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Manganese Dioxide Exposures and Respirator Performance at an Alkaline Battery Plant

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Two industrial hygiene studies were conducted at an alkaline battery plant to evaluate worker exposures to manganese dioxide particulate and the effectiveness of filtering facepiece respirators. The work areas studied included the plant's powder-processing tower and press rooms where manganese was blended, compacted with graphite, and inserted into battery cans. Full-shift personal breathing zone monitoring was conducted to estimate manganese dust exposures of press operators, mechanics, and material handlers. In-facepiece and personal breathing zone air sampling pairs were also collected using a *program protection factor* protocol to estimate the protection provided by the respirators. Particle size evaluations were made using nylon cyclones and Marple personal multi-stage impactors. All samples were analyzed for manganese by inductively coupled argon plasma, atomic emission spectroscopy via NIOSH analytical method 7300 utilizing a modified acid digestion procedure.

Fifty-four, full-shift, time-weighted average (TWA) exposures to total manganese ranged from 0.1 to 5.4 milligrams per cubic meter (mg/m^3); worker exposures were substantially lower during a follow-up study due to engineering control improvements. Concurrent area sample comparisons of total and respirable manganese revealed that the respirable particulate mass fractions ranged from 6 to 32 percent, and mass median aerodynamic diameters determined from personal breathing zone air samples were mostly greater than 10 micrometers. Fifteen respirator performance evaluations were conducted using Moldex 2200 respirators fitted with 25 millimeter cassettes and light weight sampling probes. Protection factors ranged from 5 to 220, with a geometric mean and standard deviation of 31 and 2.97, respectively. The 5th percentile protection factor estimate was 5, as calculated from the protection factor distribution for this sample set.

In 1995, the American Conference of Governmental Industrial Hygienists (ACGIH®) lowered the elemental and inorganic manganese dust Threshold Limit Value® (TLV®) from 5 mg/m^3 to 0.2 mg/m^3 to address adverse pulmonary and central nervous system effects and male infertility. Although most personal breathing zone concentrations were above 0.2 mg/m^3, none of the in-facepiece concentrations exceeded this concentration. Parkinson's-like symptoms have been reported in the literature for high manganese dust and fume exposures, but the importance of low dust exposures for producing neurological effects is uncertain.

Keywords Alkaline Battery Manufacture, SIC Code 3692, Manganese, Filtering Facepiece Respirators, In-Mask Sampling, Program Protection Factor, Particle Sizing, Inertial Cascade Impactor

Worker exposures to manganese dioxide were evaluated at an alkaline dry-cell battery manufacturing plant.(1) The evaluation followed an inquiry from an occupational physician who reported that workers in the plant's powder processing areas had experienced neurological effects, possibly due to manganese exposure. The objectives of this evaluation were to (1) estimate worker exposures to manganese dust, (2) evaluate the effectiveness of filtering facepiece respirators used at the plant, and (3) evaluate the effects of engineering and administrative changes made after an initial study.

This article includes a general process description; an overview of the health effects of manganese and the evaluation criteria; the study design, methods, and results; and the conclusions and recommendations for reducing manganese exposure.

Company air sampling records for the powder department showed that manganese exposures exceeded the National Institute for Occupational Safety and Health (NIOSH) Recommended Exposure Limit (REL), the Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL), and the American Conference of Governmental Industrial Hygienist (ACGIH®) Threshold Limit Value® (TLV®) for manganese. Moreover, manganese exposure measurements were recorded as high as 20 milligrams per cubic meter (mg/m^3), during a period when pneumatic conveyance systems for moving

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manganese powder had leaked. Although engineering improvements substantially reduced exposure levels, the company still required that workers in this department wear respirators. In particular, NIOSH approved dust and mist filtering facepiece respirators were worn by everyone in this department.

In-facepiece sampling was conducted during this study to provide a more direct estimate of worker exposures to manganese while wearing Moldex model 2200 filtering facepiece respirators (TC-21C-287). Using a *program protection factor* protocol, in-facepiece and personal breathing zone (PBZ) manganese air samples were collected simultaneously for nearly entire work shifts while workers performed their normal activities.(2,3)

PROCESS DESCRIPTION

Size C and D dry cell alkaline batteries were manufactured at the study site. The primary activities in the powder department were manufacturing manganese pellets and inserting them into battery cans. Raw materials for the manganese pellets included manganese dioxide, graphite (carbon black), and a binder containing polyacrylamide. The manganese dioxide was purified off-site from pyrolusite, a mineral ore containing approximately 60 percent manganese dioxide.

Approximately 20 employees per shift worked in the manganese processing locations, and most worked in press rooms. Job titles included process and press operators, mechanics, reworkers, material handlers, and supervisors. Material handlers included bulk loaders, powder unloaders, press material handlers, and bag house laborers.

Purified manganese dioxide and graphite were received in bulk quantity 'super' sacks containing approximately 2000 pounds of finely pulverized material. A bulk loader emptied the material into a hopper using a mechanical hoist, and the material was then transferred pneumatically to the powder processing tower. The powder processing tower was a multi-story structure where manganese dioxide and graphite were blended together with binder, compacted and granulated, size-sifted using rotary sieves, and conveyed into transfer hoppers. Each floor of the tower was dedicated to a specific sequence in the manufacturing process.

The hoppers of processed manganese granules were transferred to the adjacent press rooms. Semi-automated presses were used to compress the manganese into cylindrical pellet rings and insert the rings into battery cans.

The powder department was separated from adjacent manufacturing departments with floor-to-ceiling walls and was under negative pressure to minimize the escape of dust. The powder-processing tower was under additional negative pressure with respect to the adjacent press rooms, and recirculated air was filtered to reduce background concentrations.

HEALTH EFFECTS OF MANGANESE AND EVALUATION CRITERIA

Manganese is an abundant and ubiquitous element present throughout the environment including soil, water, air, vegetation, and food. Manganese is an essential trace element necessary for the formation of connective tissue and bone as well as the metabolism of carbohydrates and lipids. For these reasons, adults require 2 to 3 milligrams (mg) of dietary manganese per day.(4) Manganese is a very reactive metal, exists in seven oxidation states, and is a component of over 100 minerals. One of the most common and commercially important manganese containing-ores is pyrolusite, a black mineral containing approximately 60 percent manganese dioxide.

Adverse health effects were associated with heavy occupational exposures to manganese as early as 1837, when Couper reported a neurological syndrome found in workers who had been grinding manganese dioxide for several months.(5) The neurological findings of affected workers showed that manganese affects the extrapyramidal system of the brain.(6,7) More recent studies of chronic manganese toxicity have been described in the mining, ore processing, and smelting industries.(8–11) Most notably, occupational exposure to manganese dust is known to cause *manganism*, a Parkinson's-like syndrome with well-recognized characteristics. Other health effects of excessive occupational manganese exposure are primarily respiratory effects including irritation, pneumonitis, chronic bronchitis, metal fume fever, and, possibly, male infertility.(12)

Manganism is a progressive occupational disease. The symptoms of early disease such as fatigue, somnolence, and irritability are nonspecific and may be related to many factors. Advanced disease is characterized by slow or minimal speech or movement, increased muscle tone especially of the limbs, an expressionless face, tremors, disturbed gait, postural instability, increasingly small handwriting, and possibly psychological disturbance such as hallucinations, compulsive behavior, and emotional instability.(12,13) The condition may develop insidiously after months or years of manganese exposure. Although the condition may be reversible after early removal from exposure, it is often unrecognized until a worker is severely and irreversibly affected.

Chronic manganese toxicity has been found in workers exposed to manganese during operations in which high air concentrations of dust or fume were generated. Such operations have included mining, ore processing, metallurgical manufacturing processes, and welding with alloys or welding rods containing manganese.

The NIOSH REL for manganese dust is an 8-hour time-weighted average (TWA) of 1 milligram per cubic meter (mg/m^3) total manganese, with a short-term exposure limit (STEL) of 3 mg/m^3 based on central nervous system effects and pneumonitis.(14) The OSHA PEL for manganese dust is a ceiling limit of 5 mg/m^3.(15) In 1995, ACGIH lowered the TLV for elemental and inorganic manganese from either 5 mg/m^3 (manganese dust) or 1 mg/m^3 (manganese fume) to 0.2 mg/m^3, to address adverse pulmonary effects, central nervous system effects, and male infertility.(12,16) Reports of Parkinsonian-like symptoms have been reported for high manganese dust and fume exposures, but the importance of low dust exposure for producing neurological effects remains controversial. For additional information regarding manganese, the reader is referred to the report on the fifteenth International Neurotoxicology Conference.(17)

METHODS

Two separate sampling studies were conducted in the manganese powder-processing areas and press rooms. A follow-up study was conducted to evaluate the effectiveness of engineering and administrative changes. Each study occurred on two consecutive days during first shifts, when manufacturing production of the powder department approached maximum capacity. These studies included PBZ monitoring for total manganese, total and respirable manganese area air samples, as well as concurrent in-facepiece and PBZ sampling pair comparisons. Particle size analyses were also performed with the PBZ samples during the follow-up study using Marple personal cascade impactors. Fifty-four, full-shift PBZ evaluations for total manganese dust were completed on process and press operators, mechanics, material handlers, and other workers. In addition, 21 side-by-side, total versus respirable area air samples were collected throughout the powder department to estimate the respirable fraction of the manganese aerosol via 10 millimeter (mm) nylon cyclones.

Fifteen in-facepiece and PBZ sample pairs were collected simultaneously for nearly entire work shifts. Moldex 2200 respirators were evaluated using 25-millimeter filters and cassettes and lightweight, "Liu" sampling probes to prevent deformation of a respirator from a sampling train's weight.(18) Each sampling probe was inserted into a respirator facepiece so that its inlet was positioned between a respirator wearer's nose and mouth. After each use, a sampling probe was rinsed with distilled water. The rinsate was analyzed for manganese, and any resulting mass was added to the amount of manganese detected on the respective filter. In addition, eight of the PBZ air samples collected during these comparisons were performed with eight-stage Marple personal impactors to allow particle size characterization of the aerosol. The jobs selected for respirator performance evaluations included bulk loader, powder unloader, press operators, material handlers, and mechanics.

The respirator performance evaluation was conducted using a *program protection factor* protocol.(2,3) A program protection factor is defined as the contaminant concentration outside a respirator divided by the contaminant concentration measured inside the respirator facepiece as the respirator is used in the context of an existing respiratory protection program. If any part of a respirator program is deficient (i.e., proper fit, donning, selection, maintenance, etc.) or otherwise compromised by a worker's activities, then the measured protection factor will be adversely affected.(2,3)

Both the PBZ and area total manganese air samples were collected with closed-face cassettes on 0.8 micrometer (μm) pore size, mixed cellulose ester (MCE) filters at sampling air flow rates ranging between 2 and 2.5 liters per minute (lpm). The respirable manganese evaluations were made using MCE filters in 10-millimeter nylon cyclones at an air flow rate of 1.7 lpm. Marple impactor samples were collected using polyvinyl chloride substrates to measure both total weight and manganese concentrations.

All samples were analyzed for elemental manganese by inductively coupled argon plasma, atomic emission spectroscopy via NIOSH method 7300, utilizing a modified acid digestion consisting of hydrochloric, nitric, and perchloric acids in a 3:1:1 ratio.(19) The addition of hydrochloric acid was necessary to ensure that all of the manganese particulate was completely dissolved before analysis.

Because of analytical complications with manganese digestion an anti-bounce spray coating could not be used on impactor substrates. In this case, the increased potential for particle bounce was an accepted compromise for obtaining an estimate of manganese particle size distributions, which was desired to supplement in-facepiece sampling data. The sampling pump air flow rate was reduced to 1.5 lpm and eight impactor plates were used to reduce the inertia of the particles and reduce the potential for particle bounce.(20) The approximate aerodynamic diameter particle-size cut points at this air flow rate are 26, 18, 11.5, 7, 4, 1.7, 1.1, and 0.6 μm.

Geometric means and geometric standard deviations were calculated for PBZ exposure to total manganese as well as respirator performance evaluations. The 5th percentile protection factor was calculated for the sample set by using the following expression:

$$\text{Fifth Percentile Protection Factor} \\ = \text{Geometric Mean}_{\text{PF}} \div (\text{Geometric Standard Deviation}_{\text{PF}})^{Z} \quad [1]$$

where Z equals 1.645, the standard normal value that corresponds to a 95 percent confidence that 95 percent of the distribution exceeds the 5th percentile.

Particle size analysis of the Marple impactor particle size selectors was performed by extrapolating the mass median aerodynamic diameter and standard deviations from a log probability plot of the cumulative mass percentage versus the particle size cut points.

RESULTS

Table I presents the data obtained from the manganese area air samples collected near the bulk loading hopper, on all floors of the processing tower, and in both press rooms. This table includes the concurrent total and respirable manganese concentrations with sample durations of at least six hours. During the initial study, area air concentrations as high as 2 mg/m^3 of total manganese were measured. In general, higher airborne manganese concentrations were measured and more surface contamination was observed throughout the process tower than in the press rooms.

After the initial study, the company implemented engineering and administrative changes, which included process enclosures

TABLE I

Area manganese (Mn) dust concentrations in the process tower and press rooms

	Initial study			Follow-up study		
Location	Total Mn (mg/m^3)	Resp. Mn[C] (mg/m^3)	Present resp.[C]	Total Mn (mg/m^3)	Resp. Mn[C] (mg/m^3)	Percent resp.[C]
Process tower						
Bulk hopper	1.74	0.27	16	0.69	0.13	19
Blend floor	2.14	0.31	14	0.26	0.08	31
	2.10	0.67	32	0.42	—	—
Compact floor	1.28	lost[A]	—	0.14	0.025	18
	0.31	0.09	28	0.26	—	—
Sieve floor	1.36	0.28	20	0.75	0.12	16
	1.52	0.43	28	0.42	—	—
Transfer floor	1.56	0.10	6	0.86	0.08	9
	1.98	0.44	22	0.38	—	—
Press rooms						
D cell press	0.73	0.10	13	0.45	—	—
	1.04	0.24	23	0.32	0.06	20
				0.29	0.06	21
C cell press	0.24	Lost[B]	—	0.32	—	—
	0.24	0.06	24	0.35	0.09	26

[A] Sampling equipment failure.
[B] Cyclone inverted after falling.
[C] Resp. = respirable.

and local exhaust modifications, an improved general ventilation and air filtration system, transfer bin capacity sensors, and increased use of HEPA vacuums in lieu of dry sweeping. Similar locations were selected for replicating the area measurements during the follow-up study and substantially lower manganese air concentrations were measured. Total manganese in the process tower ranged from 0.31 to 2.1 mg/m^3 during the initial study and from 0.14 to 0.86 mg/m^3 during the follow-up. Sample-pair comparisons of total and respirable manganese revealed that most of the respirable manganese concentrations ranged from 13 percent to 32 percent of the total manganese concentrations (17 of 19 pairs).

Fifty-four, full-shift, PBZ TWA exposure measurements for total manganese were conducted during these evaluations. Refer to Table II for a summary of the manganese TWA concentrations for the process tower and press room personnel. (The bulk loader and powder unloader air sampling results are included in the data set for the powder processing tower.) Lower PBZ manganese concentrations occurred during the follow-up compared to the initial study, as each minimum, maximum, and geometric mean concentrations were lower for both process tower and press room workers. The geometric mean manganese TWA exposure concentrations were 1.5 and 0.39 mg/m^3 for the process tower personnel, and were 0.67 and 0.41 mg/m^3 for press room workers, respectively for the initial and follow-up data sets. The geometric standard deviation for the process tower jobs were in excess of 3, whereas it was less than 2 for press room jobs, which indicates that greater variability of exposure occurred in the process tower.

Geometric means are not provided for individual job titles in Table II because the number of samples per job were too few. The highest total manganese PBZ exposures were observed for the bulk loader and powder unloader jobs. The most notable exposure reductions were also found for these jobs as ventilation modifications were installed on equipment used by these workers. However, full-shift manganese exposure levels still exceeded the NIOSH REL of 1 mg/m^3 for these two jobs. Furthermore, over 90 percent of the manganese PBZ-TWA exposure concentrations for all jobs exceeded the current ACGIH TLV of 0.2 mg/m^3 for inorganic manganese.

Fifteen PBZ and in-facepiece respirator performance evaluations for manganese dust were conducted with both process tower and press room workers using Moldex 2200 respirators. The results of these determinations are tabulated in Table III for the initial study, and Table IV for the follow-up. All of the in-facepiece concentrations were below the ACGIH TLV for inorganic manganese.

Combining the data from both studies, the individual protection factors range from 5 to 220 with a geometric mean (GM) of 31 and a standard deviation (GSD) of 2.97. The 5th percentile

TABLE II

Summary of manganese TWA exposure concentrations by job title

Job title and location	Initial study		Follow-up study		Both studies GM (GSD)[A] (mg/m^3)
	Number	Range (mg/m^3)	Number	Range (mg/m^3)	
Process tower					
Bulk loader	2	2.16–4.85	2	0.47–1.63	
Process operator	2	0.36–0.62	1	0.10	
Rework handler	2	0.70–1.0	—	—	
Process mechanic	2	1.11–1.68	2	0.09–0.28	
Powder unloader	2	4.11–5.41	2	0.62–1.19	
GM (GSD)[A] Process tower jobs	10	1.5 (2.6)	7	0.39 (3.1)	0.87 (3.3)
Press rooms					
Material handler	4	0.43–0.70	2	0.22–0.23	
Press operator	8	0.25–2.52	10	0.34–0.89	
Press mechanic	5	0.25–1.37	5	0.14–0.52	
Bag house laborer	2	0.77–0.93	1	0.51	
GM(GSD) Press room jobs	19	0.67 (1.8)	18	0.41 (1.7)	0.50 (1.9)

[A] GM (GSD) = geometric mean and geometric standard deviation.

TABLE III

Personal breathing zone (PBZ) and in-facepiece sample comparisons for manganese (Mn) dust during the initial study

Job title	PBZ data			In-facepiece data			Program protection factor[B]
	Sampling duration (min)	Mn conc. (mg/m^3)	8-hr. TWA (mg/m^3)	Sampling duration (min)	Mn conc. (mg/m^3)	8-hr. TWA[A] (mg/m^3)	
Bulk loader	132	4.17	3.90	132	0.012	0.018	220
	113	3.76		113	0.013		
	101	8.42		101	0.036		
	40	1.15		40	0.006		
Process reworker	143	0.88	0.68	143	0.014	0.044	15
	92	0.92		92	0.095		
	92	1.26		92	0.100		
Process mechanic	148	0.78	0.91	148	0.014	0.082	11
	98	1.68		98	0.146		
	145	1.07		145	0.141		
Press operator	230	1.50	1.97	230	0.010	0.013	150
	145	4.14		145	0.018		
Press operator	110	0.77	0.74	110	0.003	0.010	74
	271	1.00		271	0.014		
Material handler	191	0.58	—	118	0.019	—	31[C]
				68	0.018		

[A] TWA calculated with Mn weight detected by facepiece probe rinse and filters.
[B] Program protection factor calculated by: PBZ-TWA ÷ In-Facepiece TWA.
[C] Material handler only worked a half shift; protection factor calculated using actual sampling periods.

TABLE IV

Personal breathing zone (PBZ) and in-facepiece sample comparisons for manganese (Mn) dust during follow-up study

	PBZ data			In-facepiece data			
Job title	Sampling duration (min)	Mn conc. (mg/m^3)	8-hr. TWA (mg/m^3)	Sampling duration (min)	Mn conc. (mg/m^3)	8-hr. TWA (mg/m^3)	Program protection factor
Bulk loader-A	371	1.63[A]	1.26	111	0.033	0.025	65[A]
				68	0.010		
Bulk loader-B				101	0.030	0.030	54[A]
Powder unloader	350	1.19	0.87	110	0.027	0.021	41
				93	0.013		
				87	0.069		
Press mechanic	377	0.84	0.66	126	0.246	0.112	6
				104	0.043		
				147	0.126		
Process mechanic	404	0.28	0.24	128	0.051	0.045	5
				96	0.073		
				180	0.044		
Press operator	398	0.67	0.56	123	0.041	0.045	12
				115	0.019		
				126	0.111		
				34	0.015		
Press mechanic	339	0.52	0.37	97	0.005	0.011	34
				97	0.011		
				145	0.030		
Press operator	414	0.34	0.29	215	0.008	0.010	29
				196	0.016		
Press operator	398	0.65	0.54	116	0.010	0.014	38
				115	0.027		
				116	0.017		
				51	0.010		

[A] Protection factor calculated separately for each bulk loader using actual sampling periods.

protection factor of this sample set is 5, as calculated by:

$$GM/(GSD)^{Z} = 31/(2.97)^{1.645} = 5$$

Mass median aerodynamic diameters (MMAD) are shown in Table V. They range from 6 to 19 μm with standard deviations ranging from 3.3 to 4.8, denoting a widely distributed polydisperse aerosol. Although one MMAD was 6 μm, the remaining MMADs were 10 μm or greater. This data is consistent with the total-respirable sampling pair results, which indicated that the majority of the manganese particulate mass was not due to respirable sizes.

DISCUSSION

The American National Standards Institute's (ANSI) assigned protection factor for all half-facepiece respirators is 10,(21) whereas the assigned protection factor published by NIOSH for filtering facepiece respirators that have not been quantitatively fit tested is 5.(22,23) Unfortunately, only a few field studies have been published that evaluated the protection provided by filtering facepiece respirators as measured in the workplace.

Reed et al. conducted a workplace protection factor study of 3M, model 9910 (TC-21C-190) respirators while workers packaged a concrete patching compound containing portland cement.(24) Twenty-two sample pairs of approximately four-hour durations were collected inside and outside of respirators during this study, and a 5th percentile protection factor of 3 was calculated.

Wallis et al. reported on a workplace protection factor study of 3M, model 8710 half-facepiece respirators (TC-21C-132) in alkaline battery manufacturing plants utilizing a workplace protection factor (WPF) protocol.(25) To determine the WPFs, manganese dust concentrations were measured simultaneously inside and outside of respirator facepieces that were properly worn during sampling periods lasting approximately one half-hour. The authors concluded that the manganese concentration

TABLE V
Mass median aerodynamic diameters determined from personal breathing zone impactor samples analyzed for manganese (Mn)

Job title	Total Mn 8-hr TWA (mg/m^3)	Mass median diameter (μm)	Standard deviation	Program protection factor
Bulk loader	1.26	11	4.4	64; 54
Powder unloader	0.87	14	3.8	41
Press mechanic	0.66	10	3.7	6
Process mechanic	0.24	15	3.3	5
Press operator	0.56	6	3.8	12
Press mechanic	0.37	10	3.4	34
Press operator	0.29	10	4.0	29
Press operator	0.54	19	4.8	38

inside a respirator was "almost independent to the concentration outside and that the protection factor, as measured by their ratio, was directly proportional to the outside concentration." Using the data provided in the Wallis et al. study, a 5th percentile protection factor of 6.8 was calculated from outside concentrations ranging between 0.14 and 5 mg/m^3, the approximate range of exposures measured in our study.

The respirator performance evaluation of our study focused on the Moldex model 2200 because it was the most widely used respirator at the plant. The Moldex 2200 dust and mist respirator was approved by NIOSH under regulations of 30 CFR Part 11.(26) As of July 10, 1995, NIOSH began certifying negative-pressure, air-purifying particulate filters under the revised regulations of 42 CFR Part 84.(27) After an upgrade of the filter material, the Moldex 2200 respirator passed NIOSH certification tests for N-95 respirators and was assigned approval number 21C-84A-0327. The facepiece design of the Moldex 2200N95 respirator did not change from its Part 11 predecessor.(28)

Laboratory testing showed that submicron particles penetrated dust and mist filters.(29) Both NIOSH and ANSI recommended that Part 11 dust and mist filtering facepiece respirators be used only for protection against aerosols having a MMAD greater than 2 μm.(21,30,31) Unlike the Part 11 procedure, a respirator submitted to NIOSH for Part 84 approval is now tested against a neutralized aerosol in the most penetrating submicron (0.3 μm) particles at a high air flow rate.

Airborne contaminants enter a filtering facepiece respirator primarily at gaps in the face-to-facepiece seal and by filter penetration. Impactor measurements at this study site revealed that PBZ manganese aerosols had MMADs ranging from 6 to 19 micrometers, and all but one of the MMADs were 10 micrometers or greater. Penetration of aerosols with these particle size distributions would be essentially negligible through the filter media of both Part 11 dust and mist respirators and Part 84 respirators. Consequently, facepiece leakage and possibly minor deposition through a sampling probe fitting are believed to be the principle sources of manganese collected by the in-facepiece samples. Filter penetration was unlikely given the exposure conditions at this facility. Furthermore, the Moldex 2200N95 respirator would be expected to provide the same level of protection at this plant as the Part 11 Moldex 2200, because facepiece seal leakage was likely the predominant pathway for manganese to enter the respirator.

CONCLUSIONS AND RECOMMENDATIONS

The majority of the PBZ exposures were below the current ACGIH TWA TLV for manganese dust (5 mg/m^3) in effect at the time of this study as well as below the OSHA ceiling PEL of 5 mg/m^3. Some PBZ exposures to total manganese dust exceeded the NIOSH REL of 1 mg/m^3. Lower manganese exposure concentrations were found during the follow-up study after engineering and administrative controls were improved; only the bulk loader and powder unloader jobs caused PBZ exposures exceeding the NIOSH REL. However, virtually all ($>90\%$) of the exposure concentrations for all jobs exceeded the revised ACGIH TLV of 0.2 mg/m^3 for total inorganic (elemental) manganese, although none of the in-facepiece concentrations exceeded this criterion. Manganese dust in both the processing tower and press rooms were largely non-respirable particulate. Therefore, the manganese concentrations, detected within the respirators at this site, were more likely due to facepiece seal leakage rather than filter penetration.

The respiratory protection program in the powder department was effective. A 5th percentile protection factor of 5 was calculated, which is consistent with the assigned protection factor published by NIOSH for this class of respirator when quantitative fit testing has not been satisfied. Based on the NIOSH REL for manganese dust of 1 mg/m^3 and the 5th percentile protection factor of 5, Moldex 2200 filtering facepiece respirators may be expected to provide adequate protection up to 5 mg/m^3. Similarly, applying this rationale to the present ACGIH TLV, these respirators could be used for full-shift manganese exposure concentrations below 1 mg/m^3. Hence, the use of filtering facepiece respirators should provide sufficient protection for most jobs at this facility. Respirators with higher assigned protection factors were recommended to be worn by the bulk loader and powder unloader material handlers.

Respirators should be used only when engineering controls are not feasible or effective, while controls are being installed or repaired, or for emergency and other temporary situations. Thus, after the follow-up, additional recommendations were provided to eliminate the need for respiratory protection. These recommendations included installing additional process enclosures, improving local exhaust ventilation, increasing filtration of recirculated air, and eliminating dry sweeping clean-up. Other recommendations included prohibiting smoking in a hallway adjacent to exposure locations (within the powder-processing department) and initiating a medical surveillance program with early alternative employment policies for workers exhibiting manganism symptoms.

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