Safety in Mines Research Advisory Committee

Final Project Report

Two phase longitudinal or prospective study of the nervous system effects of occupational environmental manganese exposure on mineworkers or processing plant workers at two manganese mines in the Northern Cape Province

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Executive summary

Occupational exposure to airborne manganese dust has been shown to produce adverse effects on the central nervous system. Concerns have also been expressed about very low level environmental exposures to Manganese resulting in revisions of both occupational and environmental recommended exposure limits.

A study was conducted amongst manganese mine employees (both white and blue collar) at two towns in the Northern Cape Province to investigate the nervous system effects of medium to low occupational manganese exposures with a view to shedding light on the potential neurotoxic effects of environmental exposures. A cross-sectional study was conducted as a phase 1 baseline of a potential longitudinal study examining the relationship between manganese exposure and nervous system outcomes. There were two mining companies (A & B). The different facilities included four underground mines with surface processing plants, one surface sinter plant and two residential/office locations.

At the inception of the study in 2000 there were roughly 2000 mine employees in total, of which half were employed by each of the two companies. Early in 2001 an active process of retrenchment led to diminishing numbers of workers at Company B.

It was intended to study each individual worker as part of their routine annual medical examinations performed by occupational health staff at the occupational medical service serving both companies.

Some 800 employees were examined during 2000/2001, 311 from Company B and 489 from Company A.

Exposures to manganese were to have been obtained by means of an independent occupational hygiene survey, but this proved to be very expensive and on exploration of the records of mandatory routine occupational hygiene measurements of dust and manganese in these facilities, it turned out that there was a rich source of occupational hygiene data already in existence. Occupational hygienists on the research team advised use of the routine data instead of embarking anew on an independent survey. Data were usable from 1995 when the GME required sampling of total as opposed to respirable dust in Company A. Company B had a different arrangement with the GME whereby they were measuring respirable dust for "risk workers" and total dust for others. "Risk" or underground workers did not have a manganese concentration determined. Although this situation was rectified in 2001 via the GME it was not possible by the end of the study to accumulate sufficient dust data points to recover any meaningful exposure index for Company B and consequently only Company A exposure data and indices derived from these were used. A validation or reliability study was performed to check certain assumptions that were made in deciding whether to use routine GME occupational hygiene data. Reliability between the IOM and the GME-approved sampling heads, reliability of the GME head, and reliability of manganese content measurement by two national laboratories (Lab A and Lab B) were examined.

Some 468 dust measurement observations were available for Company A. It was possible to use these data to derive a job exposure matrix, enabling attribution of estimated mean dust exposures to individual workers by their location (GME statistical population) and job (GME occupational code).

All workers seen at the annual medicals during 2000/2001, and who agreed to submit to additional tests, were included in the study group and answered a detailed questionnaire about demographic information, education, language, smoking and alcohol consumption, past medical history, lifetime work history and some limited symptoms. A brief physical examination, and tests from three neurobehavioural test batteries (SPES, WHO NCTB, LURIA-NEBRASKA) were performed. Blood samples were taken for manganese content. Findings of a similar study of more highly exposed workers in a South African manganese smelter indicated that a large proportion of the tests that had originally been planned were non-contributory, and this allowed substantial reduction of the number of test items performed.

Reliability was examined using the methods of Bland and Altman. Standard laboratory procedures and methods (NIOSH) were used for dust and manganese measurement. STATA version 6 was used, specifically multiple linear regression for continuous variable outcomes and multiple logistic regression for dichotomous outcomes.

Univariate analysis showed by comparison with both exposed smelter workers and unexposed referents that the study group was comparable to both these groups. Rural manganese miners, who were exposed overall at the ACGIH TLV for manganese, had lower levels of formal education and smoked and drank less. Blood manganese mean levels (8.7 SD = 7.3) were intermediate between unexposed referents (6.4 SD = 1.7) and the smelter workers (12.5 SD= 5.6), and closer to the unexposed referents. There was no association between blood manganese levels and dust exposure levels. No obvious clinical abnormalities consistent with clinical manganism were detected.

Multivariate analyses showed that no outcome (symptom, clinical sign, neurobehavioural test) was associated with any measure of exposure including blood Manganese. The absence of findings is not likely to be caused by problems of test validity as educational level and age, which are known to be consistent predictors, were found to determine test results.

The validation study shows that the IOM head reads systematically higher than the GME head for dust collection and as the dust concentration increases, the systematic difference increases, with poor overall reliability. The GME head has good reliability. Laboratory A produced systematically higher results than laboratory B with good reliability.

The absence of nervous system effects indicates that there is unlikely to be a subclinical neurotoxicity problem at exposure levels near the ACGIH TLV in these manganese miners, despite some underestimation of exposures.

Results are consistent with the smelter study which similarly found no convincing effects at exposure levels on average 4 times higher, ranging as high as 5mg/m3 for certain groups.

We recommend that there is no need for screening programmes for early effects of manganese neurotoxicity, and also therefore no point in proceeding to the next phase of the study as originally envisaged or intended rather than of the things.

There is, however, need for occupational hygiene surveillance to be rationalized and put on a more rational and less wasteful footing and to be geared to prevention by easily yielding information that could be integrated with medical surveillance programmes. With regard to the latter, a simple medical screening process developed from the smelter study could be introduced for suspect cases of clinical manganism.

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Glossary of abbreviations, symbols, terms and definitions

ACGIH TLV	The American Conference of Governmental Industrial Hygienists Threshold Limit Value for manganese
Luria Nebraska	The Luria-Nebraska test battery - a neurobehavioral test battery
SPES	The Swedish Performance Evaluation System - a neurobehavioral test battery
WHO NCTB	The World Health Organisation neurobehavioural core test battery
EPA RfC	The US Environmental Protection Agency reference concentration for environmental exposure to manganese
GME	The Government Mining Engineer
IOM	The Institute for Occupational Medicine, Edinburgh, UK
US NIOSH	The US National Institute of Occupational Safety and Health
Respirable dust	Dust particles with diameter < 7 to 10 microns collected with a cyclone attached to a sampling head.
Total dust	Dust particles with of all sizes collected on an open faced sampling head
Inhalable dust	Dust particles in the inhalable fraction collected by the UK IOM sampling head
CEI	A time (LOS) and intensity (AINT) integrated measure of dust exposure consisting of length of service in each job multiplied by the average intensity in that job and then summer over all exposed jobs on the mines.
LOS	Length of service in years on the mines
AINT	Average lifetime exposure intensity for manganese dust

1. Introduction

1.1 Purpose

- To obtain unique information which does not currently exist and which could substantially assist in the identification, quantification and solution of potential occupational neurotoxicity problems.

- To improve prevention of occupational neurotoxicity in the mining industry with application to other industry.

- To improve the effectiveness and cost-efficiency of medical surveillance systems.

1.2 Aims & objectives

- To estimate mineworker exposures to manganese in inhalable dust

- To measure a range of nervous system outcomes in exposed minerworkers

- To measure potential confounders and effect modifiers of the potential effect of manganese exposure on nervous system outcomes.

- To examine exposure-response or exposure-effect relationships between manganese exposure and nervous system outcomes.

- To determine a no observable adverse effects level (NOAEL).

- To detect early effects of manganese absorption on the nervous system.

- To identify the most practicable and sensitive clinical investigative tools for detecting the earliest effects of manganese absorption and toxicity in mineworkers

1.2.1 Implementation objectives

- To implement the findings into routine occupational medical and occupational hygiene surveillance systems at the mines, smelting works and other workplaces with exposure to manganese and other neurotoxicants e.g. lead, mercury and solvents.

- After incorporation of the results in routine medical surveillance on manganese mines and works, data generated in future years would constitute a unique database worldwide allowing for the evaluation of efforts at the mines to improve the working environment and to document such improvements quantitatively.

- Development of standardised guidelines or guidance notes regarding use of nervous system test methodology for preventive purposes or medical surveillance for the South African mining industry.

- Specification of testing technology, hardware and software for the above purposes.

- Development of codes of practice for use in the South African mining industry where potential central nervous system toxins are common exposures.

2. Literature survey

There has been increasing interest in nervous system effects of occupational manganese exposures below the ACGIH TLV of 0.2mg/m^3 in inhalable dust (ACGIH, 1996), and in environmental exposures at or above the US EPA RfC of 0.05 µg/m^3 (IRIS, 1999) sparked by increasing use of the organic manganese gasoline additive MMT (US EPA, 1994). Iregren (1999) reviewed 13 studies of manganese exposed workers, showing mostly motor effects with tests for finger tapping, diadochokinesometry and Luria-Nebraska (LN) items, along with postural tremor and sway abnormalities. Pegboard, memory, reaction time and cognitive tests were less conclusive. More recently, Lucchini et al. (1999) found manganese effects with WHO NCTB and Luria Nebraska tests in smelter workers at levels around 0.1mg/m^3. Mergler et al (1999) and Beuter et al (1999) found subtle neurobehavioural effects and exposure-age interactions with environmental exposures measured as blood manganese. As part of the same study Bowler et al (1999) found mood effects, while Hudnell et al. (1999) located these exposure-response relationships (exposure-response relationships) at environmental concentrations around the US EPA RfC· Roels et al. (1999) in a prospective study, showed reversibility of effects below 0.1mg/m^3. These studies have raised concerns that the ACGIH TLV might be too high to protect against neurobehavioural effects. On the other hand, no effects were found by either Gibbs et al. (1999) at occupational exposures averaging 0.18mg/m^3 total dust, nor by Crump and Rousseau (1999) in a prospective analysis of a battery manufacturing workers, nor by Deschamps et al (2001) at exposures averaging below 0.15 mg/m^3 over a 20 year period.

Problems with the few existing studies include small numbers of exposed subjects, (the largest study had 141 exposed) and nonstandard and possibly insensitive neurobehavioural tests. Furthermore there is relatively poor consistency for exposure effects and for the nature of the exposure-response relationships. There is still insufficient scientific information relating to subjective symptom and mood effects, especially from prospective study designs at low exposure levels, and the individual clinical implications of group effects found.

A study using similar methodology at a South African manganese smelter was conducted in tandem with the current study by the same authors (Myers et al., 2002a; Myers et al., 2002b). Some results from this study are provided for comparative purposes.

The current study in the Northern Cape was planned as the study population was anticipated to have large numbers of workers with low to medium manganese exposures, thereby complementing the smelter study where exposures ranged up to 25 times the ACGIH TLV.

Occupational health personnel in the manganese industry have expressed the need to determine effective and efficient secondary preventive interventions for mineworkers exposed to potential neurotoxins like manganese. Medical surveillance procedures able to detect the earliest preclinical evidence of manganese toxicity based on biological monitoring or clinical screening tests were felt to be desirable outputs of this study. An optimal subset of these procedures could then be developed for use in routine medical surveillance at the workplace.

Primary preventive interventions such as occupational hygiene and environmental exposure assessment procedures were also in need of identification and evaluation in relation to the early detection of potential neurotoxic effects in South African mineworkers, with important implications for permissible exposure limits in the workplace and general environments.

There have been no prospective studies of workers exposed to manganese thusfar. There are also no modern studies of current manganese mineworkers. Hochberg [1996] studied Chilean ex-miners who had previously been highly exposed and found them to have nervous system effects. As mineworkers exposure under modern industrial conditions to manganese is in the lower end of the range of occupational exposure, early effects are ideally studied in this group.

3. Methods

3.1 Study design

A cross-sectional analytic study was performed as phase 1 of a potential multiphase prospective study.

3.2 Study population

All manganese mineworkers in the Northern Cape Province.

The original intention was to examine all mining company employees numbering some 2000 in all the mining facilities operated by companies A and B, including office workers, as part of their annual medical examinations. The two companies operate four underground mines with surface processing plants, one surface sinter plant and two residential/office facilities.

It was envisaged that most employees would have medium (between 2 and 0.1mg/m^3) to low (below 0.1mg/m^3) exposure to manganese.

There were substantial retrenchments of staff in company B which also impacted indirectly on the research personnel. By the end of the study employee numbers had dwindled substantially.

3.3 Measurements

3.3.1 Exposure

Exposures to manganese were originally going to be measured by means of an independent occupational hygiene survey funded by company A and company B, but this would have proved to be very expensive. On exploration of the occupational hygiene records of measurements mandated by the GME at an initial site visit, it transpired that there was a rich source of occupational hygiene data already in existence. These data could be used from 1995 when the GME requirement changed to sampling total as opposed to respirable dust in Company A. Occupational hygienists on the research team decided after further exploration that these routine data could be used subject to some reliability assessment against methods used in the smelter study, instead of embarking anew on an independent and costly survey.

It subsequently emerged that company B had a different arrangement with the GME whereby respirable dust was measured for "risk workers" while total dust was measured for others. Manganese concentrations were not determined for the respirable dust samples. The GME agreed to change to the system used by company A, however it was not possible to accumulate sufficient dust data points between April 2001 and the end of the study to derive any meaningful exposure index for Company B. Consequently only Company A exposure data and indices derived from these were used.

3.3.2 A reliability study

A reliability study was performed to check certain assumptions that went with the use of routine GME occupational hygiene data. This involved reliability of sampling heads and laboratory analyses in a comparison of two GME heads, the IOM vs the GME head, and Lab A vs Lab B. The sampling equipment in routine use on the mines was used to collect dust samples which were weighed on the mines (see Appendix 1). The study investigated:

1) performance of two different types of sampling head IOM vs GME by means of 30 side by side samples using two pumps over variable exposure conditions. The Institute of Medicine (IOM) head is the appropriate sampling device for inhalable airborne manganese.
2) reliability of the GME sampling head by means of 30 side by side samples using two pumps with identical sampling heads over variable exposure conditions
3) performance of the 2 analytic laboratories in the measurement of manganese from the filters by means of split digestate samples analysed by the two laboratories. Lab A digested all the filters.
4) performance of the 2 analytic laboratories in the measurement of manganese from the filters by means of digesting 3 sets of duplicate spiked filters supplied by the US NIOSH.

The instructions for sampling and measuring dust for the GME measurements for Company A are provided in ***Appendix 1***. It was possible to use these routinely collected data to derive a job exposure matrix, enabling attribution of estimated mean dust exposures to individual workers according to their location (statistical population) and job (GME occupational code). The definitions of statistical populations and occupational codes for Company A are provided in ***Appendix 2.***

3.3.3 Creating the job exposure matrix

Occupational hygiene data for dust exposures were available from 1993 onwards, but the years 1996 onwards for company A were chosen for the following reasons:

1) total, as opposed to respirable, dust was measured from 1995 onwards
2) the data were fully available, of comparable form and quality, and
3) they post-dated recent improvements in underground dust control in company A.

The data supplied by the mine occupational hygienist were in 2 different tenuously linked registers – one was handwritten and the other typed on a typewriter (not on a word processor).

Some 468 dust measurement observations were available. Each of these observations comprised 11 variables, some of which were entered from the handwritten register, and then matched to the corresponding value in the typed register. The process of linking and verifying the various components that were required to calculate the ultimate time-weighted average concentration (TWA) for manganese was thus exceptionally difficult and time consuming. The handwritten register flowed vertically and the typed register flowed both horizontally and like a sentence in a book, making the linkage even more difficult.

Data on total dust for the four years 1996 to 1999 (2000 data were not available) for different mine facilities, occupational codes and statistical populations were entered into an Excel spreadsheet. Activity code was also entered but not eventually used.

Dust measurements for occupational codes in particular statistical populations were obtained in the form of TWAs.

The percentage of manganese in the dust was determined from 5 pooled dust samples for that statistical population twice for each hygiene year (April to August being the first half and October to February the second half).

The TWA for total dust in the occupational code was multiplied with the percentage concentration of manganese in the dust from the appropriate statistical population for the appropriate half year to yield a TWA for manganese.

Replicate manganese TWAs over the four year period were averaged to generate an estimate of the final manganese TWA by statistical population and occupation.

This allowed mean time weighted average values to be directly calculated for most study subjects for company A facilities by their occupations in most statistical populations. The matrix in ***Appendix 3*** provides cells with estimated exposure values for any particular statistical population and occupation. Where such mean values were not possible to calculate directly by this method, discussion with mine occupational hygiene personnel resulted in the attribution of the nearest applicable TWA to the job and location at issue e.g . a miners' assistant was given the TWA of a miner. As a result of this process every subject was provided with an estimate of their mean typical exposure. Appendix 3 shows the job exposure matrices with the highlighted cells being indirect estimates.

The data for company B were found to be unusable for the following reasons:

1) Dust measurements for risk workers who constituted 5 of the 10 statistical populations was measured as respirable dust only.
2) the measurement of total dust for all employees was instituted only from April 2001, and there were insufficient data points for total dust by the end of the study to meaningfully attribute exposures to all workers, as not all occupation codes in the statistical populations were covered.
3) Unlike company B, the occupational hygiene surveillance records do not assign occupation codes to mineworkers. It was thus not possible to assign a dust measurement to any class of mineworker, without making (possibly invalid) assumptions. People sampled were not assigned the occupational codes but rather an activity codes for the day on which they were monitored. Linking these to job titles proved to be impossible.
4) The error rate for hand calculating and hand recording TWAs was shown to be nearly 10%, despite the ready availability of a computer in the office of the hygienist.
5) Because of understaffing, gravimetric measurements were done *ad hoc* and not daily, and inappropriate correction factors which were not valid for the day of measurement were applied.
6) Supervisory systems for the management of quality control of the measurement process were poor or absent.

The combination of these factors made it impossible to create a valid job exposure matrix for company B workers.

3.3.4 A cumulative exposure index (CEI) was calculated for each subject by multiplying the mean manganese total dust concentration characteristic of each job by the number of years worked in that job, and summing these products over all jobs worked by each subject at the mines to the level of 5 previous jobs. The CEI was divided by total length of service in years at the mines (LOS) to yield a measure of average intensity of exposure over all jobs (AINT).

3.3.5 Venous blood specimens were collected at each medical examination. Specimens were kept on dry ice and sent immediately for analysis of manganese to lab A.

3.3.6 Laboratory determination of manganese

All air samples were analysed by Lab A using a modified NIOSH method 7300. The modification is designed to optimise detection of manganese (NIOSH, 1999). The GME or IOM cassettes were first rinsed with deionised water to remove any dust, which might have remained in the cowl of the filter cassette holder. The rinsate was added to the filter samples. Filters were digested using a CEM MARSX microwave digester. A combination of hydrochloric, nitric and hydrofluoric acid were used together to digest the Manganese and any silica compounds, which might have bound to Manganese compounds. A Varian® Vista simultaneous inductively coupled plasma optical emission spectrometer (ICP-OES) was used for all the analyses.

Three levels of in house quality control were prepared by spiking blank filters with stock manganese solution. The filters were digested and analysed in the same manner as the samples with each batch of analyses. The mean recovery was 102 %. The coefficient of variation (CV = SD/mean%) ranged between 3.41 – 3.48%. Three levels of Certified Reference Material (CRM) from United States National Institute of Standards and Technology No. 2676d were digested and analysed in the same manner. Mean recovery was 101.6% (standard acceptable range 95 – 105 %).

3.3.7 Nervous system-related questionnaire items were measured by a truncated battery informed by the results of the manganese smelter study. These included items from the Swedish Q16 instrument (Axelson and Hogstedt, 1988). Dummy questions were included to measure reporting bias.

3.3.8 Other questionnaire items measured potential confounders and effect modifiers such as age, educational level, home language and alcohol and tobacco consumption. A detailed life history was obtained for neurotoxic exposures in previous work, past relevant medical history including head injury, and nervous system disease.

3.3.9 A neurobehavioural test battery deemed most appropriate from a review of the literature and the smelter study included 3 items (1, 2, 23) testing motor function from the Luria-Nebraska battery (Golden et al., 1980). Test results in integers are categorized into three scores ranging from 0 for high performance to 2 for poorest performance. These were further categorized into binary variables where category 0 represented a good score (0) and categories 1 and 2 poor performance (1). The Digit-Span forward and backward and the Digit-Symbol tests for cognitive ability from the WHO NCTB, and Simple Reaction Time tests from the SPES battery (Iregren et al., 1996) were also included.

3.3.10 A brief clinical examination was conducted testing balance of the subjectwhile walking backwards on a line. Gross abnormality of the limbs was also excluded.

All of the above examinations were originally envisaged as being added on to the annual medical but this did not prove feasible. Current health personnel could not cope with the extra time load. The study had to provide full time interviewers and testers to obtain the data, even for the truncated testing regimen.

3.4 Statistical methods used included data exploration and description. Bivariate assocations were examined by means of smoothed plots (using locally weighted robust regression, see, e.g. Cleveland, 1979) for continuous data, and box and whisker graphs for categorical and grouped continuous variables. Multivariate analyses employed logistic regression for binary, and linear regression for continuous, outcomes to examine crude and adjusted exposure effects. Effects were adjusted throughout for age, years of schooling, smoking status, alcohol consumption, past job exposures to neurotoxins, previous head injury and home language (African or Western). Stata software was used (STATA, 1999). Data from the reliability study were analysed using the methods of Bland and Altman (1986).

3.5 Ethics

A Research Reference Panel was set up with representatives of workers and their trade unions, management, occupational health personnel and researchers to oversee all aspects of the study and to assist the research team. The reference panel was to have served as a conduit for stakeholder input to the research process. However, the panel did not meet again during the study and all communications were managed through the occupational physician serving both companies in the Northern Cape Province.

The study was approved by the Research Ethics Committee of the Health Sciences Faculty of the University of Cape Town. Informed consent was signed by all participants.

4. Results

800 subjects were examined of which 489 belonged to Company A and 311 to Company B. As it was not possible to generate exposure indices for Company B the rest of the results refer only to Company A employees.

4.1 Univariate analysis

Table 4.1: Descriptive Statistics For Study Subjects

Variable	Obs	Mean	Std. Dev.	Min	Max
Age	480	39.3	8.7	21	61
School standard passed	486	4.9	3.3	0	12
Length of service in Mn mines	486	10.8	5.5	1	41
Cumulative exposure index	486	2.2	2.2	0	20.8
Average intensity of exposure	486	0.21	0.14	0	0.99
Blood manganese	456	8.5	2.8	2.2	24.1
Maximum forward digit span	483	6.6	1.8	2	9
Maximum backward digit span	483	3.6	1.7	0	9
Digit symbol score	479	24.7	12	0	67
Mean reaction time	476	246.3	38.2	174	518

Variable	Frequency	Percent	[95% Conf. Interval]
Previous job involving neurotoxins	36/486	7.41	[5.1 – 9.7]
Previous head injury	208/486	42.8	[38.4 – 47.3]
Current alcohol drinker	204/486	42.0	[37.5 – 46.5]
Past alcohol drinker	78/486	16.1	[12.9 – 19.6]
Current smoker	176/486	36.2	[31.9 – 40.7]
Past smoker	78/486	20.6	[17.1 – 24.4]
Frequency of coitus < twice weekly	147/485	30.3	[26.2 – 34.4]
Frequency of coitus < colleagues	221/486	45.5	[41.0 – 49.9]
Frequency of earache	12/486	2.47	[1.1 – 3.9]
Frequency of ankle swelling	19/486	3.91	[2.2 – 5.3]
Inability to walk backwards on a line	6/419	1.43	[0.3 – 2.6]

Variable	Frequency	Percent	[95% Conf. Interval]
Luria Nebraska tests: percentage abnormal tests			
Item 1R	113/483	23.4	[19.6 – 27.2]
Item 1L	94/483	19.5	[15.9 – 23.0]
Item 2R	342/483	70.8	[66.7 – 74.9]
Item 2L	358/483	74.1	[70.2 – 78.0]
Item 23R	96/483	19.9	[16.3 – 23.4]
Item 23L	104/483	21.5	[17.9 – 25.2]

Table 4.1 shows descriptive information for the study group.

The overall mean of exposure intensity (AINT) for the study was at the ACGIH TLV of 0.2 mg/m^3 of Manganese. There was slight skewing to the left with the median at 0.16mg/m^3. Figure 4.1 shows that there was good exposure contrast in the study group as a whole ranging from no exposure up to 1mg/m^3. This point is illustrated using digit symbol score plotted against AINT.

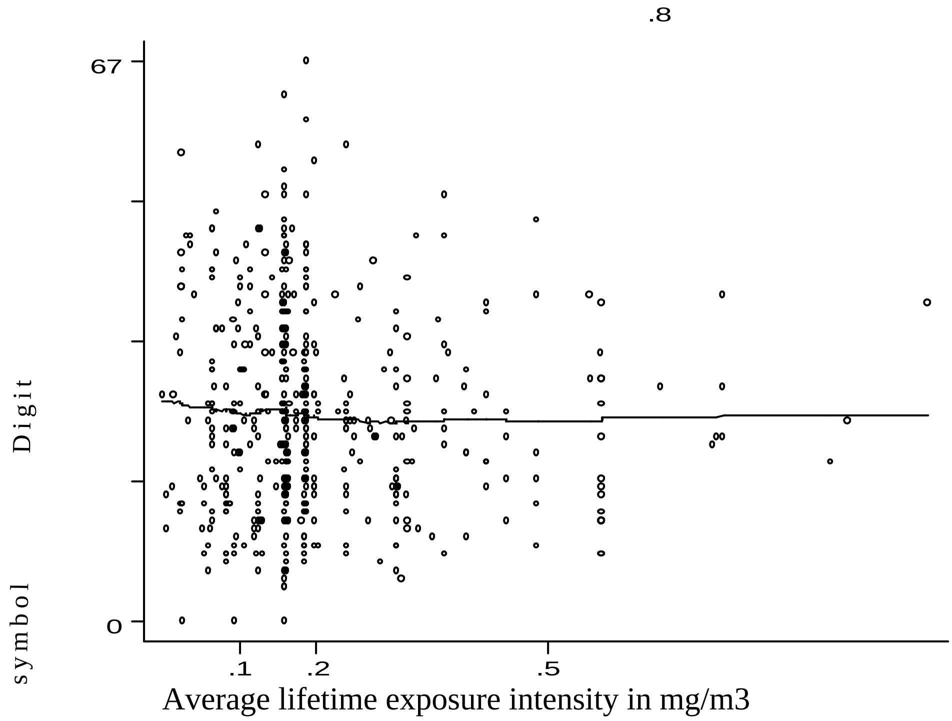

Figure 4.1: Exposure contrast by Digit Symbol score

From the questionnaire, symptom prevalences for sexual dysfunction are quite high, but there is no evidence of excess reporting of dummy symptoms (earache and ankle swelling).

Very small numbers had clinically observable balance problems.

Table 4.2: Comparison Of Manganese Miners With Smelter Workers And With Unexposed Referents From The Smelter Study

Variable	Mines Mean (SD)	Smelter Mean (SD)	Unexposed Mean (SD)
Age	39.3 (8.7)	45.1 (8.4)	38.6 (10.3)
School standard passed	4.9 (3.3	4.7 (3.2)	8.0 (2.5)
Length of service	10.8 (5.5)	18.2 (7.6)	9.4 (7.0)
Cumulative exposure index	2.2 (2.2)	16.0 (22.4)	0
Average intensity of exposure	0.21 (0.14)	0.82 (1.04)	0
Blood manganese	8.5 (2.8)	12.5(5.6)	6.4 (1.7)
Maximum forward digit span	6.6 (1.8)	6.0 (1.4)	7.0 (1.3)
Maximum backward digit span	3.6 (1.6)	3.4 (1.0)	4.4 (1.4)
Digit symbol score	24.7 (12.0)	22.9 (12.4)	33.8 (11.2)
Mean reaction time	246.3 (38.2)	285.0 (42.9)	266.4 (25.9)

Variable	Percent		
	Mines	**Smelter**	**Unexposed**
Previous job involving neurotoxins	7.41	14	6
Previous head injury	42.8	28	22
Current alcohol drinker	42.0	43	58
Past alcohol drinker	16.1	17	9
Current smoker	36.2	38	60
Past smoker	20.6	32	7
Frequency of coitus < twice weekly	30.3	24	14
Frequency of coitus < colleagues	45.5	35	1
Frequency of earache	2.47	2	1
Frequency of ankle swelling	3.91	2	0
Inability to walk backwards on a line	1.43	8	1

Variable	Percent		
Luria Nebraska tests: percentage abnormal tests			
	Mines	**Smelter**	**Unexposed**
Item 1R	23.4	49	30
Item 1L	19.5	86	75
Item 2R	70.8	34	24
Item 2L	74.1	83	73
Item 23R	19.9	17	18
Item 23L	21.5	44	36

Table 4.2 shows that by comparison with 509 manganese exposed workers and 67 unexposed referents in the smelter study, the miners are younger, less well educated and they consume less alcohol and tobacco. There average test scores appear to be within the normal range or in some cases are even supernormal e.g. their mean reaction times are better on average than both comparison groups.

The main differences relate to a higher frequency of sexual function complaints. The prevalence of balance abnormalities in the clinical examination was midway between the external unexposed referents and the smelter workers. The digit span forward score was close to the external referents and the digits backwards was lower. Digit symbol score was similar to smelter workers and lower than external referents. The six Luria-Nebraska item scores were either better than the other two groups or very similar.

Blood manganese was higher on average than the external referents, but much lower than smelter workers as well as a little higher than internal smelter low exposure referents providing additional evidence that the study group is in fact a low to medium exposed group.

4.2 Multivariate analyses

showed that no outcome variable was associated with any measure of exposure, after adjustment for confounders. This applied to symptoms, clinical examination and test results. Tables 4.3 and 4.4 provide two examples of these analyses for digit-symbol and Luria-Nebrasks item 2R scores.

Table 4.3: Multiple Linear Regression Output Of Digit Symbol Score On Cumulative Exposure Index, Standard Passed At School, Past Job Exposure, Age, Previous Head Injury, Smoking, Home Language and Alcohol Consumption

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 xi: reg digit3 cei  stdpass age pastjob headinj i.smoke1 i.alc1 lang
i.smoke1              Ismoke_0-2    (naturally coded; Ismoke_0 omitted)
i.alc1                Ialc1_0-2     (naturally coded; Ialc1_0 omitted)

  Source |       SS       df       MS               Number of obs =     472
---------+------------------------------            F( 10,   461) =   82.59
   Model |  42084.9656    10  4208.49656            Prob > F      =  0.0000
Residual |  23490.5514   461  50.9556429            R-squared     =  0.6418
---------+------------------------------            Adj R-squared =  0.6340
   Total |  65575.5169   471  139.226151            Root MSE      =  7.1383

------------------------------------------------------------------------------
  digit3 |      Coef.   Std. Err.       t     P>|t|       [95% Conf. Interval]
---------+--------------------------------------------------------------------
     cei |  -.0251476    .154327     -0.163   0.871      -.3284191     .278124
 stdpass |   2.201397   .1198966     18.361   0.000       1.965785    2.437008
     age |   -.254108   .0439215     -5.786   0.000      -.3404191   -.1677968
 pastjob |   .7529057   1.289821      0.584   0.560      -1.781751    3.287562
 headinj |   .3714268    .687305      0.540   0.589      -.9792121    1.722066
Ismoke_1 |   .7570755   1.027775      0.737   0.462      -1.262628    2.776779
Ismoke_2 |   -.444363   .9194454     -0.483   0.629      -2.251186     1.36246
 Ialc1_1 |   .9535231   1.117521      0.853   0.394      -1.242543    3.149589
 Ialc1_2 |  -.1676822   .8923705     -0.188   0.851        -1.9213    1.585936
    lang |  -5.533873   .9358974     -5.913   0.000      -7.373027    -3.69472
   _cons |    27.9605   2.279866     12.264   0.000       23.48029    32.44072
------------------------------------------------------------------------------
```

Table 4.3 shows the results of a multiple linear regression of the digit symbol test score on CEI adjusted for education level, age, past head injury, past work exposure to neurotoxins, alcohol, smoking and home language.

Table 4.4: Multiple Logistic Regression Of Luria-Nebraska Item 1R (Abnormal/Normal) On Cumulative Exposure Index, Standard Passed At School, Past Job Exposure, Age, Previous Head Injury, Smoking, Home Language and Alcohol Consumption

```
. xi: logistic ln1r cei  stdpass age pastjob headinj i.smoke1 i.alc1 lang
i.smoke1              Ismoke_0-2    (naturally coded; Ismoke_0 omitted)
i.alc1                Ialc1_0-2     (naturally coded; Ialc1_0 omitted)

Logit estimates                                   Number of obs   =        476
                                                  LR chi2(10)     =      77.64
                                                  Prob > chi2     =     0.0000
Log likelihood = -220.88159                       Pseudo R2       =     0.1495
```

ln1r	Odds Ratio	Std. Err.	z	P>|z|	[95% Conf.	Interval]
cei	1.040168	.0503415	0.814	0.416	.9460357	1.143667
stdpass	**.7973645**	**.0354246**	**-5.097**	**0.000**	**.7308706**	**.869908**
age	**1.056007**	**.0163968**	**3.510**	**0.000**	**1.024354**	**1.088638**
pastjob	.5794831	.3248408	-0.973	0.330	.1931446	1.738597
headinj	1.087469	.2690955	0.339	0.735	.6695547	1.766232
Ismoke_1	.9364922	.3465014	-0.177	0.859	.4534822	1.933963
Ismoke_2	1.569722	.5279373	1.341	0.180	.8119737	3.034613
Ialc1_1	.7400595	.2980767	-0.747	0.455	.3360662	1.629703
Ialc1_2	.9622997	.314456	-0.118	0.906	.5071757	1.825838
Lang	1.589346	.6538284	1.126	0.260	.7096584	3.559488

Table 4.4 shows the results from a multiple logistic regression of the dichotomous Luria-Nebraska test item 1R score (abnormal/normal) on the same variables.

There was no exposure effect on the performance of either test. However, consistent positive effects of years of education and to a lesser extent the negative effects of age are observed. For the digit symbol test, an African home language had a negative effect.

Alcohol consumption predicted poor scores for the questions on sexual function and performance on item 23 of the Luria-Nebraska battery.

No association was detected between blood manganese and any other measure of exposure, nor between any measure of exposure and any of the nervous system outcomes. All analyses were repeated with length of service, cumulative exposure, average exposure intensity together with length of service, and blood manganese serving as the exposure variable. Findings were unchanged as a result of different exposure modeling.

4.3 Reliability study results

Table 4.5: Reliability Study Statistics

	Mean of both methods [Mn mg/m^3 or ìg/m^3]	Mean difference (***bias***) between two methods [Mn ìg/m^3]	2*SD of the difference between the two methods (***reliability***)	Ratio of 2*SD/ mean
Side by side 37mm GME sampling heads	0.67	0.14	0.12	18%
Side by side IOM & 37mm GME sampling heads	1.19	0.32	1.89	160%
Paired laboratory Mn determinations two laboratories using same digestate	108.59	11.2	14.99	14%

These results show that the paired GME heads and the paired manganese determinations give reasonably reliable results, but the paired IOM vs GME heads give widely differing results. These are further illustrated in the following graphs:

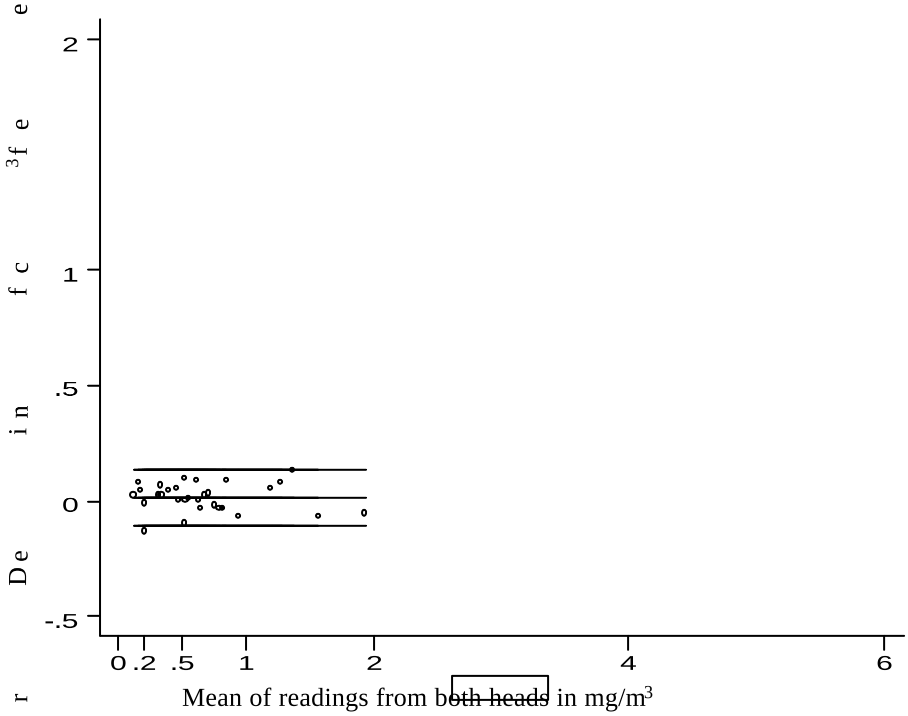

Figure 4.2: Reliability of GME vs GME head

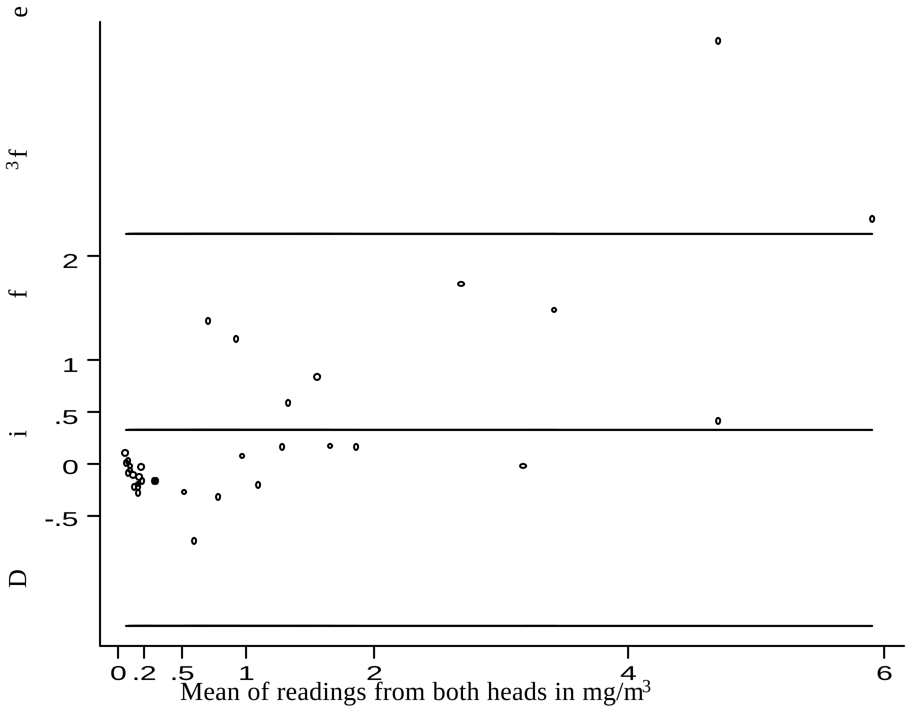

Figure 4.3: Reliability of IOM vs GME head

4.3.1 Comparison of two 37mm GME heads

All measurements in Table 4.5 and Figure 4.2 are for total dust and expressed in units of mg/m^3. The Bland-Altman plot in Figure 4.2 shows little bias and good reliability (little scatter) for the GME sampling head. Table 4.5 shows that the average difference between the dust measurements using both heads (bias) was small at 0.014 in relation to the overall mean for both heads at 0.67. The measure of reliability
[2 * SD(difference between the two heads)] is 0.12, or only 18% (coefficient of variation = 9%) of the mean overall exposure of the two heads combined. The correlation coefficient is very high at 0.99.

4.3.2 Comparison of 37mm GME vs IOM heads

All measurements in Table 4.5 and Figure 4.3 are for total dust and expressed in units of mg/m^3. The Bland-Altman plot in Figure 4.3 shows substantial bias and poor reliability (much scatter) for the two different heads. Furthermore, bias increases with increasing dust levels adding a further dimension to the underestimation of true dust exposure by the GME head. Table 4.5 shows, as expected, that the IOM head collects more dust (bias) by about 30 – 40% (an extra 0.32 mg/m^3 on just over 1 mg/m^3) than the GME head, in other words the GME method systematically underestimates manganese exposure in the collection process. The measure of reliability [2 * SD(difference)] is poor at 1.89 and is 160% of the mean overall exposure of the two heads combined. This is despite the fact the correlation coefficient seems quite respectable at 0.91.

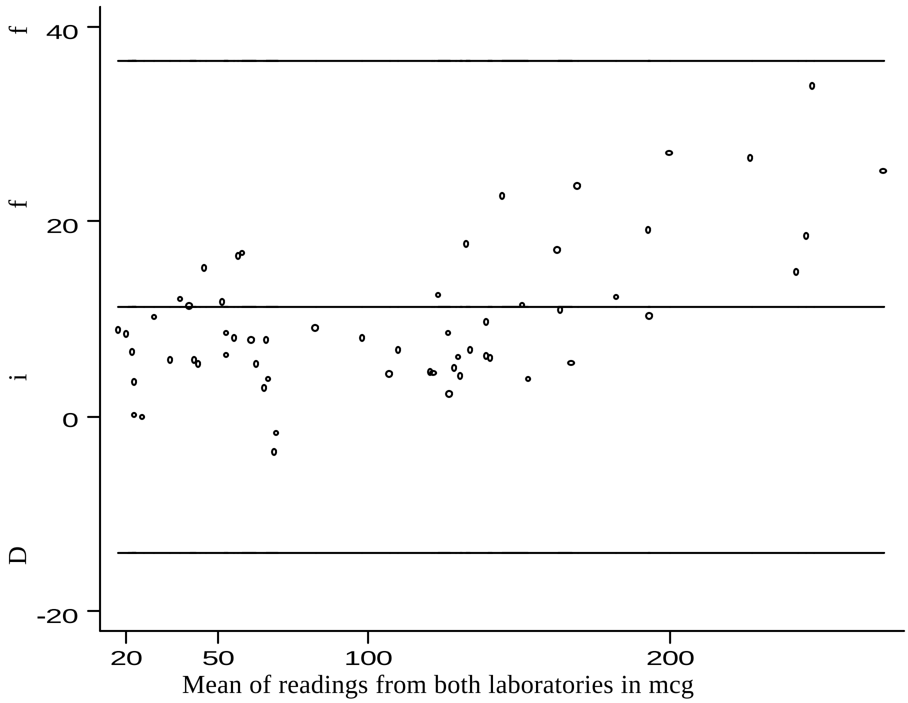

Figure 4.4: Reliability of Lab A vs Lab B

4.3.3 Comparison of Laboratory A and Laboratory B results for analysis of liquid specimens post digestion of the filters

Measurements are of liquid digestate and are expressed in ìg per filter. The Bland-Altman plot in Figure 4.5 shows some surprising bias and reasonable reliability for analytic runs on two similar machines under laboratory control conditions. The bias increases as the concentration of dust increases in the environment. This means that there are additional third and fourth dimensions to the underestimation of dust using both the GME sampling head and Lab B (the laboratory that routinely analyses samples for the mines). Table 4.5 shows that Lab A measurements of manganese levels were upwardly biased by 11.2 ìg per filter or 10% higher than Lab B overall. The measure of reliability [2 * SD(difference)] was reasonably good at 15, constituting 14% of the mean overall exposure of the two heads combined (a coefficient of variation of 7%). The correlation coefficient was very high at 0.99.

4.3.4 Comparison of Lab A and Lab B analytic methods including filter digestion.

Duplicate digestion and analysis by the two laboratories of three sets of spiked filters containing identical amounts of manganese (10.1 ± 0.23 ìg), reveals that Lab B read closer to the spiked mass (10.18 & 10.94 ìg) than Lab A at 8.30 ìg for both samples. The single blank filter was read as 0 ìg by both laboratories. These results possibly indicate the effects of differences in filter digestion methods. A further cross-reanalysis of the liquid digestates will be done in the near future.

5. DISCUSSION

This is the only study ever conducted on current manganese mineworkers working under modern conditions of production.

The exploration and subsequent reliance on GME mandatory measurements was particularly revealing. There was confusion and inconsistency of practice required of the mining occupational hygiene departments across the two companies. The situation with regard to total dust measurements could be characterized by the acronym DRIPS (Data Rich Information Poor Systems). It is clear that much effort, time and expense are incurred by mandatory occupational hygiene surveillance requirements. On the one hand, methods for determining manganese content of dust samples were based on too few samples and averaged for too large a population (the statistical population) to be adequately representative. This could lead to misclassification and potential dilution of any underlying existing exposure-response relationship that might then go undetected. On the other hand, it was a major effort of work to use the abundant data that had been collected over the years and to transform them into usable information - specifically into exposure indices that estimate the average or typical exposures for occupation codes by statistical population. The current GME system concentrates on derived indices that have no utility for attribution of exposures to individuals in different locations and occupations and, therefore, have no utility in linking occupational hygiene and medical surveillance systems or in gearing both to prevention as opposed to their traditional orientation to compliance and compensation respectively. In the case of Company B, after very substantial efforts the entire process of attempting to derive individually attributable exposure estimates had to be abandoned. This constitutes an enormous wastage in both the generation and attempted utilization of data which has little value from an information point of view.

Notwithstanding the above comments, it is clear from a comparison of the average levels of exposure for the various occupations and locations that similar exposure scenarios to those in the smelter had similar levels (both for point and interval estimates) of exposure to manganese. Supervisory, office and service workers had similar levels of exposure in both settings from fugitive dust, while miners had similar levels to those working in the raw and finished goods yards at the smelter. There were no very highly exposed workers (e.g. exposed to fumes) in Company A.

The exposure scenario was therefore as anticipated at the inception of the study, and fell within the medium to low part of the spectrum. The reliability study provides some notion of the extent of the downward bias of exposure measurements due to the use of GME methods. Nevertheless even accounting for this bias, overall exposure at the mines are still only about one quarter of overall mean exposure at the manganese smelter, and close to the ACGIH TLV for manganese.

The overall mean for blood manganese in the miners fell between that of goods yard workers and office workers in the smelter. It was also considerably higher than the unexposed referents, further confirming medium to low exposure levels for miners. Overall, only some 10% of the miners blood manganese levels exceeded the upper limit of the normal range (0.3 – 12.6 ìg /l). As expected, at these low levels of exposure and absorption, there was an absence of correlation observed between individual exposure levels and blood manganese levels. This is most likely the result of low levels of absorption largely overlapping with physiological absorption through the diet which is the major determinant of body levels of the essential mineral in non-industrial settings. It might, however, also be due to misclassification of exposure attribution at the individual level as discussed above.

It can therefore be claimed with some confidence that miners are a low to medium exposed study group with good exposure contrast allowing comparitive analyses between the lesser exposed acting as internal exposure referents, and the more highly exposed.

The miners' neurobehavioural test scores generally compared favourably with respect to the exposed smelter population overall and also with respect to the external unexposed referents in that study (e.g. the Luria-Nebraska tests of motor coordination were performed at similar or better levels by the miners). In certain respects, the mining population performed in a super-normal fashion e.g. for simple reaction time which is a more physiologically based test and not so dependent upon years of education or prior experience with computers or the formal test situation. Such factors in the more rural miners led as expected to poorer performance in difficult cognitive tests (e.g. Digit-Symbol scores were lower than the external referents in the smelter study).

Rural workers drank and smoked less which probably reflects their level of relative poverty compared to urban workers. Higher levels of sexual function complaints were not exposure related and may be culturally linked.

There were no manganese exposure related effects in the study group for any measured outcome, nor for any combination of exposure variables. This finding is consistent with the results of the manganese smelter study which similarly found no convincing nervous system effects at exposure levels on average 4 times higher than the mines, ranging for some groups of smelter workers up to $5mg/m^3$.

Alcohol, when abused, may also be a predictor for test scores, and past drinkers seemed to be a problematic category in that this status predicted adverse responses to the questionnaire items on sexual function and for the Luria-Nebraska item 23 co-ordination test.

As expected, home language correlates strongly with access to a better education system, greater familiarity with the testing situation, familiarity with computers, and for most of the scores there was a systematic improvement of Western language speakers over African language speakers. Home language was, however, not linked to exposure.

It became clear that there is an absence of a surveillance culture on the mines despite mandatory GME dust monitoring requirements and the presence of an occupational medical service. Inadequate staffing levels seemed to be the principal determinant. Levels of both appropriately skilled occupational hygiene and medical staffing must be adequate to undertake meaningful surveillance. Thought needs to be given to providing guidelines for adequate staffing to carry out those surveillance processes that are mandated by law or by concern for the health and safety of employees. The clinical staff clearly did not have the time to take on even a small number of additional screening tests, while the occupational hygiene staff, particularly in Company B, was not sufficient either in number or skill to get the job done to any degree of satisfactory performance. Once again transforming dust data in the format collected (mandatorily) into useful information for surveillance was extremely difficult even given the application of the time and energy of dedicated researchers to whom such transformation is a routine practice. Without express regulatory requirements and improved training it is unlikely that this problem will be solved voluntarily or any time soon.

5.1 Study limitations and validity considerations

Although there is downward bias in exposure estimates using GME methods, the combined results of the reliability studies and the findings in the main study show that it is possible to use existing routine data to generate useful exposure indices with sufficient contrast between lesser and greater exposed for the purposes of epidemiological analysis. Similarly, although there must be some misclassification of dust levels, the use of the existing values is nevertheless less misclassified than relying solely on length of service in years at the mines. The absence of nervous system effects in the smelter study at much higher exposure levels make it very unlikely that a real exposure-response effect has been missed amongst these miners due to effect dilution by misclassification.

The validity of the nervous system tests used is confirmed by the fact that miners' scores are in the expected range for unexposed subjects in the South African setting. Additionally, associations of test scores with known predictors education and age in the expected directions confer further validity on these tests.

6. CONCLUSIONS AND RECOMMENDATIONS

1. No manganese exposure effects were found at exposure levels on average near the ACGIH TLV in the baseline cross-sectional study. Consequently no new light could be shed on the NOAEL, as no adverse effects were found in this exposure range.

2. There is therefore no point in proceeding to phase 2 or the longitudinal aspects of the study.

3. Furthermore, it has been shown that utilising any subset of nervous system tests used in the study for the early preclinical effects of manganese exposure on the mines for medical surveillance is not feasible, and is therefore not recommended.

4. Accordingly the study has achieved its objectives.

5. A screening programme for detecting suspect cases of clinical manganism has been developed as a result of the smelter study, and this could be applied in the mining context should occupational health staff feel that this is necessary. One indication of this being necessary would be incident cases of clinical manganism of which there have been none to date.

6. The occupational hygiene surveillance system needs to be overhauled and to made consistent with rational and practical preventive goals. Attention needs to be paid to sampling and measurement strategies that yield representative data that can be easily converted into useful indices of exposure at both the group and the individual (occupation/job and work location) levels. Changes in these levels over time should be immediately and easily evident after dust measurement, and should trigger timeous and appropriate action. It is recommended that company B revise its occupational hygiene programme thoroughly.

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APPENDIX 1: GME SAMPLING METHODOLOGY IN USE AT COMPANY A

G.M.E. 16/2/2/21/2
G.M.E. 16/2/2/9/4

1. BACKGROUND

COMPANY A, MINING IN THE NORTHERN CAPE

1a The Manganese division is situated in the Northern Cape where two vertical shafts, each with its own decline from surface are in production. The two shafts namely Mine 2 and Mine 3 are producing 80 000 Tons of manganese ore per month. Mining of manganese ore is done by the board and pillar method. No chemicals are used in the processing of manganese ore. Cashing and screening is done in the two surface plants situated at the shafts. Although (some) shafts are no longer in production, the surface Workshops, Sampling crushers, Training centre, Salvage yard and Stores are still in operation. (Some) shafts are still accessible for pump maintenance underground.

LOCATION MAP ATTACHED

2. PROGRAMME COORDINATOR

2) Mr. A. Surname, Environmental Superintendent, who is appointed in terms of Regulation 2.16.1. will assume overall responsibility for the gravimetric dust sampling programme. He is the holder of a certificate in Mine Environmental Control for the past eight years.

3. SAMPLING RESPONSIBILITY

3(i) Not applicable.
3(ii) The mine will do it's own sampling.

4. PLANS AND PROCESS FLOW CHARTS

Previously submitted.

5. POLLUTANTS

5(i) Analysis for Alpha Quartz, manganese dust and soluble Iron salts will be done.
5(ii) Above pollutants are contained in the ore.

6. TYPE OF SAMPLING

Total dust.

7. ACTUAL SAMPLING

7a) Not applicable.

7b) Sampling done by mine.

PERSONNEL

7b)(i) The actual sampling is being done by Mr B. Surname, Air Quality Analyst, who is the holder of a certificate in Air Quality Analysis. He has six months experience in an environmental control department.

INSTRUMENTS
7b)(ii) Gilair Personal Sampling pumps (G.M.E. I.S. V.M. 2845 G08) with 37mm diameter cyclones (G.M.E. G05) and re-usable filter cassettes are being used. Good Quality transparent tubing, shrink seals and clamps are used to prevent leakage. 37mm Diameter cellulose nitrate filters are used. A gilibrator range 20cc - 6 LPM serial No 9670-S of the Gillian Instrument Corporation is used for calibration of sampling pumps.

Sampling pumps and gilibrator are daily cleaned with a damp cloth and stored on suitable racks and charging racks provided for the purpose in the dust laboratory.

Cyclones and reusable filter cassettes are washed with a soap water mixture and rinsed in industrial alcohol. A special cabinet is provided for storage of cyclones and cassettes in the Weighing Room.

8. STORAGE/TRANSPORTATION OF SAMPLES

8.1 CARRYING CASE
A wooden carrying case with a lid is used. The carrying case is lined out with a low density sponge with suitable recesses to protect samples against shock and vibrations. The lid is marked "Right side up" and fitted with a device to prevent inadvertent opening during handling or transportation.

8.2 METHOD OF TRANSPORT BETWEEN WORKING PLACE AND WEIGHING ROOM.
Samples are being transported in the carrying case provided for the purpose as described under 8.1 Transporting of samples is done by the person who is responsible for the actual sampling or his alternative.

8.3 STORAGE OF SAMPLES BEFORE TRANSPORTATION TO WEIGHING FACILITY/ANALYSIS AUTHORITY.
Samples are placed in petrislides with dust facing upwards and are stored in a suitable cabinet in the Weighing room.

8.4 METHOD OF TRANSPORT BETWEEN CONCERN AND ANALYSING AUTHORITY.
Samples are being collected on the mine by personnel of an approved authority responsible for the analysis. (Laboratory B).

9. WEIGHING

9(i) WEIGHING ROOM
The weighing room is situated in the environmental control office at the Office Area. Weighing of filters is done in a approved "Glove Box" supplied by Laboratory B. The "Glove Box" is fitted onto a specially designed balance table with a properly earthed antistatic mat.

The Weighing system consists of a mettler A.T. 250 analytical balance capable of Weighing to O.OOOlg and is linked to a compatible P.C. The balance will be regularly maintained, assized and a record will be kept. A 20mg standard weight is used to check the accuracy of the scale in the interim periods. Filter stabilisation is also done inside the "Glove Box".

9(ii) FILTER WEIGHING PROCEDURES
Weighing procedures are in accordance with the guide lines.

10. ANALYSIS OF SAMPLING

10(ii) The wafer preparation is done by Laboratory B and scanning by the S.A.B.S.

10 (iii) Laboratory B is S.A.B.S approved.

10(iv) A total number of 105 samples will be taken during the six months sampling period which represents 6,So of the labour force. 2.5% Of all samples with a minimum of 5 samples per statistical population per annum, will be analysed.

10 (v) Samples will be analysed on a composite basis.

11. STRATEGY

11(i) A total number of 1553 persons are identified as persons exposed or potentially exposed to harmful pollutants.

11(ii) (Four) sampling areas were established, (and each assigned a number)

11(iii) No women are employed in risk work. Contractors included in totals.

11(iv) The following statistical populations were established for all sampling areas, except for the Office area where there will be only one statistical population.

And LABOUR BREAKDOWN ATTACHED

STATISTICAL POPULATION	STATISTICAL POPULATION NO.:
Mining	11
Plants	12
Engineering	13
Supervision and Services	14
Contractors	15
Office area	10

11(v) At least 5 samples will be taken per statistical population over a period of six months. The total number of samples per statistical population will not be less than 5a. Please refer to Sampling scheduled submitted on Day/Month/95 and approved on Day/Month/95.

11(vi) At least 5 samples from each population group over a period of one year will be analysed for harmful pollutions. Where the average number of persons during the year exceeds 200gr statistical population, not less than 2,50 of samples of the average number of persons in the statistical population will be analysed.

11(vii) Refer to sampling schedule dated Day/Month/95 and approved on Day/Month/95.

12. SCHEDULING

12) Sampling will be carried out during day and night shift at Mine 3 during day and only during day shift at Mine 2 and the Office Area. Sampling will be done on a random basis from Monday to Friday. (We are working a five day week).

13. PARTIAL SUPERVISION

13.1 Not applicable.

13.2 The person issued with the sampling instrument will act as his own supervisor.

13.2.(i) The person issued with the sampling will be properly briefed to report on any abnormal conditions and on the operation of the sampling train during his shift.

13.2(ii) The induction courses for all personnel include a section on the operation and reasons for gravimetric sampling.

13.2(iii) In accordance with guideline

13.2(iv) In accordance with guideline.

Mr A Surname, ENVIRONMENTAL SUPERINTENDENT

APPENDIX 2: CODES FOR STATISTICAL POPULATION, OCCUPATION AND ACTIVITY

STATISTICAL POPULATIONS COMPANY A

Mine 1 and Mine 2

11	Mining
12	Plants
13	Engineering
14	Supervision and services
15	Contractors

CODE	OCCUPATION
1	MINER
2	SHAFT OPERATOR
3	TEAM LEADER
4	MINERS ASSISTANT
5	STOPE LABOURER
6	DEVELOPMENT LABOURER
7	OPENCASE LABOURER
8	PUMP ATTENDANT
9	CONSTRUCTION LABOUR
10	DRILL OPERATORS
11	DRIVERS
12	TRAMMING
13	SHAFT LABOURER
14	DOOR ATTENDANT
15	FIRST AIDER
16	CHANGE HOUSE ATTENDANT
17	PLANT SUPERVISOR
18	TECHNICAL OFFICIALS
19	OPERATORS
20	PLANT LABOURER
21	SLIMESDAM LABOURER
22	LOADING LABOUR
23	ELECTRICIAN
24	BIOLERMAKER
25	FITTER
26	MECHANIC
27	WELDER
28	HOIST DRIVER
29	APPRENTICE
30	INSTRUCTOR
31	DRIVER, CRANE/GRADER
32	STORE ATTENDENT
33	BELT ATTENDENT
34	HANDYMAN
35	
36	TRAINEE
37	ENGINEERING HELP
38	MANAGER
39	MINE OVERSEER
40	SHIFTBOSS
41	ENGINEER
42	FOREMAN
43	PLANNER
44	METALLURGIST

CODE	ACTIVITY
1	CONVENTIONAL MINING
2	CONTINUOUS MINER
3	LONGWALL MINING
4	HANDGOT
5	STOPING/PILLAR EXTRACTION
6	OPENCASE
7	CRUSHING
8	MILLING/PULVERISING
9	SCREENING/GRADING
10	CONCENTRATING
11	SMELTING
12	REFINING
13	ROVING UNDERGROUND
14	ROVING SURFACE
15	ROVING PLANT
16	STOPING/PILLAR EXTRACTION
17	DEVELOPMENT (SINGLE SHIFT)
18	DEVELOPMENT (MULTI BLAST)
19	SHAFT SINKING
20	RAISE BORING
21	TRACKLESS MINING
22	DUMPS/DUMP RECYCLING
23	SHAFTS & SERVICES
24	SURFACE WORKSHOPS
25	RAW MATERIALS
26	HEAT PROCESS
27	CHEMICAL PR0CESS
28	FINAL PRODUCTS
29	ASSAY/LABORATORY
30	ROCK MINING COAL
31	U/G WORKSHOPS
32	SEPARATION PROCESS

45 SAFETY OFFICER
46 ENVIRON OFFICER
47 TRAINING OFFICER
48
49
50 ORE CONTROL OFFICER
51 ASSAYER
52 SURVEYOR
53 GEOLOGIST
54 INSTRUCTOR (TRAINING)
55 ORE CONTROL LABOUR
56 TECH SERVICES HELP
57 CONTRACTOR

APPENDIX 3: JOB EXPOSURE MATRIX SHOWING DIRECTLY CALCULATED AND INDIRECTLY ESTIMATED TWAs, BY STATISTICAL POPULATION AND OCCUPATION CODE

The highlighted cells are those where the TWA was estimated from similar occupations, usually in the same statistical population.

Mine 2	StatPop	StatPop	StatPop	StatPop
Occ Code	11	12	13	14
1	0.239			
3	0.105		0.000	0.054
4	0.239			
8	0.239			
9	0.366			0.315
10	0.268			
11	0.303		0.303	0.303
12	0.422			
15	0.794			0.710
16	0.027		0.027	0.000
17		0.047		0.009
19	0.184	0.039	0.135	
20		0.887		0.000
22	0.239	0.887		0.418
23			0.728	0.676
24		5.265	0.415	0.285
25		0.296	0.107	0.880
26			0.174	
29			0.122	
32			0.084	0.000
33	0.165	0.230	0.165	
36			0.180	0.180
37	0.141	0.050	0.141	
39	0.049			
40	0.332			
41				0.098
42	0.395		0.395	0.095
43				0.042
46				0.183
47				0.393
50				0.077
51		0.000		
55		0.113		0.142
56	0.429			

Office based workers - all in Stat Pop 14			
Occ Code		Occ Code	
11	0.000	29	0.022
23	0.031	32	0.025
24	0.003	36	0.318
25	0.013	37	0.065
26	0.082	55	0.000
27	0.007	56	0.159

Mine 3	StatPop	StatPop	StatPop	StatPop
Occ Code	11	12	13	14
1	0.125			
2			0.156	0.568
3	0.093	0.062	0.156	0.134
4	0.061		0.061	
5	0.328			
6	0.200			
8			0.064	
9	0.184	0.094	0.184	0.130
10	0.083		0.083	
11	0.161	0.094	0.446	0.446
12	0.248			
13	0.113		0.156	0.568
14	0.157			
15				
16	0.157			
17		0.866		0.358
19	0.120	2.114	0.033	
20	0.486	0.094	0.486	
21				
22	0.101	0.101	0.420	0.358
23			0.420	
24		0.225	0.188	0.037
25	0.188	0.225	0.188	
26	0.188		0.188	0.037
27		0.513	0.188	
29		0.189		
30				0.355
32	0.188	0.286	0.188	2.361
33	0.570	0.055	0.570	0.127
34	0.095			
36		0.000		0.000
37		0.031	0.239	0.074
40	0.138			0.134
41			0.188	
42	0.188	0.866	0.188	0.037
43				0.156
46				0.350
50				0.049
51		0.000	0.049	0.049
55		0.087		0.000
56		0.000		0.114
57				0.021