



Occupational Exposure to Chemical and Biological Agents in the Nonproduction Departments of Pulp, Paper, and Paper Product Mills: An International Study

Kay Teschke , Wolfgang Ahrens , Aage Andersen , Paolo Boffetta , Shirley Fincham , Murray Finkelstein , Paul Henneberger , Timo Kauppinen , Manolis Kogevinas , Kari Korhonen , Gary Liss , Tuula Liukkonen , Peter Osvoll , Anja Savela , Irena Szadkowska-Stanczyk , Håkan Westberg & Krystyna Widerkiewicz

To cite this article: Kay Teschke , Wolfgang Ahrens , Aage Andersen , Paolo Boffetta , Shirley Fincham , Murray Finkelstein , Paul Henneberger , Timo Kauppinen , Manolis Kogevinas , Kari Korhonen , Gary Liss , Tuula Liukkonen , Peter Osvoll , Anja Savela , Irena Szadkowska-Stanczyk , Håkan Westberg & Krystyna Widerkiewicz (1999) Occupational Exposure to Chemical and Biological Agents in the Nonproduction Departments of Pulp, Paper, and Paper Product Mills: An International Study, American Industrial Hygiene Association Journal, 60:1, 73-83, DOI: [10.1080/00028899908984424](https://doi.org/10.1080/00028899908984424)

To link to this article: <https://doi.org/10.1080/00028899908984424>



Published online: 04 Jun 2010.



Submit your article to this journal [↗](#)



Article views: 127



View related articles [↗](#)



Citing articles: 11 View citing articles [↗](#)

AUTHORS

Kay Teschke^a
 Wolfgang Ahrens^b
 Aage Andersen^c
 Paolo Boffetta^d
 Shirley Fincham^e
 Murray Finkelstein^f
 Paul Henneberger^g
 Timo Kauppinen^h
 Manolis Kogevinasⁱ
 Kari Korhonen^j
 Gary Liss^f
 Tuula Liukkonen^k
 Peter Osvoll^l
 Anja Savela^h
 Irena Szadkowska-
 Stanczyk^l
 Håkan Westberg^m
 Krystyna
 Widerkiewiczⁿ

^aDepartment of Health Care and Epidemiology, University of British Columbia, Vancouver, Canada, V6T 1Z3;

^bInstitute for Medical Information, Biometry, and Epidemiology, Essen, Germany;

^cNorwegian Cancer Registry, Oslo, Norway;

^dInternational Agency for Research on Cancer, Lyon, France;

^eAlberta Cancer Board, Edmonton, Canada;

^fMinistry of Labour, Toronto, Canada;

^gNational Institute for Occupational Safety and Health, Morgantown, W.V.;

^hInstitute of Occupational Health, Helsinki, Finland;

ⁱRespiratory and Environmental Health Research Unit, IMIM, Barcelona, Spain;

^jLappeenranta Regional Institute of Occupational Health, Lappeenranta, Finland;

^kNational Institute of Occupational Health, Oslo, Norway;

^lInstitute of Occupational Medicine, Lodz, Poland;

^mDepartment of Occupational and Environmental Medicine, Örebro Medical Center Hospital, Sweden;

ⁿRegional Sanitary Epidemiological Station, Bydgoszcz, Poland

This study was supported in part by the European Commission BIOMED-2 program (contract no. BMH1-CT95-1100).

Occupational Exposure to Chemical and Biological Agents in the Nonproduction Departments of Pulp, Paper, and Paper Product Mills: An International Study

As part of an international epidemiological study of workers in the pulp and paper industry, previously unpublished exposure measurements were assembled in a database. This article describes 7293 measurements in nonproduction departments from 147 mills in 11 countries. The greatest variety of agents was measured in the maintenance, construction, and cleaning department, where high exposures to asbestos, chromium [VI] compounds, copper, mercury in urine, nitrogen dioxide, ozone, styrene, sulfur dioxide, trichloroethylene, and welding fumes were observed. Measurements in the storage, yard, loading, and shipping department indicated high exposures to asbestos, carbon monoxide, fungal spores, nitrogen oxides, sulfur dioxide, and total dust. The steam and power generation department had high exposures to methyl mercaptan, silica, and total dust. Measurements in process and effluent water treatment, laboratory and research, engineering, and office, administration, and cafeteria areas had few elevated exposures. Throughout the nonproduction departments, measurements of pulp-production chemicals such as chlorine and sulfur compounds tended to be low, with many below detection limits. There were some problems with the available data; in particular, detection limits were often not specified, and the data tended to be clustered in such a way that sources of exposure variability could not be distinguished. Despite these problems, the data provide new insight into the exposures of nonproduction pulp and paper industry personnel.

Keywords: epidemiology, occupational exposure, paper

To investigate patterns of cancer incidence and mortality among employees of the pulp and paper products industry, the International Agency for Research on Cancer (IARC) is coordinating a multicentric epidemiologic study involving researchers from 15 countries and representing most regions of the world. More than 100,000 employees working in over 75 mills will be included.

As one component of the exposure assessment for this study, previously unpublished data were gathered to create a database of exposure measurements in the pulp and paper industry internationally. As of August 1996 the database

included 31,502 exposure measurements of 246 agents taken from the 1950s to the 1990s. The structure and contents of the database as a whole are described elsewhere.⁽¹⁾

The purpose of this article is to describe the exposure measurements gathered from nonproduction departments in the pulp and paper industry, including maintenance, shipping, power generation, process and effluent water treatment, laboratories, engineering, and administration. In addition, we examine the limitations of such a data set. Hygiene measurements in the pulp, paper and paperboard, and paper product departments will be described in detail in future publications.

METHODS

Each investigator involved in the IARC study approached the mills included in the study for existing hygiene data. In some cases mills not participating in the study were approached, as were government personnel and researchers who had conducted sampling in the industry. Data were entered using a structured format based on similar databases.⁽¹⁾ Fields were included for the following information related to each measurement: country; mill; type of products produced by the mill; mill department; mill job; agent measured; duration of measurement; date of measurement; sampling method; analytical method; type of sample (personal, area, biological); measured concentration; assessment of the measurement's representativeness; type of personnel making the measurement; purpose of measurement; and remarks. The database was assembled at the Finnish Institute of Occupational Health.

Certain data were excluded from the data set: emission measurements, measurements that could not be converted to uniform measurements, and measurements the results of which were based on estimation. "Unspecified" departments were coded to specific departments where possible, based on the job code.

For each department and agent, the study tabulated number of samples; the number of mills; the mean, median, minimum, and maximum concentrations; and the percentages of measurements below the limit of detection and above the American Conference of Governmental Industrial Hygienists threshold limit values (TLV[®]s) or biological exposure indices (BEIs).⁽²⁾ The data were stratified by the duration of sampling: short-term, up to 59 minutes; and time-weighted average, greater than or equal to 1 hour (TWA). When available, TWA data were given priority for reporting. Measurements below detection limits were assigned the value 0, because the limits of detection were not indicated in most cases. Therefore, except where no measurements were less than detection limits, means will be somewhat underestimated.

For substances with a minimum of 100 measurements of similar duration and at least 60% of measurements greater than detection limits, the data were examined descriptively partly to look for trends in the data, but also to identify any problems. Geometric mean concentrations were calculated according to country; mill; mill products; department; job; sampling method; analytical method; type of sample; representativeness of the measurement; measurement personnel; and purpose of measurement. Categories of these variables with a minimum of 10 measurements were compared. Scatterplots were used to look for any trend in concentration with year of measurement. Because the concentration distributions were positively skewed, measurements were ln-transformed prior to these calculations. This required substitution of a nonzero value for measurements below detection limits; the value of the lowest reported nonzero concentration divided by the square root of 2 was arbitrarily assigned.

Each mill participating in the IARC epidemiologic study was asked to complete a questionnaire about the history of production processes and chemical use. The responses about nonproduction departments were examined to investigate whether potential exposures were reported for which no measurement data had been assembled in the database. These data were also used to describe typical procedures in nonproduction departments.

RESULTS

Description of Nonproduction Departments

As in most industries, pulp and paper production involves a large work force in nonproduction operations. A job and department

dictionary developed for the epidemiological study was used to classify measurement locations in the exposure database. The non-production jobs and departments are listed in Table I. Many of these jobs are well known across many industries. The following describes some of the characteristics of nonproduction processes in pulp and paper mills, using data from the questionnaires submitted by all 76 mills currently participating in the epidemiological study.

Maintenance workers are employed to service process equipment and may be exposed to any of the process-related chemicals along with their trade-specific exposures. Millwrights (industrial mechanics), pipe fitters, oilers, and welders in particular spend a great deal of time in production areas. Most routine maintenance, as well as cleaning of vessels and machines during plant shutdowns, is done by in-house maintenance personnel, with some participation by mill laborers and production personnel. Most of the mills also hire outside contractors for some of their repair and cleaning work. Some noteworthy exposures to maintenance personnel include asbestos, applied to and removed from pipes and vessels by ladders and pipefitters; stainless steel, welded by welders and millwrights and used in vessels and pipes throughout pulping, recovery, and bleaching operations, and to some extent in papermaking; radioisotopes, used in level gauges in mill vessels and serviced mainly by instrument mechanics; and polychlorinated biphenyls, contacted by electricians when servicing capacitors and transformers. Other chemicals widely used in maintenance operations include petroleum-based and chlorinated solvents, resins, greases, cutting fluids, paints and coatings, acids and caustics, babbits, and other metals.

Mills require cranes and mobile equipment to move loads in their storage and transport areas. Mobile equipment has most frequently been powered by diesel, gasoline, liquefied petroleum gas, and propane, though a large number of the mills use at least some battery-powered equipment.

Most of the mills burn fuel oil to provide steam to power electrical generators; alternatively some use coal or natural gas, and a few purchase electric power. Most also recover a significant portion of energy by burning bark, wood waste, and effluent sludge.

Sedimentation beds, filters, flocculents, chlorine, and/or ion exchange resins may be used to treat the vast amounts of fresh water used by pulp and paper mills to remove contaminants, microorganisms, and minerals. Water that is used in power or recovery boilers is further treated with oxygen scavengers, and deposit and corrosion inhibitors such as hydrazine, morpholine, and trisodium phosphate.

Description of Data

As far as is known, all mills participating in the IARC study that had hygiene data available provided these measurements. In addition, government agencies in Finland, Germany, and the United States provided all available pulp and paper inspection data recorded in national databases; this included data on mills not participating in the study. A total of 7293 exposure measurements from nonproduction areas of pulp and paper mills were received from 11 countries, 9 of which are included in the epidemiological study: Canada (N=2085); Denmark (N=55); Finland (N=1988); Germany (N=179); Japan (N=60); the Netherlands (N=12); Norway (N=1126); Poland (N=1374); Spain (N=7); Sweden (N=168); and the United States (N=239). Data were contributed from 147 mills producing a wide variety of products (Table II) and described exposures in 9 departments and 48 jobs (Table I). The earliest measurements were taken in 1956 and the most

TABLE I. Number of Exposure Measurements in Nonproduction Departments, by Department and Job

Department	N	Job ^A	N ^B
Maintenance, construction, cleaning	1,986	maintenance foreman	50
		saw repairman	34
		metal machinist	97
		plumber	27
		welder	620
		vehicle mechanic	16
		millwright	155
		insulator	1
		machine repair worker, <i>nec</i> ^C	76
		electrician	9
		instrument mechanic	5
		carpenter	48
		mason	6
		painter	94
		stone cutter	1
		construction laborer	45
		construction worker, <i>nec</i>	57
Storage, yard, loading, shipping	1,234	cleaner	49
		transport foreman	11
		locomotive engineer	11
		forklift driver	416
		work machinery operator	2
		chauffeur	8
		dock worker	19
		shipper-receiver	26
		warehouse worker	337
		power foreman	3
Steam and power generation	1,020	furnaceman (sulfite waste liquor)	52
		furnaceman (sulfate waste liquor)	64
		boilerman	114
		power plant control room operator	101
Process water treatment	58	turbine operator	7
		feed water purification worker	8
		power plant worker, <i>nec</i>	112
Effluent water treatment	2,215	water purification operator	103
Laboratories and research	233	sewage/effluent treatment operator	1,186
		laboratory technician/chemist	117
Engineering	125	quality control inspector	56
		engineer	107
Office, administration, cafeteria	358	office worker	278
Other unspecified areas	64	foreman, <i>nec</i>	128
		other specified jobs	20

^A Note that only one descriptor is listed for each job in this table, whereas the job dictionary and coding system includes many possible alternate titles.

^B N for all jobs in a department do not total N for the department, because job was less frequently specified, and because jobs were sometimes listed in other department.

^C *nec* = not elsewhere classified.

recent in 1993, with the majority from the 1980s and 1990s (N=5803).

The type of personnel who took the measurements was reported for 91% of the samples: mill personnel (N=2426); government agency personnel (N=2069); research personnel (N=1977); and consultants (N=184). Almost all (98%) of these were reported to be industrial hygienists or people with comparable training. The purpose of sampling was known for 71% of the measurements: compliance (N=410); complaint (N=1868); routine mill sampling of high exposure groups (N=691); routine mill sampling of randomly selected workers (N=739); research sampling of high exposure groups (N=295); research sampling of randomly selected workers (N=70); and follow-up sampling (N=1103).

Only 30% of the measurements had an assessment of their representativeness (likelihood of their representing 8-hour TWAs, as assessed by an industrial hygienist).⁽¹⁾ Most of these were from two

countries, Poland and Finland, though some measurements from Norway, Sweden, Japan, and Canada also were evaluated in this way. Eighty-five percent of the measurements were judged to be representative, while 10% were judged likely to be biased to the high side mainly due to the short duration of the measurement or the measurement conditions, and 5% were thought likely biased to the low side mainly due to measurement conditions.

Exposures by Department and Job

Table III presents a summary of the exposure measurements in each nonproduction department, for all agents with at least 10 measurements.

As expected given the diversity of potential exposures in both production and trades areas, a wide variety of agents was measured

TABLE II. Number of Exposure Measurements in Nonproduction Departments of Mills, by Specific Types of Pulp and/or Paper Produced

Type of Product	N ^a
Pulps	
Groundwood	2247
Refiner mechanical	249
Thermomechanical	726
Chemi-thermomechanical	3
Neutral sulfite semichemical	1595
Sulfite	1374
Sulfate	5647
Repulped recycled paper	1604
Other types of pulp	4
Papers	
Newsprint	237
Printing and writing papers	1410
Wrapping and packaging papers	124
Tissue papers	97
Other or unknown types of paper	87
More than one type of paper	2599
Paperboards	
Container board	1892
Liquid and food packaging board	141
Other types of paperboard	15
More than one type of paperboard	468
Paper or paperboard products	
Off-machine coated or laminated products	430
Containers, sacks, boxes	1495
Wallpaper	135
Other paper products	7
More than one type of paper product	101

^a Note that most mills produced more than one product; measurements are listed for every product produced in a mill.

in maintenance, construction, and cleaning. Many of the compounds measured in these areas, particularly the metals and solvents, were not measured in other nonproduction areas. Most measurements were above detection limits, though chlorine, methylene chloride, and sulfur dioxide rarely were. A number of agents had more than 10% of measurements above the TLV: asbestos; chromium [VI] compounds; copper; nitrogen dioxide; ozone; sulfur dioxide; trichloroethylene; and welding fumes. Among agents measured in multiple areas, the following had the highest levels in the maintenance department (most exposed jobs listed in brackets): mercury in urine (electrician and maintenance foreman), styrene (machine and construction repair workers), and welding fumes (welder).

Measurements in the storage, yard, loading, and shipping department focused on fuels and products of combustion, though dusts and microorganisms were also measured. There were a number of agents for which most measurements were below detection limits: benzo[a]pyrene; gasoline; lead; nitric oxide; nitrogen dioxide; silica; and sulfur dioxide. Agents with more than 10% of measurements greater than the TLV or BEI included asbestos, carbon monoxide in blood, total dust, and sulfur dioxide. Exposures to asbestos (transport foreman, forklift driver), carbon monoxide (locomotive engineer, forklift driver), nitrogen oxides (forklift driver), and fungal spores (warehouse worker) were highest in this department.

Steam and power generation measurements included products

of combustion, oxidized and reduced sulfur compounds, chlorine bleaching compounds, hydrazine, dusts, and asbestos. Levels of carbon monoxide, chlorine, chlorine dioxide, dimethyl sulfide, hydrogen sulfide, methyl mercaptan, and sulfur dioxide were usually below detection limits. Agents with more than 10% of measurements greater than the TLV included total dust and methyl mercaptan. The steam and power department had the highest exposures to silica (boilerman and furnaceman), and total dust (power plant worker).

Few measurements were made in the process water treatment department. High short-term inorganic dust levels were measured, but no silica was detected. Monitoring in the effluent water treatment area was more extensive and included reduced and oxidized sulfur compounds; chlorine bleaching compounds and by-products; acids; ammonia; microorganisms; turpentine; and carbon dioxide. As elsewhere, chlorine compounds were rarely detected; the same was true for dimethyl sulfide, hydrogen sulfide, methanol, methyl mercaptan, and sulfur dioxide. Few measurements exceeded the TLVs.

Measurements in the remaining departments tended to focus on production chemicals such as chlorine and sulfur compounds, but once again few detectable levels were found. Solvents also were measured in laboratory and research departments, though levels were low. Indoor air quality measures, such as carbon dioxide and microorganisms, were monitored in the office, administration, and cafeteria areas. Few elevated levels were found.

Variations in Exposure with Other Variables, Agents with at Least 100 Measurements

Among agents with at least 100 measurements, several had more than 40% of the measurements less than detection limits and were not examined further: ammonia; chlorine; hydrogen sulfide; dimethyl sulfide; methyl mercaptan; and sulfur dioxide. Variations in concentration according to variables other than department or job were calculated for the remaining agents: carbon monoxide; dimethyl disulfide; total dust; fungal spores; urinary mercury; nitrogen oxides; silica; and styrene (reported descriptively only in Table IV). Examining the data in this way helped to illustrate some of the limitations of exposure information compiled from diverse sources and originally collected for many different purposes.

For three of these substances (dimethyl disulfide, urinary mercury, and silica), more than 95% of the measurements were from only one mill. In these cases effects of country and type of product produced would be indistinguishable, since they are identical for a single mill. Sampling procedures were also constant for these agents, which was not surprising since standard sampling methods are often adopted within a single work site.

Similar problems existed for certain variables for other agents. For example, the assessment of the measurements' representativeness did not vary for most agents, so a relationship between this variable and concentration could not be observed.

For the remaining variables, there were very few trends that held across multiple agents. For example, though concentration tended to decrease slightly with year of sampling for five agents, it increased somewhat for the remaining three. No particular country, paper type, paperboard type, paper product type, sampling or analytical method, type of sample, measurer, or measurement purpose appeared to have generally high or low exposures. Mills producing TMP more frequently had higher geometric mean concentrations, whereas kraft mills appeared more frequently to have lower geometric means, but whether this trend was an artifact of other factors is unknown.

TABLE III. Summary of Exposure Measurements in Nonproduction Departments, by Department and Agent (Agents with N \geq 10 Only)

Department Agent	N	Number of Mills	Mean	Median	Minimum	% less than Limit of Detection		Lowest Detected Value	Maximum	% greater than TLV or BEI ^a	1995-6 TLV or BEI ^a	Type of Measurements
						Limit of Detection	Value					
Maintenance, construction, cleaning												
Acetone (ppm)	45	4	12	8	0	8.8	0.13	67	0	750	TWA	
Asbestos (f/cc)	31	12	0.081	0.004	0	42	0.001	0.5	16	0.2	TWA	
Carbon monoxide (ppm)	84	13	2	0.8	0	23	0.1	18	0	25	TWA	
Chlorine (ppm)	10	3	0	0	0	90	0.01	0.01	0	1	ST	
Chromium ($\mu\text{g}/\text{m}^3$)	48	13	19	0.12	0	35	0.001	400	0	500	TWA	
Chromium VI compounds ($\mu\text{g}/\text{m}^3$)	26	9	63	0.085	0	46	0.04	1220	19	10	TWA	
Copper ($\mu\text{g}/\text{m}^3$)	11	6	1032	9	0.002	0	0.002	8200	18	1000	TWA	
Dust, inorganic (mg/m^3)	26	7	3.9	2.6	0.2	0	0.2	13	—	—	TWA	
Dust, total (mg/m^3)	206	14	1.8	0.96	0	5.2	0.08	32	1.9	10	TWA	
Hydrogen sulfide (ppm)	20	6	2.9	0.17	0	45	0.04	53	1.8	10	TWA	
Iron ($\mu\text{g}/\text{m}^3$)	28	9	914	0.37	0	0	0.02	6800	—	—	TWA	
Iron oxide (mg/m^3)	10	1	0.26	0.06	0	10	0.01	1.7	0	5	TWA	
Iron oxide fumes (mg/m^3)	10	1	0.26	0.06	0	10	0.01	1.7	0	5	TWA	
Lead ($\mu\text{g}/\text{m}^3$)	14	10	5.1	4.5	0	14	0.003	13	0	50	TWA	
Manganese ($\mu\text{g}/\text{m}^3$)	23	6	4.3	0.04	0	22	0.002	33	0	200	TWA	
Mercury ($\mu\text{g}/\text{m}^3$)	20	2	3.1	0.015	0	45	0.01	16	—	—	ST	
Mercury in urine ($\mu\text{g}/\text{L}$)	129	1	26	20	0	1.6	1	89	—	—	B	
Methyl ethyl ketone (ppm)	26	3	23	0	0	54	0.92	282	3.8	200	TWA	
Methylene chloride (ppm)	15	3	30	0	0	60	6.1	100	—	—	ST	
Nickel ($\mu\text{g}/\text{m}^3$)	54	12	8.1	0.085	0	42	0.001	210	0	1000	TWA	
Nitrogen dioxide (ppm)	14	6	1.9	0.25	0	50	0.5	14	14	5	ST	
Nitrogen oxides (ppm)	12	4	1.8	0.1	0	50	0.2	10	—	—	ST	
Oil mist (mg/m^3)	23	7	0.38	0.28	0.05	0	0.05	1.7	0	5	TWA	
Ozone (ppm)	16	3	0.16	0.03	0	37	0.03	0.7	31	0.1	ST	
Silica (mg/m^3)	24	1	0.034	0.04	0	21	0.02	0.05	—	—	ST	
Solvents, hygienic effect	18	2	0.62	0.42	0.01	0	0.01	2.2	—	—	TWA	
Solvents, total (ppm)	18	2	47	34	0.61	0	0.61	171	—	—	TWA	
Styrene (ppm)	93	6	9.9	3.1	0	5.4	0.1	110	4.3	50	TWA	
Sulfur dioxide (ppm)	40	4	7.1	0	0	70	0.17	70	28	2	TWA	
Toluene (ppm)	39	7	20	3	0	41	1	258	10	50	TWA	
Trichloroethylene (ppm)	10	6	133	17	0	10	5	1006	20	100	ST	
Welding fumes (mg/m^3)	90	10	3.5	2.1	0.1	0	0.1	27	19	5	TWA	
Xylene (ppm)	22	6	23	17	0	4.5	1	82	0	100	TWA	
Storage, yard, loading, shipping												
Asbestos (f/cc)	26	4	7.2	0.18	0	19	0.01	28	50	0.2	TWA	
Bacteria (cfu/ m^3)	20	2	5357	3550	40	0	40	21,000	—	—	ST	
Benzo(a)pyrene (ng/m^3)	10	4	1.9	0	0	70	1.3	10	—	—	TWA	
Carbon monoxide (ppm)	270	12	39	4	0	11	0.3	2800	8.8	25	TWA	
Benzo(a)pyrene (ng/m^3)	10	4	1.9	0	0	70	1.3	10	—	—	TWA	
Carbon monoxide (ppm)	270	12	39	4	0	11	0.3	2800	8.8	25	TWA	
Carbon monoxide in blood (%)	12	1	3.6	3.9	1	0	1	4.8	50	3.5	B	
Dust, total (mg/m^3)	83	21	4.8	0.6	0	18	0.1	68	11	10	TWA	
Fluorene (ng/m^3)	10	4	672	3	0	40	1.8	5400	—	—	TWA	

TABLE III. Continued

Department Agent	N	Number of Mills	Mean	Median	Minimum	% less than Limit of Detection		Lowest Detected Value	Maximum	% greater than TLV or BEI	1995-6 TLV or BEI ^A	Type of Measurements
						Minimum	Detection					
Fungal spores (cfu/m ³)	29	3	3296	1442	10	0	0	10	19,000	—	—	ST
Gasoline (ppm)	17	1	0.91	0	0	94	16	10	16	0	500	ST
Lead (µg/m ³)	10	1	7	0	0	70	10	10	40	—	—	ST
Nitric oxide (ppm)	28	2	0.34	0	0	60	0.2	0.2	2.5	0	25	TWA
Nitrogen dioxide (ppm)	29	3	0.22	0	0	79	0.14	0.14	3.6	3.4	3	TWA
Nitrogen oxides (ppm)	30	4	11	0	0	57	0.5	0.5	100	—	—	TWA
Silica (mg/m ³)	10	1	0.01	0	0	60	0.02	0.02	0.05	—	—	ST
Sulfur dioxide (ppm)	11	2	7.3	0	0	82	40	40	40	18	2	TWA
Sulfuric acid (mg/m ³)	19	1	0.48	0	0	53	0.08	0.08	4	5.3	3	ST
Steam and power generation												
Asbestos (f/cc)	16	6	0.013	0	0	56	0.005	0.005	0.1	0	0.2	TWA
Carbon monoxide (ppm)	212	6	2.3	0	0	91	2	2	108	—	—	ST
Chlorine (ppm)	64	5	0	0	0	100	nd	nd	0	0	1	ST
Chlorine dioxide (ppm)	13	3	0	0	0	85	0.001	0.001	0.06	0	0.1	TWA
Dimethyl disulfide (ppm)	31	1	0.04	0.018	0	39	0.008	0.008	0.26	—	—	TWA
Dimethyl sulfide (ppm)	32	2	0	0	0	97	0.16	0.16	0.16	—	—	TWA
Dust cont. silica (mg/m ³)	132	1	16	9	1.2	0	1.2	1.2	102	—	—	ST
Dust, total (mg/m ³)	37	13	6	1.3	0	5.4	0.14	0.14	78	16	10	TWA
Hydrazine (ppm)	15	5	0.09	0.02	0	13	0.01	0.01	1	—	—	ST
Hydrogen sulfide (ppm)	62	8	0.43	0	0	68	0.03	0.03	6	0	0	TWA
Methyl mercaptan (ppm)	44	5	7.7	0	0	75	0.016	0.016	100	11	0.5	TWA
Nitrogen oxides (ppm)	30	1	87	90	65	0	65	65	98	—	—	TWA
Silica (mg/m ³)	10	5	3.9	0.02	0	40	0.02	0.02	30	—	—	TWA
Sulfur dioxide (ppm)	45	11	0.71	0	0	62	0.03	0.03	25	2.2	2	TWA
Sulfur oxides, as SO ₂ (mg/m ³)	30	1	25	19	10	0	10	10	63	—	—	TWA
Process water treatment												
Dust, inorganic (mg/m ³)	20	1	4.6	2.8	1	0	1	1	16	—	—	ST
Silica (mg/m ³)	19	1	0	0	0	100	nd	nd	0	—	—	ST
Effluent water treatment												
Acetic acid (ppm)	20	2	0.097	0.1	0	30	0.01	0.01	0.3	0	10	TWA
Ammonia (ppm)	24	4	1.2	0.095	0	33	0.04	0.04	20	0	25	TWA
Bacteria (cfu/m ³)	39	6	13,877	2500	20	0	20	20	120,000	—	—	ST
Carbon dioxide (ppm)	31	4	597	400	300	0	300	300	2500	0	30,000	ST
Chlorine (ppm)	135	3	0.26	0	0	96	0.04	0.04	30	1.5	1	ST
Chlorine dioxide (ppm)	12	2	0	0	0	100	nd	nd	0.003	0	0.1	TWA
Chloroform (ppm)	15	1	0	0	0	100	nd	nd	0	0	10	TWA
Dimethyl disulfide (ppm)	251	3	0.17	0.01	0	32	0.002	0.002	3.7	—	—	TWA
Dimethyl sulfide (ppm)	263	5	0.35	0	0	66	0.004	0.004	14	—	—	TWA
Endotoxins (µg/m ³)	22	5	4.8	0.02	0	46	0.02	0.02	64	—	—	TWA
Formic acid (ppm)	17	2	0.088	0	0	5.9	0.1	0.1	0.4	0	5	TWA
Fungal spores (cfu/m ³)	41	7	594	150	0	12	10	10	15,270	—	—	ST
Hydrogen sulfide (ppm)	257	5	0.5	0	0	88	0.006	0.006	44	1.5	10	TWA

TABLE III. Continued

Department Agent	N	Number of Mills	Mean	Median	Minimum	% less than Limit of Detection	Lowest Detected Value	Maximum	% greater than TLV or BEI ^A	1995-6 TLV or BEI ^A	Type of Measurements
Methanol (ppm)	14	1	0	0	0	100	nd	0	0	200	TWA
Methyl mercaptan (ppm)	284	5	0.12	0	0	71	0.004	9.6	3.9	0.5	TWA
Sulfur dioxide (ppm)	39	3	0.005	0	0	92	0.003	0.1	0	2	TWA
Total germ count (cfu/m ³)	12	1	260,910	10,600	240	0	240	2,100,000	—	—	TWA
Turpentine (ppm)	16	2	0.06	0.007	0	31	0.002	0.92	0	100	TWA
Laboratories and research											
Ethanol (ppm)	13	3	4.9	5	0	31	1.2	18	0	1000	TWA
Hydrogen sulfide (ppm)	38	3	0.73	0	0	84	2.2	12	0	15	ST
Toluene (ppm)	22	4	7.7	5	0.04	0	0.04	25	0	50	TWA
Engineering											
Chlorine (ppm)	31	1	0	0	0	100	nd	0	0	1	ST
Dimethyl disulfide (ppm)	16	1	0.05	0.022	0	31	0.011	0.28	—	—	TWA
Dimethyl sulfide (ppm)	16	1	0	0	0	94	0.007	0.01	—	—	TWA
Hydrogen sulfide (ppm)	17	2	29	0	0	88	0.006	500	5.9	10	TWA
Methyl mercaptan (ppm)	16	1	0	0	0	100	nd	0	0	0.5	TWA
Office, administration, cafeteria											
Bacteria (cfu/m ³)	15	3	147	70	20	0	20	610	—	—	TWA
Carbon dioxide (ppm)	15	1	678	650	440	0	440	970	0	30,000	ST
Chlorine (ppm)	88	1	0	0	0	100	nd	0	0	1	ST
Dimethyl disulfide (ppm)	42	1	0.05	0.013	0	36	0.003	0.74	—	—	TWA
Dimethyl sulfide (ppm)	42	1	0	0	0	100	nd	0	—	—	TWA
Fungal spores (cfu/m ³)	27	4	552	20	0	30	10	5600	—	—	ST
Hydrogen sulfide (ppm)	43	2	0	0	0	100	nd	0	0	10	TWA
Methyl mercaptan (ppm)	42	1	0	0	0	100	nd	0	0	0.5	TWA
Ozone (ppm)	12	1	0	0	0	75	0.01	0.02	0	0.1	ST
Other nonproduction areas											
Dust, total (mg/m ³)	33	1	1.2	1	0.1	0	0.1	5.9	0	10	TWA
Sulfur dioxide (ppm)	31	1	0	0	0	100	nd	0	0	5	ST

Note: TWA = time-weighted average air samples, sample durations ≥ 1 hour; ST = short-term air samples, sample durations ≤ 59 minutes; B = biological samples; nd = no samples above detection limit; — = no comparable TLV.
^A = TLV selected as appropriate, given type of measurements.

TABLE IV. Trends in Geometric Mean Concentrations for Other Variables, and Illustrations of Some Limitations of the Data (Agents with N ≥ 100 Only)

Variable	Trend	Carbon Monoxide (TWA) N=355	Dimethyl Disulfide (TWA) N=343	Total Dust (TWA) N=321
Year	Direction	Decreasing	Increasing	Decreasing
Country	highest	U.S.	^A	Finland
	lowest	Norway		Denmark
Pulp type	highest	TMP ^C	^A	GW, TMP, sulfite ^{C,D}
	lowest	sulfite		kraft
Paper type	highest	newsprint	^A	mixed
	lowest	printing/writing		no paper
Paperboard type	highest	^B	^A	containerboard
	lowest			liquid, food containers
Paper product type	highest	^B	^A	^B
	lowest			
Sampling method	highest	Bag	^A	^A
	lowest	direct reading		
Analytical method	highest	CO meter	^A	^A
	lowest	indicator tube		
Type of sample	highest	area	^A	^B
	lowest	personal		
Assessment of representativeness	highest	^A	^A	low due to site
	lowest		^A	representative
Measurer	highest	government hygienist	^A	mill personnel
	lowest	mill personnel		consulting hygienist
Purpose of measurement	highest	routine-worst-case	^A	study-worst-case
	lowest	routine-random		routine-worst case

Notes: TWA = time-weighted average air samples, measurement duration ≥ 1 hour; ST = short-term air samples, measurement duration ≤ 59 minute; B = biological monitoring.

^A = fewer than 2 categories of this variable with ≥ 10 measurements

^B = little difference in concentration between levels of this variable

^C TMP = thermomechanical pulping

^D GW = groundwood pulping

^E NSSC = neutral sulfite semi-chemical pulping

To discover which of the available variables were the most important predictors of exposure, after adjusting for other factors, investigators would usually conduct multivariate analyses. For example, it was of interest whether differences in exposure between departments (Table III) remained after taking other variables (Table IV) into account, since department is likely to be the basis for exposure assignment in the epidemiologic study. However, examination of the data indicated that such inferences from this data set would likely be highly unreliable. Because of the multiplicity of data sources and the multiple purposes of the original data collection, the measurements are likely to be heterogeneous and heteroscedastic. The data is unbalanced, as is common in observational studies, though in this case the result is extreme. More problematic is that many of the measurements are unlikely to be independent because they are clustered according to time and place, as well as such factors as sampling and analytical methods, and measurement personnel. The data includes measurements of single agents with differing and often unknown detection limits. These problems mean that the assumptions required for statistical modeling were not likely to be met.

DISCUSSION

Although the measurements compiled in this database came from more than 100 mills in 11 countries, the number of mills reporting data for any one agent in a particular department was

usually fewer than 10, and in a number of cases only 1. In some instances, this may have resulted from individual mills labeling their monitoring data on similar agents in slightly different ways (e.g., total dust, inorganic dust, welding fumes). But it is also likely that the differences in substances monitored represented both different materials used in the mills and differences in the foci of monitoring. Whether the data summarized here are representative of the industry as a whole is likely to differ from agent to agent. Where the data set for an agent is large, from many mills, consistent across several departments (e.g., the low levels of reduced sulfur and chlorine gases throughout most nonproduction areas), and agrees with other literature, the generalizability of the results is most credible.

Because this database was assembled post hoc, the data were not structured in a way to allow many of the comparisons that would be useful to the epidemiological study. Many agents were not measured in multiple departments, but it is not known whether unmeasured exposures did not occur or simply were not considered for measurement. Measurements were frequently clustered in such a way that the source of exposure variability could not be distinguished, for example, between country, department, year of measurement, type of product, or characteristics of the measurement method or strategy. The database did not collect information about other potential exposure determinants, such as ventilation or enclosure. Many of the measurements were below detection limits, and most often the detection limits were not reported.

TABLE IV. Extended

Fungal Spores (ST) N=109	Urinary Hg (B) N=144	Nitrogen Oxides (ST) N=139	Silica (ST) N=105	Styrene (TWA) N=103
Decreasing	Increasing	Decreasing	Decreasing	Increasing
France	A	Finland	A	Norway
Finland		Poland		New Zealand
recycled	A	TMP	A	TMP ^c
GW, TNT, kraft ^{c,D}		NSSC, kraft, recycled ^E		sulfite, GW, kraft ^D
tissue	A	B	A	mixed
mixed				printing writing
no paperboard	A	no paperboard	A	liquid/food containers
containerboard		containerboard		no board
A	A	coating lamination	A	A
		containers, sacks, boxes		
filter, Laskeutumamalja	A	bag	A	A
Anderson sampler		glass tube		
A	A	indicator tube	A	gas chromatography
		spectrophotometry		indicator tube
A	A	B	A	personal
				area
A	A	A	A	A
mill hygienist	A	research hygienist	A	research hygienist
research hygienist		mill hygienist		mill hygienist
A	A	routine-random	B	B
		follow-up		

Notes: TWA = time-weighted average air samples, measurement duration ≥ 1 hour; ST = short-term air samples, measurement duration ≤ 59 minute; B = biological monitoring.

^A = fewer than 2 categories of this variable with ≥ 10 measurements

^B = little difference in concentration between levels of this variable

^C TMP = thermomechanical pulping

^D GW = groundwood pulping

^E NSSC = neutral sulfite semi-chemical pulping

These problems indicate the potential value not only of standard quality control procedures (e.g., reporting of limits of detection), but also of more broad-based routine sampling of workers' potential exposures. Relatively few measurements in this database arose from random sampling programs; the greatest number arose from complaint, worst-case, and follow-up sampling, strategies more likely to result in the data clustering observed here.

The data do provide information about exposures in nonproduction departments of pulp and paper mills not previously reported. The maintenance, construction, and cleaning department had the greatest variety of agents measured, and a number of agents with high exposures, in particular, metals, solvents, asbestos, ozone, and oxides of sulfur and nitrogen. The storage, yard, loading, and shipping department had high exposures to combustion gases, fungi, and dust including asbestos. Steam and power generation had high exposures to methyl mercaptan and dusts including silica. The remaining departments had few elevated exposures. Throughout the nonproduction departments, measurements of pulp-production chemicals such as chlorine and sulfur compounds tended to be low, with many measurements below detection limits. It is interesting to note, however, that in Salisbury et al.'s⁽³⁾ report of 348 gassing incidents (mostly due to chlorine or chlorine dioxide) in a Canadian pulp and paper plant, 37% occurred in pipe fitters, millwrights, or instrument mechanics. Such incidents may not be detected in monitoring programs.

An earlier article⁽¹⁾ reporting on the whole database of measurements throughout all pulp and paper mill departments serves as a comparison for the nonproduction measurements. Gases arising from pulp production and bleaching operations—such as methyl mercaptan, nitrogen dioxide, sulfur dioxide, and chlorine dioxide—exceeded the TLV more often in mill production areas. Hexavalent chromium compounds and asbestos were considerably higher in the maintenance and storage departments reported here.

Some exposure measurements in nonproduction departments have been reported in the scientific literature (Table V).⁽⁴⁻¹²⁾ Most of the data reported in these studies is consistent with that in the database. Some differences include detectable chlorine levels in the office area reported by Enarson et al.,⁽⁶⁾ detectable chloroform levels in effluent treatment reported by Crawford et al.,⁽⁷⁾ and lower maximum levels of respirable dust in the storage area reported by Kennedy et al.⁽⁵⁾

Some measurements reported in the literature were not included in the database: formic acid in urine of canteen workers,⁽⁸⁾ coal dust in the boiler house,⁽⁹⁾ endotoxins in the storage area,⁽¹⁰⁾ and polychlorinated dioxins and furans in effluent treatment and maintenance.^(11,12) Other investigators have described additional agents present in nonproduction workers' environments, but without exposure measurements. Rycroft and Calnan⁽¹³⁾ reported three maintenance men who contracted dermatitis from slimicides (bis-1,4-bromoacetoxy-2-butene in butyl diglycol and 2,3-dichloro-bromotetrahydrothiophene-1,1-dioxide) used in a computer paper

TABLE V. Summary of Exposure Measurements in Nonproduction Departments Reported in the Literature

Agent	Department	N	Measure	Concentration	Country	Reference
Chlorine dioxide	maintenance	49	GM (4 mills)	< DL to 5.8 ppb	U.S.	7
Chlorine/ClO ₂	maintenance	5	range	< 0.1 ppm	Canada	8
Chlorine	maintenance	49	GM (4 mills)	< DL to 10.3 ppb	U.S.	7
Chlorine/ClO ₂	shops/storage	2	range	< 0.1 ppm	Canada	8
Chlorine dioxide	power, recovery	25	GM (4 mills)	< DL	U.S.	7
Chlorine	powerhouse	9	mean/max	< DL/0.03 ppm	Canada	9
Chlorine	power, recovery	25	GM (4 mills)	< DL to 26.9 ppb	U.S.	7
Chlorine	office	6	mean/max	0.01/0.03 ppm	Canada	9
Chloroform	effluent treatment	10	range	0.015 to 1.67 ppm	U.S.	10
Sulfur dioxide	maintenance	5	range	< 0.2 ppm	Canada	8
Sulfur dioxide	shops/storage	4	range	< 0.2 ppm	Canada	8
Sulfur dioxide	powerhouse	9	mean/max	< DL	Canada	9
Sulfur dioxide	office	6	mean/max	< DL	Canada	9
Hydrogen sulfide	maintenance	5	range	< 0.5 ppm	Canada	8
Hydrogen sulfide	shops/storage	3	range	< 0.5 ppm	Canada	8
Hydrogen sulfide	powerhouse	9	mean/max	< DL /0.1 ppm	Canada	9
Hydrogen sulfide	office	6	mean/max	< DL	Canada	9
Methyl mercaptan	maintenance	5	range	< 0.2 to 1.9 ppm	Canada	8
Methyl mercaptan	shops/storage	3	range	< 0.2 ppm	Canada	8
Methyl mercaptan	powerhouse	9	mean/max	< DL	Canada	9
Methyl mercaptan	office	6	mean/max	< DL/0.2 ppm	Canada	9
Formic acid in urine	canteen	27	mean	20.3 mg/L	India	11
Respirable dust	shops/storage	2	range	< 0.1 to 0.2 mg/m ³	Canada	8
Coal dust	boiler house	4	range	3 to 64 mppcf	India	12
Endotoxins	storage	40	mean	1 ng/m ³	Finland	13
PCDD/F TEQ	effluent treatment	1	—	0.01 pg/m ³	U.S.	14 ^A
PCDD/F TEQ in blood	bleach plant	14 ^A	range	19–150 pg/g	Finland	15

Notes: DL = detection limit, level not reported; GM = geometric mean; PCDD/F TEQ = international toxic equivalent concentration of polychlorinated dibenzo-p-dioxins and dibenzofurans.

^A = 4 of 14 workers in the bleach plant were maintenance employees.

making area. Reviews^(14,15) of the chemicals present in spent bleaching liquors and pulp mill effluents reveal a complex mixture of organics, including phenols, guaiacols, vanillins, catechols, syringols, aldehydes, ketones, terpenes, resins, sugars, and acids, many of which may be chlorinated. Most were not reported in the database, though exposures might occur to nonproduction maintenance, effluent treatment, and power boiler personnel. A number of compounds used by mills participating in the epidemiological study had few (<10) or no measurements reported in the exposure database, for example: polychlorinated biphenyls, limonene, wood preservatives, and muriatic acid in the maintenance department; and coal dust, morpholine, cyclohexylamine, hydroquinone, and trisodium phosphate in the steam and power generation department.

The database did not collect data on exposures to physical agents, such as ionizing and nonionizing radiation, noise, and vibration, which are known to occur in pulp and paper mills⁽¹⁶⁾

In summary, although this database is not the ideal form of exposure data for an epidemiological study, it provides a starting point for describing nonproduction exposures. In the assessment of relevant exposures for the international epidemiological study, a team of industrial hygienists will integrate the database measurements with mill-specific information from the questionnaires answered by the participating companies, to create a department-exposure matrix. In addition, the database places previously unpublished information in the public domain, providing hygienists in the pulp and paper industry with a basis for identifying agents and areas of potential concern.

ACKNOWLEDGMENTS

The authors would like to thank Agneta Hollander (Canadian Pulp and Paper Association), Steve Prahacs (Paprican), and Paavo Jäppinen (Enso Oy) for their help in the construction of the classifications used in this project. Numerous people from mills, government agencies, and research institutions contributed data for this study. Data from the National Institute for Occupational Safety and Health (Health Hazard Evaluations) and the Occupational Safety and Health Administration (integrated management information system) were included.

REFERENCES

1. Kauppinen, T., K. Teschke, A. Savela, M. Kogevinas, and P. Boffetta: International data base of exposure measurements in the pulp, paper, and paper product industries. *Int. Arch. Occup. Environ. Health* 70:119–127 (1997).
2. American Conference of Governmental Industrial Hygienists (ACGIH): *1995–1996 Threshold Limit Values (TLVs) for Chemical Substances and Physical Agents and Biological Exposure Indices (BEIs)*. Cincinnati, OH: ACGIH, 1995.
3. Salisbury, D.A., D.A. Enarson, M. Chan-Yeung, and S.M. Kennedy: First-aid reports of acute chlorine gassing among pulp mill workers as predictors of lung health consequences. *Am. J. Ind. Med.* 20: 71–81 (1991).
4. Poovey, H.G., and R.J. Rando: Determination of chlorine and chlorine dioxide by non-suppressed ion chromatography and application

- to exposure assessment in the paper industry. *J. Liquid Chromatog.* 18:261–275 (1995).
5. **Kennedy, S.M., D.A. Enarson, R.G. Janssen, and M. Chan-Yeung:** Lung health consequences of reported accidental chlorine gas exposures among pulp mill workers. *Am. Rev. Respir. Dis.* 143:74–79 (1991).
 6. **Enarson, D.A., L. Maclean, M. Chan-Yeung, S. Grzybowski, A. Johnson, G. Block, and K. Schragg:** Respiratory health at a pulp mill in British Columbia. *Arch. Environ. Health* 39:325–330 (1984).
 7. **Crawford, R.J., S.L. Cloutier, and D.C. Rovell-Rixx:** Evaluation of OSHA Method 5 for measuring chloroform in pulp and paper workplace and ambient atmospheres. *Am. Ind. Hyg. Assoc. J.* 53:210–215 (1992).
 8. **Srivastava, A.K., B.N. Gupta, V. Bihari, J.S. Gaur, N. Mathur, and V.K. Awasthi:** Clinical studies of employees in a sheet-forming process at a paper mill. *Vet. Hum. Toxicol.* 34:525–527 (1992).
 9. **Gautam, S.S., A.V. Venkatanarayanan, and B. Parthasarathy:** Occupational environment of paper mill workers in south India. *Ann. Occup. Hyg.* 22:371–382 (1979).
 10. **Liesivuori, J., M. Kotimaa, S. Laitinen, K. Louhelainen, et al.:** Airborne endotoxin concentrations in different work conditions. *Am. J. Ind. Med.* 25:123–124 (1994).
 11. **Crandall, M.S., G.M. Kinnes, and R.W. Hartle:** Levels of chlorinated dioxins and furans in three occupational environments. *Chemosphere* 25:255–258 (1992).
 12. **Rosenberg, C., H. Kotsas, J. Tornaeus, P. Mutanan et al.:** PCDD/PCDF levels in the blood of workers at a pulp and paper mill. *Chemosphere* 31:3933–3944 (1995).
 13. **Rycroft, R.J.G., and C.D. Calnan:** Dermatitis from slimicides in a paper mill. *Contact Dermatitis* 6:435–439 (1980).
 14. **Kringstad, K.P., and K. Lindström:** Spent liquors from pulp bleaching. *Environ. Sci. Technol.* 18:236A–248A (1984).
 15. **Suntio, L.R., W.Y. Shiu, and D. Mackay:** A review of the nature and properties of chemicals present in pulp mill effluents. *Chemosphere* 17:1249–1290 (1988).
 16. **Barroetavena, M.C., R. Ross, and K. Teschke:** Electric and magnetic field exposures at three pulp and paper mills. *Am. Ind. Hyg. Assoc. J.* 55:358–363 (1994).