ANNUAL REPORT TO THE LEGISLATURE
MINNESOTA TACONITE WORKERS HEALTH STUDY

DATE: **April 19, 2013**

TO:

Sen. David Tomassoni, chair
Senate Jobs and Economic Growth Committee
317 Capitol

Sen. Tony Lourey, chair
Senate Health and Human Services Finance Division
120 Captiol

Sen. Kathy Sheran, chair
Senate Health, Human Services and Housing Committee
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Rep. Tim Mahoney, chair
House Jobs and Economic Development Finance & Policy Committee
591 State Office Building

Rep. Sheldon Johnson, chair
House Labor, Workplace and Regulated Industries
549 State Office Building

Rep. Tom Huntley, chair
Health and Human Services Finance Committee
585 State Office Building

Rep. Tina Liebling, chair
House Health and Human Services Policy Committee
367 State Office Building

FROM:

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Rep. David Dill
Rep. Mary Murphy
Sen. Tom Bakk
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Rep. Tom Anzelc
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April 11, 2013

Dear Legislators:

We are pleased to present the annual report on our research regarding the health status of taconite workers and Iron Range community air quality.

This report, as in the past, details the progress made by the University of Minnesota School of Public Health and the Natural Resources Research Institute (NRRI) in all research areas, including occupational exposure, mortality and incidence studies, the respiratory health survey of taconite workers and spouses and the environmental study of airborne particles.

In addition, this report contains specific information regarding the assessment of mesothelioma as it pertains to exposure to mineral fibers, referred to as elongate mineral particles (EMP). For this report, the EMP measurement is a standard technique that identifies those fibers (EMP) considered long (over 5 microns). Although the research team felt this was the most important exposure to be assessed with the cases of mesothelioma, in the next several months there will be additional analyses that may provide further insight, including exposure to short EMP, silica and respirable dust. A final report is planned for the end of the year when all components are expected to be completed.

As our scientific efforts continue, we remain committed to open communication and transparency. We plan to hold at least one additional stakeholder meeting through the Minnesota Taconite Workers Lung Health Partnership and will continue to update our website, www.taconiteworkers.umn.edu.

We welcome your comments and suggestions, and would be delighted to discuss the report at a convenient time.

We would like to thank those current and former workers who participated in our screening study. We'd also like to thank the companies and union officials for cooperating with several parts of this work. Finally, thank you for the opportunity to advance scientific knowledge on this critical issue facing Minnesota.

John R. Finnegan, Jr., PhD
Professor and Dean

Jeffrey H. Mandel, MD, MPH
Associate Professor
Principal Investigator

ABREVIATIONS USED IN THIS REPORT

ACGHI	American Conference of Governmental Industrial Hygienist
BMI	Body Mass Index
CI	Confidence Interval
CF	Conversion Factors
EBSD	Electron Back Scattered Diffraction
EDS	Energy Dispersive X-ray Spectroscopy
EDXA	Energy Dispersive X-ray Analysis
EMP	Elongate Mineral Particle
ICD	International Classification of Disease
ISO	International Standards Organization
LTAS	Life Table Analysis System
MCE	Mixed Cellulose Ester
MCSS	Minnesota Cancer Surveillance System
MDH	Minnesota Department of Health
MIR	Mesabi Iron Range
MRHAP	Mineral Resources Health Assessment Program
MSHA	Mine Safety and Health Administration
NAAQS	National Ambient Air Quality Standard
NDI	National Death Index
NIOSH	National Institute of Occupational Safety and Health
NRRI	Natural Resources Research Institute
OEL	Occupational Exposure Limit
PCM	Phase Contrast Microscopy

PEL	Permissible Exposure Limit
PIXE	Proton Induced X-ray Spectroscopy
PM	Particulate Matter
RHS	Respiratory Health Survey
SAED	Selected Area Electron Diffraction
SEG	Similar Exposure Group
SEM	Scanning Electron Microscopy
SMR	Standardized Mortality Rate
SSA	Social Security Administration
TEM	Transmission Electron Microscopy
TSP	Total Suspended Particulate
TWA	Time Weighted Average
TWHS	Taconite Worker Health Study
UMN	University of Minnesota
UMD	University of Minnesota Duluth
UMTC	University of Minnesota Twin Cities

Taconite Workers Health Study
Progress Report to the Minnesota Legislature

Taconite Workers Health Study
Executive Summary as of April 12, 2013

The Taconite Workers Health Study (TWHS) was funded by the State of Minnesota and began in 2008. The study is being conducted in response to earlier findings by the Minnesota Department of Health (MDH), which described an apparent excess of mesothelioma within a cohort of iron ore industry workers. The cohort originated from work done at the University of Minnesota (UMN) in the 1980s, which attempted to identify all workers in the iron ore industry, and included around 72,000 individuals.

The finding of excess cases of mesothelioma, a sentinel disease, could indicate exposure to certain minerals, including asbestos (referred to EMP of the asbestiform type in this report), and could signal risk for other conditions like lung cancer and non-cancerous lung disease. To assess this situation, UMN researchers developed a multi-pronged strategy, including the assessment of exposures to dust from taconite operations in the workplace and in the community, a mortality (cause-of-death) study, incidence studies for mesothelioma and lung cancer where exposures to dusts from the workplace could be studied in more detail and a screening of current and former workers (and spouses) for non-cancerous lung disease. These collective studies form the TWHS.

As of this date, important insights have resulted from each of these studies:
1. The air in Iron Range communities is lower in particulates than a comparison sample in Minneapolis. The eastern end of the Range does have low levels of a type of mineral fiber called an elongate mineral particles or EMP. These are of the amphibole type and they're also present at low levels in air samples.
2. The cause-of-death investigation revealed that three important diseases are present in numbers that are higher than expected. These include mesothelioma, lung cancer and cardiovascular disease. Mesothelioma was present nearly 200% higher than expected. Lung cancer was higher than expected by 20% and heart disease by 11%. All three of these occurred elevated in each of four geologic zones of the Iron Range, so designated by their different mineralogy. The latter two diseases are important given their high prevalence in the cohort. Other factors besides workplace exposures are likely involved at least in part, for these two diseases.
3. A cross-sectional screening of current and former workers and spouses revealed that 6% of workers had evidence for non-cancerous lung disease involving the lung substance (parenchyma), which can occur most commonly from silica or mixed dust exposure. Workers also had evidence of pleural abnormalities. These were present in 17% of those screened, part of which is likely to be related to exposure to asbestiform EMP. Spouses did not appear to have elevations in either of these two lung conditions, suggesting the lack of dust-related diseases in the non-working Range population.
4. Current exposures measured in the workplace are felt to generally be below exposure guidelines, as measured by the approach considered relevant by the federal government (NIOSH 7400 method). Analysis by the NIOSH 7402 method reveals that amphibole EMP measures are well-controlled and lower than those measured by the 7400 approach. Past exposure estimates from ore processing

were anchored by current measures, but were more difficult to estimate further back in time, as were estimates of commercial asbestos use.

5. The study of mesothelioma cases and controls also utilized the NIOSH 7400 counting method and identified EMP over 5 microns in length, with a length to width ratio of 3:1. This method doesn't distinguish amphibole vs. non-amphibole or asbestiform vs. non-asbestiform EMP. This assessment revealed that the longer people worked in the taconite industry, the higher their risk for mesothelioma. The risk went up by about 3% per year worked in those with more, compared to those with less, work time. The absolute risk within the cohort is small, given the rarity of this disease.

6. Mesothelioma risk was associated with more exposure to long EMP (over 5 microns) over time. The magnitude of this risk appeared small, but was notable with sufficient duration of work at higher exposure levels. This risk could be influenced by the presence of commercial asbestos known to have been used in the industry. Additional context to this finding will depend on analyses that assess the relationship of mesothelioma to short EMPs, to silica and to respirable dust exposures and upon data generated after completion of the other study components.

Taconite Workers Health Study
General Update Information

The Taconite Workers Health Study is in the 5th year of investigation. All components have progressed satisfactorily and are on target with projected time and budgetary matters. The critical work needed to complete the five initial project areas will occur during the current year. This report will summarize the each project's status as of April 12, 2013. Conclusions are stated at the end of each component. Final conclusions will be made at the time of the final report, when all information from the studies is available.

All on-site exposure testing has been completed. Around 1300 on-site occupational samples were taken with various methodologies, including samples that have been analyzed using electron microscopy including the NIOSH 7402 methodology and the ISO 13794. The latter results will be the topic of a subsequent report. The on-site samples have been combined with historical samples to obtain insights into past workplace dust levels. For elongate mineral particles (EMP), measured by the NIOSH 7400 method, a job-exposure matrix has been developed. This used the current samples as an anchoring point, with historical measures taken by the companies or by the Mining Safety and Health Administration (MSHA), and with work histories to estimate previous exposures for all major jobs. The same approach will be completed for exposures to short EMP, silica and respirable dust exposures. These exposures will then be integrated into the human epidemiology studies. NRRI has completed the community sampling process. Those samples have been finalized and lake sediment analyses are near completion.

The mortality and incidence studies previously reported the number of deaths from mesothelioma and lung cancer. The mesothelioma study has completed the analysis of long EMP exposure, with other exposures currently being analyzed. The lung cancer study will be completed later this year. The Respiratory Health Survey (RHS) analyses will also be completed this year. All of these studies have been in the process of integrating exposure information, the critical part of obtaining insight into the role of dusts from taconite operations in respiratory disease.

This report addresses the assessment of mesothelioma as it relates to exposures to long EMP exposure, as measured by the NIOSH 7400 approach. This is the type of exposure that was felt most likely to be linked to mesothelioma. Although this is an important analysis, it is not the only analysis of exposures that could be linked to mesothelioma. Others will include short EMP, silica and respirable dust. Although this report contains the most information on the potential work-related aspects of mesothelioma in this work group to date, there will be additional, important context on mesothelioma provided by the completion of the other epidemiology studies mentioned above. We anticipate additional insight after all of the work has been completed. The final report is planned for the end of 2013, which will be the last report issued to the legislature.

An updated estimate of when each study component will report findings has been assembled and is shown below.

Minnesota Taconite Workers Health Study Timeline

This timeline is an estimate based on current information and is subject to change as new information becomes available.

Component	Study Purpose	Status	Report Expected
Occupational Exposure Assessment	To understand current and historical worker exposure to components of dust from taconite operations	• On-site measurements complete • Historical measurements gathered • Engineering controls assessed • Data have been integrated into mesothelioma case-control study • Data to be integrated into remaining epidemiology studies	Completed
Mortality (cause of death) Study	To compare the causes of death among the taconite workers to the general population	• Causes of death identified • Data quality control and verification completed • Data analysis done for general mortality	Completed
Incidence Study (Mesothelioma, Lung Cancer and Non-malignant Respiratory Diseases Sub-studies)	To compare the incidence of diseases of interest among the taconite workers to other groups or the general population	• Long EMP analysis completed • Data verification and quality control done • Data integration in progress for lung cancer	2013

		• Other exposures in progress	
Respiratory Health Survey of Taconite Workers and Spouses	To estimate non-malignant respiratory disease in workers and their spouses	• Screening complete • Exposure data integration in progress	2013
Environmental Study of Airborne Particulates	To evaluate the effects of past and present taconite mining emissions on community air quality	• Community sampling complete • Detailed analyses in progress • Sediment study in progress	2013

Study Issues

Investigations of the case-control, mortality and cross-sectional types have different strengths and weaknesses. Those will be reviewed as study components become completed. The case-control study of mesothelioma (involving long EMP) will be addressed in this report.

Overall, the mesothelioma case-control analysis is the first study in this industry to include detailed exposure estimates. It has the advantage of including any case identified in the state by the Minnesota Cancer Surveillance System (MCSS) as well as cases identified on death certificate from around the United States. The combination of these two sources is likely to result in the identification of a high percentage of the total actual number of cases. It is also the first investigation to evaluate exposures to EMP. The study team felt that this exposure was the most important to assess, given the known facts concerning EMP disease risk. For example, exposure to EMP of the asbestiform type (commonly referred to as "asbestos") has a well-established association with mesothelioma risk, which generally is related to the amount and duration of exposure. On this basis, it was an important initial exposure to consider. The measurement used was a traditional one, the NIOSH 7400. This is the measurement approach recognized as most relevant by the federal government agencies. It measures all EMP over 5 microns, and with a 3:1 aspect ratio, but doesn't differentiate amphibole or asbestiform types of EMP. Other exposures that will be reported later this year include shorter EMP, silica and respirable dust. These will utilize different measurement approaches.

Even though this assessment likely has a high proportion of the total cases, the number of cases (80) is still considered a relatively small study. The study size is an important potential problem, in that statistical relationships to be explored will have some limits in ability to find associations that may truly exist.

Another type of problem with this study is the potential for exposures to be misclassified. This means that the true or actual exposure that a worker experienced may be inaccurately estimated. Much of this is due to the incompleteness of work history records which are used to estimate past exposures and which were obtained from the companies. In general, this was more of a problem with exposures that occurred in the more distant past. There was some variation in the detail from these types of records throughout the Iron Range. This type of error may result in inaccurate assessment of risk and may either increase or decrease the actual or true risk. Even though this potential error exists, the investigators feel that the historical exposure estimates were reasonable approximations. An important feature of these estimates is that they were based on around 1300 "current" exposure samples that were taken on the premises of the existing mining facilities. These current samples have an anchoring effect for estimating historical exposures.

An important exposure that these investigations will not be able to quantify is the exposure from commercial asbestos (EMP of the asbestiform variety). The construction of the initial taconite mining and processing facilities occurred in the mid-1950s. This is a time when commercial asbestos products were used quite widely, due to their excellent insulation and fire retardant properties. The use preceded important health investigations that identified risks related to certain types of asbestos exposure, which were reported in the subsequent decade. In the 1960s to the 1980s many important studies were able to demonstrate a strong link with different types of asbestos (EMP of the abestiform type), some of which was used commercially, and mesothelioma, lung cancer and non-malignant respiratory disease. Unfortunately, some of the health insights occurred after the installation of asbestos materials widely used in construction.

I. Occupational Exposure Assessment
A Comprehensive Assessment of Exposures to Elongate Mineral Particles in the Taconite Mining Industry

The three main goals for the exposure assessment effort related to elongate mineral particles (EMP) were:

1. Assess present-day exposures of workers to EMP in dust from taconite operations in relation to current occupational exposure limits.
2. Assess historical exposures of workers to EMP in the taconite industry for the time period 1955-present to evaluate the relationship between exposures and health effects.
3. Evaluate existing practices and methods to reduce worker exposures in this industry and, where appropriate, suggest improvements in these methods.

Current Exposure Characterization

This section describes our approach to comprehensively assess current exposure levels to total and amphibole EMP in the taconite mining industry. The term "total EMP" refers to any mineral particle with a minimum aspect ratio of 3:1. This would include the chrysotile type of asbestos, although the NIOSH 7400 approach is unable to differentiate this type. The term "amphibole EMP" refers to a subset of double chain silicate minerals (riebeckite (crocidolite), cummingtonite/grunerite (amosite), anthophyllite, tremolite, and actinolite) that can be asbestiform or non-asbestiform (NIOSH, 2011). Hornblende is not included in this definition. Although the chemical composition of asbestiform and non-asbestiform EMP can be the same, they differ in their “habit” or morphology.

The first and most critical step of our exposure assessment involves the classification of workers into similar exposure groups (SEGs). A detailed assessment of current exposure levels was carried out. This served two purposes, (a) to compare the current exposure levels with occupational exposure limits for EMP, and (b) to understand exposure variability between and within SEGs.

The mineralogy of the Mesabi Iron Range changes from east to west, with the three taconite mining companies owning five operating mines in the western and one in the eastern zone. Amphiboles are mainly detected in the east. Phyllosilicates such as minnesotaite, greenalite, and stilpnomelane, which are not regulated as asbestiform or amphibole EMP, dominate the west (McSwiggen and Morey, 2008; Zanko *et al*., 2008). The amphiboles in the east are principally of the cummingtonite-grunerite series and include some actinolite (ferroactinolite). The silicate minerals that form EMP have different morphologies in the east; however, the vast majority of the amphiboles are non-asbestiform EMP (Wilson et al., 2008; Zanko et al., 2008). Due to the distinct metamorphic mineralogical characteristics of the eastern versus the western zones, workers in the two zones may potentially be exposed to different types of EMP.

METHODS

Using information on the tasks and processes related to these job titles obtained from MSHA and industrial hygiene and human resources databases maintained by the three companies currently operating (U.S. Steel, Cliffs Natural Resources, Arcelor Mittal), we created a set of 28 SEGs. These were created using the subjective professional judgments of the lead industrial hygienists at the three mining companies. Personal exposure assessment was conducted across all operating mines in both zones of the Mesabi Iron Range beginning in January 2010 and ending in May 2011. The purpose of the personal sampling was to assess the current levels of worker exposures to EMP in the taconite mining industry. Two workers per SEG were selected for personal EMP sampling in the eastern zone and each worker was sampled during three different shifts. In the western zone, approximately eight workers per SEG were chosen, with each worker being sampled on three different shifts. For the SEGs in the western zone, the eight workers were drawn from five different mines. This design allows us to study exposure variability between and within SEGs, between and within mines, and between and within zones.

Each consenting participant wore a personal sampler with a mixed cellulose ester (MCE) membrane filter and an attached sampling pump over three different work shifts. The personal filter samples were analyzed by phase contrast microscopy (PCM) using NIOSH Method 7400, which identifies all EMP longer than 5 µm with an aspect ratio ≥ 3.0. While this method can be used to count the numbers of EMP, it cannot differentiate between amphibole and non-amphibole or asbestiform and non-asbestiform EMP.

In contrast, the NIOSH Method 7402 enables the detection of EMP with much smaller widths and is used to identify EMP that meet the PCM counting criteria. This method includes expanded characterization of elemental composition with energy dispersive X-ray analysis (EDXA) and crystalline structure by selected area electron diffraction (SAED). Therefore, it can identify EMP that may be amphiboles or chrysotile. While laboratories typically claim to distinguish between asbestiform and non-asbestiform EMP using transmission electron microscopy (TEM), a more conservative assessment is that this method can identify amphibole versus non-amphibole EMP (in addition to chrysotile EMP), especially in the heterogeneous mixture of particles found in the taconite industry in Minnesota. While all personal EMP samples were analyzed using NIOSH 7400, 18% of samples were also analyzed using NIOSH 7402.

Table 1. Number of personal samples by mine and mineralogical zone

Zone	Mine	Workers	Samples analyzed by PCM[a]	Samples analyzed by TEM[b]
Eastern	A	56	276	102
Western	B	34	200	34
	C	38	221	40
	D	34	203	34
	E	48	273	48
	F	22	130	22
Total		232	1303	280

[a] Personal samples analyzed by NIOSH 7400 phase contrast microscopy (PCM), counting all EMP with length > 5 μm and aspect ratio > 3.
[b] Personal samples analyzed by NIOSH 7402 transmission electron microscopy (TEM), counting only amosite, non-amosite, and chrysotile EMP with length > 5 μm and aspect ratio > 3.

RESULTS

The box-plots in Figure 1 show the total EMP concentrations by SEG across all mines. The concentration of total EMP in mine A tended to be higher than in the mines in the western zone. The amphibole EMP concentrations by SEG across all mines are illustrated in Figure 2. Note that the y-axis scale (EMP concentration) for amphibole EMP extends almost 10-fold lower than that for total EMP. Figure 2 shows that, with a few exceptions, the concentrations of amphibole EMP were below the NIOSH Recommended Exposure Limit (REL) of 0.1 particles/cm^3 for EMP.

This is the first study to report on the concentrations of total and amphibole EMP in the taconite mining industry. Overall, higher concentrations of total EMP were found in mine A. The lowest concentration of total EMP was found in mine F. The concentrations of amphibole EMP were much less than the concentrations of total EMP, indicating that amphibole EMP are not major components of taconite EMP. In general, the amphibole EMP concentrations were lower than the REL, except for a few SEGs in mine A. While some individual measurements exceeded the REL, the arithmetic means of the amphibole EMP exposures for each SEG were below the REL in each mine.

Overall, the exposure levels were higher in the eastern zone than in the western zone. The differences in the exposure levels support the idea of considering the SEGs in the eastern and western zones separately, and are consistent with the geological differences between the zones. For both total and amphibole EMP categories, the SEG with the highest exposure level in the eastern zone was Operating technician. In the western zone, the Pelletizing operator and Crusher operator were the SEGs with the highest exposure levels for total and amphibole EMP, respectively. More than half of the SEGs had significantly different levels of total EMP exposures between the eastern and western zones. This analysis provides empirical evidence that the geological differences between the two zones are reflected in EMP exposures.

The highest concentration in each mine was observed not only in departments directly involved in the mining process (Mining, Crushing, Concentrating, and Pelletizing departments), but also in the Shop (mobile) department, suggesting that the non-mining process may be similarly affected. The employees in the Shop (mobile) department work at various places in the mine, rather than at specific workstations. Therefore, the characteristics of the exposure levels for this department can be similar to those found in the mining process, and these SEGs potentially can have high exposure levels.

CONCLUSIONS

For some SEGs in several mines, the exposure levels of total EMP were higher than the REL. However, the total EMP classification does not refer to asbestiform or corresponding non-asbestiform analogs alone, because the NIOSH 7400 cannot differentiate between these. The concentrations of amphibole EMP were well-controlled across all mines and were much lower than the concentrations of total EMP, indicating that amphibole EMP are not major components of taconite total EMP.

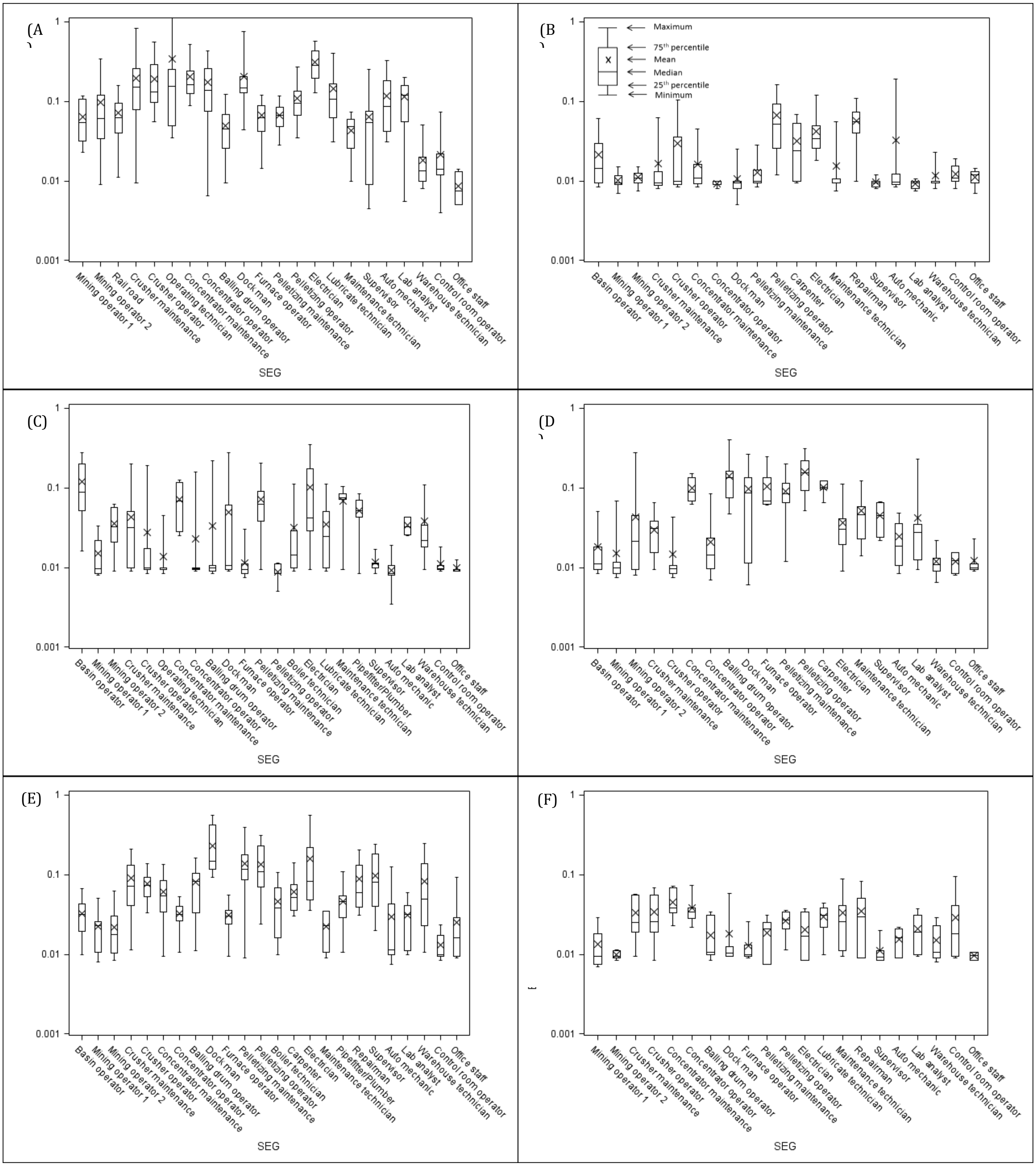


Figure 1. Box plot of total EMP for each SEG in mines A-F

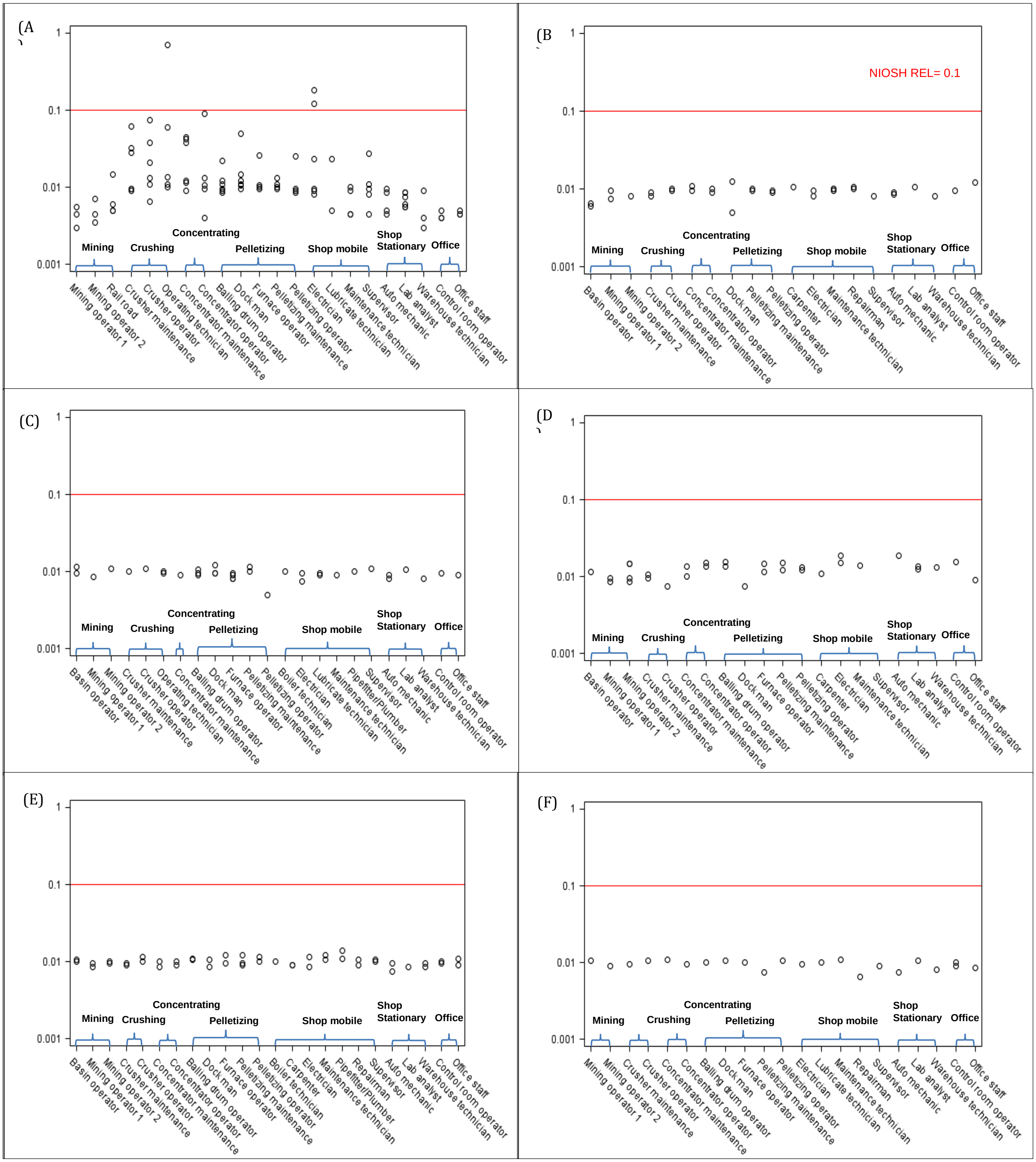


Figure 2. Scatter plot of amphibole EMP for each SEG in mines A-F (the horizontal line indicates the NIOSH REL for EMP = 0.1 particles/cm^3

Historical Exposure Reconstruction

CONSTRUCTION OF HISTORICAL EXPOSURE DATABASE

Exposure reconstruction was conducted using historically available data as well as data collected during this study (referred to as present-day data). Historical exposure data were extracted from three sources: (a) the mine data retrieval system maintained by MSHA, (b) data collected in a previous UMN study conducted in 1986 by Dr. John Sheehy as part of his doctoral thesis, and (c) the internal databases of three currently operating taconite mining companies in the Mesabi Iron Range (U.S. Steel, Cliffs Natural Resources, and Arcelor Mittal). For the purposes of this study, only the data for total EMP were integrated into the retrospective exposure database. We could not detect any amphibole EMP in the five mines in the western zone in our present-day measurements and there were no historical measurements of amphibole EMP available. Table 2 shows the number of historical and present-day data points (based on the NIOSH 7400 method) in each SEG by mine. This includes the six currently active mines (Northshore, Hibbtac, Utac, Keetac, Minntac, and Minorca) and one inactive mine (LTV). The LTV mine in Hoyt Lakes closed in 2001; therefore, no present-day measurements were available. In total, the historical dataset for taconite EMP consists of approximately 682 data points, and exposure data are missing for many time periods.

DATA ANALYSIS

After combining the historical and present-day data into a master database, we used two different models to impute the missing EMP exposures for any combination of SEG, year or mine. The first approach was to use the quintile regression model (time-varying exposure model) and the second approach was to use the median of both historical and present-day EMP data (constant exposure model). Statistical significance was defined as p-values of 0.05 or lower. All statistical analyses reported here were conducted using SAS Version 9.3 (SAS Institute, Cary, NC, USA).

Quintile regression analysis, which is not as sensitive to outliers or the assumption of a normal or lognormal distribution, was used to reconstruct the exposure for each SEG by mine for each year. We used one year as the time interval for the time frame of our study (1955-2010), treating 1955 as year 0.

Our exposure matrix includes 7 mines, 2 in the east, 5 in the west, and 28 SEGs, covering 56 years between 1955 and 2010. The exposure matrix consists of 10976 cells (7 x 28 x 56), each of which was filled with an NIOSH 7400 EMP exposure estimate. For each SEG exposure matrix, we used separate models to estimate the 25^{th}, 50^{th}, and 75^{th} percentiles for each mine.

The resulting exposure matrix was combined with each worker's employment history to estimate a cumulative exposure. These cumulative exposures are used for the exposure-response assessment in the epidemiological analyses.

Table 2. Number of EMP observations by mine in historical and present-day databases

SEG	Northshore		Hibbtac		Utac		Keetac		Minntac		Minorca		LTV [a]
	H [b]	P [c]	H	P	H	P	H	P	H	P	H	P	H
Basin operator	. [d]	.	0 [e]	12	0	12	0	6	0	12	.	.	0
Mining operator 1	31	6	6	12	14	6	7	12	22	12	14	6	3
Mining operator 2	29	9	8	6	6	6	6	24	25	12	14	5	14
Rail road	0	6	.	.	.	.	.	.	.	.	.	.	2
Crusher maintenance	6	22	0	12	3	12	0	12	0	12	1	5	32
Crusher operator	81	22	6	11	24	11	4	6	19	10	33	6	.
Operating technician	2	10	.	.	4	12	1	0	.	.	.	.	0
Concentrator maintenance	0	10	0	12	0	6	0	12	0	12	0	6	.
Concentrator operator	13	22	4	12	4	11	4	12	29	12	6	6	3
Balling drum operator	0	18	.	.	0	9	0	12	3	12	0	6	0
Dock man	2	10	0	11	1	12	0	6	0	11	1	6	0
Furnace operator	3	9	3	0	0	18	0	12	10	9	1	6	0
Pelletizing maintenance	0	12	0	12	0	12	0	12	0	12	0	5	.
Pelletizing operator	1	11	7	11	3	5	3	12	22	11	3	6	2
Boiler technician	.	.	.	.	0	6	.	.	1	12	.	.	.
Carpenter	4	0	0	6	.	.	0	6	0	12	.	.	0
Electrician	5	12	0	12	0	12	0	12	0	12	0	6	.
Janitor	6	0	3	0	4	0	.	.	12	0	.	.	0
Lubricate technician	0	6	1	0	0	18	.	.	.	.	0	6	0
Maintenance technician	25	9	2	17	14	5	0	6	8	7	2	6	1
Pipefitter/Plumber	11	0	.	.	0	6	.	.	3	12	.	.	2
Repairman	.	.	0	12	.	.	5	0	1	10	0	6	.
Supervisor	1	15	0	5	0	5	0	6	0	11	1	6	0
Auto mechanic	0	10	0	11	12	11	0	5	0	12	1	6	8
Lab analyst	0	24	0	6	0	6	0	12	0	6	0	6	0
Warehouse technician	1	8	0	6	0	5	0	6	0	12	0	6	0
Control room operator	0	9	0	6	0	6	0	6	0	12	0	12	3
Office staff	0	6	0	5	0	6	0	6	0	12	0	6	0
Total N=	221	266	40	197	89	218	30	203	155	267	77	129	70

[a] LTV does not have present-day measurement, [b] Historical data, [c] Present-day measurement, [d] SEGs are not present, [e] SEGs do not have measurement

RESULTS

A substantially higher percentage of NIOSH 7400 EMP data points came from the present-day measurements (65%), collected during 2010-2011, than from the historical data (35%), which covered the years 1978-2009. Eighteen percent of the present-day EMP samples were randomly chosen and analyzed for amphibole EMP using NIOSH 7402; no measurements for amphibole EMP existed in the historical database. Therefore, conversion factors (CF) from total EMP (NIOSH 7400) to amphibole EMP (NIOSH 7402) were calculated using the present-day data. Specifically, a CF was calculated for each SEG by mine. Because we did not collect present-day data at the LTV mine, which is currently closed, we used the CF from the Northshore mine, which has similar geological characteristics.

Figure 3 shows the exposure levels for each year in each SEG in Northshore mine using two different models. First, the exposures were estimated using a time-varying exposure model with quintile regression to estimate the exposure estimate for each year in each SEG in each mine (solid line). Second, we used a constant exposure model based on the median of actual exposure data (dashed line). The median value for each SEG by mine was calculated to represent the exposure estimate for all years (1955-2010). An example comparison of the time-varying and constant exposure models for the Northshore mine is provided in Figure 3. The two models predict similar values for present day exposure estimates, when most of the actual data were obtained. However, the exposure estimates of the two models differed by a factor of as much as 10 during the earliest time periods.

Figure 4 shows the exposure estimates for the NIOSH 7400 total EMP definition as well as NIOSH 7402 amphibole EMP definition for each SEG by mine between 1955 and 2010. Because the amphibole EMP using NIOSH 7402 is a fraction of the total EMP using NIOSH 7400, the level of exposure estimates for amphibole EMP are significantly lower. Since the historical estimates for amphibole EMP are predictions based on conversion factors calculated from present-day data, some of these estimates could be lower than the limits of detection of the NIOSH 7402 method. In such instances, the estimates were bounded at the limit of detection.

The resulting exposure matrix was combined with employment history of each worker in the case-control analysis to estimate a cumulative exposure for total and amphibole EMP for each worker. The cumulative exposure divided by the total years of employment for the worker is the worker's average exposure over his/her career. Figure 5(a) shows that ~60% of the workers in the mesothelioma case control study had lifetime average total EMP exposure levels greater than the occupational exposure limit (OEL: 0.1 EMP/cc) and Figure 5(a) shows that ~8% of the workers had amphibole EMP levels exceeding the OEL.

Assessment of Exposure Controls

In these surveys, we also evaluated the efficacy of existing exposure control measures including primary engineering controls (enclosures, ventilation, and particle collectors), work practice and administrative controls, and personal protective equipment. We toured the control systems of all the mines. We measured air velocity into selected enclosures and in selected ducts in four mines, and have compared our findings to the American Conference of Government Industrial Hygienists (ACGIH) ventilation guidelines. In general, the types of installed controls match ACGIH guidelines, although the velocity into some enclosures is lower than recommended. We have arrived at the following conclusions: (a) Engineering controls are appropriate for normal operations; (b) Miners may be exposed to elevated dust levels when making repairs or performing maintenance; (c) Atypical conditions may lead to significant exposures, and respiratory protection should be used under atypical conditions that contribute to excessive exposures. However, anticipating atypical conditions that require respiratory protection is a challenge.

Figure 3. Panel comparing time-varying and constant exposure models for each SEG at Northshore mine. The solid line is the quintile regression model and the dashed line is the constant exposure model. Both historical and present-day measurements are plotted.

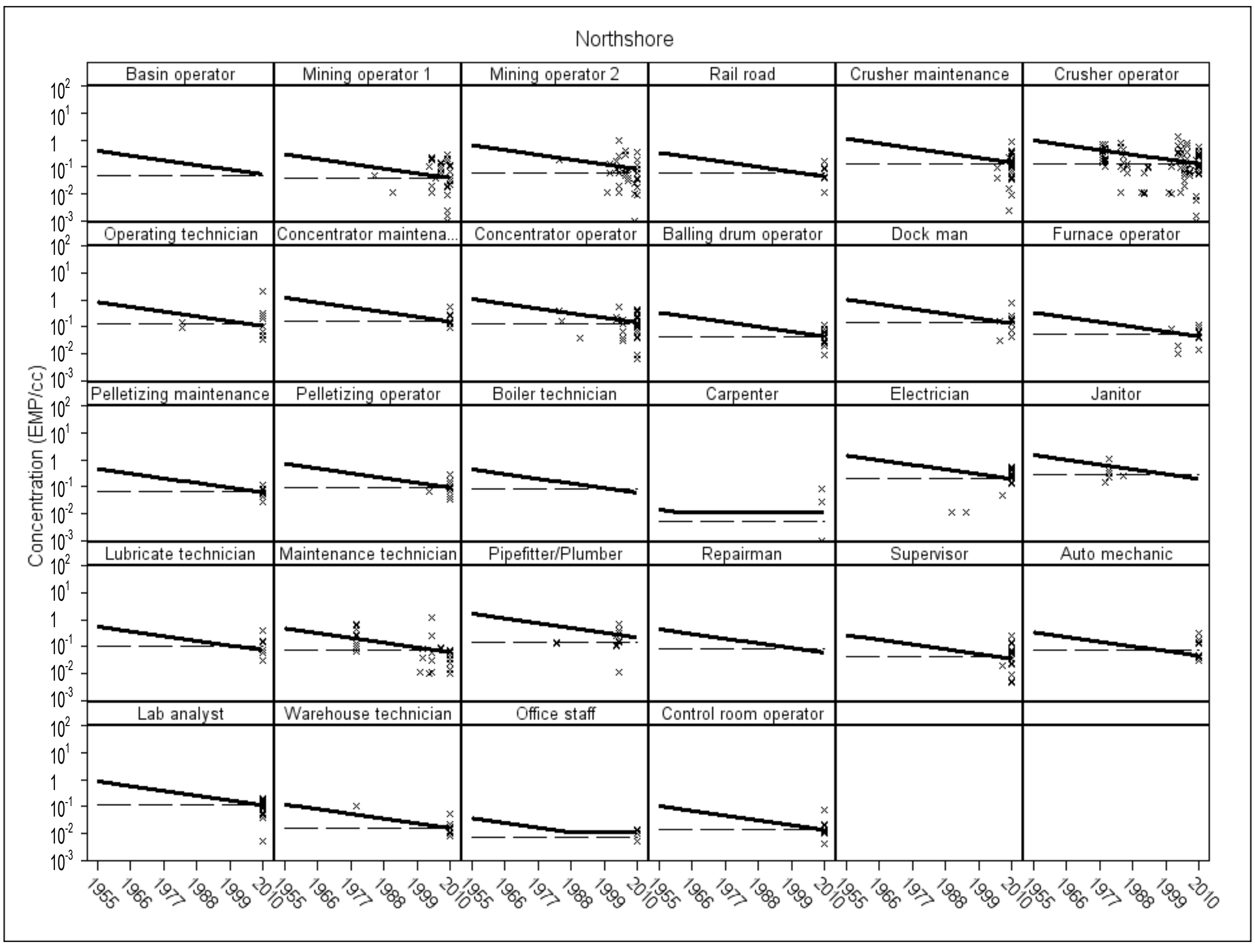


Figure 4. Panel comparing the time-varying exposure model for total EMP (based on NIOSH 7400) and amphibole EMP (based on NIOSH 7402) for each SEG at Northshore mine. The solid line = NIOSH 7400 EMP; and the dashed line is for amphibole NIOSH 7402 EMP. Both historical and present-day measurements based on NIOSH 7400 are plotted.

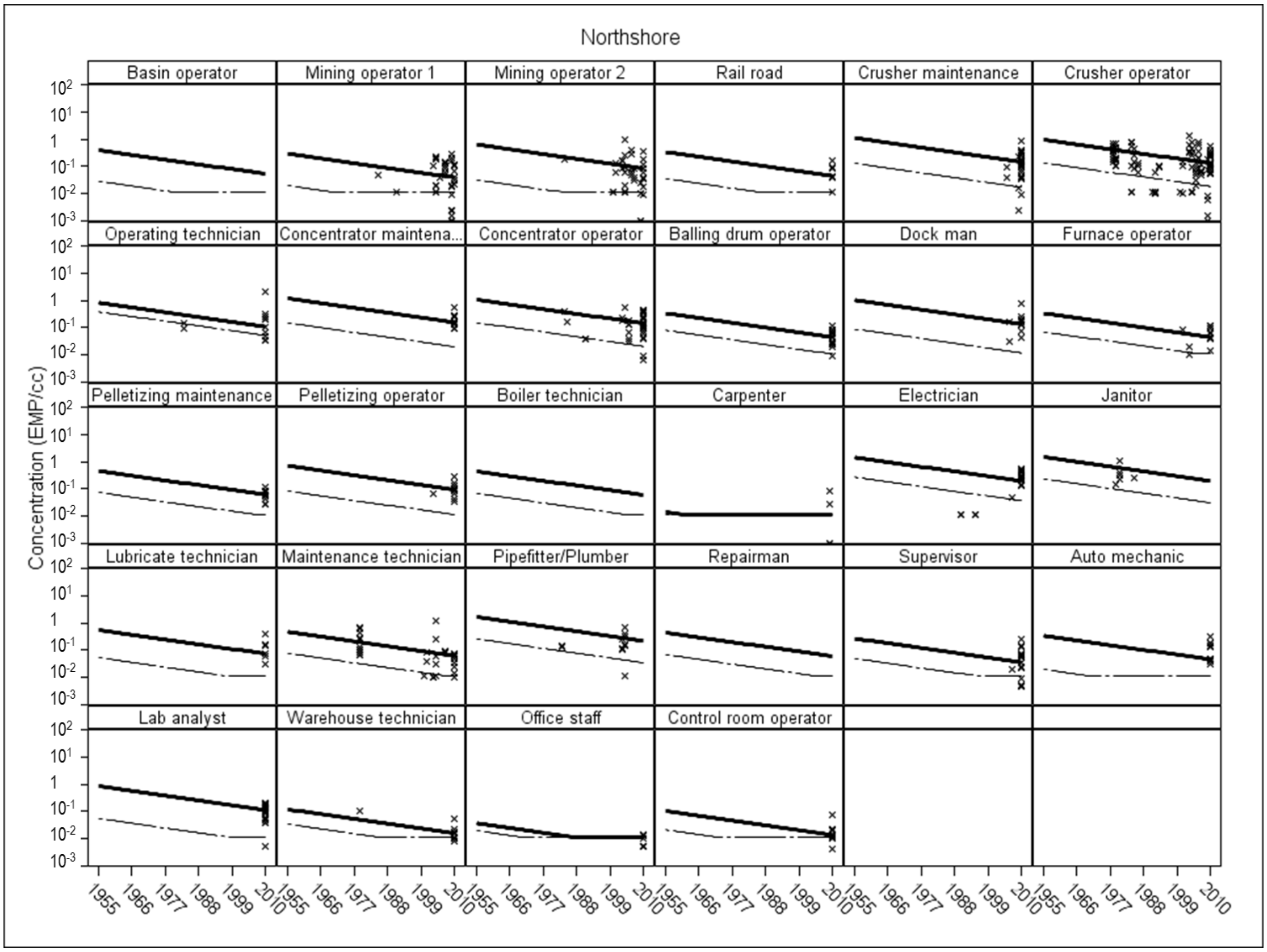
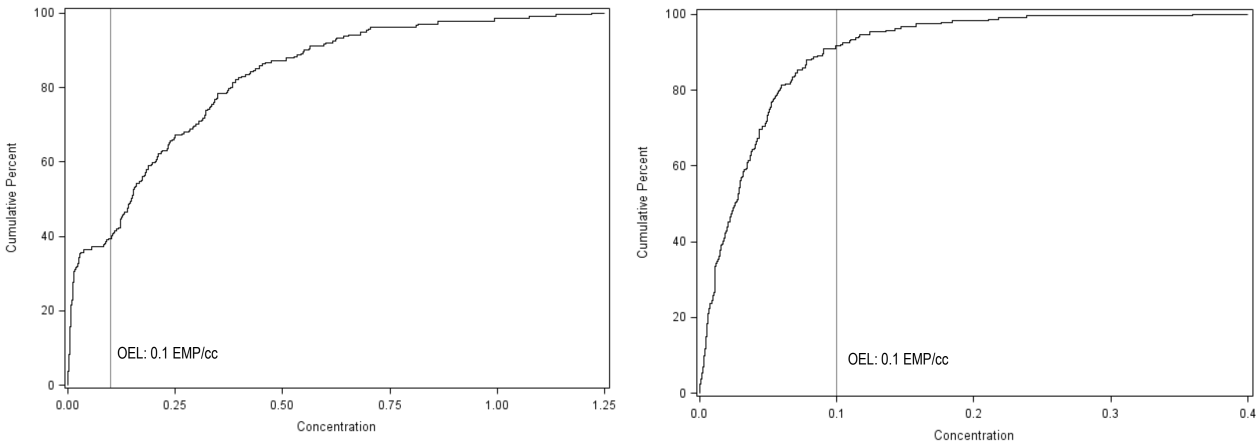


Fig 5. Cumulative distribution of the average exposure concentration using both time-varying and constant exposure models for cases and controls (n=241) for (a) NIOSH 7400 and (b) NIOSH 7402



(a) NIOSH 7400 (b) NIOSH 7402

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II. Mortality Study

Taconite mining and processing creates a combination of exposures that include EMP 5 microns or more, EMP under 5 microns, silica, respirable dust and cleavage fragments of various dimensions. There is disagreement as to which sized particles pose the greatest health risk. Initial health studies in this region began in the 1970s and 80s but have been limited in scope with small sample sizes, relatively short follow-up times, and limited exposure data. In 1997 the Minnesota Department of Health (MDH) reported an apparent excess of mesothelioma cases among men in the northeastern region of Minnesota. The extent to which mining-related exposures contributed to this excess in mesothelioma was not explored by MDH. To date, few studies have explored the health risks from exposures in this industry and no studies have examined the overall health of all taconite mining employees across the industry.

The purpose of this mortality study is to characterize the overall health of taconite industry workers in Minnesota by comparing death rates in taconite workers to the rates seen in the general population. Characterizing the mortality patterns of taconite workers provides a better understanding of overall health concerns for the population, including occupational and non-occupational exposures.

METHODS

The protocol for this study was reviewed and approved annually by the Human Subjects Committee of the UMN Institutional Review Board. All data in this study were held under strict control for the protection of confidentiality and privacy.

Study population

This study used a retrospective cohort design. The study cohort was enumerated in the early 1980s as part of the Mineral Resources Health Assessment Program (MRHAP). Company employment records were gathered from 7 mines in operation in 1983 (US Steel Corporation, Hanna Mining Company, Pickands-Mather and Company, Reserve Mining Company, Eveleth Taconite Company, Inland Steel Company, and Jones and Laughlin Corporation). This cohort is referred to as the MRHAP cohort and consisted of approximately 72,000 individuals who had ever worked in the mining industry. The cohort included taconite workers and those who had worked in hematite mining operations. In order to capture workers who were most likely to have been working in the mines after taconite mining began in the 1950s, this analysis limited the cohort to those born in 1920 or later. Cause-specific mortality rates were available beginning in 1960, thus those who died before 1960 were not included in this analysis.

Work history

The volume and complexity of the work history records prevented full record abstraction for the entire population. To summarize the work history for this study all available work records from the companies that made up the MRHAP cohort were reviewed to abstract the first and last dates of employment at the specific company. In many cases, the work records contained start dates but were missing end dates. In this case, the last date of activity on record was used as the end date to calculate duration of employment. Total duration of employment for each company record was estimated using the end date minus the start date and the total years of employment in the iron mining industry was a sum of jobs held at all companies.

Vital Status Determination

The vital status of cohort members was ascertained through December 31, 2007 using several sources including the Social Security Administration (SSA), the National Death Index (NDI), MDH, and other state health departments across the United States. The records of individuals identified from the work histories were sent to the SSA and were returned with a vital status of deceased, alive, or unknown, with the state of death and date of death identified for decedents. Death certificate data from MDH provided the cause of death for workers who had died in Minnesota. For those who died outside of Minnesota, vital status and causes of death were provided by NDI for those who died in the year 1979 or later. For workers who died before 1979, death certificates were obtained from the state health departments of the state where the individual died. A certified nosologist reviewed death certificates and coded causes of death to the International Classification of Disease (ICD) version in effect at the year of death. The underlying cause of death was used for the mortality analysis.

Sex verification

A preliminary analysis determined that the classification of sex of cohort members using the work history records were not entirely accurate and often missing. To correct these records additional sources were used to help verify the sex of individuals in the cohort. For individuals with a cancer diagnosis or who had been identified as deceased, the sex was recorded from the Minnesota Cancer Surveillance System (MCSS), the National Death Index, Minnesota Department of Health (MDH) death records, or the individual death certificate. The remaining sources included the following: Erie Mining company records, MDH birth certificates, abstraction from the MRHAP work records, Minnesota and Wisconsin driver's license data records, and a commercial skip-tracing vendor that aggregates public data from multiple sources. Workers were matched to these sources and sex was assigned to the worker in a hierarchical system with the most reliable sources filling in sex information first.

Analysis

The objective of this analysis was to compare mortality rates in the iron mining workers cohort to the general population by estimating standardized mortality rates (SMRs). Person years for each worker were computed from the start of employment until the date of death or end of the follow-up period (December 31, 2007). The expected number of deaths was calculated by applying age, sex, calendar time, and cause-specific mortality rates of the Minnesota population to the person-year observations of the study population. Standardized mortality ratios were obtained by computing the ratio of the observed to the expected number of deaths for the overall mortality and specific causes of death. Confidence intervals were calculated based on an assumed Poisson distribution. All SMRs were estimated using the Life Table Analysis System (LTAS) 3.0 software. The SMR gives a relative comparison of the cause specific rate of death in the mining cohort to the state. An SMR above 1 means there are more deaths than expected. For example an SMR of 1.10 means there are 10 percent more deaths in the cohort that are expected. An SMR below 1 means there are fewer than expected.

RESULTS

The final population for analysis consisted of 44,161 people born 1920 or later who had ever worked for the iron mining companies in Minnesota. From this population a total of 13,318 were determined to be deceased as of December 31, 2007. Of those determined to be deceased, the cause of death could not be located for only 254 decedents yielding a capture of 98.1 percent of the causes of death. The population was predominately male (93%) (Table 1). Approximately 40 percent of the cohort had documented employment of more than five years (Table 1). Nearly 30 percent of the cohort worked for less than one year, but this number included a number of people with incomplete work history records.

There were 3,969 deaths from all cancers combined, including 1,400 from lung cancer and 45 deaths from mesothelioma. Deaths from mesothelioma were only available from 1999 forward when a specific ICD code for mesothelioma was adopted in ICD version 10. A total of 3,871 deaths from heart disease and 883 deaths from nonmalignant respiratory diseases were observed. Only 3 deaths from asbestosis and one from silicosis were reported (Table 2).

Compared to the population of the state of Minnesota, rates of death for all causes combined (SMR=1.05, 95% CI=1.03-1.06), all cancers combined (SMR=1.06, 95% CI=1.03-1.09), lung cancer (SMR=1.20, 95% CI=1.13-1.26), mesothelioma (SMR=2.90, 95% CI=2.11-3.87), and heart diseases (SMR=1.11, 95% CI=1.08-1.15) were elevated in the study population of people who worked in the taconite industry (Table 2).

When restricting the population to workers with at least one year of documented employment we observed similar increases in the SMRs for these diseases (Table 3). The rates of death for all other causes were generally at or below the expected rates for Minnesota.

The geology of the Iron Range varies by location and is classified into 4 zones, with Zone 1 in the western end of the range, Zone 4 in the east, and 2 and 3 are transition zones. The details of the geologic differences are presented in section V, Environmental Study of Airborne Particulates, of this report. Briefly, the geology of the iron range varies by mineral composition and the eastern end of the range includes minerals that are classified as amphiboles. The minerals in the western end of the range are not likely to be amphiboles. The companies included in this study had operations in Zones 1, 2, and 4. An analysis restricted by ever employed in one of the zones, and ever employed in the zone for at least a year indicated that the rates of mesothelioma and lung cancer death were elevated in all three of these zones, when compared to the Minnesota general population (Table 4).

The SMRs for lung cancer were elevated over time beginning about 1985. Prior to 1985 the SMRs indicated the death rates in the iron mining population were similar to the general population (Table 5). The SMRs for mesothelioma were elevated from 2000 forward; keeping in mind mesothelioma was not specifically identified on death records prior to 1999.

DISCUSSION

The iron mining worker population of northeastern Minnesota has higher rates of death from all causes combined, all cancers combined, lung cancer, mesothelioma, and heart disease. The higher death rates for all causes combined and all cancers combined are a function of the excess mortality from lung cancer and heart disease as they are major causes of death for the overall population. While lifestyle factors cannot be ruled out, occupational exposures in the iron mining industry may have an important role in these deaths, particularly for mesothelioma.

Mesothelioma is a sentinel disease for asbestos exposure, which is known as the primary cause. A general assumption about mesothelioma is that cases will have a history of exposure to asbestos. Like many industries in the early to mid-20th century the taconite industry used asbestos in buildings and some operations. It is quite likely that asbestos was used in all facilities in the taconite operations. Unlike other industries that used asbestos, the taconite operations generated mineral dust exposures that included EMPs with a range of sizes. The nearly three-fold increase in mortality rates from mesothelioma raises the obvious suspicion about asbestifrom EMP exposure; however other exposures unique to the taconite industry could be important. Taconite workers have exposure to other EMP (thought to be non-asbestiform). These types of EMP have not been well-studied. These will be explored further in the mesothelioma and lung cancer incidence (case-control) studies.

The rates of lung cancer were about 20 percent higher than the general population of Minnesota. The single most important cause of lung cancer is cigarette smoking. While smoking likely contributes to this excess risk of lung cancer among taconite workers, occupational exposures cannot be ruled out. In addition to smoking, the other known causes of lung cancer include occupational exposures such as silica, asbestos, radon, and chromium. The mortality rates for lung cancer similar to the state of Minnesota before 1985, but were elevated from 1985 onward, suggesting a change in risk factors in the previous thirty years. The reasons for this change are speculative, but could include diverging rates of smoking in miners compared to the general population, or an effect of occupational exposures as the mines moved from hematite to taconite. However this issue cannot be directly addressed in this mortality study. A case-control study of lung cancer is an ongoing part of the TWHS and will evaluate the risk of lung cancer related to duration of employment and exposure to EMP in the taconite industry.

Heart disease was also elevated in the iron mining workers. This observation was unexpected for an occupational cohort study. Death rates from heart disease in working populations tend to be lower than the general population. A common theory for this is that people who are well enough to go to work are healthier than the general population, which includes people not well enough to work. This is frequently referred to as the 'healthy worker effect'. The increased rate of death from heart disease could be linked to several factors. Heart disease is associated with smoking, diet, obesity, physical activity, family history, and air pollution. Data from the TWHS Respiratory Health Survey suggest that men and women in this work group tend to smoke more than average and tend to have a higher body mass index (BMI), a common measure of obesity. It is possible that the excess number of deaths is due to these and other lifestyle factors, but the possibility of some role of occupational exposures cannot be ruled out with this type of study.

Mortality studies are good for characterizing the overall health of a population. Death certificates are uniform sources of population based health information. There are some limitations to this study that should be noted. Death certificates are very good for describing diseases that regularly result in death. Many cancers, like mesothelioma and lung cancer, heart disease, and traumatic injuries are well characterized by death records. Other diseases, like the more treatable cancers such as thyroid or bladder cancer, non-cancerous lung disease and other chronic diseases like diabetes do not always show up on death certificates.

CONCLUSION

The mortality study provided a systematic overall evaluation of the health of people who have worked in the iron mining industry in Minnesota. It is likely that lifestyle factors, including smoking and diet, are important determinants of mortality in this group. The elevated rates of mesothelioma and lung cancer, however, indicate a potential impact of occupational exposure on the health of this population. The ongoing investigations into mesothelioma, lung cancer, and non-malignant respiratory disease of the TWHS will clarify the role of occupational exposures in the health of iron mining workers.

Table 1: Characteristics of Minnesota iron mining worker mortality by duration of employment

	Duration of employment				Total	
	Worked < 1 year*		Worked ≥1 year			
	N	%	N	%	N	%
Length of employment (years)						
< 1	13,144	100.0	.	.	13,144	29.76
1-4	.	.	13,180	42.49	13,180	29.85
5-9	.	.	7,385	23.81	7,385	16.72
10-14	.	.	3,658	11.79	3,658	8.28
15-19	.	.	1,890	6.09	1,890	4.28
20-24	.	.	1,443	4.65	1,443	3.27
25+	.	.	3,461	11.16	3,461	7.84
Sex						
Male	12,317	93.71	28,811	92.89	41,128	93.13
Female	819	6.23	2201	7.10	3020	6.84
Unknown	8	0.06	5	0.02	13	0.03
Age at hire						
< 20	4,215	32.07	11,615	37.45	15,830	35.85
20-29	7,669	58.35	15,939	51.39	23,608	53.46
30-39	1,096	8.34	2,844	9.17	3,940	8.92
40+	164	1.25	619	2.00	783	1.77
Decade of hire						
1930 to 1939	1	0.01	17	0.05	18	0.04
1940 to 1949	1,816	13.82	4,527	14.60	6,343	14.59
1950 to 1959	4,572	34.78	9,048	29.17	13,620	31.32
1960 to 1969	2,961	22.53	6,888	22.21	9,849	22.65
1970 to 1979	3,331	25.34	10,328	33.30	13,659	31.41
> 1980	463	3.52	209	0.67	672	1.52
Vital status						
Alive	8,891	67.64	21,952	70.77	30,843	69.84
Deceased	4,253	32.35	9,065	29.23	13,318	30.17
Total	13,144	100.0	31,017	100.0	44,161	100.0

*Those employed less than one year include people with incomplete records, thus they may have been employed more than one year.

Table 2: Selected SMRs for Minnesota iron mining workers

Underlying cause of death	Obs	Expected	SMR	95% CI
All Causes	13,318	12,719.77	1.05	1.03-1.06
All Cancers	3,969	3,748.09	1.06	1.03-1.09
Respiratory	1,449	1,213.24	1.19	1.13-1.26
Larynx	41	34.17	1.20	0.86-1.63
Trachea, bronchus, lung	1,400	1,168.49	1.20	1.14-1.26
Pleura	3	2.60	1.16	0.24-3.38
Mesothelioma	45	15.54	2.90	2.11-3.87
Heart diseases	3,871	3,483.84	1.11	1.08-1.15
Hypertension w/heart disease	90	48.88	1.84	1.48-2.26
Ischemic heart disease	3,155	2,808.87	1.12	1.08-1.16
Cerebrovascular disease	567	549.22	1.03	0.95-1.12
Hypertension w/o heart disease	50	75.57	0.66	0.49-0.87
Respiratory Diseases	883	888.57	0.99	0.93-1.06
COPD	563	527.15	1.07	0.98-1.16
Asbestosis	3	4.13	0.73	0.15-2.12
Silicosis	1	1.57	0.64	0.02-3.54
Transportation injuries	529	570.51	0.93	0.85-1.01
Other injury (major)	354	350.76	1.01	0.91-1.12
Violence	420	389.33	1.08	0.98-1.19

Table 3: Selected SMRs for Minnesota iron mining workers with ≥ 1 year employment in the industry

Underlying Cause of Death	Obs	Expected	SMR	95% CI
All Causes	9,065	8,748.32	1.04	1.01-1.06
All Cancers	2,701	2,604.95	1.04	1.00-1.08
Respiratory	977	845.11	1.16	1.08-1.23
Larynx	26	23.79	1.09	0.71-1.60
Trachea, bronchus, lung	945	814.10	1.16	1.09-1.24
Pleura	1	1.81	0.55	0.01-3.08
Mesothelioma	30	10.80	2.78	1.87-3.97
Heart diseases	2,668	2,431.00	1.10	1.06-1.14
Hypertension w/heart disease	61	34.10	1.79	1.37-2.30
Ischemic heart disease	2,180	1,961.01	1.11	1.07-1.16
Cerebrovascular disease	390	383.58	1.02	0.92-1.12
Hypertension w/o heart disease	33	52.70	0.63	0.43-0.88
Respiratory Diseases	581	620.01	0.94	0.86-1.02
COPD	362	369.19	0.98	0.88-1.09
Asbestosis	1	2.89	0.35	0.01-1.93
Silicosis	1	1.09	0.91	0.02-5.10
Transportation injuries	336	328.59	1.02	0.92-1.14
Other injury (major)	238	221.39	1.08	0.94-1.22
Violence	289	258.01	1.12	0.99-1.26

Table 4: Mesothelioma and lung cancer SMRs for Minnesota iron mining workers by location of employment in geologic zones[1] on the Iron Range

		Mesothelioma			Lung Cancer		
	N	Obs	SMR	95% CI	Obs	SMR	95% CI
Overall cohort							
Total	44,161	45	2.9	(2.1, 3.9)	1400	1.2	(1.1, 1.3)
Worked ≥1 year	31,017	30	2.8	(1.9, 4.0)	945	1.2	(1.1, 1.2)
Zone 1							
Total	28,126	22	1.9	(1.2, 2.9)	933	1.1	(1.1, 1.2)
Worked ≥1 year	20,237	13	1.6	(0.9, 2.8)	638	1.1	(1.0, 1.2)
Zone 2							
Total	7,845	20	5.6	(3.4, 8.7)	350	1.5	(1.3, 1.7)
Worked ≥1 year	5,578	17	6.4	(3.8, 10.3)	235	1.3	(1.2, 1.5)
Zone 4							
Total	8,716	11	3.0	(1.5, 5.3)	255	1.1	(0.9, 1.2)
Worked ≥1 year	6,456	8	2.8	(1.2, 5.4)	206	1.1	(0.9, 1.3)

[1] Some cohort members worked in more than one zone.

Table 5: SMRs for lung cancer and mesothelioma by five year calendar period for iron mining workers

Lung Cancer

Calendar Period	Observed	Expected	SMR	95% CI
1960-1964	2	2.7	0.73	0.09-2.65
1965-1969	8	9.6	0.84	0.36-1.65
1970-1974	25	22.0	1.14	0.74-1.68
1975-1979	46	46.5	0.99	0.72-1.32
1980-1984	81	84.5	0.96	0.76-1.19
1985-1989	168	135.0	1.24	1.06-1.45
1990-1994	228	192.2	1.19	1.04-1.35
1995-1999	294	242.4	1.21	1.08-1.36
2000-2004	322	266.7	1.21	1.08-1.35
2005-2009	226	165.7	1.36	1.19-1.55
Total	1,400	1,167.4	1.20	1.14-1.26

Mesothelioma*

Calendar Period	Observed	Expected	SMR	95% CI
1995-1999	3	1.8	1.65	0.34-4.81
2000-2004	26	8.3	3.15	2.05-4.61
2005-2009	16	5.6	2.93	1.67-4.76
Total	45	15.5	2.90	2.11-3.87

*Mesothelioma was only identified on death certificates from 1999 forward

III. Mesothelioma Study

BACKGROUND

Using MCSS, the MDH identified an apparent excess of mesothelioma in the MRHAP cohort, which ultimately became the driver for the TWHS. The excess of mesothelioma was confirmed in the TWHS mortality analysis, which indicated that there was a 2.9 fold increase in the rate of mesothelioma in the iron mining industry workers when compared to the rest of Minnesota. While this result confirmed that people working in the iron mining industry were at higher risk of mesothelioma mortality, it did not reveal specifically how work in the taconite industry was related to this risk. The objective of the Mesothelioma Study was to determine if the risk of developing mesothelioma differed by length of employment and exposure to one type of dust generated by the taconite industry (long EMP). (Note: Other exposures will be assessed in the ensuing months.)

There are several types of exposures in the taconite industry that may be related to mesothelioma risk, including commercial asbestos previously used in the industry and dust generated from the mining and processing of iron ore that may contain EMP of various sizes. In this report we focus on the EMP measured by the NIOSH 7400 methodology (see section I, Occupational Exposure Assessment, of this report for details). These EMP, identified using phase contrast microscopy, are at least 5 µm in length and have an aspect ratio of 3 to 1, meaning the particles are three times longer than they are wide.

METHODS

The protocol for this study was reviewed and approved annually by the Human Subjects Committee of the UMN Institutional Review Board. All data in this study were held under strict control for the protection of confidentiality and privacy.

MRHAP Cohort

The MRHAP study was conducted by the UMN from 1980-1983. As part of MRHAP, a cohort of individuals who ever worked in the iron ore mining industry, before 1983, was compiled. The original MRHAP cohort consisted of approximately 72,000 individuals from seven different mining companies in operation at the time of the study. After the creation of the TWHS, work was undertaken to update the MRHAP cohort, removing duplicate records or records of people with no proven work in mining. Presently the MRHAP cohort contains 68,737 individuals from the following mining companies: Eveleth Taconite Company, Hanna Mining Company, Inland Steel Company, Jones and Laughlin, Pickands-Mather (Erie Mining Company and Hibbing Taconite Company), Reserve Mining Company, and U.S. Steel Company. A determination of the vital status of all members of the cohort was conducted using the Social Security Administration, the National Death Index, the Minnesota Department of Health, and state death certificates. Cause of death was recorded using the International Classification of Disease (ICD) codes in effect at the time of death.

Mesothelioma Case Identification

Mesothelioma cases were identified using two sources; the MCSS and death certificate records. MCSS has pathologically confirmed cancer information dating back to 1988 for cancer cases diagnosed in residents of the state of Minnesota. Linkage of the MRHAP cohort to MCSS identified 63 cases of mesothelioma. Mesothelioma was coded using ICD-O-3 histology codes 9050-9053. Death certificates can be used to identify mesothelioma following the year 2000 when a specific ICD code for mesothelioma was instituted. Death records from Minnesota and other states identified 53 mesothelioma cases, 17 of which were outside of Minnesota and not captured by MCSS. Mesothelioma deaths were coded according to the ICD 10th revision code C45. The final total was 80 cases of mesothelioma. In contrast to the mortality study, this analysis did not limit inclusion by year of birth as it was intended to include all cases of mesothelioma identified in the MRHAP cohort.

Control Sample Selection

A random sample of the MRHAP cohort was selected to compare the mesothelioma cases with respect to work and exposure histories. Four controls were selected for each case. Controls were individuals from the cohort who were born in the same five year interval as the case, and who had not died of, or been diagnosed with, mesothelioma at the date the case was either diagnosed or died. All cases and controls were nested within the MRHAP cohort, and must have had evidence of employment in the mining industry on record with some documentation of a start date. Five controls were eliminated from the study due to lack of evidence of employment in mining, giving a total of 315 controls for the 80 mesothelioma cases.

Work History

Work history information was collected from mining company work records gathered by MRHAP. The work records of all cases and controls were abstracted in detail to record the company, mine, department, and specific job titles with respective start and stop dates. Mining job titles varied greatly across companies, and were standardized to the greatest extent possible. Job title abbreviations were expanded and duplicate job titles removed. Mapping phrases for each job title were created and used to assign jobs to the similarly-exposed groups (SEGs). An SEG was determined by experienced industrial hygienists and represented a major work activity that was part of the taconite ore processing (see section I, Occupational Exposure Assessment, for details). Ultimately, we derived 28 SEGs. If information from the job title was not sufficient to classify to a specific SEG, the job was assigned to an SEG using department information. For some work records, the job titles were missing or were too vague to be assigned to a specific SEG. Three additional SEGs (general mine, general plant or general shop) were created for jobs that could be broadly classified at the departmental level. Job titles that couldn't be assigned to a general or specific SEG or were missing were assigned as an 'Unknown' SEG.

A portion of MRHAP members worked in the earlier hematite industry. As hematite is a high-grade iron ore, it does not require the extensive processing and concentrating techniques used in taconite, and does not have the same exposures as the taconite industry. The hematite mining work histories were separated from taconite. Historical data on mining operations and yearly taconite production totals were used to determine a taconite start date for each company. Jobs held before the taconite start dates were assigned to a specific hematite SEG.

Exposure Estimates

To link exposure and SEG, a job exposure matrix was created using the SEGs to estimate a cumulative exposure value for the EMP exposures meeting the NIOSH 7400 criteria for each individual. This matrix compiled all exposures from all taconite jobs held in the mining industry. Historical exposures were reconstructed utilizing current data from the TWHS, historical data from the MSHA, mining company records and a previous exposure assessment done by the UMN in the 1980s (see section I, Occupational Exposure Assessment, for details). Each SEG had a daily exposure estimate, based on a time weighted average (TWA) for an 8-hour day. The SEG exposure estimates were specific to the company and year of employment. The exposure values for department level SEGs were based on the average of other SEGs in that department. Exposures for unknown SEGs were an average of all SEGs in that mine for that year. Each case and control's work history was combined with the SEG-specific exposure estimates to generate each individual's cumulative occupational exposure. Using the work history for each case and control, the exposure value for an SEG was multiplied by the length of time spent working in the SEG, and the values for all SEGs summed to give the cumulative exposure for a worker (in EMP/cc-days). This value was divided by 365 to convert it to EMP/cc-years.

The main focus of the exposure models was EMP exposure received during employment in taconite mining, but exposure to commercial asbestos and dust from hematite operations may have also occurred among workers. It was important to evaluate the potential influence of these exposures on any association between taconite exposures and mesothelioma. Commercial asbestos was used throughout the taconite operations for maintenance and building purposes. Commercial asbestos could have included serpentine chrysotile, as well as the amphiboles amosite, crocidolite, actinolite, anthophyllite, and tremolite. The potential for exposure to commercial asbestos was estimated as a probability of exposure by SEG. The research team reviewed the jobs in each SEG and assigned each SEG a score as having a high, medium or low probability of exposure to asbestos on the basis of likelihood of exposure and frequency of exposure. The classifications were reviewed by industrial hygienists in the taconite industry to ensure proper identification of jobs with potential commercial asbestos exposure. The estimates of commercial asbestos exposure for each individual were summarized as ever working in one of these jobs with high, medium, or low exposure, and the cumulative time working at each level.

Data Analysis

The cases and controls were compared descriptively by birth year, year of first employment, gender, form of ore mining, zones of employment, and departments of employment. Cases and controls were compared by employment duration (years) across the Iron Range and by specific zone. Cases and controls were also compared by cumulative exposure (EMP/cc-years) across the range and by specific zone worked.

Rate ratios and 95% confidence intervals were estimated using conditional logistic regression to determine the association between risk of mesothelioma and both duration of employment in taconite operations and cumulative exposure to the EMP. Mesothelioma risk was also estimated by cumulative EMP/cc-years categorized as high, medium, and low, and high and low based on the tertile and median, respectively, of cumulative exposure. Models also included Iron Range mineralogy zone to determine if associations varied across zones. The estimates of exposure to commercial asbestos were included in the models of cumulative EMP exposure and mesothelioma to control for potential confounding from asbestos exposure. Length of time employed in hematite mining was also included in all statistical models to account for any effects from this type of mining. Models were run with no latency, where all obtained exposures were included, and with a twenty year latency in which only exposures that occurred at least twenty years prior to the date of case diagnosis or death were accounted for in the model (20 year lag).

RESULTS

Study Population

A total of 80 cases and 315 controls were included in the analysis (Table 1). All of the cases and the majority of controls were male, with females making up 5% of controls. The median birth year for both cases and controls was 1927. Cases and controls that ever worked in Zone 2 or Zone 4 were slightly younger than those who ever worked in Zone 1, and also started working at a later date as shown by first year of employment. Approximately one third of cases and one fourth of controls worked in both taconite and hematite mining. A greater number of cases worked exclusively in taconite, while a greater number of controls worked exclusively in hematite. The largest percentage of cases occurred in taconite workers who ever worked in Zone 2. The departments in which the greatest number of both cases and controls worked at some point were the mining and shop departments. Among those who worked in the taconite industry 22 percent of cases and 11 percent of controls ever held a job with probable high commercial asbestos exposure. The median years of employment in these high exposure jobs was 6.5 years for cases and 1.4 for controls.

The median length of employment in all iron ore mining and in taconite mining specifically was longer for cases, while the median length of employment in hematite was longer for controls (Table 2). Median length of taconite employment was greatest in Zone 1 for both cases and controls. Within departments, median length of employment was greatest for cases in the mining and shop departments, versus in the shop and office departments for controls. The median EMP/cc-year value for cases is greater than that for controls when looking at overall values across the entire Iron Range (Table 3). The median exposure values for cases are greater than those for controls in Zones 1 and 2. Zone 1 has the maximum exposure value and smallest median exposure for cases and Zone 4 the maximum exposure values for controls.

Length of Employment in Taconite Mining

The risk of mesothelioma increases slightly for each additional year worked in taconite mining (Table 4). The relative rate of 1.03 represents a three percent increase in the risk of mesothelioma for each additional year worked in the taconite industry. The risk of mesothelioma was elevated associated with duration of employment in both Zone 1 and Zone 2, but was not associated with duration in Zone 4 (Table 4). The risk estimates for taconite years were adjusted for years in hematite mining, and models that incorporated the 20 year lagged exposure were substantively similar.

Exposure to EMP

Higher exposure to EMP, as measured by the NIOSH 7400 method, was associated with an increased risk of mesothelioma. Each additional EMP/cc-year of exposure was associated with a 7% increased risk of mesothelioma. While the relative rate of 1.07 was considered as the best estimate, given the observed data, a range of other relative rates are compatible with the data as well. This range of relative rates includes 1.0, which would suggest no increased risk of mesothelioma (Table 5). When the cumulative exposure was divided into high and low based on the median cumulative exposures of the cases, the risk of mesothelioma was about 2.1 times greater for the workers in the highest exposure category relative to those in the lowest. When the cumulative exposure was categorized as high, medium and low based on tertiles, the medium category showed the greatest risk, but the risk estimates between medium and high were statistically indistinguishable. As with years of employment, the associations varied across zones. The risk estimates for EMP/cc-year were adjusted for years in hematite mining and years of employment with high probability of exposure to commercial asbestos. Using other classifications of commercial asbestos exposure did not change the interpretation of the models, nor did use of the 20 year lagged exposure data. Excluding the few (n=17) female controls did not change the risk estimates appreciably.

DISCUSSION

In this analysis of workers employed in the iron mining industry of Minnesota an association was observed between duration of employment in taconite operations and risk of mesothelioma. There was also some evidence of an increased risk of mesothelioma with increasing exposure to EMP as identified by the NIOSH 7400 method. This method does not distinguish amphibole from non-amphibole or asbestiform from non-asbestiform EMP.

The results for employment duration showed an association corresponding to an average of a 3 percent increase in risk with an additional year of employment in taconite operations. While this may appear to be a minimal risk, when the model estimates are applied to a 20 or 30 year career, the risk of mesothelioma would increase approximately 75 and 130 percent respectively compared to similar people who worked only one year in the industry. The impact of working in the industry can also be described by estimating the excess mesothelioma cases in a given population living to a specific age by duration of employment. In the general population we would expect 14.4 cases of mesothelioma in a population of 10,000 men living to age 80. If a similar population of men worked 30 years in the taconite industry, the model predicts about 33.3 cases, 18.9 more cases than expected (Figure 1). It is important to keep in mind that these excess cases are representative of all types of exposure experienced in the taconite industry in the past and not just the long EMP exposures.

The risk for mesothelioma was associated with cumulative EMP (NIOSH 7400 definition; EMP/cc-years) exposure. For each EMP/cc-year of exposure the risk of mesothelioma increased approximately 7 percent. This measure of cumulative exposure is based on time and intensity of exposure. One EMP/cc-year is equivalent to 1 year working at an average of 1 EMP/cc or 10 years working at an average 0.1 EMP/cc. As with duration of employment we can estimate the number of excess mesothelioma cases in 10,000 men who live to be 80 years old (as above) for a given cumulative exposure to long EMP. An additional 0.4 cases of mesothelioma would occur if they worked 30 years at the current median EMP exposure levels (0.016 EMP/cc) (Figure 2). If they worked for 30 years at the 95th percentile (0.13 EMP/cc) of the current exposure level, we would expect an additional 4.3 cases of mesothelioma.

There was also more than a two-fold increase in risk for higher exposed workers when the exposures were classified as high or low at the median of exposure. While the magnitude of this estimate can be susceptible to changes in the exposure category cut point, this analysis lends support to the hypothesis that workers who had higher cumulative exposure to long EMP had a higher risk for mesothelioma.

There are limitations to this study that should be considered when interpreting the results. First, the associations between long EMP and mesothelioma risk are based on our best ability to predict historical long EMP exposures. Although we used all data we could find, there were little data on EMP exposure prior to the 1970s. The exposure estimates are influenced by the completeness of company work history information and the accuracy of time worked in a specific job (SEG). This was a particular concern, as we did not have employment records after 1982 and company records varied in level of detail. Nevertheless, the latency of mesothelioma (30-40 years) would suggest that work exposures prior to 1982 may be the most important. While several factors could lead to the associations being either artificially higher or lower, the exposure reconstruction was based on all available work history without regard to case or control status. We believe these estimates represent a reasonable classification of relative exposure by job and time. Sensitivity analyses of long EMP estimates, in which we assume no time trend in historical exposures, give similar results.

Further refinements in estimates with other types of exposures may clarify the reported associations, especially those utilizing more common exposures (short EMPs, silica, respirable dust). Exposures other than the long EMP estimated in the exposure reconstruction may be important factors in the risk of mesothelioma. Exposures could occur from commercial asbestos that was used in the taconite mining and processing operations, or from exposures in jobs outside the taconite industry (no information was available on jobs outside the industry in this design). Amphibole asbestiform EMP exposures are known causes of mesothelioma. Although amphibole EMP exposures exist in the eastern Iron Range zone (see section V, Environmental Exposure, for details) these are believed to be predominantly of the non-asbestiform type. Context into the risk associated with this EMP is expected from additional exposure analyses.

The facilities were constructed in the 1950s and 60s, a time when commercial asbestos materials were not regulated. The analysis of EMP exposures controlled for potential commercial asbestos exposure in the jobs held in the taconite industry, but our ability to do this was limited by the absence of data on the amount of exposure and type of commercial asbestos. The categorization of commercial asbestos into low, medium and high represented the effort to control for possible commercial asbestos exposure. Despite this effort, it is possible that exposure to commercial asbestos remains as a confounding variable in this assessment.

It is also plausible that other components of the taconite dust are partially responsible for the risk associated with employment in the taconite industry. In fact, the predominant EMP exposure in the industry would be to EMP exposures that are shorter than the 5 micron regulatory definition. Another exposure that could be related to mesothelioma risk is silica, perhaps in combination with EMP, although this has not been well-assessed in earlier studies. Further analyses of these other exposures will be undertaken before a better understanding of risk associated with any of these exposures is obtained.

CONCLUSION

The results from the mesothelioma case-control study suggest an association between duration of employment in the taconite industry and risk of mesothelioma. There was also a positive association with exposure to cumulative EMP, defined by the NIOSH 7400 method. Given the estimated quantity of exposure to long EMP and the potential importance of other exposure types, these findings will require additional assessment before final conclusions can be reached. In future analyses, additional context to the role of workplace exposures will be provided from assessment of the relationship between mesothelioma and exposures in addition to long EMPs, including short EMPs, silica, respirable dust.

Table 1: Demographic and work history characteristics of mesothelioma cases and controls

	Cases		Controls	
	N	Median	N	Median
Birth Year	80	1927	315	1927
First Year of Employment				
Overall	80	1953	315	1952
Ever Zone 1	45	1948	220	1950
Ever Zone 2	33	1957	64	1957
Ever Zone 4	12	1957	66	1956
	N	%	N	%
Gender				
Female	0	0	17	5.4
Male	80	100	298	94.6
Type of Ore Mining				
Hematite and Taconite	25	31.3	81	25.7
Hematite only	23	28.7	131	41.6
Taconite only	32	40.0	103	32.7
Taconite Zone				
Ever Zone 1	18	22.5	74	23.5
Ever Zone 2	31	38.8	58	18.4
Ever Zone 4	12	15.0	66	21.0
Hematite	23	28.7	131	41.6
Department –Ever worked				
Mining	20	25.0	73	23.2
Crushing	6	7.5	37	11.7
Concentrating	12	15.0	35	11.1
Pelletizing	14	17.5	43	13.7
General Plant	0	0.0	7	2.2
Shop Mobile	33	41.3	82	26.0
Shop Stationary	9	11.3	35	11.1
General Shop	0	0	3	1.0
Office	4	5.0	20	6.3
Unknown/Missing	16	20.0	63	20.0
Hematite	48	60.0	212	67.3
Commercial Asbestos Exposure*				
High exposure	13	22.8	35	11.1
Low/Moderate	44	77.2	149	80.9

*Commercial asbestos exposure estimated for SEGs in taconite processing only.

Table 2: Years of employment in all mining operations, by zone, and in specific departments in taconite production for mesothelioma cases and controls

	Cases				Controls			
	N	Median	Min	Max	N	Median	Min	Max
Ore Type								
All Mining	80	4.05	0.01	35.23	315	2.42	0.003	37.31
Hematite	48	0.69	0.01	27.69	212	1.29	0.003	29.74
Taconite	57	8.1	0.01	31.06	184	6.79	0.003	30.62
Zone								
Zone 1	18	11.68	0.05	31.06	74	8.75	0.01	22.21
Zone 2	31	6.02	0.06	26	58	1.95	0.01	28.61
Zone 4	12	2.4	0.01	27.09	66	6.11	0.003	30.62
Department								
Mining	20	4.53	0.07	22.36	73	1.12	0.01	24.58
Crushing	6	1.36	0.19	3.51	37	0.65	0.01	13.68
Concentrating	12	0.53	0.03	7.67	35	0.49	0.02	17.30
Pelletizing	14	0.49	0.01	12.24	43	0.44	0.003	14.5
General Plant	0	0	0	0	7	0.08	0.01	5.33
Shop Mobile	33	5.75	0.01	24.87	82	4.79	0.003	30.62
Shop Stationary	9	6.18	1.29	30.66	35	1.15	0.02	22.02
General Shop	0	0	0	0	3	0.41	0.08	2.93
Office	4	1.74	0.32	9.21	20	4.2	0.03	25.36
Unknown	16	1	0.01	11.31	63	1.74	0.01	19.77
Hematite	48	0.69	0.01	27.69	212	1.29	0.003	29.74

Table 3: Overall and zone specific median, 75th, and 95th, percentile cumulative exposure (EMP/cc-years) for mesothelioma cases and controls who ever worked in taconite operations

	Cases			Controls		
	N	Median	75th Percentile	N	Median	75th Percentile
Overall	57	1.15	2.95	184	0.24	2.63
Zone 1	18	0.22	0.73	74	0.12	0.18
Zone 2	31	1.88	2.95	58	0.58	2.61
Zone 4	12	1.10	3.23	66	2.09	5.97

Table 4: Overall and zone specific relative risk estimates for mesothelioma by years of employment in taconite.

	Cases	Controls	RR[1]	95% CI[2]
Taconite Years	57	184	1.03	1.00-1.06
Zone 1 Taconite Years	18	74	1.05	1.00-1.11
Zone 2 Taconite Years	31	58	1.06	1.02-1.09
Zone 4 Taconite Years	12	66	0.97	0.92-1.02

[1] Relative rate; adjusted for age, and years of employment in hematite.
[2] 95% CI= 95% confidence interval

Table 5: Overall and zone specific risk of mesothelioma by cumulative EMP exposure* as a continuous measure and overall risk with exposure classified as high and low.

	Cases	Controls	RR[1]	95% CI[2]
EMP/cc-year (continuous)	57	184	1.07	0.97-1.18
Exposure category (EMP/cc-Year)				
Low[3] (<1.153)	28	124	1	
High (≥1.153)	29	60	2.12	1.11-4.04
Low[4] (<0.320)	19	98	1	
Medium (≥ 0.320-<2.36)	19	38	2.75	1.26-6.00
High (≥ 2.36)	19	48	1.85	0.86-3.99

*Measured by the NIOSH 7400 counting method

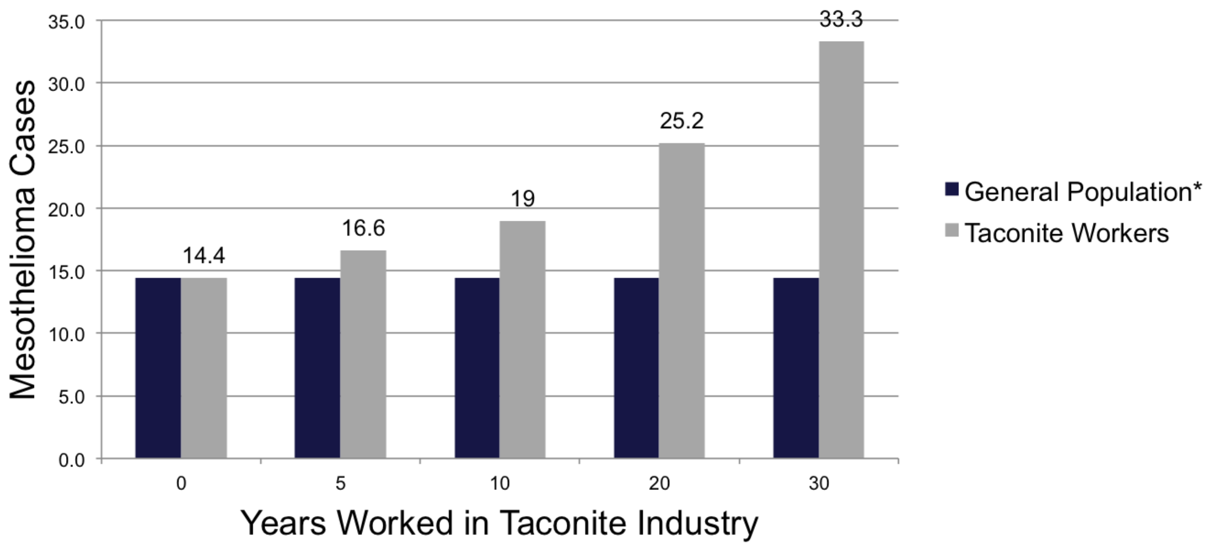
[1] RR=Relative rate adjusted for age, employment in hematite, and estimated exposure to commercial asbestos

[2] 95% CI= 95% confidence interval

[3] High and low based on the median cumulative exposures for cases.

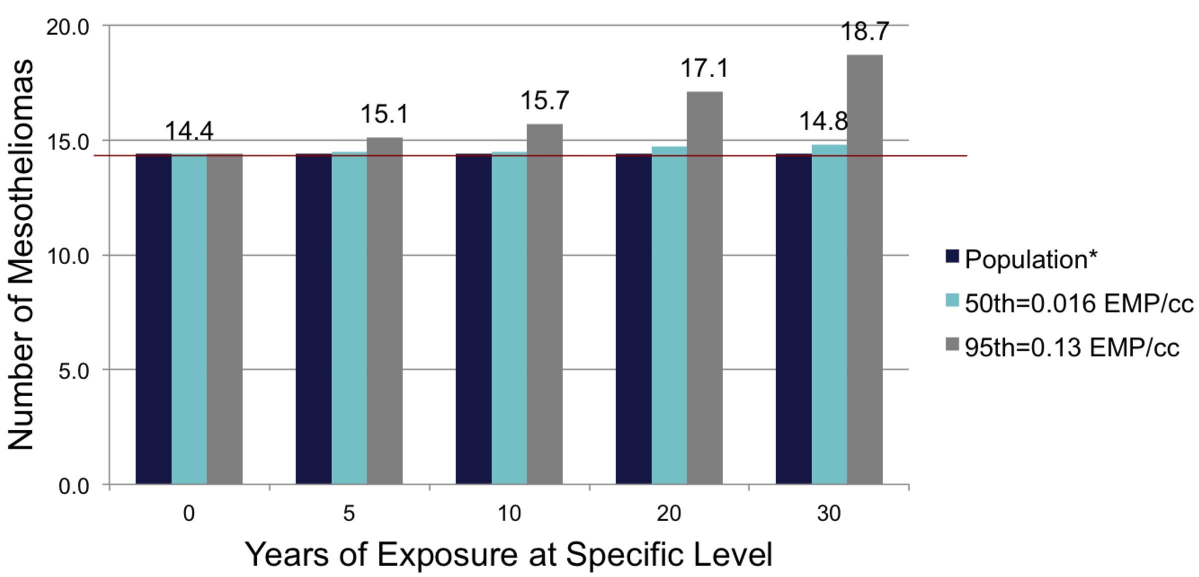
[4] Low, medium and high, exposure based on tertile of cumulative exposure for cases.

Figure 1: Estimated cases of mesothelioma in 10,000 men living to age 80 working in taconite up to 30 years and the expected cases in 10,000 men in the general population



*Lifetime risk for white males at age 80 is 0.144 percent.
Surveillance Epidemiology and End Results Program of the National Cancer Institute.

Figure 2: Estimated cases of mesothelioma in 10,000 men living to age 80, working in taconite up to 30 years at 50th and 95th percentiles § of long EMP exposure



*Lifetime risk for white males at age 80 is 0.144 percent.
Surveillance Epidemiology and End Results Program of the National Cancer Institute.
§ Based on current range of exposure

IV. Respiratory Health Survey

The Respiratory Health Survey (RHS) was designed to identify non-malignant respiratory disease (NMRD) in taconite workers. These diseases are the result of scarring of the lungs from dust exposure and are not well-captured through the state's cancer or mortality surveillance systems. Several of the dusts generated in the taconite processing may be capable of producing these diseases. These exposures involve dusts with concentrations of EMP, silica dusts and general dusts that are respirable. The last category, in the case of dusts from taconite processing, contains iron. All three types are being analyzed in connection with the RHS.

All of these dusts were measured on the sites of current mining operations. Around 2000 samples were gathered in this manner from all major job categories within each facility (see Occupational Exposure Assessment). Other measurement information concerning these dusts was provided by the active companies. Measurement data were obtained from the MSHA, during their regulatory role with the industry. Finally, work done by Dr. John Sheehy, a graduate student at the UMN in the 1980s, provided another source of exposure measurement data for iron ore processing (see section I, Occupational Exposure Assessment).

Exposure information from these sources is being combined with health data obtained during the RHS screening process. Health data of prime concern include chest x-rays and lung function tests. These tests were gathered during 2009-2010, along with detailed work, medical and smoking histories. The combination of the exposure measurement information, medical tests and health/work/smoking histories is designed to determine the extent to which workplace exposures are related to non-cancerous respiratory disease.

Descriptive results from the RHS have revealed that 1188 workers fully participated, along with 498 spouses. Another 134 workers completed questionnaire information but did not undergo medical testing. Within the workers around 5-6% have non-cancerous, parenchymal (lung substance) findings that are consistent with dust-related lung disease, as per results from chest x-rays and lung function tests. Pleural abnormalities (involving the lining around the lungs) occurred in around 17% of workers. Spouses had less evidence of abnormalities on these tests and approximated the abnormality rate in the general population (see Table 1).

The focus of work in this study over the past 12 months has been to incorporate exposures into the medical test findings, to see how much of the described abnormalities may have a work-related (exposure) association. Although this process has taken longer than anticipated, it is in the final stages. To date, the following have been completed in the incorporation of exposure information:

- Medical test results have been finalized, with the adjudication of discrepancies.
- Standardized job categories have been identified for each of the active plants, in total 28 per site.

- Exposure matrices have been developed for each of these standardized job categories, going back to 1955. For each job, utilizing the on-site measurements and the historical exposures, estimates on the likely exposure each year for each standard job was done for each facility.
- Work histories have been standardized. This involves identifying what participants indicated as their work in the taconite industry, and adopting standard nomenclature for different expressions of the same job. For example crusher operator is the final title for all variations given by the participants for that job (crush. op., crusher oper., crusher op., etc.)
- Work histories have been mapped to the standard job categories, including the length of time in that job, for each participant.
- Cumulative exposures for EMP, silica and respirable dust for each worker have been determined.

The final work involves utilizing these cumulative exposures in the group with abnormal tests and compares their exposures with the group with normal tests. This is being done for both chest x-rays and for lung function tests, with the inclusion of medical symptoms (chest discomfort, shortness of breath) to enhance the accuracy of the medical test interpretation. Control of other occupational exposure, smoking and other medical conditions will also be incorporated into these analyses.

Based on the descriptive information already analyzed, some patterns have appeared. First of all, the chest x-ray findings suggest a low prevalence of dust-related respiratory disease in spouses that resembles findings in the general public, based on other studies. This suggests that individuals living in the communities in close proximity to the mining operations would not be expected to have higher amounts of dust-related respiratory disease. In this case, spouses would likely have more exposure than those in the communities, since they would have community exposure and, potentially, exposure from their working partner.

Second, results from chest x-rays suggests the presence of some dust-related disease in workers (6%). This appears to be elevated from the background rates and is probably related to silica or mixed dusts. Last, there also appears to be an increased amount of pleural abnormalities. It is likely that some of the pleural findings are related to obesity, but also reflect some degree of EMP exposure. These results will have additional context following the incorporation of exposure and other information (above), which we anticipate being completed later this year.

Table 1. Chest x-ray findings from RHS

	Parenchymal (silicosis?)	Pleural (EMP?)
Workers	5.4%	16.8%
Spouses	0.6%	4.5%

V. Environmental Study of Airborne Particulates - NRRI

During 2012, the Natural Resources Research Institute (NRRI) Environmental Study of Airborne Particulate Matter completed numerous tasks including sample submission to external laboratories, sample analysis at the NRRI and the Research Instrumentation Laboratory at the University of Minnesota Duluth, compilation and evaluation of laboratory analyses, prioritization and preparation of lake sediment samples for analysis, presentations at professional conferences, and training. An update on these various study components is provided below.

Definitions

Before discussing results, it is imperative that certain terms used in this report be defined. This is especially true in light of the many ways that terms have historically been utilized in studies related to mineral dust and disease. In particular, seven terms (“asbestos”, asbestiform”, “elongate mineral particle”, “fiber”, “countable elongate mineral particle”, “covered mineral” and “covered elongate mineral particle”) must be precisely defined if the results in this study are to be interpreted accurately.

Asbestos: A commercial term used to describe a group of silicate minerals that readily separate into thin, strong fibers that are chemically inert, heat resistant, and flexible, making them suitable for a variety of uses.

Asbestiform: A term used to describe minerals with a macroscopic habit similar to that of asbestos.

Total Elongate Mineral Particle (TEMP): All mineral fragments with an aspect ratio greater than 3:1 regardless of mineral species (synonymous with “Total Elongate Mineral Particle Structures”).

Fiber: The term “mineral fiber” is imprecise, as it has been utilized to describe elongate mineral particles that occur in a variety of crystal habits or morphological structures that result from breaking or crushing of minerals. Therefore, for this study, “fiber” is equated (and used interchangeably) with the term “elongate mineral particle” unless described and defined otherwise.

Countable Elongate Mineral Particle (EMP): Any fiber or fragment of a mineral longer than 5µm with a minimum aspect ratio of 3:1 when viewed microscopically with use of NIOSH Analytical Method 7400 (“A” rules) or equivalent.

Covered Mineral (CM): Any mineral having the crystal structure and elemental composition:

- of one of the asbestos varieties (chrysotile, riebeckite asbestos (crocidolite), cummingtonite-grunerite asbestos (amosite), anthophyllite asbestos, tremolite asbestos, and actinolite asbestos); or

- of one their non-asbestos analogues (the serpentine minerals antigorite and lizardite, and the amphibole minerals contained in the cummingtonite-grunerite mineral series, the tremolite-ferroactinolite mineral series, and the glaucophane-riebeckite mineral series).

Covered Elongate Mineral Particle (CEMP): Any of the covered minerals that have an aspect ratio ≥ 3:1, irrespective of length.

Analytical Methods

Airborne particulate matter was collected using a MOUDI II Model 120 micro orifice uniform deposit impactor and a total suspended particulate matter (TSP) filter during this study. Several different analytical methods have been utilized to assess the mass, mineralogical composition, mineral particulate matter morphology, mineral particulate matter concentrations, mineral particulate matter chemistry, and mineral compositions and textures within the Biwabik Iron Formation during these studies. These methods include:

- Diamond drill core logging and sampling of two exploration diamond drill holes from different areas of the Biwabik Iron Formation;
- Petrographic analysis of samples from the two exploration drill holes from different areas of the Biwabik Iron Formation;
- Elutriation and transmission electron microscope (TEM) to determine the concentration of asbestos fibers in the respirable portion of dust from these diamond drill holes (analysis by EMS Laboratories);
- Gravimetric (mass) analysis of particulate matter to determine the distribution of mineral dust based on aerodynamic diameter;
- TEM analysis of mineral fibers in air utilizing Minnesota Department of Health MDH 852 Method (analysis by Braun Intertec Corp.);
- Determination of asbestos fibers via indirect transfer TEM analysis (International Standards Organizations (ISO) Method 13794 completed by EMSL Analytical, Inc.);
- Chemical analysis of particulate matter utilizing proton-induced x-ray transmission (PIXE) analysis (Elemental Analysis, Inc.); and
- Scanning electron microscopy (SEM) imaging, energy dispersive x-ray spectroscopy (EDS), and electron backscattered diffraction (EBSD) (University of Minnesota Duluth Research Instrumentation Laboratory).

Individual measurements and analyses have been performed, including over 6500 gravimetric analyses, over 140 TEM analysis of mineral fibers in air (MDH 852 Method), over 260 determinations of asbestos fibers via indirect transfer TEM analysis (ISO Method 13794), approximately 250 chemical analyses of particulate matter using PIXE analysis, and hundreds of SEM images, EDS analyses, and EBSD analyses.

Geological Setting

Several previous geological studies have established that the mineralogy of the Biwabik Iron formation changes from west to east. This mineralogical change is believed to have occurred as the eastern part of the Mesabi Iron Range (MIR) was subjected to contact metamorphism (also known as thermal metamorphism, which is essentially heating or "baking" of the rock) during intrusion of the magma bodies approximately 1.1 billion years ago that later solidified into the rock body known as the Duluth Complex (Figure 1). This thermal metamorphic process is believed to have resulted in essentially no chemical change in the affected rocks except the loss of water and carbon dioxide as a result of increased heating.

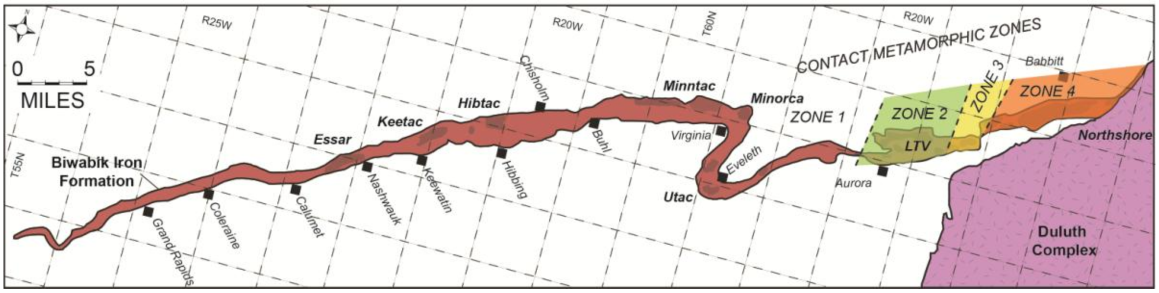


Figure 1. Simplified geology of the Mesabi Iron Range. The distribution of the Biwabik Iron Formation and the Duluth Complex are shown. Note that contact metamorphic Zone 3 and Zone 4 comprise the easternmost parts of the total length of the Biwabik Iron Formation.

Four metamorphic zones have been identified in these previous studies, and these zones are identified by changes in textures and the minerals present in the rocks. Zone 1 (unmetamorphosed iron-formation) and Zone 2 (transitional iron-formation) are similar in terms of their mineral contents; however, Zone 2 can be identified by textures representative of extensive recrystallization and mineral replacement. The mineralogy of Zones 1 and 2 comprises quartz, magnetite, hematite, various species of carbonate minerals, talc, chamosite, greenalite, minnesotaite and stilpnomelane. None of these minerals are amphiboles.

Zone 3 and Zone 4 represent moderately to highly thermally metamorphosed iron-formation. The boundary between Zone 2 and Zone 3 is marked by the first occurrence of amphibole minerals as well as the disappearance of iron carbonate and iron silicate minerals characteristic of unmetamorphosed or transitional iron-formation. The generalized mineralogy of Zones 3 and 4 comprises quartz, magnetite, cummingtonite - grunerite, hornblende, hedenbergite, ferrohypersthene, and fayalite. The minerals cummingtonite-grunerite and hornblende are amphibole minerals; the minerals hedenbergite and ferrohypersthene are pyroxene minerals; and the mineral fayalite is an iron-rich variety of olivine.

In summary, amphibole minerals occur in metamorphic zones 3 and 4 in the Biwabik Iron Formation; chrysotile has not been identified in any of the metamorphic zones in this geological unit.

Airborne Particulate Matter in Iron Range Communities – Sampling and Results to Date

The community air sampling program was completed in 2011, and included sampling in five MIR communities and three non-iron range background sites (Figure 2). Each of the eight sampling locations were sampled a minimum of three times during winter (November through April) and three times during summer (May through October). Total sampling events for each of the community sampling sites are summarized below:

- Mesabi Iron Range Communities
    - Silver Bay High School 11 sampling events (4 winter, 7 summer)
    - Virginia City Hall 9 sampling events (4 winter, 5 summer)
    - Hibbing High School 9 sampling events (4 winter, 5 summer)
    - Keewatin Elementary School 6 sampling events (3 winter, 3 summer)
    - Babbitt Municipal Building 16 sampling events (7 winter, 9 summer)

Figure 2. Map of Minnesota illustrating the five MIR community sampling sites, as well as the three background sampling sites, utilized for this study.

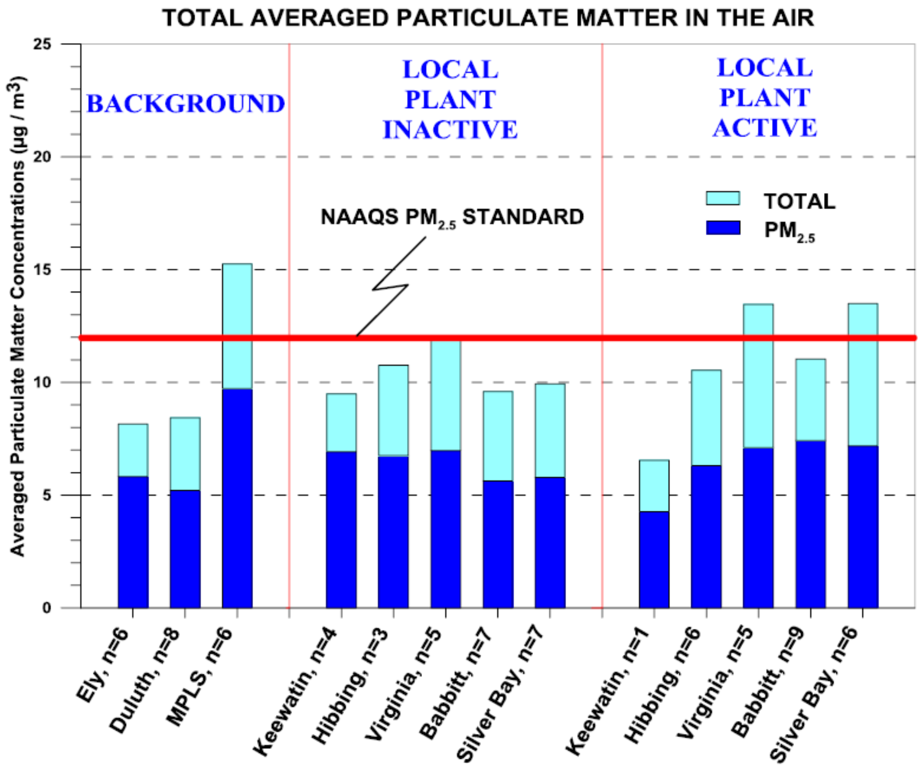


Figure 3. Average total particulate matter (PM) versus $PM_{2.5}$ for MIR communities and background sampling locations. The letter "n" refers to the number of sampling events at each location.

- Non-Iron Range Communities
  - Duluth NRRI Rooftop 10 sampling events (4 winter, 6 summer)
  - Ely Fernberg Site 7 sampling events (4 winter, 3 summer)
  - UMTC Mechanical Engineering 6 sampling events (3 winter, 3 summer)

Figure 3 illustrates the results of $PM_{2.5}$ and total particulate matter measurements completed at the five MIR communities and three background sites evaluated for this study. Samples were collected over time periods ranging from five to seven days. As illustrated, all MIR communities meet the National Ambient Air Quality Standard (NAAQS) $PM_{2.5}$ standard of 12µg/m^3. All MIR communities meet the NAAQS PM_{10} standard of 150µg/m^3, with individual MIR communities having measured levels ranging from 5µg/m^3 to 21µg/m^3, and averaging approximately an order an order of magnitude less than the PM_{10} standard. Particulate levels (PM_1, $PM_{2.5}$, PM_{10} and total PM) show a slight increase in the five Mesabi Iron Range communities during plant/mine activity, but this is not statistically significant compared to when the plants/mines are not in operation.

Figure 4 illustrates average EMP concentrations for the five MIR communities and three background sites. EMP was identified at three MIR communities (Virginia, Babbitt, and Silver Bay). Concentrations of EMPs at these locations (Table 1) ranged from 0.00005 EMP/cm^3 to 0.00022 EMP/cm^3. No EMP was identified at the three background sampling sites. There are no NAAQS standards specifically for EMP.

Figure 5 illustrates EMP concentrations by mineral species for each of the five MIR communities and the three background sampling sites. Summarizing these results for the five sampling sites on the MIR:

- No EMP was identified at Keewatin Elementary School during sampling events when taconite processing/mining were active or inactive.
- No EMP was identified at Hibbing High School during sampling events when taconite processing/mining were active or inactive.
- Actinolite and chrysotile EMP were identified in one sampling event at Virginia City Hall. This sampling event occurred when taconite processing/mining was active. Combined, the concentration of these minerals was less than 0.001 EMP/cm^3.
- Actinolite EMP was identified in one sampling event at Babbitt Municipal Building. This sampling event occurred when taconite mining and primary crushing was active at the Peter Mitchell Mine*. The concentration of actinolite during this sampling event was below 0.001 EMP/cm^3.
- EMP was detected during four sampling events at Silver Bay High School. Two of these sampling events occurred when taconite processing* was inactive, and the other two sampling events occurred when taconite processing* was active.

**NOTE: Babbitt and Silver Bay are unique relative to the other MIR communities, in that taconite ore mining and primary crushing takes place near Babbitt (at the Peter Mitchell Mine), and taconite processing takes place about 43 miles to the southeast in Silver Bay.*

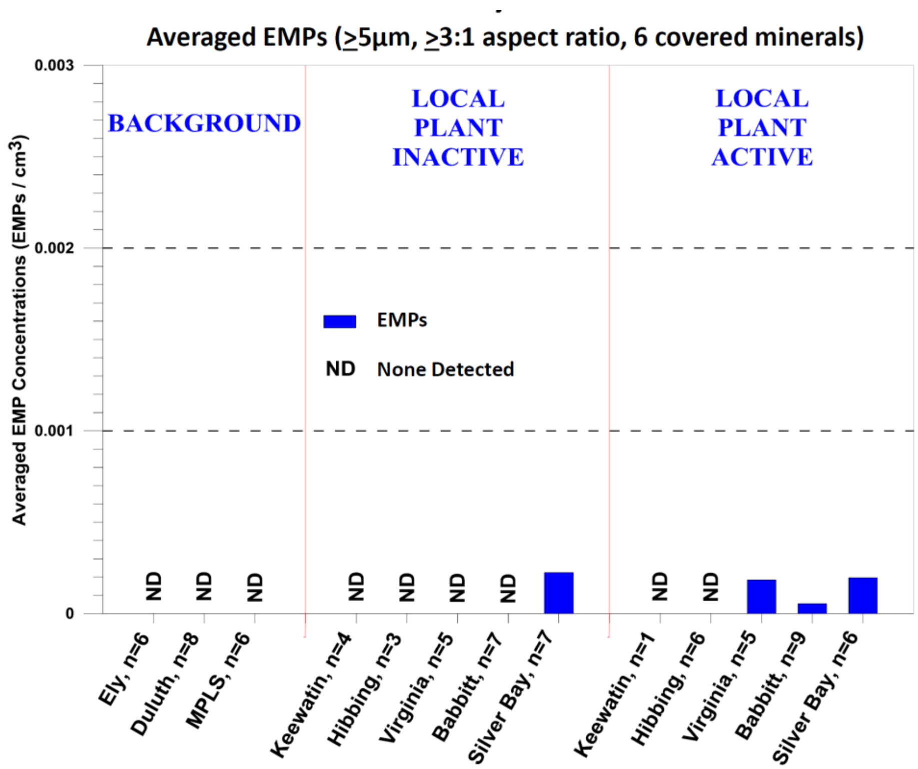


Figure 4. Average EMP concentrations for MIR community and background sampling locations. The letter "n" refers to the number of sampling events at each location.

COMMUNITY	LOCAL PLANT ACTIVITY	AVERAGE EMP CONCENTRATION (EMP/cm^3)
Keewatin	Inactive	None Detected
	Active	None Detected
Hibbing	Inactive	None Detected
	Active	None Detected
Virginia	Inactive	None Detected
	Active	0.00018
Babbitt	Inactive	None Detected
	Active	0.00005
Silver Bay	Inactive	0.00022
	Active	0.00020
EMP = >5µm, > 3:1 aspect ratio, covered minerals		

Table 1. Average community EMP concentrations for the five Mesabi Iron Range communities sampled during this study. EMP concentrations were not detected at the three Minnesota background sampling sites.

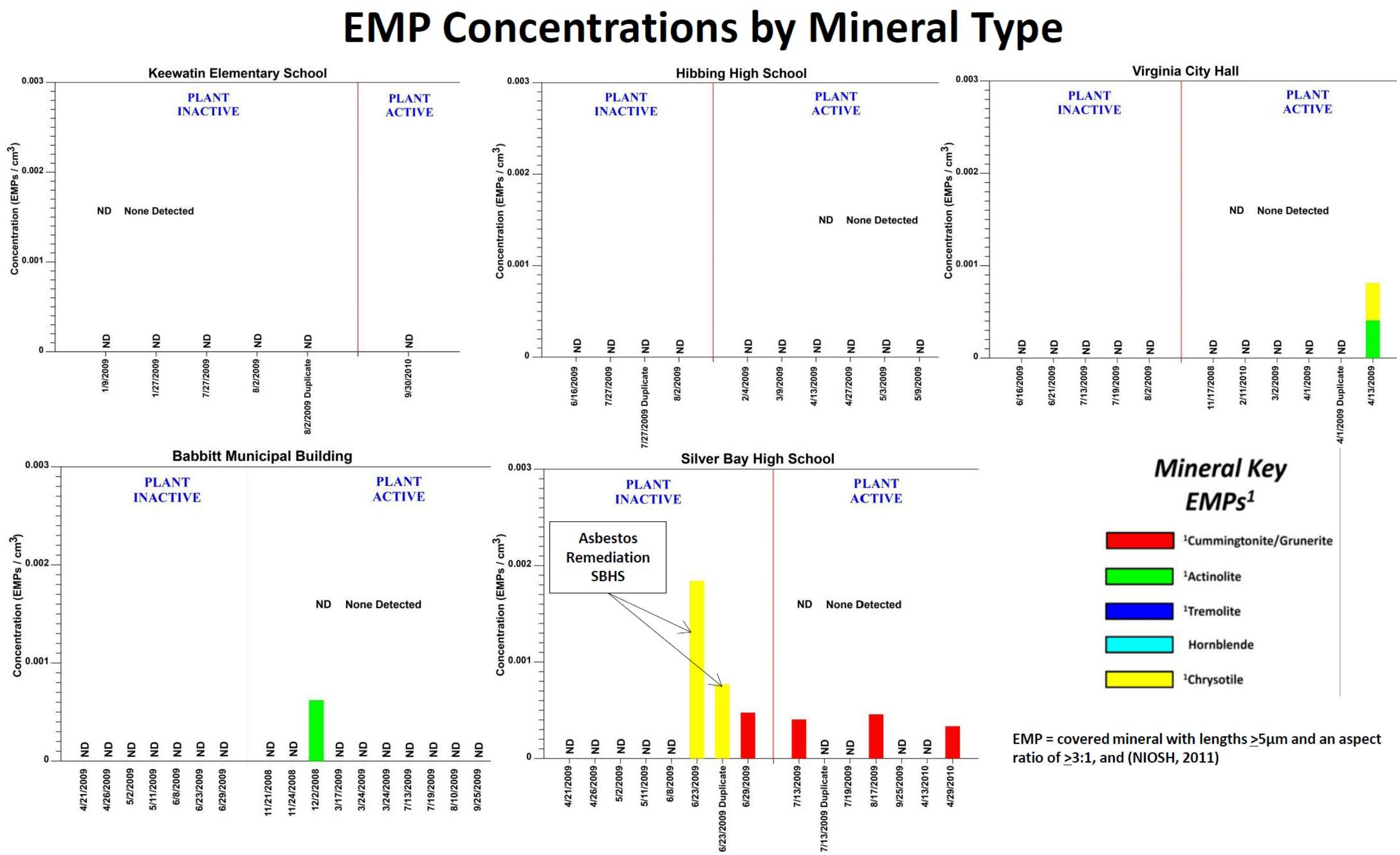


Figure 5. EMP concentrations by mineral species for each of the five MIR communities. No EMP were identified at the three background sampling sites.

Chrysotile and cummingtonite-grunerite were identified when taconite processing was inactive, with chrysotile concentrations below 0.002 EMP/cm^3 and actinolite concentrations below 0.001 EMP/cm^3. Field notes indicate that Silver Bay High School was conducting asbestos remediation during the sampling event that chrysotile was identified. Circumstantially, it appears that the detection of chrysotile may have been related to the remediation activity, but lacking a sample of the remediated material, we do not know what type of asbestos was being remediated and therefore cannot say with certainty that this was the contributing chrysotile source.

Summarizing the results for the background sampling sites:

- No EMP was identified at the Ely Fernberg site, the Duluth NRRI site, or the UMTC Mechanical Engineering site in Minneapolis.

Analysis and interpretation of TEM data (ISO 13794), PIXE data, scanning electron microscopy (SEM) imaging, energy dispersive x-ray spectroscopy (EDS), and electron backscattered diffraction (EBSD) continues, and will be reported at a later date.

Airborne Particulate Matter in Taconite Operations – Sampling and Results to Date

Sampling at the six taconite processing facilities on the Mesabi Iron Range was completed in 2011. At each plant (Figure 6), four locations were sampled, including: 1) crusher; 2) magnetic separator; 3) agglomerator/ball drums; and 4) kiln pellet discharge area. All plants have been sampled at least once during active operations (active), and several plants were also sampled during plant shutdowns (inactive). Total sampling events for each of the taconite processing plants are summarized below:

- Utac — 2 sampling events (2 active)
- Hibtac — 2 sampling events (1 active, 1 inactive)
- Minntac — 1 sampling event (1 active)
- Keetac — 2 sampling events (1 active, 1 inactive)
- Northshore — 4 sampling events (3 active, 1 inactive)
- Minorca — 3 sampling events (3 active)

Figure 7 illustrates the average concentrations of total particulate matter and $PM_{2.5}$ particulate matter based on taconite plant process site. As can be observed, the concentrator (a wet process) has the lowest average total particulate matter and $PM_{2.5}$ particulate matter concentrations, whereas the kiln discharge area illustrates the highest total particulate matter and $PM_{2.5}$ particulate matter concentrations. Also note that *community average total particulate matter concentrations and $PM_{2.5}$ particulate matter concentrations observed when the taconite operations (processing/mining) were active are approximately one- to two orders of magnitude less than total particulate matter and $PM_{2.5}$ particulate matter concentrations in the plants.* This suggests that processing plant dust control devices are working to prevent excessive dust release to the community environments.

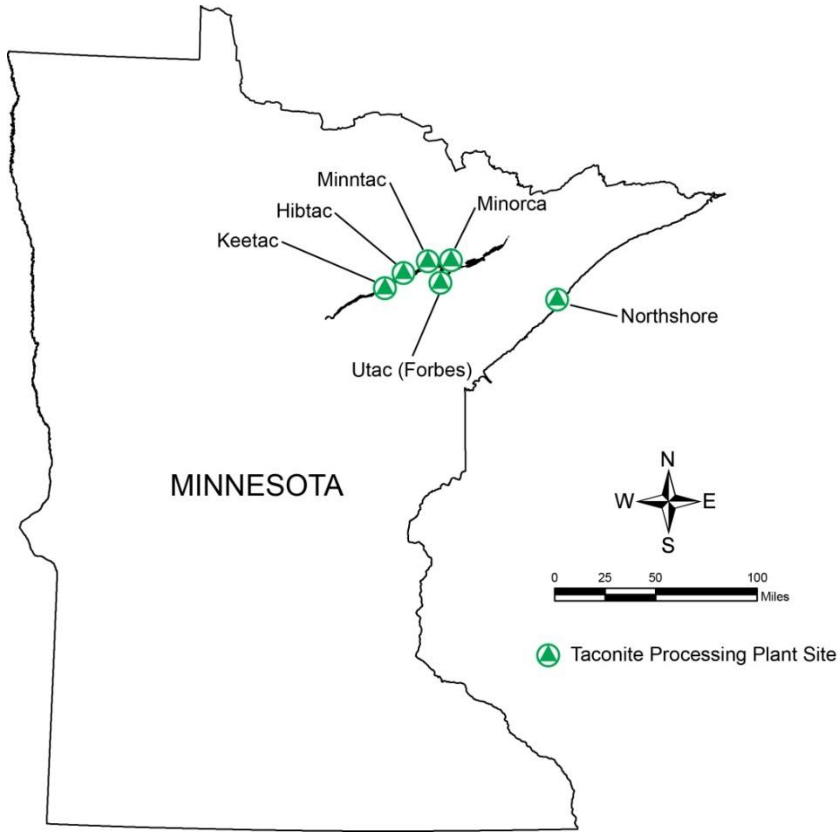


Figure 6. Map of Minnesota illustrating the six taconite processing plants sampled during this study.

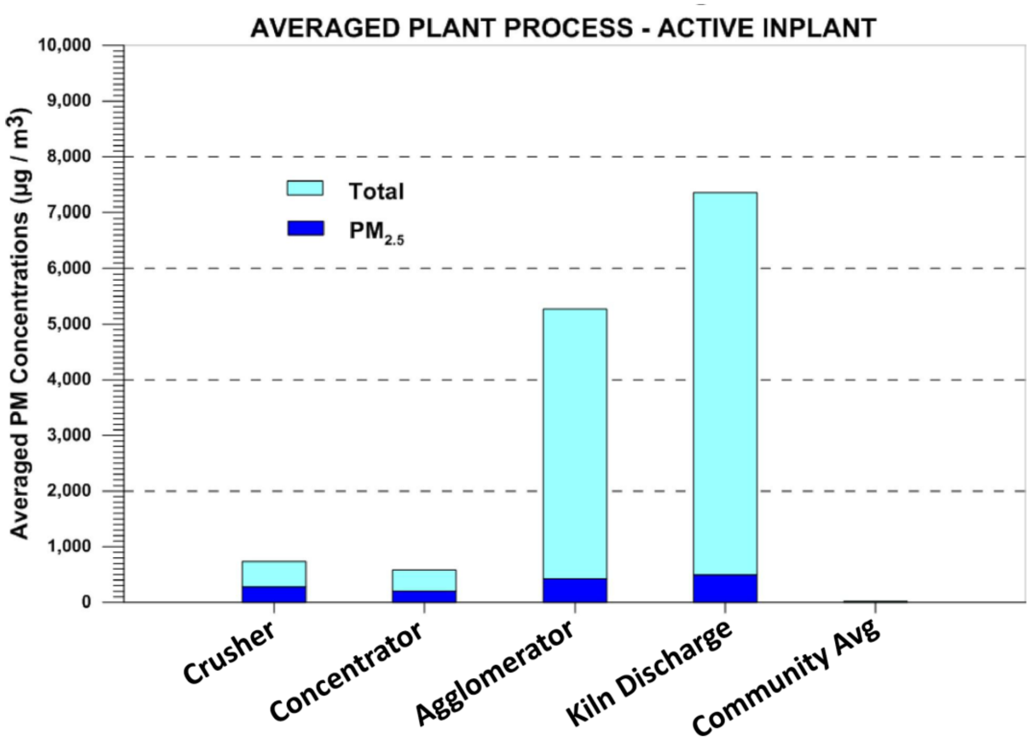


Figure 7. Average total particulate matter (light blue) and $PM_{2.5}$ particulate matter (dark blue) for each of the four taconite processing operation areas sampled in this study.

In-plant EMP concentrations are summarized in Table 2 for each of the process areas sampled. For the secondary crusher, EMP was identified at the Northshore plant, with

Process Area	EMP Not Detected	EMP Detected (Average, EMP/cm^3)
Secondary Crusher	5 Plants	Northshore (0.2)
Concentrator	4 Plants	Northshore (0.1) Minntac (0.03)
Agglomerator	6 Plants	No Plants
Kiln Discharge	6 Plants	No Plants
EMP = >5µm, >3:1 aspect ratio, 6 covered minerals		

Table 2. Average community EMP concentrations for the five Mesabi Iron Range communities sampled during this study. EMP concentrations were not detected at the three Minnesota background sampling sites.

an average concentration of 0.2 EMP/cm^3. At the concentrator, EMP was identified in two plants, Northshore (0.1 EMP/cm^3) and Minntac (0.03 EMP/cm^3). No EMP was identified in the agglomerator and kiln discharge areas in any of the plants.

Additional analysis and interpretation of TEM data (MDH 852, ISO 13794), PIXE data, scanning electron microscopy (SEM) imaging, energy dispersive x-ray spectroscopy (EDS), and electron backscattered diffraction (EBSD) for taconite processing plants during inactive and active periods continues, and will be reported at a later date.

Lake Sediment Samples

Lake sediment core samples collected at two sites (one site near the Northshore/Dunka Pit (“North of Snort” Lake) and the other site within the limits of the City of Virginia (Silver Lake) have been processed and dated using Pb-210 and Cs-137 methodologies. Preparation for chemical, mineralogical, and microscopic analysis of dated sediment intervals is ongoing, with completion anticipated during summer, 2013.

Summary of Results to Date

Results to date indicate:

- Concentrations of EMP are based on point source sampling and are *not* to be confused with exposure measurements;
- Particulate matter concentrations in all MIR communities were below NAAQS particulate standards;
- Particulate matter concentrations on the MIR were similar to those in the two NE Minnesota background sites, and lower than Minneapolis;

- Mineral particulate matter in community air samples can reflect the mineralogy of the Biwabik Iron Formation and other northern Minnesota rock types and geological materials;
    - EMP was present in air from eastern MIR communities;
    - No asbestiform amphibole EMP has been identified to date;
- Plant environments can be very dusty, with the agglomerator and the kiln discharge being the most dusty process areas;
- Particulate levels (PM_1, $PM_{2.5}$, PM_{10} and total PM) show a slight increase in the five Mesabi Iron Range communities during plant/mine activity, but this is not statistically significant compared to when the plants/mines are not in operation;
- The low levels of total PM measured in the MIR communities suggest the taconite plants are isolating the dusty conditions;
    - Control devices seem to be working to prevent excessive dust release to the community environments.