

Characterisation of respiratory health and exposures at a sintered permanent magnet manufacturer

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Abstract

Sintered permanent magnets are made from the powdered metals of cobalt, nickel, aluminium, and various rare earths. During production, exposure to respirable crystalline silica and asbestos may also occur. Reported here is a cross sectional study of 310 current and 52 retired hourly employees who worked 10 or more years making sintered magnets. Each participant had a chest radiograph, spirometry, and completed a respiratory questionnaire. Illness logs were also reviewed to calculate the incidence of recorded respiratory disorders. The prevalences of abnormalities in pulmonary function and respiratory symptoms were not higher than found in an external referent population. Although the prevalence of diffuse parenchymal opacities consistent with pneumoconiosis (four workers) was similar to the referent population, one worker had radiographic findings consistent with silicosis and two workers had profusion scores of 1/2 or above, not seen in the referent group. The incidence of reported respiratory conditions in the log, including asthma, was 10 times that of other manufacturers in the same industrial classification category. Excessive exposures to cobalt, nickel, and respirable silica were shown by environmental measurements.

Permanent sintered magnets are produced by 20 companies in the United States. The raw materials used include various respirable metal powders

(aluminium, nickel, cobalt, samarium, neodymium, etc) and may pose a significant hazard to the workers employed by this industry. Although the respirable hazards from these metals have been established, no published reports exist on the respiratory health of workers in this industry.

In March 1988 The National Institute for Occupational Safety and Health (NIOSH) initiated a health hazard evaluation at a sintered rare earth magnet manufacturer located in the mid-western United States.¹ Workers at the plant requested this evaluation because of the diagnosis, in one worker, of pneumoconiosis of an unspecified nature. The purpose of our investigation was to determine the prevalence of respiratory conditions among the hourly workforce, characterise current exposures to the respiratory hazards present, and make recommendations based on the conclusions of our investigation.

Methods

The workforce consisted of 416 hourly workers and 115 salaried employees. Small permanent magnets have been manufactured at this site since 1952 and rare earth permanent magnets since 1973. The five processes in use manufactured sintered magnets, cast magnets, rare earth magnets, ceramic (ferrite) magnets, and lodex magnets. Cobalt has been used as a major component in each process (except ceramic magnets). Nickel has been used in sintered and cast magnets and neodymium and samarium in rare earth magnets. Exposures to cobalt, nickel, neodymium, samarium, and other metal constituents occur during preparation of raw materials, pressing, casting, break out, blasting, and grinding. The cast process includes a small foundry, where respirable silica is used. Asbestos was used in several processes until 1985 when it was replaced with a man made mineral fibre product. The plant also manufactured tungsten carbide cutting tools from 1952 to the end of 1986.

The medical evaluation consisted of a cross sectional survey of respiratory conditions and a review of Occupational Safety and Health (OSHA) logs of injuries and illnesses (form 200). The environmental exposure assessment included sampling for metals and respirable dusts containing respirable silica.

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CROSS SECTIONAL SURVEY

The study protocol was approved by the NIOSH Human Subjects Review Board; volunteers gave informed consent and were notified of their individual test results. Current workers with 10 or more years of production experience were considered eligible to participate in the medical survey, which included spirometry, a questionnaire, and a chest radiograph. Retired workers were also invited to participate.

The questionnaire incorporated pertinent parts of the American Thoracic Society (ATS) questionnaire² and was administered to all participants by trained personnel, who reviewed it for completion. It sought basic demographic information, work history, medical history, active medical problems, and current symptoms (especially respiratory complaints). The prevalences of self reported chronic cough, chronic bronchitis, grades 1 and 2 shortness of breath, wheezing, and wheezing with shortness of breath using standardised definitions were obtained.³ The prevalences of these symptoms in the current workforce were compared with the prevalences reported for a population of blue collar workers not exposed to fibrogenic dusts.³ The referent population had been administered a modified version of the respiratory symptoms questionnaire developed by the Medical Research Council of Great Britain.⁴

Spirometry was performed using an Ohio Medical model 822 dry rolling seal spirometer. Procedures conformed to the American Thoracic Society's criteria for spirometry.⁵ We attempted to collect at least three reproducible and acceptable maximal expirations from each study subject. For participants who were unable to complete three acceptable curves, the forced vital capacity (FVC) and forced expiratory volume in one second ($FEV_{1.0}$) of the best two curves being within 5%, were maintained in the analysis. Predicted values were calculated using the Knudson regression equations as described by Hankinson.⁶ Predicted values for black workers were determined by multiplying the Knudson predicted value by 0.85.^{6,7} Forced vital capacity of less than 80% of predicted, with $FEV_{1.0}$ /FVC ratio of 70% or more was considered a restrictive pattern. A $FEV_{1.0}$ /FVC ratio less than 70% was considered an obstructive abnormality. Workers with FVCs less than 80% of predicted and $FEV_{1.0}$ /FVC ratios less than 70% were considered to have an obstructive pattern with a possible restrictive abnormality.

Predicted values of $FEV_{1.0}$ and FVC were also calculated using equations developed from a referent working population and included adjustments for race, sex, age, height, and smoking state.⁸ Observed $FEV_{1.0}$ and FVC values were subtracted from the values predicted for blue collar workers and the mean of the differences (FEV_{Δ} and FVC_{Δ}) were then compared with 0 by Student's *t* test.⁹ Two levels were created by dividing the study group into

equal sized groups of those with less than 22 working years and those with 22 or more working years.

Chest radiographs were read by three B readers trained and NIOSH certified in the use of the International Labour Organisation standardised interpretation and classification of radiographs for pneumoconiosis.¹⁰ The majority opinion was used for analysis of results.

REVIEW OF OSHA LOGS OF INJURY AND ILLNESS

To assess the risk of asthma in this workforce the company OSHA logs of injury and illness (form 200) were reviewed for January 1984–September 1988. The observed number of reported respiratory conditions was compared with an expected number, calculated from incidence rates reported for the miscellaneous fabricated metal products industry (standard industrial classification 3499).^{11,12} The number of full time worker-years at risk was estimated at 1976 (416 full time production workers at the time of our survey multiplied by the 4.75 years for which the OSHA logs were available).

ENVIRONMENTAL MEASUREMENTS

The sampling strategy was to determine the highest personal airborne exposures to cobalt, nickel, and respirable silica. The jobs sampled were selected according to the observed potential for exposure, historical exposure data, and information provided by the company and the union. Full shift personal breathing zone (PBZ) air samples for trace metals were collected throughout the plant during the first shift for three consecutive days. Full shift PBZ air samples were also collected for respirable silica.

The quantitative determination of trace metals was made by inductively coupled plasma atomic emission spectrometry according to NIOSH method 7300.¹³ The limit of detection (LOD) for this analysis was 0.5 µg/filter, and the limit of quantification (LOQ) was 1.0 µg/filter. Quantitative respirable silica analysis was performed on respirable dust filters by x ray powder diffraction according to the NIOSH method 7500.¹³ The LOD for this analysis was 5 µg/filter, and the LOQ was 10 µg/filter.

The PBZ environmental measurements were compared with the more conservative published exposure limits of OSHA or NIOSH. The standard used for exposure to cobalt was the OSHA 8 h time weighted average (TWA) of 50 µg/m³.¹⁴ The standard used for exposure to nickel was the NIOSH recommended exposure level (REL) of below 15 µg/m³ for a 10 hour TWA.¹⁵ The NIOSH REL of 50 µg/m³ respirable silica for a 10 hour TWA was used as the criterion for respirable silica.¹⁶

Results

CROSS SECTIONAL SURVEY

Eligible current workers included 326 hourly

Table 1 Prevalence of respiratory symptoms among current workers at a sintered rare earth permanent magnet manufacturer

	Smokers No (% affected)	Ex-smokers No (% affected)	Never smokers No (% affected)
Chronic cough:			
Magnet workers	107 (26)	80 (9)	119 (8)
Referent*	592 (18)	182 (8)	452 (8)
Chronic bronchitis:			
Magnet workers	107 (21)	80 (8)	119 (3)
Referent	590 (17)	181 (11)	452 (8)
Dyspnoea (breathlessness):			
Grade 1 or higher			
Magnet workers	104 (34)	79 (25)	116 (17)
Referent	589 (32)	182 (32)	450 (25)
Grade 2 or higher			
Magnet workers	104 (7)	79 (2)	116 (6)
Referent	588 (9)	182 (8)	450 (7)
Wheezing:			
Magnet workers	106 (19)	80 (2)	113 (4)
Referent	651 (10)	207 (7)	512 (5)
Wheezing with attacks of shortness of breath:			
Magnet workers	106 (13)	80 (0)	113 (3)
Referent	651 (10)	207 (10)	512 (8)

No = Total No of workers in the category.

*The referent population refers to a cross sectional study of blue collar workers 20–59 years of age not exposed to respiratory hazards.¹

employees and 36 salaried workers. A total of 256 eligible retirees were notified of the study by mail. The participation rate for current workers was 86% (310 of 362 eligibles) and was substantially higher than the 20% (52 of 256 eligible retired workers) participation rate for retired workers. Current workers averaged 45 years of age and 21 years of employment at the plant. Retired workers averaged 66 years of age and 26 years of employment. Seventy five per cent of all participants were men.

The current workforce did not have increased rates for any of the respiratory symptoms compared with the external referent group (table 1). The current workforce had prevalences of chronic cough of 15% and chronic bronchitis of 9%. Both chronic cough and bronchitis were associated, as expected, with smoking. Magnet workers who were current smokers had a higher prevalence of chronic cough (relative risk (RR) = 1.45; 95% confidence interval (95% CI) 1.01–2.08) than current smokers in the referent population. Ninety one (25%) participants reported a history of shortness of breath; 23 (6%) of these were classified as grade 2 or greater. Eleven (3%) reported symptoms more severe than grade 2. Twenty seven (9%) current workers reported wheezing on most days and nights and seventeen (6%) had wheezing with periodic attacks of shortness of breath. Twenty four (9%) workers with wheezing reported that this condition started after their employment began. Twenty three (8%) current workers claimed to have asthma; 20 had been diagnosed by a physician. Ten workers with asthma developed it after beginning work at the facility.

Three hundred and fifty seven (99%) of the participants completed spirometry. Three reproducible curves were obtained for 94% of the

participants. The spirometry curves of 22 persons did not meet the 5% reproducibility criteria. Sixteen per cent of those tested did not achieve a two second plateau; nevertheless the expiratory flow had dropped to zero and the curves were otherwise adequate.

Eleven (3%) workers showed a restrictive pattern, 52 (15%) an obstructive pattern, and eight (2%) workers had an obstructive pattern with a possible restrictive abnormality. Smoking, as expected, was associated with an obstructive pattern. The RR for an obstructive pattern was 3.49 (95% CI 1.62–7.51) for current smokers and 4.31 (95% CI 2.02–9.22) for ex-smokers compared with never smokers. No association was found between workers having a restrictive pattern and smoking.

The FEV_{1.0} and FVC for current workers were 3.51 (SD 0.81) l and 4.55 (SD 0.97) l. These values were slightly higher than those predicted (accounting for race, sex, age, height, and smoking state) for blue collar workers (FEVDELTA = 0.16 l, $p < 0.01$; FVCDELTA = 0.18 l, $p < 0.01$) indicating that ventilatory capacity was slightly better than predicted, either because the study population was healthier or because of ethnic or other demographic differences not accounted for by the prediction equations.⁸

The mean FEV_{1.0} for current workers was lower for workers with 22 or more years duration of employment compared with workers with less experience (3.38 (SD 0.72) l *v* 3.61 (SD 0.86) l; $p = 0.01$). After adjusting for age and smoking state, however, the differences between observed and expected FEV_{1.0} (FEVDELTA) were smaller and not statistically different (0.12 (SD 0.56) l in workers with 22 or more years of working experience *v* 0.19 (SD 0.49) l in workers with less than 22 years or working

Table 2 Abnormal chest x ray films consistent with pneumoconiosis in workers at a sintered rare earth permanent magnet manufacturer

<i>Abnormal chest x ray films</i>									
<i>Profusion scores (B readers)</i>									
<i>Worker</i>	<i>1</i>	<i>2</i>	<i>3</i>	<i>Shape</i>	<i>Opacities</i>	<i>Spirometry</i>	<i>Years worked</i>	<i>Age</i>	<i>Pack-years smoked</i>
A	Normal	1/0	1/0	Irregular	All fields	Obstruction	33	54	36
B	un	2/2	1/2	Irregular	Lower/middle	Obstruction	30	59	41
C	1/0	1/0	1/0	Rounded	Upper fields	Normal	34	63	0
D	Normal	2/1	1/2	Irregular	Lower/middle	Normal	> 30	75	25

un = Unreadable.

experience; $p = 0.21$). The mean FVC did not differ significantly by years worked for current workers (4.50 (SD 0.89) l v 4.59 (SD 1.04) l, $p = 0.45$).

A total of 359 workers (308 current, 51 retired), or 99% of all participants, had chest radiographs. Two films were considered unreadable by at least two B readers and were not included in the results. The 357 workers with readable chest radiographs were on average 48.5 years old, had worked at the facility 21.8 years, and 76% were men. The 357 readable films were rated for quality with scores from 1 to 3, where 1 was the highest film quality. Most of these films (184 (51.5%)) were scored with a quality rating of 1 or 2. The remainder (173 (48.5%)) were scored with a quality rating of 3. The predominant reason for films being scored 3 was overpenetration.

Four workers had small, rounded, or irregular parenchymal opacities consistent with pneumoconiosis (table 2). Two had a profusion category of 1/0. The two others had profusions of 1/2 or above. Two workers (both current workers) had pleural thickening (table 3). The pleural thickening was unilateral in one worker and bilateral in the other.

REVIEW OF OSHA 200 LOGS

A total of six episodes of respiratory conditions were recorded on the OSHA 200 logs. These conditions were recorded as asthma (three episodes in two workers), dyspnoea due to inhalation of neodymium powder (one worker), chemical bronchitis (one worker), and small airways obstruction (one worker). These six recorded respiratory conditions were more than 10 times (RR = 10.5, 95% CI 7.8–14.5) the expected number (table 4).

ENVIRONMENTAL MEASUREMENTS

Limited historical industrial hygiene data indicated that exposures above recommended or permissible exposure limits for cobalt, respirable silica, and asbestos had occurred at this plant.¹

We collected 100 PBZ air samples for 36 process jobs and 12 air samples for five office worker jobs and analysed these for exposure to trace metals. The concentration of cobalt, nickel, and samarium were below the limit of detection ($1 \mu\text{g}/\text{m}^3$) in all samples taken from the office areas. Trace amounts of neodymium ($1\text{--}2 \mu\text{g}/\text{m}^3$) were found in the personnel office, production engineering office, and the sales office.

In the process area, cobalt and nickel were in excess of environmental exposure criteria (table 5). Exposure to cobalt exceeded the OSHA PEL in 18 samples (18%) and 10 jobs (28% of the process jobs sampled). Nickel exposure exceeded the NIOSH REL in 15 samples (15%) and eight process jobs (22%). Various machine operators (grinders, millers, and press operators), boat loaders, and powder mixer/weighers were over exposed to cobalt and nickel. Only one worker (a powder mixer/weigher) wore a respirator (powered air purifying respirator with high efficiency particulate air (HEPA) canister) to reduce exposure to the metal dust.

Exposures to trace amounts of neodymium and samarium were found throughout the production areas (table 5). Because of its propensity to burn when exposed to a normal atmosphere, neodymium powder was maintained in an argon gas environment and exposures to neodymium were low. Exposures to samarium were somewhat higher.

Exposure to respirable silica dust was identified in

Table 3 Pleural thickening in two workers at a sintered rare earth permanent magnet manufacturer

Worker	Pleural thickening		Spirometry	Years worked	Age	Pack-years smoked
	Location	Diffuse or circumscribed				
E	Left costophrenic angle and left chest wall	Diffuse	Restrictive	26	55	26
F	Bilateral costophrenic angles and chest wall	Diffuse	Normal	34	54	0

Table 4 Reports of respiratory illness on the OSHA 200 logs at a sintered rare earth permanent magnet manufacturer

Year	Dust diseases of lungs	Respiratory conditions due to toxic agents	Total
1984	1	0	1
1985	0	0	0
1986	0	0	0
1987	0	2	2
1988	2	1	3
Total	3	3	6
Expected	0.06	0.5	0.56
RR	50.0	6.0	10.5
95% CI	43.0-63.1	3.9-9.4	7.8-14.5

Reports of dust disease of lungs should properly have been classified as respiratory conditions due to toxic agents. The total column accurately reflects the observed and expected numbers for the two conditions combined.

Expected numbers were based on incidence rates for the miscellaneous metal manufacturing industry (standard industrial classification 3499).¹²

95% CIs were calculated by the method of Rothman and Boice.¹⁷

RR = Relative risk = observed illness/expected illness.

eight of 18 jobs sampled (table 5). Exposures in four of these jobs (sand mixer, furnace operator, core checker, and machine moulder) exceeded the NIOSH REL.

Discussion and conclusions

This is the first published survey of respiratory conditions and environmental exposures at a sintered permanent magnet manufacturer. The findings reported here may be indicative of conditions throughout this industry. The cross sectional survey focused on chronically exposed workers (those with at least 10 years of experience). Given the high participation rate for current workers (86%), the results reported here are representative of the current workforce with 10 or more years of experience. The poor participation rate for retired workers (20%), however, and our inability to identify workers who left employment before retirement, prevents these findings from being extrapolated to these workers.

Table 5 Process area personal breathing zone sampling results at a sintered rare earth permanent magnet manufacturer

	Geometric mean (SD) $\mu\text{g}/\text{m}^3$	Samples above exposure limit
Metals (100 samples, 36 jobs):		
Cobalt	17.5 (3.1) 1-466*	18
Nickel	4.4 (5.3) ND-368*	15
Neodymium	2.6 (3.3) ND-52*	na
Samarium	3.9 (9.6) ND-528*	na
Respirable silica (18 jobs sampled)	9.0 (4.7) ND-110*	4

na = Not applicable; ND = not detected.

Cobalt: OSHA PEL = 50 $\mu\text{g}/\text{m}^3$;

nickel: NIOSH REL = 15 $\mu\text{g}/\text{m}^3$;

respirable silica: NIOSH REL = 50 $\mu\text{g}/\text{m}^3$.

*Range.

In this survey, the prevalence of current workers (0.6%) with parenchymal opacities (profusion 1/0 or greater) was comparable with the 0.9% prevalence found in a study of 1422 non-exposed blue collar workers.²² Two magnet workers, however, (one current and one retired worker) had profusion scores of 1/2 or higher, while none of the referent group had parenchymal markings graded higher than 1/1. Also, one further (retired) worker, having worked with silica flour in the foundry area of the plant for seven years, had bilateral small rounded opacities in the upper lung fields, classic radiographic signs of silicosis. Silica flour, no longer used at the plant, is an extremely hazardous form of respirable silica.²³

Some caution should be taken when interpreting the chest radiograph results. The large number (48%) of quality 3 radiographs may have resulted in some misclassification of pneumoconiosis. Early stages of pneumoconiosis may be more difficult to identify when films are overpenetrated. A study by Reger *et al*²⁴ found that overpenetrated films were scored lower for profusion than films of better quality. Although there may have been some under-scoring of profusion in the quality 3 films, the number of such films was probably small. This was apparent as none of the films with quality scores of 1 or 2 were interpreted as having parenchymal opacities.

Workers who develop occupational asthma may, as a result, leave employment. This could have created a survivor bias²⁵ in the cross sectional survey due to the imposed 10 year selection criteria. To account for this potential bias, we evaluated the risk of asthma by reviewing the OSHA 200 logs. Information collected from these logs reflects the health of all workers, regardless of duration of employment, although limitations of these data include under-reporting and misclassification. We noted a 10-fold excess for various respiratory conditions, including asthma, at this plant when compared with other manufacturers within the miscellaneous fabricated metal industry.

This excess risk could reflect over-reporting by this company or under-reporting by other manufacturers included in standard industrial classification 3499. An alternative explanation is that workers at this plant were indeed at higher risk. This last hypothesis is supported by the documented overexposures to cobalt and nickel.

In general, the prevalence of respiratory symptoms in this workforce was similar to that of a previously studied workforce unexposed to any known respiratory hazards. We did find that current smokers in the magnet workforce were more likely, however, to have chronic cough than current smokers in the referent group. One possible explanation for this finding is a synergism between smoking and the respiratory hazards present in the magnet industry. Alternatively, the magnet workers may have been heavier smokers than those in the referent group or this finding may have been a random occurrence consistent with chance.

We documented airborne exposures to nickel, cobalt, and respirable silica that were above applicable exposure criteria. Historical sampling data suggest that these exposures, as well as exposure to asbestos, existed in the past at this facility. Chronic exposures to cobalt, respirable silica, and asbestos have been associated with hard metal disease, silicosis, and asbestosis, various forms of pneumoconiosis.¹⁸⁻²⁰ Cobalt and nickel are also known sensitizers and have been associated with occupational asthma.^{18,21}

The study had several limitations. Already mentioned were a potential survivor bias for investigating asthma, limited participation from those who were not current employees, and a large proportion of overpenetrated chest radiographs. Also, most of the workforce had been exposed to various respiratory toxins and no group of unexposed workers was available to evaluate. This prevented us from examining the association between exposure to specific toxins with the prevalence of respiratory symptoms, spirometry results, and chest radiograph results. The external referent group was used to correct for this situation. The consequence of this is that the generalisability of the comparisons between the magnet manufacturer workforce and the referent group rely on how well the last represent unexposed workers. The referent group was selected from a variety of industries which, according to the investigators, "had a large number of production employees working in atmospheres free of respiratory hazards." Workers in jobs having respirable dust exposures greater than 0.75 mg/m³ were excluded. Also excluded from the referent group were persons who had worked for five years in industries thought to have significant respiratory hazards.

From our results, we concluded that a health

hazard existed in this plant due to exposures to dusts containing cobalt, nickel, and respirable silica and that workers were at excess risk of respiratory disease from these respiratory toxins. As a consequence of these findings, we recommended specific engineering controls to decrease environmental exposures and the implementation of medical surveillance of exposed workers.¹ Our findings suggest that respiratory hazards may exist in this industry and that further environmental and medical surveys should be conducted. Those employed in this industry and occupational health workers should be aware that several potentially hazardous exposures occur during the manufacturing of sintered permanent magnets. Given the respiratory hazards in this industry, and the positive associations between smoking and respiratory conditions, smoking cessation programmes should also be encouraged and smoking should be prohibited in work areas and other common use areas.

We express our thanks to Dr Robert Castellan, Dr John Parker, and Mr Kenneth Wallingford for their comments on an earlier version of this manuscript and to Patricia McGraw for its preparation.

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Accepted 21 January 1991

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