

## Cross-Sectional Silica Exposure Measurements at Two Zambian Copper Mines of Nkana and Mufulira

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Received: 17 September 2007 / Accepted: 30 April 2008 / Published: 30 June 2008

**Abstract:** We measured the quartz content of 20 bulk settled dust and 200 respirable dust samples in a cross-sectional dust exposure assessment that is part of an epidemiological study to ascertain the risk of nonmalignant respiratory diseases among Zambian copper miners. Dust samples were collected from the copper mines of Mopani Copper Mine plc (Mufulira and Nkana Mines). Analytical measurements employed NIOSH Method 0600 for gravimetric analysis of respirable dust and NIOSH Method 7500 for quartz analysis in bulk and respirable dust samples. The measured quartz content of respirable dust showed that 59% and 26% of Mufulira and Nkana Mine samples, respectively, were above the calculated U.S. Occupational Safety and Health Administration permissible exposure limit. The mean intensities of respirable dust exposure at Mufulira and Nkana were 0.992 mg/m<sup>3</sup> (range 0-7.674) and 0.868 mg/m<sup>3</sup> (range 0-6.944), respectively while the mean intensities of respirable quartz at Mufulira and Nkana were 0.143 mg/m<sup>3</sup> (range 0-1.302) and 0.060 mg/m<sup>3</sup> (range 0-0.317), respectively. These results indicate weak dust monitoring at these mines which may increase the risk of nonmalignant disease in many miners. Since Zambian mining regulations do not have crystalline silica exposure limits, these results accord with the recommendation that Zambian mining houses and the government establish crystalline silica analysis laboratory capacity and adopt dust mass concentration occupational exposure limits for more protective dust monitoring of workers.

**Key words:** crystalline silica, silicosis, exposure, respirable dust, monitoring, mining.

### Introduction

Adverse health outcomes associated with occupational exposure to respirable crystalline silica include silicosis, tuberculosis, chronic obstructive pulmonary disease (COPD) and lung cancer. Silicosis is a debilitating and often fatal lung disease of continuing worldwide importance whose cumulative estimates exceed 1 million cases in developing countries [1-4].

In Zambia, the silica exposure hazard and silicosis morbidity levels have been poorly studied among nearly half a million miners that have been employed in the copper mining industry since large-scale Zambian copper mining started in the early 1930s. This is because control of silicosis, as implemented in Zambia, using the two methods of monitoring dust in mines and annual

pneumoconiosis screening of miners has notable gaps [5-7]. For example, Zambian dust control regulations used over the past 50 years have only utilized total dust occupational exposure limits (reported as konimeter measured count data) that do not take account of the quantitative silica content in dust to which miners are exposed. This paper reports on a cross-sectional dust exposure assessment that is part of an on-going epidemiological study at four of the largest Zambian copper mines. Results from two mines are reported here.

The overall aim of the epidemiological study is to ascertain the risk of nonmalignant respiratory diseases (silicosis, tuberculosis and COPD) among miners while examining the relationship of disease outcomes to occupational cumulative exposure to respirable dust and respirable crystalline silica. The specific objective of dust

exposure assessment at Nkana and Mufulira Mines was to characterize current respirable dust and crystalline silica exposure at the two copper mines of Mopani Copper Mines plc (MCM).

### Experimental Design and Methods

Reported dust exposure measurements at the two mines were of a cross-sectional design. At each mine, bulk and personal respirable dust samples were collected at scheduled areas. Scheduled areas are production areas of the mine where mining regulations of the Zambian mining regulatory authorities apply. In these areas, the main production activities are ore mining and its metallurgical processing. Sampling was restricted to sections of scheduled areas of each mine that are frequently associated with dust, namely; underground work areas of the mine and sections of the metallurgical works of the mine that deal with ore diminution (crushing and milling) and handle tailings.

In each scheduled area, personal dust sampling design required collecting samples from two primary groups of workers, namely; those doing jobs with low and high potential dust exposure. In underground work areas high potential exposure jobs included those of miners working at the ore face and those engaged in ore transportation while jobs in the ore diminution sections of the metallurgical areas with high exposure potential included those of crusher, milling and conveyor attendants. In both areas jobs with low dust exposure potential were those of workers engaged in the provision of mining and metallurgical support services.

Personal dust samples were collected on 5 µm PVC filters using Gil Air 5 sampling pumps with a nylon cyclone pre-selector for respirable particulates. Samplers were pre- and post-calibrated to ensure that pump flow rates during sampling were within 5% of the recommended pump flowrate of 1.7 litres/minute [8]. Filters collected with samplers that did not meet this criterion due to pump failure were rejected.

Collected dust samples were sent to an accredited analytical laboratory (Bureau Veritas North America, Inc.) in the U.S. for analysis. The instrumental technique of x-ray diffraction spectrometry (XRD) employing NIOSH Method 7500 [8] was used for analyses of crystalline silica in bulk and respirable dust while total respirable dust in personal dust samples was gravimetrically determined using NIOSH Method 0600.

### Results

All bulk and respirable samples were scanned for all three forms of crystalline silica that may be found in workplaces, namely; quartz, cristobalite and tridymite. The only form of crystalline silica detected in the samples was quartz. The mean bulk dust silica content of Nkana and Mufulira Mines were 20 and 57%, respectively.

At Nkana and Mufulira Mines, 102 and 101 personal dust samples were collected during eight hour shifts, respectively. The mean sampling times for Nkana and

Mufulira Mines were 307 and 312 minutes, respectively. These respirable dust samples were analyzed for quartz content (%) and exposure concentrations of respirable dust and quartz (mg/m<sup>3</sup>).

Table 1 shows the number of samples in which each analyte was not detected (ND), was determined to lie between the limit of detection and the limit of quantification (LOD-LOQ) and was determined to be greater than or equal to the limit of quantification (≥LOQ). The LOD and LOQ for quartz were 10 µg/sample and 33 µg/sample, respectively while the LOD and LOQ for respirable dust were 30 µg/sample and 87 µg/sample, respectively.

**Table 1:** Description of ease of detection of analytes in respirable dust samples: LOD and LOQ for silica were 10 and 30 ug/sample while LOD and LOQ for respirable dust were 30 ug/sample and 87 ug/sample. The analytical range for respirable crystalline silica was 10 to 200 ug/sample. The analytical range for respirable dust was 30 to 200 mg.

Descriptor for number of samples detected	Nkana (n=102)		Mufulira (n=101)	
	Dust	Silica	Dust	Silica
Not detected (ND)	17	41	12	18
Between limit of detection and limit of quantification (LOD-LOQ)	16	31	12	20
Greater than or equal to limit of quantification (≥LOQ)	69	30	77	71

Table 2 shows exposure descriptive parameters for each analyte at these mines. Results from the two mines are comparable with respect to gravimetric measures. Mufulira Mine had 77 (76 %) samples above the LOQ and a mean respirable dust concentration of 0.992 mg/m<sup>3</sup> (range 0 - 7.674) while Nkana Mine had 69 (68 %) samples above the LOQ and a mean respirable dust concentration of 0.868 mg/m<sup>3</sup> (range 0 - 6.944). Although Table 2 shows that the two mines have comparable mean respirable quartz content (Nkana, 13.6% and Mufulira, 17.5%), Table 1 shows that quartz was more frequently above the LOQ in personal dust samples collected at Mufulira Mine.

The understanding of what constitutes a safe exposure to a workplace contaminant has led to development of occupational exposure limits (OELs) by professional bodies and many national regulatory authorities. Table 3 shows OELs of respirable dust and crystalline silica for various U.S. institutions (namely, Occupational Safety and Health Administration – OSHA, Mine Safety and Health Administration – MSHA, National Institute for Occupational Safety and Health – NIOSH, American Conference of Governmental Industrial Hygienists – ACGIH) and the Zambian mining industry regulatory authority (Mine Safety Department - MSD) that are of

**Table 2:** Some descriptive statistical parameters for Mufulira and Nkana respirable dust samples

Descriptive	Crystalline SiO <sub>2</sub> content quartz (%)		Total respirable dust (mg/m <sup>3</sup> )		Respirable crystalline SiO <sub>2</sub> quartz (mg/m <sup>3</sup> )	
	Mufulira	Nkana	Mufulira	Nkana	Mufulira	Nkana
Count	87	85	101	102	101	102
Mean	17.5	13.6	0.992	0.868	0.143	0.060
Stdev	12.0	12.4	1.162	1.246	0.197	0.059
Minimum	1.5	0.9	0.000	0.000	0.000	0.000
Maximum	82.5	62.5	7.674	6.944	1.302	0.317
Percentile 5 <sup>th</sup>	3.8	2.1	0.043	0.056	0.014	0.015
Percentile 10 <sup>th</sup>	5.8	2.8	0.069	0.069	0.017	0.016
Percentile 25 <sup>th</sup>	9.6	4.7	0.258	0.109	0.029	0.020
Median	16.8	9.0	0.735	0.366	0.098	0.039
Percentile 75 <sup>th</sup>	20.3	20.0	1.244	1.279	0.160	0.082
Percentile 90 <sup>th</sup>	25.8	29.7	2.286	2.242	0.262	0.130
Percentile 95 <sup>th</sup>	40.9	37.1	3.023	2.725	0.400	0.166

**Table 3:** Occupational exposure limits (OELs) of dust and crystalline silica for US and Zambian institutions

Institution	Substance	Name of OEL	OEL value (mg/m <sup>3</sup> ) or definition
OSHA, U.S.	Dust (respirable) containing quartz	Permissible exposure limit (PEL)	10/(SiO <sub>2</sub> %+2)
ACGIH, U.S.	Quartz Cristobalite Tridymite	Threshold limit value (TLV)	0.025
NIOSH, U.S.	Crystalline silica	Recommended exposure limit (REL)	0.05
MSHA, U.S.	Dust (respirable) containing >1% quartz in surface and underground metal and nonmetal mines	Threshold limit value (TLV)	10/(SiO <sub>2</sub> %+2)
MSD, Zambia	Dust	(legal limit)	1.75

interest to this study. The Zambian mass concentration OEL in the table is derived from the konimeter dust count

OEL by applying a conversion factor given by van der Linde [5].

Figure 1 shows the percent of samples at each mine that exceed various U.S. OELs for respirable crystalline silica. The first pair of bars shows samples above the OSHA PEL for respirable dust containing quartz. The quartz content of each sample was used in the OSHA PEL equation to determine the OSHA PEL for that sample. The second pair of bars shows the percent of samples above the NIOSH Recommended Exposure Limit (REL) of 0.050 mg/m<sup>3</sup> for respirable crystalline silica. The third pair of bars shows samples above the ACGIH Threshold Limit Value (TLV) of 0.025 mg/m<sup>3</sup> for respirable crystalline silica.

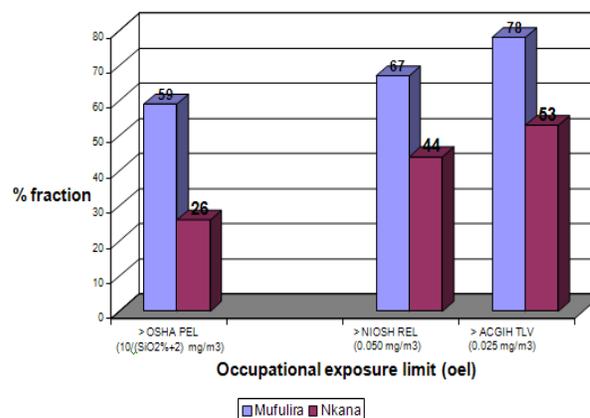
**Figure 1:** MCM personal samples of respirable dust containing crystalline silica higher than specified U.S. OEL

Figure 1 shows that 26% and 59% of the samples at Nkana and Mufulira Mines, respectively, were above the

OSHA (which in this case is the same as the MSHA) exposure limit for respirable dust containing quartz.

## Discussion and Conclusion

The results of bulk dust silica content of Nkana and Mufulira Mines do not vary much from those reported by Paul [9] and by Mchaina and Misra [11].

Table 3 shows the Zambian dust OEL contrasted to several U.S. OELs of interest to this study. In a risk assessment report of some Zambian copper mines, van der Linde [5] pointed out that lack of mass concentration dust exposure data (total respirable dust and respirable crystalline silica) for Zambian copper mines makes it difficult to judge the effectiveness of dust control strategies in these mines. The average crystalline silica content of copper ores measured at two mines in this study is close to 15%. As shown in Table 3, the Zambian OEL does not take account of the silica content of ore dust. This situation suggests that many miners may be exposed to levels of total respirable dust and respirable crystalline silica that are higher than OSHA PELs for respirable dust containing crystalline silica. With respect to total respirable dust, Table 2 confirms that although the average total respirable dust exposure concentration measured at each mine is below the Zambian legal limit of 1.75 mg/m<sup>3</sup>, the maximum measured concentration at each mine exceeds the total respirable dust OSHA PEL of 5 mg/m<sup>3</sup> and the Zambian OEL. Thus, if U.S. regulations were used as guidelines for mass concentration OELs for these Zambian mines, the maximum exposure to non-silica dust would exceed the OELs for both mines.

When the mean crystalline silica exposure concentration at each mine is considered, Table 2 shows that the average respirable quartz concentration is 0.143 mg/m<sup>3</sup> (range 0 - 1.302) at Mufulira Mine and 0.060 mg/m<sup>3</sup> (range 0 - 0.317) at Nkana Mine. These mean respirable quartz levels are both higher than that reported in a recent South African study of older black gold miners [10] in which it was indicated that there was an urgent need for improved dust control in the industry. In that study, the mean intensity of respirable quartz was 0.053 mg/m<sup>3</sup> (range 0-0.095), while the prevalence of silicosis was 18.3-19.9% depending on the chest radiograph reader. In addition, the average total respirable dust concentration is 0.992 mg/m<sup>3</sup> (range 0 - 7.674) at Mufulira Mine and is 0.868 mg/m<sup>3</sup> (range 0 - 6.944) at Nkana Mine. The mean total respirable dust levels compare to 0.37 mg/m<sup>3</sup> in the cited South African gold mine study. This suggests that Zambian miners may be at a substantial risk for the development of silicosis.

In 1983, Mchaina and Misra [11] recommended that Zambian mining regulations be updated to using silica mass concentration OEL equivalent to the then ACGIH TLV, 0.1 mg/m<sup>3</sup>. The recommendation to use a mass concentration OEL for dust exposure control among miners, first recommended at the 1959 Johannesburg Silicosis Conference [12] is yet to be followed in Zambia. In the past 24 years since Mchaina and Misra's

recommendation, the ACGIH has lowered its silica TLV by a factor of 4. This shows that protection of workers from silica exposure continues to be an important occupational health requirement.

In Zambia, unfortunately, there is not a single silica analysis laboratory in the country that can be used to provide exposure data needed to judge the effectiveness of dust control strategies being implemented in the country's mining industry despite the fact that this industry employs more than 30,000 miners. Based on the results of this study, it is recommended that Zambian mining houses and the Zambian government work together to establish at least one national silica measurement laboratory. The envisaged role of international institutions like the University of Michigan and NIOSH will be to help Zambia develop technical capacity of the established laboratory to a level that it becomes internationally certified.

**Acknowledgements:** The authors thank the University of Michigan, National Institute for Occupational Safety and Health, National Institute for Scientific and Industrial Research and Mopani Copper Mines plc for support. Doctoral Fellowship of the Fogarty International Centre (for Public Health) is also highly appreciated. Mention of company names and products does not constitute endorsement by the Centers for Disease Control and Prevention (CDC). The findings and conclusions of this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

## References

1. WHO: Elimination of Silicosis. *Global Health Occupational Health Network*, Issue 12-2007, World Health Organization, Geneva, Switzerland, **2007**.
2. NIOSH: NIOSH Hazard Review: Health Effects of Occupational Exposure to Respirable Crystalline Silica. US Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 2002-129, Cincinnati, Ohio, USA, **2002**.
3. Parker, J. E.; Wagner, G. R.: Silicosis. In: Stellman JM, ed. *Encyclopaedia of occupational health and safety*. 4<sup>th</sup> ed. Geneva, Switzerland: International Labor Organization, **1998**, pp. 10.43-10.46.
4. ATS (American Thoracic Society): Adverse effects of crystalline silica exposure. *Am J Respir Crit Care Med*, **1997**, *155*, 761-768.
5. van der Linde, A.: Konkola Copper Mines occupational hygiene baseline risk assessment. Marshalltown, South Africa, **2000**, pp. 7-8.
6. Mulenga, E. M.; Miller, H. B.; Sinkala, T.; Hysong, T. A.; and Burgess, L. J.: Silicosis and Tuberculosis in Zambian Miners. *Int J Occup Environ Health*; **2005**, *11*(3): 259-262.
7. Hayumbu, P.: Respiratory diseases among Zambian copper miners: silicosis and tuberculosis incidence trends during the period 1995-2003. *Occupational*

- and Environmental Epidemiology MPH Research Paper (EHS 697). *University of Michigan, Ann Arbor, USA*, **2005**.
8. NIOSH: Crystalline Silica, by XRD: Method 7500. In: NIOSH manual of analytical methods, 4<sup>th</sup> rev. ed., 2<sup>nd</sup> suppl. US Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 98-119, Cincinnati, Ohio, USA, **1998**.
  9. Paul, R.: Silicosis in Northern Rhodesia copper mines. *Arch Environ Health*, **1961**, *2*, 96-109.
  10. Churchyard, G. J.; Ehrlich, R.; teWaterNaude, J. M.; Pemba, L.; Dekker, K.; Vermeijs, M.; White, N.; Myers, J.: Silicosis prevalence and exposure-response relations in South African goldminers. *Occup Environ Med*, **2004**, *61*, 811–816.
  11. Mchaina, D. M.; Misra, G. B.: Incidence of silicosis and its relation to dust dosage at Mufulira Copper Mines, Zambia. University of Zambia School of Mines, Lusaka, **1983**.
  12. Orestein A. J. (Ed.): Proceedings of Pneumoconiosis Conference, Johannesburg, 1959. Churchill **1960**, pp 617-621.