOSE been burning, itchy, stuffy, or irritated since getting up today OR since the last questionnaire?	1) NO__ Mild__ Mod__ Severe__ Still have Sxs : Y / N If no, dur. Sxs __ (qtr hr) 2) NO__ Mild__ Mod__ Severe__ Still have Sxs : Y / N If no, dur. Sxs ___ 3) NO__ Mild__ Mod__ Severe__ Still have Sxs : Y / N If no, dur. Sxs ___ 4) NO__ Mild__ Mod__ Severe__ Still have Sxs : Y / N If no, dur. Sxs ___ 5) NO__ Mild__ Mod__ Severe__ Still have Sxs : Y / N If no, dur. Sxs ___
Has your THROAT been sore, dry, scratchy, or irritated since getting up today OR since the last questionnaire?	1) NO__ Mild__ Mod__ Severe__ Still have Sxs : Y / N If no, dur. Sxs __ (qtr hr) 2) NO__ Mild__ Mod__ Severe__ Still have Sxs : Y / N If no, dur. Sxs ___ 3) NO__ Mild__ Mod__ Severe__ Still have Sxs : Y / N If no, dur. Sxs ___ 4) NO__ Mild__ Mod__ Severe__ Still have Sxs : Y / N If no, dur. Sxs ___ 5) NO__ Mild__ Mod__ Severe__ Still have Sxs : Y / N If no, dur. Sxs ___
Has your SKIN been burning, itchy, irritated or developed a rash since getting up today OR since the last questionnaire?	1) NO__ Mild__ Mod__ Severe__ Still have Sxs : Y / N If no, dur. Sxs __ (qtr hr) 2) NO__ Mild__ Mod__ Severe__ Still have Sxs : Y / N If no, dur. Sxs ___ 3) NO__ Mild__ Mod__ Severe__ Still have Sxs : Y / N If no, dur. Sxs ___ 4) NO__ Mild__ Mod__ Severe__ Still have Sxs : Y / N If no, dur. Sxs ___ 5) NO__ Mild__ Mod__ Severe__ Still have Sxs : Y / N If no, dur. Sxs ___
Have you been bothered by COUGHING since getting up today OR since the last questionnaire?	1) NO__ Mild__ Mod__ Severe__ Still have Sxs : Y / N If no, dur. Sxs __ (qtr hr) 2) NO__ Mild__ Mod__ Severe__ Still have Sxs : Y / N If no, dur. Sxs ___ 3) NO__ Mild__ Mod__ Severe__ Still have Sxs : Y / N If no, dur. Sxs ___ 4) NO__ Mild__ Mod__ Severe__ Still have Sxs : Y / N If no, dur. Sxs ___ 5) NO__ Mild__ Mod__ Severe__ Still have Sxs : Y / N If no, dur. Sxs ___
Have you experienced CHEST TIGHTNESS, or difficulty breathing since getting up today OR since the last questionnaire?	1) NO__ Mild__ Mod__ Severe__ Still have Sxs : Y / N If no, dur. Sxs __ (qtr hr) 2) NO__ Mild__ Mod__ Severe__ Still have Sxs : Y / N If no, dur. Sxs ___ 3) NO__ Mild__ Mod__ Severe__ Still have Sxs : Y / N If no, dur. Sxs ___ 4) NO__ Mild__ Mod__ Severe__ Still have Sxs : Y / N If no, dur. Sxs ___ 5) NO__ Mild__ Mod__ Severe__ Still have Sxs : Y / N If no, dur. Sxs ___
Have you experienced WHEEZING or whistling in your chest since getting up today OR since the last questionnaire?	1) NO__ Mild__ Mod__ Severe__ Still have Sxs : Y / N If no, dur. Sxs __ (qtr hr) 2) NO__ Mild__ Mod__ Severe__ Still have Sxs : Y / N If no, dur. Sxs ___ 3) NO__ Mild__ Mod__ Severe__ Still have Sxs : Y / N If no, dur. Sxs ___ 4) NO__ Mild__ Mod__ Severe__ Still have Sxs : Y / N If no, dur. Sxs ___ 5) NO__ Mild__ Mod__ Severe__ Still have Sxs : Y / N If no, dur. Sxs ___

Erratum -- **TOX-74**, NTP Toxicity Study Report on the Atmospheric Characterization, Particle Size, Chemical Composition, and Workplace Exposure Assessment of Cellulose Insulation. The following sentences found on page 14, section on *Use and Human Exposure* are deleted from this report:

> CI is more economical than other types of thermal insulation because it is more efficient. It can also reach more areas than other insulation materials because of its blown application process (Anonymous, 1977; Zicherman and Fisher, 1978; Chrenka, 1980; Sinanoglu, 1994).

National Toxicology Program
National Institute of Environmental Health Sciences
National Institutes of Health
P.O. Box 12233, MD K2-05
Durham, NC 27709
Tel: 984-287-3211
ntpwebrequest@niehs.nih.gov

https://ntp.niehs.nih.gov

ISSN 2378-8992