DUST EXPOSURE AND PNEUMOCONIOSIS IN MINES

A THESIS

SUBMITTED TO THE SCHOOL OF MINES

THE UNIVERSITY OF ZAMBIA

BY

DAVID MHINA MCHAINA

IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF MINERAL SCIENCES

DEPARTMENT OF MINING ENGINEERING

MAY, 1985

I, David S. M. R. B. Mchaina, do declare that this dissertation has never before been submitted for a degree in this or any other University.

Signed ....

This Thesis of David Mchaina is approved as fulfilling the requirements for the award of the Degree of Master of Mineral Sciences in Mining Engineering by the University of Zambia.

Signature of Examiners

Dr. Mehmet Guney, Prof of Mining Engg.
....

Dr M. M. Mbande
....

....

Dr. T. Guyagula
....

DUST EXPOSURE AND PNEUMOCONIOSIS IN MINES

Abstract

Attempts to develop Threshold Limit Values together with the correlation between results of various sampling instruments are described.

The main objectives of the investigations were: to establish the relstionship between dust exposure and the development of pneumoconiosis, to study the effect of free silica content of dust on the development of silicosis, to study the concentration of respirable dust encountered in various mining occupations and to establish acceptable limits based on the gravimetric dust samplers. A subsidiary objective was to establish a correlation between mass and particle number concentrations.

The miners involved in the study were those suffering from pneumoconiosis. Their stages of pneumoconiosis were related to cumulative dust doses to which the progression of pneumoconiosis was determined on the basis of ILO u/c International Classification of Radiographs of Pneumoconiosis, of 1971 using 1968 standard films for comparison. The cumulative doses to which the individual miners were exposed were compared with the profusion categories and the Nodule size progression. The hazard of silicosis was

evaluated by determining the free silica content of the respirable portion of dust breathed by mine workers.

Dust samples were collected from the breathing zones of miners with the use of gravimetric samplers. These samples were then analysed using X-ray diffraction. Free silica was determined, both qualitatively and quantitatively. The amount of quartz was determined by comparing the intensities of diffraction peaks of quartz in the samples with those of corundum.

It is concluded that the maximum allowable concentrations of 350 particles per cubic centimetre in force on the Zambian Copperbelt and 2 mgm^{-3} adopted at Wankie Colliery can be considered as adequate standards for guarding against the hazards of pneumoconiosis. Cumulative doses for total dust of 275 $mgmonthm^{-3}$ and 700 $mgmonthm^{-3}$ are recommended for the Zambian Copperbelt and Wankie Colliery respectively. Cumulative dose for free silica of 55 $mgmonthm^{-3}$ was set for the Zambian mines.

The comparison between the results of the sampling instruments showed that the particle concentration measured by the Konimeter did not correlate with the mass concentration measured by gravimetric dust samplers. Of all sampling instruments, MRE 113A was found to be reliable and for control purposes this instrument should be used as a standard sampler.

ACKNOWLEDGEMENTS

Grateful acknowledgement is made to my supervisor, Dr. T. Guyaguler, for his guidance, encouragement, and his unlimited patience during the course of this work.

Special thanks are due to my previous supervisor, Prof. G. B. Misra, for his professional advice, skilled guidance, help and co-operation, and for providing an atmosphere of friendship.

I would like to thank Drs. W. Lombe (Assistant Dean, Postgraduate Affairs) and M. Mpande (Head of Department of Mining Engineering) for making contacts with the Mining Companies and my sponsors.

Deep appreciation is expressed to Dr. Kasonde (former Permanent Secretary, Ministry of Health) and Dr. G. M. D. Mhango (Director of Pneumoconiosis Bureau) for allowing me to go through records at the Bureau of Pneumoconiosis.

Thanks to Dr. D. M. Mody (Deputy Director of Pneumoconiosis Bureau) for his assistance in reading the X-ray films.

Thanks are due to:
The Ventilation staff of Mufulira Division for all the professional guidance rendered - in particular special thanks go to Messrs: F. Mukelabai (Assistant Mine Superitendent - Technical), Richard Zyambo (Ventilation Engineer) and Y. Chabala (Sectional Ventilation Officer) for their technical assistance rendered to me during my stay at Mufulira.

The Ventilation staff and Management of Wankie Colliery for their hospitality, useful hints and criticism. Special thanks go to Messrs: Creasy (Assistant General Manager), David Grice (Senior Mine Captain) and Jackson Banda (Ventilation Officer) for making my sampling work enjoyable.

The Ventilation staff of Luanshya Division for the excellent co-operation received during my field work - in particular special thanks go to Messrs Aaron Ndlovu (Ventilation Engineer), Edward Wazili (Assistant Ventilation Engineer), Steve Chilumba (Sectional Ventilation Officer - 18 and 14 Shafts) and Charles Mudenda (Sectional Ventilation Officer) for organising my sampling work.

Mine Safety Department for the analysis of the dust samples. Special thanks go to Messrs H. H. E. Kambaila (Chief Inspector of Mines), Bari (Chief Physist), V. Champemba (Technical Officer) and Levy Chomba (Laboratory Technician) for their technical assistance.

Geological Survey staff for allowing me to use their X-ray diffractogram for qualitative analysis of rock samples.

Mining Industry Technical Services (MITS) for analysing Mufulira dust samples.

Thanks are due to Miss Agnes Mufuzi and Mrs. Angela Chiluba for their co-operation.

All those who directly or indirectly contributed towards the realisation of this thesis are gratefully acknowledged.

The financial support from the Norwegian Agency for International Development is gratefully acknowledged.

The last but not least, thanks to the State Mining Corporation (Tanzania) for granting me the study leave and for regularly paying my salary.

DEDICATION

This thesis is dedicated to mum, wife, son and daughter

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Pneumoconiosis is one of the many health and safety problems associated with mining. As a condition it is serious in terms of suffering and financial cost. Pneumoconiosis is a condition of respiratory system caused by inhalation of airborne dust over long periods of time (17, 33, 80, 112, 40).

To reduce the incicence of pneumoconiosis, it is necessary to provide a relatively dust free working environment. This means that the dust concentration at the working place should be lower than the maximum allowable concentration. Various governments prescribe different Threshold Limit Values e.g. 350 particles per cubic centimetre of scheduled areas in Zambia. It is the airborne dust particles in the range of 0.5 to 7.0 microns which cause pulmonary damage (63, 65, 9, 100, 62, 15). In this study the word "dust" therefore implies airborne particles less than 10 microns in diameter.

The pathological action of the dust on the lung alveoli is not clearly understood (75). The means of treatment are also not well known at the moment. This implies that the control of dust in mines is a very important preventive measure in the fight against pneumoconiosis.

At present the known techniques in controlling pneumoconiosis are based on engineering and medical procedures. Both approaches of pneumoconiosis control program are used at all times.

The main techniques employed for the reduction of airborne dust in the mine air include (25, 39):

i. Procedures directed at reducing or stopping the production of dangerous dust;

ii. Methods designed to prevent the escape of dust into the mine air;

iii. Use of individual respiratory protection;

iv. Dilution of dust containing mine air with fresh air;

v. Isolation during blasting.

Pneumoconiosis or specifically silicosis is predominant on the Zambian Copperbelt (13). On the Zambian Copperbelt alone 281 new cases were certified as stage 1 of simple pneumoconiosis and were receiving benefits for pneumoconiosis disability between 1977 and 1983 while in the same period there were 353 men certified to have silico-tuberculosis. Out of the 281 pneumoconiosis cases, 204 were from Mufulira and the remaining 77 cases were from other mining divisions of Zambia Consolidated Copper Mines Limited while out of 353 silico-tuberculosis cases, 130 were from Mufulira mine alone. Coal workers pneumoconiosis prevalence at Wankie Colliery Limited was quite low, less than 10 cases were discovered from records. The number of cases of sickness due to dust in these mines is not decreasing at present although the fight against dust is gradually improving, because of improved working conditions. It is this alarming rate of pneumoconiosis which prompted the investigations into dustiness conditions in working places.

The main objectives of the investigation were:

i. to establish a relationship between the development of Pneumoconiosis and dust exposure in order to predict the possibility of a miner contacting pneumoconiosis after working for a specified number of shifts at a specific concentration;

ii. to study the effect of free silica content of dust on development of silicosis;

iii. to study the concentration of respirable dust to which men are exposed in various mining operations and identify hazardous operations from pneumoconiosis point of view;

iv. to establish acceptable concentration levels based on the gravimetric dust samplers.

Subsidiary objectives were to establish, if possible a correlation between gravimetric and Konimeter concentrations. An attempt was made to meet the aforementioned objectives with the following experimental measurements: mass and particle concentrations of airborne dust as determined by gravimetric and Konimeter dust samplers; free silica in the respirable dust, duration of exposure; and dust particle size.

Sample of miners involved in the study were those with pneumoconiosis. Their stages of pneumoconiosis were related to cumulative dust doses.

The progression of pneumoconiosis was determined on the basis of ILO u/c International Classification of Radiographs of Pneumoconiosis, of 1971 using 1968 standing films for comparison. The cumulative doses of the individual miners were compared with profusion category and nodule size progression.

The establishment of Occupational Exposure Limit is a two step process. The investigations concentrated on the development of recommended"health-based exposure limit" derived from data on "exposure-effect"and "exposure-response" relationships. The interpretation of these "health-based exposure limits" into"operational limits" (a second step) requires taking the following factors into account: the views of governments, employees and workers, as well as the social, cultural, economic and technical aspects.

Experimental work involved qualitative and quantitative analyses of settled dust, incombustible dust and rock samples from three mines: Mufulira, Luanshya and Wankie. The analyses were done with the use of X-ray diffraction, microscopic and chemical methods. The results were analysed using regression analysis techniques.

The details of the investigation are presented beginning with Chapter II which gives a review of mine dustiness. Chapter III deals with methods used in the investigation. Estimation of dust concentration, free silica (SiO_2) determination in samples, radiological data and occupational histories are explained in this chapter.

Field measurements are presented in Chapter IV.

The results are discussed in Chapter V which gives a summary of experimental results.

Chapter VI covers the conclusion drawn and an outline of future work in connection with dust exposure.

Appendix A gives cumulative dosage in relation to time contributing to the exposure for various profusion categories.

Appendix B gives a comparison between cumulative total dust and silica dose to profusion categories.

Appendix C shows a comparison of exposure to nodule size classification for total and silica dust.

Appendix D covers detailed results of individuals' dust exposures.

Finally, Appendix E includes sampling results for various occupations.

CHAPTER II

2. REVIEW OF MINE DUSTINESS

2.1 Relation Between Exposure and Dust Content in the Lungs

Pneumoconiosis is regarded as a criterion for determining health-based exposure limits. This section describes relationships between dust exposure and measure of pneumoconiosis in post mortem material.

It has been shown that the amount of dust retained in lungs of miners without pneumoconiosis is not directly proportional to the duration of exposure, but reaches a steady-state value after about 20 years of work underground (97). The amount of dust found in lungs of miners after the same duration of exposure ranged from a few grams to more than 50g. The differences may be due to different levels of exposure or by inter-individual variation in retention rate. For this reason, the dust content in the lungs does not seem to be a good indicator of the level of exposure to dust in non-pneumoconiosis workers. Several researchers have examined the dust content in the lungs and pneumoconiosis.

Einbrodt and Kloster Kotter (27) evaluated the dust content of 65 affected coal miners. They positively correlated the massive fibrosis with both free silica content in the lung tissue and dust residence time. The concept of residence time (27) is given by the formular below:

$$\frac{\text{time of exposure in years}}{2} + \text{interval until death in years}$$

and is based on the consideration that the free silica containing dust does not lose fibrogenicity when present in lungs. In massive fibrotic cases, a high silica (100 mg/100000 mg dry lung tissue) was associated with a residence time of less than 20 years. Lower silica levels (500 - 1000 mg/100000 mg) were associated with residence times of 20 to 40 years. Naeya (72) also found a positive correlation between the number of crystals of silica in the lungs and radiological stage of pneumoconiosis in coal miners of Pennsylvania (bituminous coal rich nin ash). There was also a significant correlation between the duration of exposure and the number of crystals. He found about 250 crystals of silica in the lungs of miners without pneumoconiosis and with pneumoconiosis radiographic category 1, 560 in category 2 - 3 and above 1,500 in categories with large lopacities. Rossiter (82) reported good correlation between dust content in the lungs of 88 deceased British coal workers and radiographic category of pneumoconiosis. The average total dust cont'd of lung was 1029 mg (range 900 to 35300 mg), the total silica content 950 mg (range 150 to 7100 mg) and the quartz content of 280 mg (range 10 to 3360 mg). The average total dust content in radiographic categories 0, 1, 2 and 3 were 4170, 10310, 13310 and 19080mg respectively. Silica content followed the same pattern.

The same author (81) and Casswell et al. (12) have also demonstrated a very good relationship between radiographic category of pneumoconiosis and the coal content, other minerals, quartz and iron in the lungs of deceased British coal miners. A report by Davis et al. (18) showed a similar relation between lung quartz content and X-ray appearance in 74 British coal miners. They found dust content of about 6 to 16 g in both lungs while in the progressive massive fibrosis lesions, the dust concentration was found to be 2-3 times higher, on average, than the concentration in the rest of the lung. Another study of 20 deceased coal miners and 29 control subjects found, in the right upper lobe, $12.78 + 9.40 \times 10^3$ mg dust per 100000 mg dry tissue in miners and 890 + 650 mg in controls, as averages and standard deviations. Approximately 15% of the dust in the lungs was silica, whereas the silica content in the mine dust was only 3% (1o). Dobreva et al. (20) examined the lungs of 25 deceased miners from metal-ore mines and tunnelling and quarry operations, who had been exposed to dust containing 20 - 25% free silica. The amount of dust was in the range 800 to 8000 mg per 100000 mg dry tissue, the mineral residue 300 to 7000 mg/100000 mg and the free silica content 20 to 1810 mg/100000 mg. There was no significant correlation between lung deposition and the duration of the work, but there was a correlation between the quartz content and the radiographic category of silicosis. It can be noticed that most studies have included only workers with many years of dust exposure. However, three cases of sub-acute silicosis have been described in metal-ore miners which developed after 4 to 5 years of underground work and resulted in death 5 years after leaving work (100). The total dust content in the lungs was 9.01, 16.19 and 17.39 x 10^3 mg and the quartz fraction represented 18.0% to 24.0%. In three control persons, the total dust content in the lung was less than 1500 mg.

2.2 Relationship between Exposure to Dust Pneumoconiosis

There are many published papers describing pneumoconiosis risks in different occupations. However, the overwhelming majority of them do not include quantitative data on levels of exposure or concentrations of dust in the air. "Exposure" implies here the product (concentration X time), and all these variables have to be documented, explicitly or implicitly in order to establish exposure - effect, or exposure - response relationships. "Effect" implies a biological reaction (in this case radiographic category of pneumoconiosis) measured on a continuous scale.

2.2.1 Silica

Incidence of silicosis in Vermont Granite Sheds has been analysed by several researchers. The earliest report is by Russel et al. (83) who studies 972 granite shed workers, dividing them into four exposure groups according to average dustiness: 37 - 40, 27 - 44, 20, and 3 - 9 mppcf. In the group exposed at an average of 20 mppcf there was little indication of severe effects upon the health of the workers. The authors concluded that one would hesitate to state positively that no harm would come to persons exposed for many years to a concentration under 20 mppcf. In the case of the lowest exposure group, where the average dust concentration was 6 mppcf (range 3 - 9 mppcf). there was no indication of any significant effect of dust exposure on workers. The authors concluded a safe limit of dust exposure lying between 10 and 20 mppcf. In his later studies, Russel (84) revised his original estimates of 10 - 20 mppcf as the desirable limit for granite dust exposure. His new limit of about 10 mppcf was based on a further complication of tuberculosis in the highest average dust exposure group (27-44 mppcf). Supporting this decision was evidence that progression of silicosis was marked in the highly exposed cutters in contrast to workers exposed to lower concentrations to dust, emphasizing that differences in reaction to dust hazard were in direct proportion to the dustiness. It was concluded that where average dust concentrations were found 6 mppcf, there was no indication of unfavourable effects. Following the re-analysis by Russell (84) and enforcement of the 10 mppcf limit by the Vermont Department of Health, dust control progressed in the granite sheds so that by the time of the study by Hosey et al (44), few exposures in the granite sheds studied exceeded 5 mppcf and a survey of chest roentgenographic showed a reduction in the prevalence of silicosis from 45% in 1937 to 15% in 1956. Confirmation of the safety of the 5 mppcf level was reported by Ashe and Hergstrom (5). Their study, 26 years after dust control began, likewise found no cases of silicosis in workers employed after the start of dust control. Environmental data also indicated probable greater margin of safety for dust exposure at the time of the study; average concentrations were 3 mppcf.

The latest studies of Vermont granite workers by Theriault et al (101, 102) used size-selective respirable dust mass sampling coupled with gravimetric determinations of dust concentrations, instead of impinger counts, as in earlier studies. Theriault et al (102) analysed estimated lifetime exposures in conjuction with postero-anterior radiographs of 784 workers with the response variable being category 1 or more silicosis. It has been reported elsewhere that 50 percent of the workers studied by Theriault et al. (101) had radiographic evidence of silicosis at 46 dust years (i.e. 46 years of exposure at a dust level equivalent to about 50 mgm^{-3} of free silica). Based on a plot of radiographically evident silicosis against dust years, 30 percent of the working population had radiographic lung abnormalities compatible with silicosis with no exposure in granite shade. In a routine survey (89), 21 men showed rapid progression of simple pneumoconiosis with low exposure to mixed coal mine dust. A case - control study was thus organised. It revealed that the cases progressing worked in average respirable coal-dust concentrations of 1.9 mgm^{-3} with 13% quartz, while controls were exposed to 1.4 mgm^{-3} with 8% quartz. Seaton et al. (89) have related measures of quartz exposure to radiological changes of pneumoconiosis, and a risk of disease in men with cumulative exposure of 0.1 mgm^{-3} quartz has been demonstrated. The work done by the Japanese Association of Industrial Health (55) on 1115 workers in whom radiographic evidence of silicosis was related to environmental exposure revealed that a 5% attach rate of silicosis (by definition used - radiographic category 2) corresponded to an average exposure of around 8.0 mgm^{-3} X years, and a corresponding attack rate of 16%

quartz yield an exposure level of 4.5 mgm^{-3} years. The critical exposure level to produce a 5% attack rate for 30% quartz was 13.2 mgm^{-3} X years. Thus, limits established on the basis of 5% incidence of category 2 silicosis and 25 years exposure were suggested as shown in Table 2.1 below:

Table 2.1 Exposure Limits in Relation to Free-Silica Content of Respirable Dust at 5% Incidence of Category 2 and 25 years of Exposure.

Exposure Limit (mgm^{-3})	Free-Silica Content %
0.47	30
0.54	16
0.96	7

Mcdonald and Oakes (66) re-analysed previously published data from a radiographic survey of 241 British gypsum miners (74) from a view point of silica exposure. Instruments used for sampling were personal and gravimetric samplers and analysis of total and respirable dust were made. The results revealed that in one mine, a man in a top - exposure job (crusher) had an average exposure to respirable dust of 0.006 mgm^{-3} and to respirable quartz of 0.07 mgm^{-3}, whereas in another mine of 0.0028 and 0.12 mgm^{-3}, respectively (74). Chest x-rays from 221 men were assessed independently by three readers using the 1971 ILO u/c classification. Among 64 miners with at least 20 years of service, 16 were detected as having radiographic category 1 or more silicosis.

They found a linear relationship between the prevalence of small radiographic opacities (category 1/0 or more) and exposure. Cases of silicosis were observed in miners exposed to concentration of 0.05 g quartz/m^3 or higher. A threshold model passing through the exposure axis at around 0.035 mgm^{-3} fits the radiographic data better than a non-threshold model. Given such a threshold, the prevalence then rises by about 0.9% for each 1000 mgm^{-3} above that level. At respirable quartz concentration of 1 mgm^{-3}, about half of the miners employed 20 years or more had radiographic changes. The authors emphasize that the number of long-term gypsum miners were small and that the exposure estimates were of limited reliability. Gardner (34) found no evidence of serious lung pathology in men exposed to diatomaceous earth dust but intracheal instillation in animals caused progressive modular fibrosis. Tabbens and Beard (99) exposed guinea pigs to uncalcined distomaceous earth at an average concentration of 60 mgm^{-3} for 37 to 50 weeks and observed no fibrosis, although there were extensive gross and microscopic changes in the lungs while Schepers (87) in his studies in the United States of America found that rats exposed to a precipitated amorphous silica for as long as one year, and guinea pigs and rabbits for two years, at a concentration of 126 mgm^{-3}, develop no pulmonary fibrosis. Kovalevich (59) induced silicosis in animals by intrachea instillation of diatomaceous earth and by inhalation of concentrations of 0.075 to 0.13 mgm^{-3}. Timar (106) cited that dust of higher quartz content does not cause progressive fibrosis in some cases by giving an example of pearlite dust containing 25 percent. He did not mention the reason to such cases. In rock tunnelling, he found that the silica ranges between 50 - 80% and acute silicosis developed from 6 to 18 months of continuous exposure. Early studies of the Public Health Service of the United States of America and others (44) showed that the results of engineering and medical studies were consistent with a value k = 250 when Threshold Limit Value (TLV) was expressed in terms of million particles per cubic foot (mmpcf) from the relationship.

$$TLV = \frac{k}{\%\ quartz}$$

The formula would permit exposure to very high concentrations of dust with low silica count, so in 1962 it was modified as:

$$TLV = \frac{250}{\%\ quartz + 5} \quad mppcf$$

On the basis of the findings of Hosey et al. (44) and Russell et al. (83) findings and in order to make the TLV consistent with a nuisance dust of TLV of 30 mppcf, the formula was revised in 1970 to:

$$TLV = \frac{300}{\%\ quartz + 10} \quad mppcf$$

Results from anthracite region of Pennsylvania by Sayers (86) and non-ferrous, metal mine study by Dressen et al. (23) and studies of pegmatite workers by Dressen et al. showed reasonable matching with the revised formula. Studies of foundry workers by Reves et al. (78), Pottery workers by Flinn et al. (31) and metal miners by Flinn et al. (32) found chest roentgenograms consistent with silicosis in workers who were exposed below this threshold limit value at the time of survey. Early limits for count concentration of dust from South Africa, Australia, and Ontario reported by Hamlin (41) were reasonably consistent with the count formula even though sampling methods and counting procedures were somewhat different from the United States' practice.

Research by Dutoit (26) revealed that a mean dust exposure limit of about 4 million particle hours can be taken as a base for pneumoconiosis in the first stage and suggested that the dust exposure should not get beyond this dose.

2.2.2 Coal-Mine Dust

Suhanov (93) has described results from a multiple regression analysis of post-mortem observations in coal miners from the Donetsk basin. He estimated the total dust levels associated with no lung damage after 7000 working shifts ranged from 2 mg/m^3 total dust for high rank coal with 2% volatile to 9 mg/m^3 for coal low rank (44% volatile material). Gonzalez et al. (36) have reported results from a retrospective analysis of the relationship between dust exposure and pneumoconiosis in Spanish coal mines. The probability of developing radiographic category 1/1 pneumoconiosis after 35 years of exposure was estimated to be approximately 9% at an average respirable dust level of 8 mg/m^3, about 2.5% at a level of 4 mg/m^3, and about 1.5% at a level of 2 mg/m^3. They did not give the range of silica content, but constituted 8.6% of dust in one of the 22 mines. Vekeny (110) developed a relationship between dust exposure and pneumoconiosis in Hungarian coal miners. The probability of developing pneumoconiosis radiographic category 1 or greater after 6500 workshifts was estimated to be 80% at an average respirable dust concentration of 4 mg/m^3, 18% at a level of about 0.5 mg/m^3. The quartz content of the coal face dust ranged from 3 - 10%, and that of dust in the haulage ways was 28-47%, the average mixed dust levels were 4.2 mg/m^3 and 1.6 mg/m^3, respectively. Hurley et al. (46) described data showing classification of each of 2600 coal miner's chest radiographs, using ILO radiographic classification of 1972. The proportions of miners who developed category 2/1 or more simple pneumoconiosis for different ranges of cumulative exposure and at each of the 10 mines is shown in Table 2.2. The results reported by Hurley et al. (46) show also that in men with similar cumulative exposure those with longer exposure times had higher ricks of developing pneumoconiosis. They found that the average of the quartz fractions in the 2600 mixed dust exposures was 5% and no evidence that the quartz content of the exposures affected the probability of developing simple pneumoconiosis.

Table 2.2 Number of Men Studied and (In parentheses) percentage Classified* as Category 2/1 or More CWP, by Colliery (46)*

Colliery	Cumulative Dust Exposure (gh/m^3)								
	≤79	80-119	120-159	160-199	240-239	240-279	280-359	≥360	All
C	42(0)	53(0)	70(0.3)	44(2.30)	9(2.2)	1(20.0)			219(0.7)
F	17(0)	5(0)	5(0)	16(0)	7(0)	27(1.5)	37(7.6)	67(16.10)	181(7.7)
K	70(0.3)	53(0)	61(1.6)	44(2.30)	40(6.50)	29(1.40)	11(10.90)	1(0)	309(1.7)
P	106(0)	82(0)	16(0)	1(0)					205(0)
Q	39(0)	23(0)	26(0)	33(0)	45(0.4)	36(0)	70(0.6)	54(3.70)	326(0.8)
T	34(0)	24(0)	28(12.10)	19(10.50)	19(21.10)	16(42.50)	20(30.0)	1(0)	161(13.80)
V	44(0)	32(0)	38(0)	43(3.3)	34(1.8)	43(2.80)	68(5.6)	36(11.10)	338(3.20)
W	39(0)	30(0)	20(0)	16(0)	23(5.2)	15(10.7)	18(14.4)	2(0)	162(3.3)
X	37(0)	18(0)	46(0)	64(3.10)	65(2.8)	36(6.10)	23(15.7)		289(3.3)
Y	54(0)	54(0)	62(0)	75(0)	56(0)	58(6.6)	44(5.0)	7(8.6)	410(1.6)
All	481(0.0)	374(0)	372(1.2)	355(2.10)	298(3.6)	261(6.4)	291(7.8)	168(10.4)	2600(3.1

*An average of five readers' independent randomised classifications of fifth survey radiographs. For each reader's classifications, the number of men with category 2/1 or more CWP in any group was expressed as a percentage of the total number of men studied in that group. Figure in parentheses is an average of these five values.

Jacobsen and Maclaren (53) showed subsequently that the quartz-related unusually rapid progression of simple pneumoconiosis in these men (2600) associated with a disproportionately frequent occurrence of massive fibrosis while Seaton et al. (89) showed that high quartz levels in low concentrations of coal-mine dust can be linked to rapid development and progression of simple pneumoconiosis over four years. A survey of twenty British coal mines which begun in 1953 revealed a significant overall correlation between the number of steps of progression of coal workers pneumoconiosis (CWP) per million shifts and the mean mass concentration of respirable dust, Jackson et al. (51). The survey also revealed that mass concentration (mgm^{-3}) gave a far better correlation (correlation coefficient $r = 0.80$) than particles concentration (number of particles per cm^3) as measured by a very accurate sampling instrument, the thermal precipitator ($r = 0.44$). The same recorded the probability of contracting 2/1 or above stage of pneumoconiosis for a recommended standard concentration of 8 mgm^{-3} to be 0.05 while that for 1/0 or greater was of the order of 0.15 (see Figure 2.1). These probability figures were confirmed in a later study by Hurley et. al. (46) in eight collieries out of ten over a longer period of survey. Curve III in Fig. 2.1 shows the probability of CWP in German coal workers which slowly agrees with the US coal miners as reported by Constantino (15). It is generally agreed that the risk of development of complicated pneumoconiosis or progressive massive fibrosis (PMF) does not arise before the stage 2/1 if simple pneumoconiosis and an assumption of this stage as

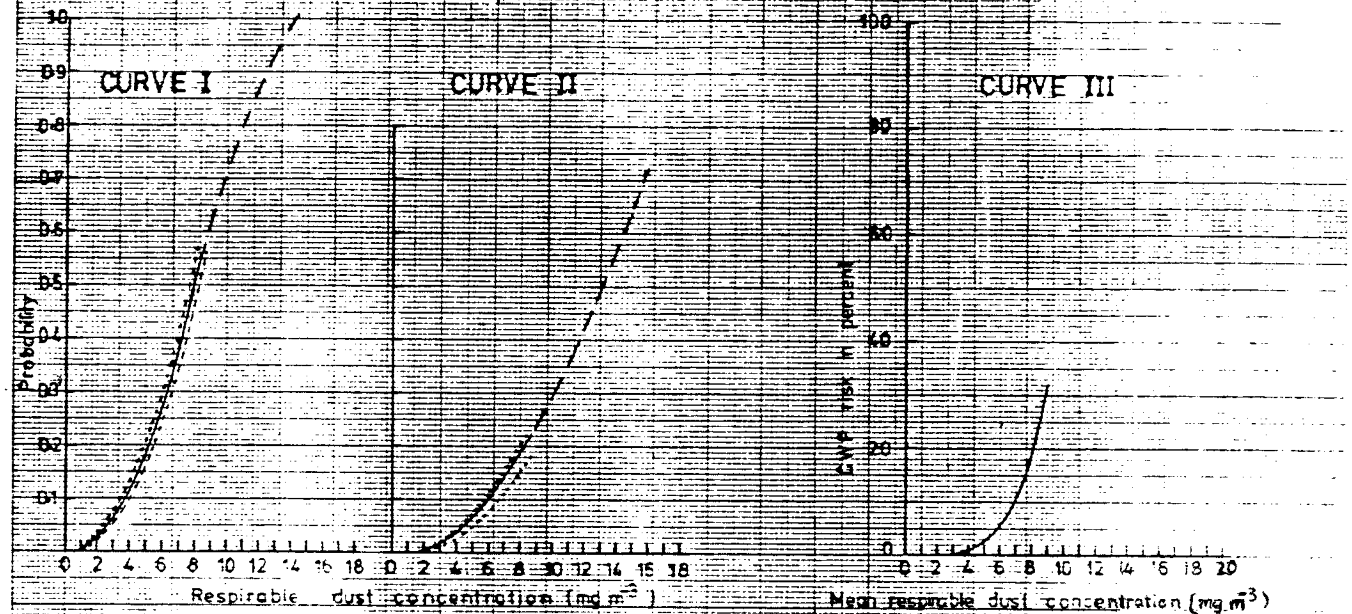

Fig.2.1 PROBABILITIES OF CONTRACTING SIMPLE PNEUMOCONIOSIS

Curve I category 1/0 or greater, curve II category 2/1 or greater after 35 years exposure to dust, starting from category 0/0 and curve III German CWP exposure-response.

a criterion for TLV is quite in order. A study in a Scottish coal mine by Seaton et atl. (89) clearly established the role of quartz in the progression of pneumoconiosis. Progression of CWP was noticed in a group of 21 cases and an equal number of controls over a period of 50 months even at low average dust concentration of 1.9 and 1.4 mgm^{-3}, respectively. Reports by Jacobsen et al. (54) and Hurley et al. (46) gave comparisons of pneumoconiosis rick estimates from their two studies, under various assumptions about mining condition and the distribution of dust concentration at British coal mines as shown in Table 2.3.

2.3 Factors of Pneumoconiosis

Previous work on the aetiology of pneumoconiosis has emphasized on composition (i.e. free-silica content), size, particle shape of airborne dust, duration of exposure, concentration of the airborne dust and individual susceptibility as responsible factors of pneumoconiosis. Before the mass concentration standard came in the 1970's most countries were using number basis concentration of dust particles.

2.3.1. Concentration

For silicosis to develop, the worker must be exposed to relative high atmospheric concentrations of fine dust. When the tolerance limit value is passed, the disease develops at a rate proportionate to the concentration of dust in the air and the percentage of free-silica present in the dust.

Watson (112) reported on maximum allowable concentrations adopted by the American Conference of Government Industrial Hygienists for mineral dust as measured by thermal precipitator instrument as follows:

Table 2.3 Pneumoconiosis Risk Estimates and Distribution of Dust Concentrations

Exposure Details		A*		B**	
		1970	1977	1970	1977
Maximum allowable concentration in the return airway during a working shift (mgm^{-3})		8	7	8	7
Longterm average concentration likely to be experienced (mgm^{-3})		5.7	5	4.3	3.8
Estimates of Probabilities of developing category 2 or 3 simple pneumoconiosis (% age)	(a) Over 35 years working-life 1969 study; Jacobsen et al.(54) and Jacobsen (52)	7.8	5.3	3.4	2.

Table 2.3 continued

	(b) Over 35 years x(1740 working hours per year); 1979 study; Hurley et al. (46)	8.5	6.5	4.8	3.6
	(c) Over a mine's expected working life since about 1977 i.e 30 yearsx(1631 working hours per year); 1979 study; Hurley et al. (46)	3.8	2.8	2.0	1.5

*Men working continuously at coal faces that just meet the standard

**Men working continuously in collieries where the dustiest face, dust meets the standards.

High(above 50% free SiO_2) .... 5 mppcf

Medium (5 to 50% free SiO_2)............... 20 mppcf

Low (below 5% free SiO_2) .... 50 mppcf

These values were considered on the basis of 1 million particles per cubic foot equivalent to 350 ppcc.

Spurny (96) reported on maximum permissible dust concentrations of dust particles in the sphere of 0.1 to 3 microns using midget impinger instrument as follows:

SiO_2 content %	USA (1957) (ppcc)	FRANCE (1958 (ppcc)
Over 50	176	180
5-50	706	700
Under 5	1765	1770

He also reported that the permissible limits in the USSR were 2 mgm^{-3} and 10 mgm^{-3} for dust with free-silica content of over 5 percent and under 5 percent respectively.

Skochinsky and Komarov (93) recommended the permissible concentrations for non-poisonous airborne dust in industrial working as given below:

1.00 and 2.00 mgm^{-3} for dust concentration more than 70% free silica and dust containing 10 - 70% free silica respectively. These values were based on aspiration ejector devices (types A→P - 4, A→4M and A→PA).

Ayer (6) recommended a Threshold Limit Value of 0.1 mgm^{-3} of respirable quartz value for the quartz range of greater than 5% in coal dust for the mines in USA.

Knight (58) suggested 0.1 mgm^{-3} as a safe level for South African gold mines. Quilliam (77) cited a formula for determining the Threshold Limit Value (TLV) of respirable dust containing quartz as follows:

$$TLV \quad \frac{10}{\%\ \text{respirable quartz} + 2}, \qquad mgm^{-3}$$

Carver (11) gave a threshold limit value of 0.1 mgm^{-3} for quartz in South African gold mines and Canadian mines. He also quoted a value of 3 mgm^{-3} for quartz content less than 15 percent using SIMPEDS (SMRE) sampling instrument. Knight and Cochrane (57) recommended the dust levels based on Canadian mining personal dust sampler (CAMPEDS) as follows:

	Upper Level (mgm^{-3})	Lower Level (mgm^{-3})	Target (mgm^{-3})
Total respirable dust	5	1.50	2
Respirable combustible dust	3	0.50	1
Respirable quartz dust	0.50	0.05	0.1

These dust levels assume a working lifetime of 35 years at 8 hours per day, five days a week. American Conference for Governmental Industrial Hygienists (1) specified a Threshold Limit Value - Time Weighted Average (TLV-TWA) of 0.1 mgm^{-3}

respirable free silica. American Conference for Governmental Industrial Hygienists (2) reported on the German MAC for fine dust containing quartz as 0.15 mgm^{-3} (for fine dust corresponding to mean aerodynamic diameter of microns - Johannesburg Convention) while the Swedish limit value for respirable silica using Johannesburg definition was 0.1 mgm^{-3}, accordingly the Japanese limit was reported to be 0.08 mgm^{-3} for free silica (7 um particle size). In order to give a method of maximal simplicity for routine monitoring of dust concentrations, a TLV 0.3 mgm^{-3} for crystalline silica total airborne dust was provided by ACGIH (3). The margin of safety of the quartz dust is not well known, it was recommended that quartz concentration be maintained as far below the TLV for total dust containing quartz and the following formula was suggested:

$$TLV \quad \frac{30}{\%\ quartz + 3} \quad , \quad mgm^{-3}$$

This formula corresponds to a TLV of 0.29 mgm^{-3} for dust containing 100% quartz, which is essentially the same as the proposed TLV of 0.3 mgm^{-3}. Thus as with respirable dust, the proposed TLV for total dust containing quartz represent a re-evaluation of the toxicity of quartz. American Conference for Governmental Industrial Hygienists (4) recommended the following Threshold Limit for various forms of silica, SiO_2 as shown in Table 2.4 and accordingly recommended 0.1 mgm^{-3} of respirable quartz value for the quartz of greater than 5% in coal dust. Sinha et al. (91) reported on Threshold Limit Value of respirable dust for Indian mines as follows:

Material	Threshold Limit Value
Crystalline quartz	(10 mgm^{-3}/(% responsible quartz + 2
Crytalline quartz total dust	(30 mgm^{-3}/(% quartz + 3 for all sizes)
Crystoballite	58% of quartz value

Table 2.4 Threshold Limit Values for Various Types of Silica Dust

Nature of the Silica	Name of Silica or Silicate	Threshold Limit Value (mgm^{-3})	Type of Dust
	Quartz	0.1	Respirable dust
		0.3	Total dust
Crystalline	Cristobalite	0.05	Respirable dust
		0.15	Total dust
	Tridymite	0.05	Respirable dust
		0.15	Total dust
Amorphous	Silica	5	Respirable dust
		10	Total dust
Silicates (<1%SiO_2)	Diatomaceous	5	Respirable dust
	Uncalcined	10	Total dust
Precipitated	Silica and	5	Respirable dust
	Silica gel	10	Total dust

ILO (48) released occupational exposure limits for silica and coal-dust in selected countries as shown in Table 2.5

Table 2.5 Occupational Exposure Limits for Silica and Coal

Country	Recommended Threshold Limit Values (R = respirable dust, T = Total dust)
Australia	R Recommended Value: - coal dust with ≤ 5% respirable free silica (RFS): $5 mgm^{-3}$ - silica containing dust: $\frac{25\ mgm^{-3}}{\%RFS + 5}$
Belgium	T Silica - (a) amorphous, including diatomaceous earth: 700 particles/ml -(b) Crystalline: quartz; (i) particle count: $\frac{10,600}{\%quartz+10}$ ppcc (ii) gravimetric: $\frac{30mgm^{-3}}{\%quartz + 3}$ R (iii) gravimetric: $\frac{10\ mgm^{-3}}{\%\ respirable\ quartz + 2}$ crystobalite, tridymite: half the limit Value of quartz. T silicates (with less than 1% of free silica) : perlite, Portland cement: 6,060 particles/ml; mica, steatite, talc : 700 particles/ml.

Table 2.5 continued

Czechoslovakia	T	Dust with predominant fibrogenic effect Bituminous coal ..... 5 mgm^{-3} Ceramic clay, kaoline ..... 8 mgm^{-3} Dust in steel foundries ... 1 mgm^{-3} Other fibrogenic dusts: free silica content: 10%....5 mgm^{-3} 10%- 70% ..... 2 mgm^{-3} 70% ....1 mgm^{-3} Non-fibrogenic dust brown coal .... 8 mgm^{-3} other dusts .... 10 mgm^{-3}
Finland	T	Quartz: less than 1% ...... 10 mgm^{-3} more than 1% ...... respirable standard can be used.
	R	fine dust (sizeless than 5 um-0.2 mgm^{-3} Cristobalite, tridymite ... 0.1 mgm^{-3} Coal dust ...... 2.0 mgm^{-3}
German Democratic Republic	T	Crystalline silica 50%..100 particles/ml 20%..250 particles/ml 5%-20%..500 " 5%...800 particle/ml

Table 2.5 continued

Fedral Republic of Germany	R Quartz, cristobalite, tridymite..0.15 mgm^{-3} Quartz-containing dust......... 4.0 mgm^{-3} Coal-mine dust with 5% quartz..0.15 mgm^{-3}
Italy	Silica T particles Count: $\frac{4,500}{q + 3}$ particles/ml where q numerical percentage of quartz particles. gravimetric: $\frac{30\ mgm^{-3}}{q + 3}$ R gravimetric: $\frac{10\ mgm^{-3}}{q + 3}$ where q % of quartz (mass) For tridymite and crystobalite, 2q is valid. Coal quartz content 1% - formula for quartz can be used 1%-Tcount 1500 particles/m mass 10 mgm^{-3} R mass 3.33 mgm^{-3}
Netherlands	R Cristobâlite, tridymite 0.075 mgm^{-3}

Table 2.5 continued

Poland	T Dust containing free silica: Silica content 70%..... 1 mgm^{-3} 10%-70%..... 2 mgm^{-3} 10%..... 4 mgm^{-3}
USSR	T Threshold Quartz, crystobalite, tridymite Silica Content 70% ..... 1 mgm^{-3} 10%-70% ..... 2 mgm^{-3} 2%-70% ..... 4 mgm^{-3} Diatomite............... 1 mgm^{-3} Bituminous Coal with 2% silica: 10 mgm^{-3}
USA (MSHA)**	T quartz: $\frac{30\ mg/m^3}{\%\ quartz + 3}$ R quartz: $\frac{10\ mgm^{-3}}{\%\ resp.\ quartz + 2}$ Coal dust (silica (5%) .... 2.0 mgm^{-3} (Silica 5%) .... $\frac{10\ mgm^{-3}}{\%\ SiO_2}$

Table 2.5 continued

Yugoslavia	T	free silica content 2% ....10 mgm^{-3}
		2% - 5% ....1 mgm^{-3}
		5% -50%.....6 mgm^{-3}
		50% ..... 1 mgm^{-3}
	R	pure quartz fine dust: 0.07 mgm^{-3}
		fine dust 2% free crystalline silica(f.c.s.)
		- $\frac{0.07 \times 100 \ mgm^{-3}}{\% \ f.c.s.}$
		fine dust 2% free crystalline silica 4 mgm^{-3}
Brazil*	R	$\frac{8 \ mgm^{-3}}{\% \ respirable \ quartz + 2}$

** MSHA - Mine Safety and Health Administration

* WHO Evaluation of exposure to airborne particles in the work environment

WHO offset Publication No. 80. Geneva, WHO, 1984

Silica fused	as in quartz
Tridymite	50% of quartz value

Doyle (21) exerpted the standards recommended by the United States Health Services in December 1968 as 1 mgm^{-3} and 1.6 mgm^{-3} when measured by MRE instrument and AEC cyclone respectively, these dust standards were based on data and sources of information from Great Britain and studies made in the state of Pennyslvania. At that time the available technology could not permit all mines to meet these standards. Therefore a feasible standard of 4.5 mgm^{-3} was suggested as measured by MRE instrument until such a time when the appropriate technology for meeting the 3.00 mgm^{-3} standard was available. Based on studies by Schepers (87) and Wilson et al. (114), Threshold Limit Values of 5 mgm^{-3} for respirable dust and 10 mgm^{-3} silica and silica gel were recommended by the American Conference for Governmental Industrial Hygienists in 1983.

The predominant component of coal mine airborne dusts is the coal material itself. Coal is a non-uniform substance with physical and chemical properties which vary markedly with coal 'rank'. This non specific term is used to indicate the position of the coal in the carboniferous series: peat, brown coal or lingnite (the lowest rank coal), bituminous coal, and anthracite (the highest rank coal). Rank related properties of coal may well affect the characteristics of the dust produced during mining e.g. hardness, porosity or moisture content.

Watson (112) reported on standards of dustiness as follows: Coal dust (anthracite only): 650 ppcc within the range of particle size 1 to 5 microns. All other coal dusts were set at 850 particles per cubic centimetre within the range of particle size 0.5 to 5 micrometre. Skochinsky and Komarov (93) recommended the following permissible dust the USSR as follows: 2.00, 4.00 and 10 mgm^{-3} for dust containing more than 10% free silica, coal dust with no free silica respectively. They also gave an account of mass of dust inhaled as the criterion to be considered for harmfulness of non-poinous mineral dust. Doyle (21) reported on mass concentration of 2.00 mgm^{-3} for total respirable dust in British coal mines while Carver (11) gave a Threshold Limit Value of 0.45 mgm^{-3} for quartz in South African coal mines. Constantino (15) recommended a respirable coal dust standard of 7.00 mgm^{-3} for return airways of the dustiest face in British coal mines. Sinha et al. (91) reported on Threshold Limit Values of respirable dust for Indian mines as given below: Coal dust (Bituminous) - 2 mgm^{-3} (for respirable dust fraction with less than 5% quartz). Sinha (92) reported that the average concentration of respirable dust in the mine atmosphere during each shift shall not exceed the TLV as follows:

$$TLV = \frac{15}{\text{\% respirable quantity of free-silica in the dust}}, mgm^{-3}$$

For coal dust, free silica is considered to be maximum of 5%, hence for coal mines TLV 3 mgm^{-3}. Engineering and

Mining Journal (28) reported about the Swedish limit value for respirable silica using Johannesburg definition as 0.1 mgm^{-3}.

2.3.2 Dust Particle Size

Dust particles of diameter less than 5 micrometre are the relevant particles for silicosis as these are the ones which get access to the lungs, the larger particles being removed in the upper respiratory tract and the finer particles offer a large surface area for dissolution of free silica that leads to the development of silicosis.

Mavrogrodato (63) defined phith is producing dust particles of free silica as particles of 0.5 to 5 micrometre in diameter. Bloomfield and Dreesen (8); Bloomfield and Dallavale (9) found that particles of less than 5 micrometre in size were responsible for the development of silicosis. McCrae (65) established that 70% of the particles in silicotic lungs were less than 1 micrometre, and the largest particles did not exceed 10 micrometre while Tebbens et al. (100) found that the potency of quartz increased markedly as one goes down from 3 to 0.6 micrometre. Skochinsky and Komarov (93) reported on the work by E.V. Kukhrin that silicosis started more quickly from dust of size 2 - 3 micrometre than from coarser dust of 5 - 10 micrometre. The American Conference for Governmental Industrial Hygienists (ACGIH) and the British Medical research Councils defined the aerodynamic diameter limit differently as quoted by Malik and Viswanathan (62), The British Medical Research Councils' recommended aerodynamic diameter of less than 7 micrometre while ACGIH defined particles of less than 10 micrometre in aerodynamic diameter as responsible for pneumoconiosis. Recent work in Britain by Constantino (15) described particles of less than 5 micrometre as responsible for coal workers' pneumoconiosis. Guyaguler (40) found that the average size of dust particles produced during drilling operation in different rock type is around one micron. These particles have a maximum probability of being retained in the lungs during respiration.

2.3.3 Composition of Dust

The ability of dust to cause lung injury is dependent upon the content of silica in its free and chemically uncombined state-SiO_2 or silicon dioxide. Dust consist of finely comminuted grain or particles composed of the same mineral constituents as the parent material. It does not follow, however, that the percentage composition of the airborne dust is the same as that of the parent substance, there are, on the contrary, two important factors that act to change the composition: (1) differential disintegration and (2) selective settling of the dispersed particles. Under the action of the first, the material may shatter in such a way that one of more constituents tend to break free as large particles while others are released in the form of minute particles. When all these particles are thrown out into the air, the large ones, because of their much higher settling velocity, are rapidly removed from the air. This leaves the finer particles which may be of different composition in suspension. These finer particles are subsequently inhaled by the exposed miners. Selective settling is also affected by the shape of the particles, and for a given size, flat or platy particles will remain longer in suspension than roundish particles; this may cause a further change in the percentage composition of the suspended dust. The importance of these factors was emphasized by Jones (56) for the South African gold mines. Moir (71) pointed out that many particles in mine air, particularly after blasting, are not quartz, but come from the aluminous matrix of the banket: particles of sericite, chlorite and rutile are comparatively frequent in air after blasting, and when water blasts are in use, seem to resist wetting more than quartz particles do, and consequently remain unlaid. Work at the University of Birmingham (107) confirmed the importance of differential disintegration and selective sampling. Analysis of air-borne dusts produced by rock drills showed almost invariably that the free-silica content is appreciably less than fôr the coarse borings from the same rock. Hurlbut and Beyer (45) showed that the selective settling of certain foundry dust resulted in the rapid concentration of sericite in the air-borne dust so that the dust inspired by the foundry workers was rich in sericite in spite of its very low concentration in the original foundry sand.

2.3.4. Duration of Exposure

Silicosis normally requires years of exposure to silica dust before it can develop. The rapidity of extent of development are related directly to the number and size ranges of particles that enter the lungs and are retained.

Watkins Pitchford (111), Mavrogordata (64), Sayers et al. (85, 86); Bloomfield and Dreesen (8) emphasized on the duration of exposure to silica as one of the parameters responsible for silicosis. Lambie (60) found no silicosis in workers exposed up to 8 years to 'tripoli' dust in concentration first measured by midget impinger while Cooper and Crawley (16) found only doubtful linear - nodular changes in workers exposed only to amorphous silica dust for five years or more in the United States. Deuguldre (19) reported that an overall gravimetric dose greater than 70 - 80 mg year m^{-3} was found to be dangerous, whatever the nature of the coal dust. Doyle (21) reported on the study in the United States of America that no silicosis was detected in workers with less than 5 years' of underground experience while on the basis of data of the National Coal Board in Britain, the critical dose for the development of simple pneumoconiosis was found to be in the vicinity of 70 mg year m^{-3} (35 years x 2.00 mgm^{-3}). Malik and Viswanatham (62) reported that with up to 0.1 mgm^{-3} of respirable free silica the workers could be exposed repeatedly for a normal eight-hour workday, 40 hours a week, without adverse effects. Constantino (15) reported on the coal dust exposure in Germany that a miner who experienced an average exposure of 5 mgm^{-3} for 35 years would have approximately a 4.3% chance of developing coal workers' pneumoconiosis of category 2 or higher. Seaton (90) emphasized on the cumulative dose of respirable dust to which a man has been exposed as one known factor of quartz and non-quartz induced progressive massive fibrosis.

2.3.5 Individual Susceptibility

This may be a factor in the development or progress of the disease because of structural or functional variations in individuals. Persons equally exposed do not necessarily develop the disease simultaneously or to the same degree, and some escape it altogether. Only few factors to this effect are known but generally the final amount of deposited dust depends on the total amount of dust inhaled and its quality, the anatomical conditions of the respiratory tract, and the individual bronco-pulmonary clearance mechanism.

2.4 Dustiness, Measuring Techniques and Relation.

Exposure to airborne particulate matter results in retention of a certain amount of dust in the lungs. This amount cannot be measured directly in man. Exposure levels are assessed indirectly according to the concentration of airborne particles, duration of work and lung respiratory rate. Determination of concentration of particles in the air can be done in two ways: determination of the number of the particles in a given volume (particle count) or their mass (gravimetric method). The particle count method was almost exclusively used up to the 1960's, but has since been replaced in an overwhelming majority of countries by the gravimetric method. Particle-count assessment remains, however, the dominant method for the determination of fibrous dust, e.g. asbestos.

2.4.1 Measuring Techniques

The sizes of airborne particles in the work environment range from smaller than one micron to about 50 um aerodynamic diameter, above this size particles settle rather quickly and do not remain airborne for very long. Also, the intensity of suction at the mouth and nose as a result of breathing is not high enough for inhalation of particles above 50 um. Therefore, such particles are not usually considered as "inhalable".

Field methods of dust sampling and analysis can be classified into three broad categories, as follows (113):

(a) Collection without size segregation (total dust sample). Dust samples thus collected can be further analysed by techniques such as particle counting (optical microscopy), gravimetric analysis (weighing of the sample), and chemical analysis. Such samples can also be analysed for particle size distribution through techniques such as microscopy, elutriation, and sedimentation.

(b) Collection with size segregation. This type of sampling involves some kind of separation of portions of the collected dust sample, according to particle size, at the sampling stage. This can be, for example, the separation into two portions respirable and non-respirable or into multiple portions, each covering a range of particle size, eg elutriators, impactors . Such samples can be further analysed by gravimetric analysis, particle count or chemical analysis.

(c) Sizing without collection. The particle size characteristics of the dust cloud can be established, for example, by electrical or optical size analysis, without collection of a sample. In some countries, standards for exposure to airborne particles are given both in terms of total and "respirable" dust; in others, only in terms of "respirable dust" and "total dust".

Different types of instruments can be used for total dust sampling according to the type and level of exposure, e.g. personal samplers with membrane filters, high volume samplers with filters, electrostatic precipitators, all with the basic elements like air mover, flowmeter and sampling head. The basic elements of a sampling system for respirable dust are those as for the total dust, with the exception that the sampling head consists of a precollector. The most common instruments are described by I.L.O. (49).

2.4.2 Count-Weight Relations

In order to make older measurements based on particle count comparable with gravimetric values, attempts have been made to convert particle counts to mass concentration. This is possible only in cases where the particle size distribution and the relative density of dust is known. For industrial dust, no general conversion factor can be given.

Comparative impinger-counts and gravimetric size-selective mass measurements permitted conversion of particle count to mass of quartz. It was concluded that 10 mppcf of granite dust (containing approximately 25-35% free silica) was equivalent to 100 $\mu g/m^3$ of free silica (108) while Russell et al. (83) in their study of granite dust showed that the 9-10 mppcf concentration contains 0.1 mg/m^3 of respirable quartz.

Bedford and Warner (7) found acceptable correlation between count as measured by midget imprringer and Weight only when the weight was confined to the fraction of dust smaller than 5 micrometre and the count, to particles larger than 1 micrometre. They reported that the count - weight ratio for coal dust was 65 x 10^6 particles per milligram and for typical mineral dusts, lmg was equivalent to 30 million to 50 million particles. Calculations by Bedford and Warner (7) on samples of coal dust in South Wales, United Kingdon produced a figure of about 12.5 mgm^{-3} equivalent to 850 particles per cubic centimetre, 1-5 micrometre particle sizes. These results were different from those given by Fay (29) who reported that the "approved" level of 850 particles per cubic centimetre for non-anthacite coal dust corresponded to about $21mgm^{-3}$ of respirable dust, with a standard deviation of $4mgm^{-3}$. The discrepancy between the two findings was due to the use of an elutriated Hexhlet in the former sampling work. Skochinsky and Komarov (93) related weight standards to dust count standards based on aspiration ejector devices as $1mgm^{-3}$ corresponding to approximately 200 dust particles (up to 2 micrometre) per cubic centimetre. Jacobsen et al. (54) reported on trials set-up at each colliery in which thermal precipitators and NCB-MRE gravimetric dust samplers type 113A were operated side by side and the results were compared. The first results showed that the ratio between the two measurements was very variable from one colliery to another, varying between 7.8

and 38.2 mgm^{-3} per thousand particles per cubic metre with a mean of 16.4. They established that the ratio could not be reliably estimated from the number concentration size distribution and other data available from the thermal precipitator sampling. Doyle (21) noted that 25mppcf when measured by midget impinger was equivalent to approximately 2.00mgm^{-3} when measured by AEC cyclone for the coal mines in U.S.A. American Conference for Governmental Industrial Hygienists (4) endorsed equivalent Threshold Limit Values in mppcf and mgm^{-3} (respirable mass) for mineral dust as shown in Table 2.6

Table 2.6 Equivalent Threshold Limit Values in mppcf and mgm^{-3} (Respirable Mass) for Mineral Dust.

Substance	Threshold Limit Values		
	Count (mppcf)	Respirable Mass (mgm^{-3})	Total Mass (mgm^{-3})
SiO_2 (silica)	20	(3)*	(6)*
Cristobalite	1.50	0.05	0.15
Fused silica	3	0.10	0.30
Quartz	3	0.10	0.3
Tridymite	1.50	0.05	0.15
Coal dust	(12)*	2	(4)*

( )* represent newly calculated values based on equivalence of 6mppcf = 1mgm^{-3} respirable mass and respirable mass = 5% total mass.

2.5 Dustiness in Zambian Mines

The Konimeter is widely used on the Zambian Copperbelt for routine sampling of respirable dust. A modern modification to this instrument is the addition of a 'size-selecting pre-impinger' which is designed to produce clearer and easier-to-count dust spots by removing agglomerates. However, the use of this pre-impinger also reduces the actual dust count and the South African Research Laboratory has shown that this reduction is approximately 20% of the original dust count. The maximum allowable concentration on the copperbelt is fixed at 350 p.p.c.c. as measured by a Konimeter.

Extensive work done on the Zambian Copperbelt regarded concentration as one of the factors responsible for silicosis. Lambretchs (61) suggested that in the case of Northern Rhodesia Copper Mines a maximum dust count of 600 p p c c could be viewed as the TLV in the first instance, using Kotze Konimeter. He reported on Mufulira Mine average dust concentration from his survey of 133 working places as 580 p p c c and their distributions were as follows: percentage working places with counts < 600 was 48.1 and, percentage working places with dust count > 1000 was 38.8. Annual report by Zambian Mines Department (67) gave average counts for various operations in 1969 as follows: 484, 172, 138, 191, 160, 200, 240, and 139 p p c c for blasting, drilling, handlashing, mechanical lashing, tramming, skip-loading, underground crushing and miscellaneous respectively.

The maximum allowable concentration for intake to faces, coal plants and face conditions recommended were 200, 900 and 350 ppcc respectively.
The same report showed the following average counts for 1970 as 103, 184, 154, 240 -, 170, 455 and 179 p p c c for the corresponding operations stated above. A survey done on the copperbelt by Mines Department (68) found the following concentrations: 213, 340, 212, 323, 270, 269, 274, 319, 165 and 132 p p c c for drilling, secondary blasting, hand lashing, mechanical lashing, tramming, box loading, underground crushing, tipping, scrapping and miscellaneous mining activities respectively. Charman (13) reported that the average concentration of total particulate (particle size between 0.5 - 5.00 micrometre) for mechanical lashing and rock drilling as 4.40 and 2.13mgm^{-3} respectively using time averaging Hexhlet gravimetric sampler. He also reported that the average concentration of particulate pollution occuring in the general body of air underground in the absence of any adjacent mining operation was 0.71mgm^{-3}. The average concentrations for drilling and mechanised lashing were 18% and 8% free silica respectively while the

other operations have high free silica content with values ranging up to 26% in respirable size fraction (13). Irvine et al. (50) in their report concluded that there was a definite incidence of silicosis at Mufulira Mine while at the other mines on the copperbelt only isolated cases occurred. Lambretchts (61) in his report concluded that Mufulira Mine all work is done in rock of high silica content while in other mines on the Zambian Copperbelt, most work was done in rock of relatively low free silica content although the rock could be considered siliceous.
Ritson (79) reported that in native miners, silicosis began to manifest after 72 months of service and by reason of intermittent service it probably indicated 8 to 10 years' employment and he registered dust counts of 200 to 1000 particles per cubic centimetre as measured by Konimeter in various working places. Zyambo (115) reported on Mufulira Mine, that the average dust count for all underground operations was 144 p p c c as measured by Konimeter. Similarly he reported on average dust count in intakes and faces as 83 and 119 p p c c , respectively.

CHAPTER III

3. MATERIALS AND METHODS

Field dust sampling in various typical mining operations were conducted at Mufulira, Luanshya Divisions of Zambia Consolidated Copper Mines Ltd and Wankie Colliery Company Limited of Zimbabwe, between December 1983 and February, 1985. The question of the most advantageous and most correct method of taking dust samples in the working place is made more complex by the fact that the samples taken must be characteristic not only of the dust content of air at the given working place, but also of the type and quality of air breathed in by the operative during a shift. The method of collecting the most correct characteristic samples was just as difficult as the whole method of measuring. The measured quantities should represent the most correct and typical concentrations of dust in the place where measuring is carried out. Most of the sampling was done over a period of eight hours, i.e. a shift . Typical operations selected for the measurement were based on a survey of typical dusty operations the miners affected with pneumoconiosis had been involved in. Case histories of miners who have contracted silicosis and coal workers pneumoconiosis were studied and their X-ray radiographs examined in order to establish the degree of pneumoconiosis.

3.1 Estimation of Dust Concentration

Dust concentrations were determined in two ways namely number of particles per unit volume and a weight of particles per unit volume. From the mass concentration approach the following information was obtained from the sample: total respirable mass; percentage quartz (by X-ray diffraction) and, hence, mass of respirable quartz (i.e. percentage quartz x average total respirable dust concentration). The qualitative and quantitative analysis of free silica was done with the use of an X-ray diffractometer. The analysis was done at the Mining Industry Technical Services (MITS) Laboratory in Kalulushi, Zambia; the Geological Survey X-ray Laboratory in Lusaka, Zambia and further analysis was done by the Institute of Occupational Medicine - United Kingdom. The various peaks were identified by using conversion tables for the Mathews coordinate index (95) while the qualitative X-ray diffraction approach for free silica, utilised a method developed by Chung (14). A reference intensity ratio was measured on a diffractogram using an artificial sample composed only of equal parts by weight of quartz and corundum.

There was no reliable previous data available which could associate change in ventilating practice, total installed ventilating capacity and mining techniques in order to extrapolate the results over the relevant period of study. However, there were coefficient of variations of 17% and 22% over the period based on dust count concentrations and air tonnage ratios respectively.

3.1.1 Mass Concentration Determination

Two gravimetric dust samplers, type MRE 113A; two Hexhlets and two Casella personal samplers were used for the Mufulira part; four MRE 113A were used at Wankie Colliery; three MRE 113A were used in Luanshya. For representative results of underground conditions the location of sampling instrument plays an important role.
The Hexhlet and MRE 113A samplers were placed at a height of 1.5m from the floor and the Hexhlet was about 5m on the return side of the face. Sampling using MRE 113A samplers started immediately after the miner to be sampled has boarded the cage down to his working place. The sampling helper followed the miner in his routine work up to the end of the shift. In this case MRE 113A, was used as an occupational sampling instrument. Casella personal samplers were normally worn by the miners. All instruments (except Casella personal sampler) are recommended to be stood or hung in a horizontal position. In cases where the air velocity was over 4 - 5 m/s, the MRE 113A was placed at right angles to the wind direction and where the air velocity was under 4m/s the instrument was facing into or sometimes placed at any angle up to 90° to the general direction of air flow. Hexhlet

was allowed only up to a maximum of $\pm 5^{\circ}$ deviation from the air flow direction.

Hexhlet sampler comprises of a vacuum source which is provided by an air ejector operated by compressed air; a critical orifice in the filter holder which controls the rate at which air is drawn through a millipore membrane filter. The sampling rate of Hexhlet air sampler remains constant, irrespective of the pressure of the compressed air or dust loading on the filter paper. The function of an elutriator was to ensure that only the respirable fraction of dust was sampled. MRE 113A is battery operated and its design is based on particle selection principles which simulate the behaviour of the human respiratory tract in a dust cloud. Casella personal sampler works on the same principle except that it carries a cyclone instead of an elutriator. The details on the reproducibility and lumitations of gravimetric sampling instruments have been reviewed in their instruction leaflets (37,38,43). Millipore membrane filters were used for Hexhlets and personal dust samplers whereas GDS 113A - 5cm dia mounted glass filter papers were used for MRE 113A. Regarding the work done in Wankie and Luanshya both types of filters (millipore and GDS 113A) were used in MRE 113A sampling procedures. Millipore membrane filters were of the following specifications:

MF type......................RAW

Mean Pore Size	1.2 micrometre
Flow rate	15 litres per minute per cm^2 @ 70cm Hg.
Thickness	150± 10 micrometre
Porosity	80%

These filters were ashed and washed while glass fibre filters were neither washed nor ashed. The filters were prepared according to the specifications of the sampling instrument. Filters of diameters 69mm of Hexhlets, 37mm for personal samplers and 55mm for MRE 113A were cut out from filters sheet. Filter holders were stored in dessicators containing silica gel. The filters were weighed by means of E. METTLER grammatic balances with sensitivity of 0.01mg. The weighing was done only when the relative humidity in the laboratory was less than 80%. One hour after the first weighing, a second check weight was taken.

The least weight was considered for calculations and designated as the clean weight. GDs 113A fibre glass filters were already prepared but were stored in an activated silica gel dessicators. Every weighed filter was given a serial number at the time of weighing and a number sticker was affixed to the top cover of the plastic petric dish in which the filter was stored until required. After sampling, the used filters were individually placed in desiccators for overnight drying. The dry filters were weighed when the room relative humidity was less than 80% too. The stable weight was taken for calculations as the laden weight. The mass concentration of the air sampled was calculated using the following formula:

$$\text{Concentration} = \frac{\text{Laden Filter Weight(mg)} - \text{Clean Filter Weight(mg)}}{\text{Air Volume Sampled } (m^3)}$$

The mineral composition of dust samples was assessed by the following method to give mass concentrations of various constituents mainly soot, mineral oil and incombustible dust. After the laden weight had been established the filters were individually washed in 30ml of clean fresh xylene for 5 minutes in order to dissolve away any soluble hydrocarbons on the filter. The filters were then removed and placed in clean glass petri dishes which were covered with lens tissue paper and left to dry for an average period of 5 hours while the extraction fan was running to extract the xylene vapour. The filters were transferred to the desiccators for overnight drying. Weighing of the filters was repeated accordingly as in the previous mentioned procedures. The stable weight was taken for calculations as the washed laden weight. In order to assess the quality of incombustible dust on the filter, the residue was ashed. Pre-weighed clean platinum crucibles were used and each filter was ashed individually. Some isopropyl alcohol was sprayed onto the filter and ignited. After the filter had charred, the crucible was placed on the furnace at a stabilized temperature of 550°C for 2½ hours in order to achieve a complete combustion. Finally, after ashing, the crucibles were placed in the desiccators to cool for 20 minutes The cool crucibles were weighed and the crucible laden weight was obtained.

3.1.2 Particle Number Concentration

These values were ascertained by means of circular type Konimeter which superseded the original Kotze type. In Wankie no particle count sampling was done. The Luanshya and Mufulira projects covered two types of konimeters the W series and the RO series but the RO series results were used for computations. The glass slides were prepared by cleaning using good quality linen cloth. This eliminated any spots from previous work. The slides were examined after this cleaning to ensure that no spots from previous ignition have fused on it. Then one side of the slide was smeared with xylene and sometimes Vaseline was used. After sampling, the slides were heated to 550°C and immersed in a solution of hydrochloric acid to remove solid or liquid organic substances. The particles were counted under the microscope in a dark field at a magnification of 150. The slide carrying the samples was mounted on the microscope stage and eyepiece graticule adjusted until the two 18^o sectors cover a representative section of the spot. The area covered by the two 18^o sectors being one tenth of the whole spot. As each spot is obtained from 5ml of air, the count represents the dust counted in 5x0.1ml, i.e 0.5ml. Therefore, concentration in particles per millilitre equals 2x actual count,i.e. 2n, where n is the number of particles in a sector.

3.2 Rock and Settled Dust Sampling.

This involved a collection of rock and coal samples from development and stope faces across various orebodies and coal seams, settled dust samples from various locations were also collected. The aim of this exercise was to determine the mineralogical composition of different types of rock formations from which mine dust originates.

3.2.1 Free Silica Determination in Rock Samples

A representative portion was cut from each hand specimen, generally about $\frac{1}{3}$ of the volume and perpendicular to the bedding where this structural feature was evident. The seperated portions were then reduced to minus 10 mesh and the powder riffled in order to obtain a manageable sample for mineralogical examination. The examination in transmitted light was carried out on minus 100 mesh material, this size being ideal for identifying and quantifying both major and accessory rock forming minerals by their optical properties. Several samples contained significant amounts of opaque material and polished briquettes were prepared from these in order to identify the opaque minerals. No coal sample was treated in this manner.

3.2.2 Silica Determination in Settled Dust Sample

Because of the very fine nature of the dust samples, optical mineralogical methods were not used, thus total silica was obtained by chemical analysis and free silica (quartz) was derived from quantitative X-ray diffraction method. The chemical analysis of free silica was done using pyrophosphoric acid, however it was found that the platinum crucibles were being damaged very quickly and therefore the determinations were suspended. The quantitative X-ray diffraction approach for free silica utilizes a method whereby a reference intensity ratio of the major peaks of quartz and corundum (Al_2O_3) was measured on a diffractogram using an artificial sample composed only of equal parts by weight of quartz and corundum. Once the reference intensity has been established, a known weight of sample for examination and the peak heights of quartz and corundum can be used to calculate the weight and percentage of quartz present in the sample. This method has been tested on known composition samples with reasonable results. Evaluation of free silica percentage in a sample was done as follows: the major peaks of the mineral to be analysed (quartz) and of corundum were measured to give K_i factor.

$$K_i = \frac{I_i}{I_c}$$

where I_i = peak height of mineral to be analysed (quartz)

I_c = peak height of corundum (reference mineral).

The weight fraction of the mineral to be analysed in an unknown sample with a known amount of corundum. The weight fraction was calculated from

$$X_i = \frac{X_c}{K_i} \cdot \frac{I_i}{I_c}$$

where X_i = Weight fraction of mineral i

X_c = Weight fraction of corundum

K_i = Reference intensity of mineral i

I_i = Peak height of the strongest peak of mineral i

I_c = Peak height of the strongest peak of corundum.

The grain size distribution in settled dust samples were obtained by means of the Leitz TAS Image Analyser. A very small portion of the dust sample was placed on a glass slide and evenly spread using optical clove oil and then examined in transmitted light with a cover slip in place. The grains now appear in partial silhouette and using a x16 objective an 'electronic sieve interval' of 5.6μm was selected for use in the grain size programme. The results are expressed in 'area percentage' which means that x area percentage of the total area of all grains examined fell in the 0-5.6μm size category and y area percentage fell in the 5.6-11.3μm size category and so on. The average grain size is obtained mathematically using a 'weighed average' method. A total of 200 fields of view were automatically examined for each sample.

3.3 Incombustible Dust Samples

These dusts consist of the residue left from high temperature ignition of millipore filters from Hexhlet, MRE 113A and personal respirable dust samples used in the research. Due to very small quantities and low weights the dusts were composited on the basis of location and operation. The composite was mixed with a very small volume of ethanol which when left to evaporate on a circular glass slide placed in the sample holder, produced a thin but reasonably uniform layer suitable for X-ray diffraction work. The same quantitative X-ray diffraction technique for quartz used on the settled dust samples was employed again and extended to cover microcline feldspars. The other minerals that constitute most of the remainder of the composites were tentatively identified using minor diffraction peaks. This technique was chosen over other techniques due to the following reasons: it is not destructive since the sample remains intact for further analysis if necessary; the method does not require bigger samples. The wet chemical method is not as fast and accurate for this particular application and required a high input of materials - while the infrared method is certainly fast but interference is a serious problem when dealing with samples from hard rock mines and it is hard to get good resolution of peaks. Aluminium oxide and quartz as standardised respirable dusts were also successfully used by Smith et al. (94).

3.4 Radiological Data and Occupational Histories

3.4.1 Radiological Data

Physicians experienced in the radiology of pneumoconiosis classified the chest radiographs of the mean separately independently and in random order according tothe ILO u/c International Classification of Radiographs of Pneumoconiosis (47), using 1968 standard films for the cases of Mufulira and Luanshya Divisions. Additionally, the readers classified all cases on the viewing box. The Deputy Director of Pneumoconiosis Bureau in Kitwe, Zambia assisted the researcher to re-read the films for a check. Chest radiograph records for Wankie Colliery Co. Ltd were not counterchecked by the researcher due to little cooperation from the Chairman of the Pneumoconiosis Board. Two letters and physical presentation to the Chairman of the Board did not produce fruitful results. The analysis of the results was based on a report sent to Wankie Colliery Co. Ltd ambulance officer. The records were lacking the extended ILO classification of pneumoconiosis. The International Labour Organisation (ILO) classification of simple pneumoconiosis subdivides the appearance of simple pneumoconiosis according to a four point scale of increasing abnomality. The instructions were to classify the film in the usual way into one of the four categories, 0 to 3, and if, during the process, neighbouring category 2/1 is a film which is category 2, but category 1 could be considered as an alternative. The basic ILO categories of 0-3 have been subdivided into 0/-, 0/0, 0/1, 1/0, 1/1, 1/2, 2/1, 2/2, 2/3, 3/2, 3/3 and 3/-. These sub-divisions show the levels of profusion. Simple pneumoconiosis is only slightly disabling and does not progress from one category to the next in the absence of further exposure to dust. The nodules were classified according to the approximate diameter of the predominant opacities namely p,m and n, where p indicate rounded opacities up to about 1.5mm diameter; m, rounded opacities exceeding about 1.5mm diameter and up to about 3mm diameter; and n, rounded opacities exceeding about 3mm diameter and up to about 10mm diameter. The higher the category of simple pneumoconiosis, the greater is the chance that it may change to the second form known as progressive massive fibrosis (PMF) which is seriously disabling and which progresses in the absence of further dust exposure. This form of the disease is classified as A, B and C with increasing size of the massive fibrosis. Large opacities category A are those opacities with greatest diameter between 1cm and 5cm, or several such opacities whose sum of greatest diameters does not exceed 5 cm. Category B opacities are those larger or more numerous than those in category A and those whose combined area does not exceed the equivalent of the right upper zone area and category C are those large opacities whose combined area exceeds the equivalent of the right upper zone.

3.4.2 Occupational Histories

To determine the etiological significance of the total exposure on a worker a complete occupational history has to be studied. A sufficient number of miners who had contracted pneumoconiosis were selected for the case of Mufulira Mine and miners who have working histories between 120 to 400 months of exposure were selected for Wankie Colliery Co. Ltd and Luanshya Division of Zambia Consolidated Copper Mines. Only those with 'pure' environmental histories in the sense of having worked primarily at Mufulira, Luanshya Mines and Wankie Colliery Co. Ltd were sampled and their occupational records taken. The mining population selected within the company was divided into occupational groups based on place of work and occupation. Details of men's occupations other than mining work were obtained from the divisions central records office and central registry in the case of Wankie Colliery Co. Ltd. The time spent working in non-mining and mining operations were both summarised in months. There were other approaches to this study, like the extraction of a number of men from various 'pure' exposure categories, e.g. 'pure driller', 'pure crusher men' and so on. Another possibility was to select men who contracted silicosis or coal workers pneumoconiosis regardless of having worked at other. The 'pure' exposure approach was not possible due to insufficient number of men available. It was difficult to get enough cases of men with silicosis or coal workers pneumoconiosis who were involved in only one mining operation throughout their mining life. The 'random' selection of men was also not possible due to lack of operational average dust concentrations from other mines. The mining operations extracted from men's occupational histories from the two Copperbelt Mines were drilling,crushing, tramming, secondary blasting, timbering, conveying, hoisting, tipping and service work underground while in the case of Wankie Colliery there was need to classify workers into main groups. The following main classifications were made:

1. Virgin Rock Breakers - those employed essentially on the three main operations of coal extraction, viz., stoping, lashing and development. This group is subdivided into: drill operator, cutting machine operator, production lashing crew, coal drill operator and shot firer or charging crew.

2. Mine Officials - these were treated in such a way that the dustiness of their underground shift would approximate the mean dustiness of the main groups on non-official workers who they supervise. The sub-divisions included miner in charge, shift bosses, mine captain and underground manager.

3. Surface workers - include screen operator, chaker attandant and belt attendant etc.

4. Miscellaneous - those workers employed essentially in and around the shaft, travelling ways (haulages) and entraces to working places, e.g. hoise drivers, shaft timbermen, hanger men, tub cleaners, track layers, pump attendants etc.

For Luanshya Division of Zambia Consolidated Copper Mines, the workers were classified into 8 main groups including the officials. Officials and non-officials were considered seperately. The non-officials were classified according to the position in the mine where the main portion of the shift is spent and on this basis, the following main classification were made:

1. Drilling workers - those employed essentially in working places where rock is excavated which include main and sub development drillers and stope drillers etc.

2. Hand Lashing Workers - it constitutes miners employed in cleaning spilages in main, sub-development ends and haulages.

3. Blasting Workers - those miners employed essentially in the rock breaking areas, e.g. grizzley, secondary blasting,etc.

4. Conveying Workers - employed essentially in ore/waste transfer points. This category includes tips, conveyors, chutes, etc.

5. Crushermen - those employed in size reduction points e.g. primary crusher, secondary crusher and tertiary crusher, etc.

6. Mechanical Lashing Workers - this class essentially involves those workers employed in loading and tipping of ore and waste to locomotive or tips e.g. diesel loader operators, scraper operators and cavo operators, etc.

7. Miscellaneous Miners - this class includes timbermen, trammers, tracklayers, pipe fitters, etc.

8. Mine Officials - were treated differently. In this case it was argued that the dustiness of their underground shift would approximate the mean dustiness of the main group of non-official workers whom they supervise. The following figures were considered reasonable estimates of the duration of underground shifts:

Non-officials

Artisans - 7 hours

All others - 8 hours

Officials

A. Mining:

i. Shift Bosses - 6 hours

ii. Mine Captains (this occupation did not "come up).

iii. Managers - 3 hours (this occupation did not "come up").

B. Survey, Geology and similar officials:

i. Juniors - 6 hours (this occupation did not "come up")

ii. Seniors - 3½ hours (this occupation did not "come up")

C. Engineering Officials:

i. Underground Foremen - 6 hours

ii. Underground Engineers - 3½ hours

These figures were used to compute the dust exposure as the product of time (expressed in hours), and gravimetric concentration.

The average dust concentrations were determined from a survey of typical dusty operations the miners affected with pneumoconiosis were involved in. The sum of products, (Months worked in occupation x average dust concentration in an occupation), was taken as a measure of individuals' total exposure' to respirable dust for the mining services duration. Exposures to quartz during this period were obtained in the same manner. The exposure units are mg. months per cubic metre of sampled air (mg months mg^{-3}). An individuals' cumulative dust exposure were divided by the total number of working months to give a measure of the average dust concentration experienced by the man. The concentration units are milligrammes per cubic metre of sample air (mgm^{-3}).

3.5 Statistical Methods Applied

To analyse the collected data and to find the reliability of the results some statistical methods were applied.

3.5.1 Mean and Standard Deviation

The mean values of the population were calculated using simple arithmetic mean formula given below:

$$\bar{x} = \frac{1}{n} \sum_{i=1}^{n} X_i$$

where n is the total number of data points.

Once the correct value has been estimated the extent of scatter around this value was established. The measure of scatter was given by the standard deviation, σ, which is a particular measure of dispersion. This is expressed by the formula:

$$\sigma = \sqrt{\frac{1}{n-1} \left[\sum_{i=1}^{n} (X_i - \bar{X})^2 \right]}$$

where $\bar{x}$ is the mean and n is the number of samples

3.5.2 Reliability of Collected Data

Control limits on the results were calculated by making use of their standard deviations. The region around the mean within which the true mean is to be found was computed from the standard error of the mean given by

$$\frac{\sigma}{n}$$

where n is the number of readings taken. At 95% confidence level the true mean will lie within

$$\pm \frac{\sigma}{2\ n}$$ of the estimate.

3.5.3 Regression Analyses

The general tendency of the data was determined by regression analyses. In this way equation of lines expressing the relationship between particle concentration and mass concentration were determined. The least squares methods were used. The variable being examined is the dependent or regressed variable, designated Mi. Deviations of Mi from the fitted line were minimized. The other variable is the independent or regressor variable and is denoted by K_i. The fitted line will cross the M_i axis of a point b_o (the intercept) and will have a slope b_1. The equation of this line is $M_i = b_o + b_1K_i$, M and K are mass and particle number concentrations respectively. A simplified form of the method can be expressed in a matrix form:

$$\begin{vmatrix} n & \Sigma K \\ \Sigma K & \Sigma K^2 \end{vmatrix} \cdot \begin{vmatrix} b_o \\ b_1 \end{vmatrix} = \begin{vmatrix} \Sigma M \\ \Sigma MK \end{vmatrix}$$

Solving the matrix expression, the regression line can be determined.

3.5.4 Determination of Correlation Coefficient

Correlation is the ratio of the covaviance of two variables to the product of their standard deviations:

$$jk = \frac{Cov_{jk}}{S_j S_k}$$

The procedure used is as follows:

$$SP_{jk} = \sum_{i=1}^{n} (X_{ij} - \bar{X}_j)(X_{ik} - \bar{X}_k)$$

where SP_{jk} is the sum of the products between variables j and k. In computational form, this becomes:

$$SP_{jk} = \sum_{i=1}^{n} (X_{ij}X_{ik}) - \frac{\sum_{i=1}^{n} X_{ij} \sum_{i=1}^{n} X_{ik}}{n}$$

where $(X_{ij}X_{ik})$ is called the Uncorrected sum of products and in all cases studied j and k were similar e.g. j = k

$$SP_{jj} = \sum_{i=1}^{n} (X_{ij}\ X_{ij}) - \frac{\sum_{i=1}^{n} X_{ij} \sum_{i=1}^{n} X_{ij}}{n}$$

$$= \frac{\sum_{i=1}^{n} X_{ij}^2 - \sum_{i=1}^{n} X_{ij}^{\ 2}}{n} = SS_j$$

$$Cov_{jk} = \frac{SP_{jk}}{n-1}$$

where Cov_{jk} is covariance between variables j and k.

CHAPTER IV

4. MEASUREMENTS

Measurements were carried out for three mines namely Mufulira, Wankie and Luanshya.

4.1 Dust Sampling Results

4.1.1 Mufulira Mine

To measure the dust concentration to which each occupational group was exposed and the correlation between instruments, three gravimetric dust sampling instruments were used. The results are shown in Table 4.1. For finding the relationship between Konimeter-Casella personal sampler and Konimeter-Hexhlet sampling was done for different operations. Results are shown in Tables 4.2 and 4.3. Details or these results are given in Appendix Tables E-1 to E-9.

4.1.2 Wankie Colliery

Dust concentration measurements of the respirable fraction were performed using MRE 113A sampling instruments and the results are shown in Table 4.4 and detailed in Appendix Tables E-10 to E-15.

4.1.3 Luanshya Mine

All investigations on dustiness at Luanshya were done by means of MRE 113A and the Konimeter. Dustiness conditions underground for various occupational groups are shown in Table 4.5. Table

4.6 shows count weight relationships as measured by MRE 113A and the Konimeter. The details of the results are shown in Appendix Tables E - 16 to E - 22.

Table 4.1 Average Occupation Dust Concentration Results for Various Mining Operations Using Hexhlet, Casella Personal and MRE 113A Sampler.

Mining Occupation	Average Concentration/Standard Deviation (mgm^{-3})		
	Hexhlet	Casella Personal Sampler	MRE 113A
Lashing	1.369/0.914 (25)	1.766/1.210 (62)	2.390/1.260 (13)
Conveying	-	1.173/0.710	0.996/0.860
Crushing	4.00/1.910 (12)	1.970/1.06 (29)	2.600/1.570 (15)
Tramming	0.763/0.100 (4)	1.299/1.030 (39)	1.280/0.696 (18)
Timbering	-	0.671/0.530 (10)	-
Drilling	1.140/0.790 (25)	-	1.594/0.910 (17)
Tipping	3.346/4.219 (14)	-	2.410/2.279 (15)

( ) Number of Samples

Table 4.2 Count-Weight Relations as Determined by Konimeter and Casella Personal Sampler

Lashing		Conveying		Crushing		Tramming	
Konimeter dust Counts (ppcc)	* Incombustible dust Concentration (mgm^{-3})	Konimeter dust Counts (ppcc)	Incombustible dust Concentration (mgm^{-3})	Konimeter dust Counts (ppcc)	Incombustible dust Concentration (mgm^{-3})	Konimeter dust Counts (ppcc)	Incombustible dust Concentration (mgm^{-3})
300	0.29	330	1.91	390	1.92	250	0.06
350	0.57	250	0.12	370	0.82	150	0.51
150	0.43	220	0.52	250	0.12	100	1.71
150	1.32	340	0.13	420	1.72	40	0.12
290	1.00	270	0.40	270	1.54	340	1.31
240	0.70	320	0.11	430	3.05	100	0.12
270	1.38			390	1.22	260	0.65
520	1.55			380	0.78	440	1.06
200	0.90			250	2.99	490	0.72

Table 4.2 Continued

250	1.67	320	0.73	340	0.42
560	0.36	380	2.02	550	0.87
270	0.63	300	0.66	300	0.83
190	0.21	190	2.73	420	1.57
				860	3.45
250	0.39	196	2.66	380	0.52
				190	0.32
400	0.46	200	1.74	280	0.32
				270	0.26
140	0.21	770	2.42	250	0.38
				200	0.26
300	1.34	360	2.26	350	0.18
		230	0.11	260	0.13
170	0.13		0.45	160	0.54
		210			
290	0.29	400	0.79	300	0.59
		330	1.91	240	0.78
530	0.97	330	1.03		
		340	0.13	210	0.57
		220	0.52		
		250	0.12	230	0.33
		270	0.40		
		320	0.11	300	0.41

Table 4.3 Count-Weight Relations for Various Mining Operations as Determined by Konimeter and Hexhlet

Crushing		Drilling		Lashing	
Konimeter dust Counts (ppcc)	Incombustible dust* Concentration (mgm^{-3})	Konimeter dust Counts (ppcc)	Incombustible dust Concentration (mgm^{-3})	Konimeter dust Counts (ppcc)	Incombustible dust Concentration (mgm^{-3})
179	2.22	360	1.84	500	0.81
207	1.98	430	0.28	500	0.59
428	2.78	420	1.32	500	0.16
2.11	0.37	430	0.91	500	1.60
938	3.33	280	0.32	418	1.16
196	0.47	210	0.29	483	1.20
430	3.33	200	0.27	250	0.70
1000	3.86	290	0.22	500	0.73
		320	0.28	480	0.53
		300	0.36	130	0.26
				320	0.53

Table 4.3 Continued

	300	0.36	130	0.26
			320	0.53
	60	0.11	120	0.05
			370	0.11
	50	0.19	250	0.21
			320	0.22
			280	0.42
			230	0.44
			220	0.08
			280	0.23
			550	0.42
			560	0.53
			160	0.20
			170	0.14
			190	0.20
			230	0.79

*Incombustible dust concentration as determined by Hexhlet

Table 4.4 Occupation Dust Concentration Results for Various mining groups using MRE 113A

Mining Group	Occupation	Number of Samples	Average Concentration (mgm^{-3})
Virgin Rock Breakers	Cutting Machine Operator	19	2.145
	Production/Development Lashing Crew	14	4.00
	Shot Firer/Charging crew	14	2.53
	Coal Drill Operator	16	3.61
Mine Officials	Production Gang Leaders Shift Bosses, Mine Captains etc.		2.61*
Surface Workers	Screening Plant	1	5.90
	Belt Attendant	5	2.33
Miscellaneous	Haulagemen, Beltway Attendants, Timber-men etc	110	0.78

* Details are given in Chapter 3

Table 4.5 Continued

Hand Lashing	Main and sub - development ends cleaners etc	10	0.173 (0.0167)	0.493 (0.051)	0.320/0.109 (0.0285)/0.011
Crushermen	Crushing	18	0.463 (0.114)	1.490 (0.965)	0.865/0.304 (0.465)/0.227
Miscellaneous Workers	Timbermen, Trammers, Pipe fitters Track layers etc	9	0.867 (0.638)	1.950 (1.434)	1.250/0.340 0.890/0.250

* Incombustible dust results

Table 4.6 Count-Weight Relations for Various Mining Operations as Determined by MRE 113A and Konimeter

Blasting worked		Drilling Workers		Conveying Workers		Mechanical Lashers		Crushermen		Miscellaneous	
Konimeter dust Counts	* Incombustible dust Concentration	Konimeter dust Counts	Incombustible dust Concentration	Konimeter dust Counts	Incombustible dust Concentration	Konimeter dust Counts	Incombutible dust Concentration	Konimeter dust Counts	Incombustible dust Concentration	Konimeter dust Counts	Incombustible dust Concentration
(ppcc)	(mgm^{-3})	(ppcc)	(mgm^{-3})	(ppcc)	(mgm^{-3})	(ppcc)	(mgm^{-3})	(ppcc)	(mgm^{-3})	(ppcc)	(mgm^{-3})
240	0.65	400	0.786	100	0.210	380	0.916	160	0.32	480	1.001
260	0.698	460	1.002	180	0.344	800	1.945	120	0.188	400	0.82
560	1.75	360	0.782	140	0.246	680	1.52	140	0.255	300	0.792
460	1.50	240	0.52	160	0.301	640	1.35	220	0.40	280	0.862
440	1.24	840	2.065	180	0.324	360	0.923	140	0.246	320	1.052
500	1.65	380	1.22	160	0.320	540	1.741	120	0.273	260	0.692

Table 4.6 Continued

160	0.382	120	0.226	480	1.201	160	0.370	360	0.638
100	0.181			380	1.243	240	0.450	420	1.434
				360	0.952	340	0.965	280	0.707
						320	0.613		
						460	0.80		
						400	0.69		
						260	0.40		
						360	0.72		

* Incombustible dust Concentration as determined by MRE 113A

4.2 Petrographic Analyses

Petrographical analyses of rock samples airborne (incombustible) and settled dust were undertaken for samples from various locations of the three mines.

4.2.1 Mufulira Mine

In order to determine free silica and total silica in the rock samples, thin sections were prepared and viewed through a microscope. The results together with those from chemical analysis are shown in Table 4.7. Incombustible dust analysis of airborne dust was done by means of X-ray diffraction method and the results are indicated in Table 4.8 while for settled dust both X-ray diffraction and chemical methods were used and grain size distribution analysis was carried out. The results are given in Table 4.9.

4.2.2 Wankie Colliery

Qualitative analyses of the collected coal samples from various production areas of the colliery were conducted and silica contents determined as shown in Table 4.10. In order to determine the free silica content of stone dust which is used in stone dusting operation four samples were examined and the results tabulated in Table 4.11.

Table 4.7 Rock Samples Qualitative and Quantitative Analysis Results

Sample Number	Location	Rock Type	Weight of Free Silica (quartz) by Observation	Weight of Total Silica by Observation	Weight of Total Silica by Chemical Analysis	Free Silica x100 (% age) by observation	Main Minerals (Percentage Weight	Accessory Minerals (Percentage Total Weight)
1	N.D.*	Lufubu Schist	60	74	59.50	81	Quartz (60) Biotite (20) Epidote (10), Muscovite (3) and Apatite (2)**	Zircon, Tourmaline, Fe-Oxide, Carbonate and chlorite [5] ***

Table 4.7 Continued

2	N.D	Basement Granite (Mufulira West)	61	76	62.50	80	Quartz (61), Biotite (15), Muscovite/ sericite (10), Epidote (5), Feldspar (Z) and Pyrite (Z)	Fe-oxide, Apatite, Rutile, Zircon and Tourmaline [5]
3	730mC73/ P5	Footwall	68	80	72.70	85	Quartz (68), Feldspar (12) Carbonate (8) Biotite (5) Muscovite/ Sericite (3)	Tourmaline, Carbonaceous matter, Fe-oxide, Opaques and Apatite [4]

Table 4.7 Continued

4	730mL C^{73}/P5	Footwall Quartzite (predominantly Arenaceous)	62	70	56.90	89	Quartz (62), Carbonate (6) Feldspar (10), Anhydrite (8) and Biotite (2)	Tourmaline, white mica, Fe-Oxide, Rutile and Opaques [2]
5		Footwall Quartzite (with Argillaceous Bending)					Quartz (55) Feldspar (20) Biotite (8), sericite/clay (8) and Anhydrite (6)	Apatite, Rutile, Zircon, Tourmaline, Fe-oxide and carbonate [3]

Table 4.7 continued

6	730mLC[73]/P5	Orebody Quartzite	51	63	59.30	81	Quartz (51), Carbonate (18), Feldspar (12), Cu-Sulphides (18), Epidote/clay (3) and Biotite (2)	Carbonaceous matter, Apatite, Zircon and Tourmaline [3]
7	N.D.	Orebody Greywracke	72	73	66.10	99	Quartz (72), Cu-Sulphides (15), carbonaceous matter (6) and Carbonate (4)	Apatite, Feldspar, Epidote, Biotite, Tourmaline, Fe-oxide [3]
8	730mLC[73]/P5	Inter B/C Quartzite	65	74	68.00	88	Quartz (65), Carbonate (12) Feldspar (10), Cu-Sulphides (8) and sericite/clay (2)	Rutile, Zircon, Tourmaline, Apatite and Fe-oxide [3]
9	730mLC[73]/P5	Lower Dolomite	5	5	4.3	100	Quartz(5), Carbonate (92), opaques (2) and clay (1)	Fe-Oxide [<1]

* N.D. Not Determined

** ( ) Percentage Composition

*** Percentage Overall Composition

Table 4.7 Continued

10	73OmLC^{73}/P5	Banded Shales	25	48	47.80	52	Quartz (25) Biotite + coloured mica (25) Carbonate (30) and Feldspar (20)	White mica, Opaques and Tourmaline [<1]
11	N.D	Mudseam	39	66	58.00	59	Quartz (39), sericite/ clay (25), Feldspar (20), Biotite (8) and Muscovite (20)	Opaques, Apatite, Zircon and Tourmaline [<1]
12	73OmLC^{73}/P5	A-orebody (Grit)	56	75	66.60	75.00	Quartz (56), Feldspar (22), Cu-Sulphides (12), sericite/clay (5) and white mica (3)	Rutile, Zircon, Tourmaline and Fe-Oxide [2]

Table 4.8 Airborne Dust X-Ray Diffraction Results

Composite Number	Location	Operation	Percentage Quartz by Weight	Percentage Microcline Feldspar by Weight
1 (8*)	810mL Main Haulage C^{81}/37-39*	Tramming	26	14
2(4)	760mL B^{81}/42-43 P1 ventilation Raise	Draw Point Lashing	34	24
3(4)	775mL B^{81}/41 P9 Ventilation Raise	Sublevel Development	26	15
4(3)	760mL^{81}/42 P-6-7 Crosscut	Draw Point Lashing	28	13
5(4)	775mL B^{81}/42P3 Crosscut North	Development Drilling	24	18
6 (3)	775mL B^{81}/41P9 Ventilation Raise	Sublevel Development Drilling	19	13
7(2)	730mL C^{73}/55P5 Ventilation Raise	Development Drilling	30	20
8(1)	760mL C^{81}/55P5 Ventilation Raise	Sublevel Development Drilling	20	16

Table 4.8 Continued

9(4)	775mLC^{81}/42P3 Crosscut South	Production Drilling	28	23
10(1)	810mL Conveyor Tunnel C^{81}/14U$_2$	Conveying	21	19
11(6)	900mLC^{96}/49 Crusher Station	Crushing	25	23

* ( ) Number of Samples Composited

* 810mL Main Haulage C^{81}/37-39 / ·810 Metre Level Main Haulage on C orebody Block 37-39

Table 4.9 Analysis of Settled Dust Samples: Grain Size and Silica content

Sample Identity	Sample Location	Average Grain size (μm) (BY TAS)	Weight Percentage Silica (Quartz) (BY XRD)	Weight Percentage Total Silica (By chemical Analysis)	$\frac{\text{Free Silica}}{\text{Total Silica}}$x100 (percentage)
A	P3 Construction Shop 660m level	11.80	17.80	27.50	64.70
B	49-50m Haulage 730mL	7.50	35.20	53.80	80.30
C	49-50m Main Haulage 810mL	7.80	36.00	54.10	66.50
D	51-52 Hanging Wall Drive 660mL	16.70	40.20	59.30	67.80
E	46-47m Main Haulage 810mL	5.10	32.90	48.70	67.60
F	49m P9 Haulage 660mL	26.40	58.90	72.50	81.30
G	17 Imp BL Haulage 660mL	20.90	40.90	57.80	70.80
H	58-59m Loop 730mL	44.20	45.50	68.50	66.40

Table 4.9 Continued

I	M2 Shaft Cross cut 960mL	12.00	29.80	45.20	65.90
J	Subvertical Shaft 500mL	15.50	21.00	47.80	43.90
K	13Imp BL Main Haulage 500mL	27.20	48.50	55.20	87.80
L	49m P5 Tip 810mL	28.40	52.00	56.40	92.20
M	11 Main Haualge 580mL	19.90	32.90	34.80	94.60
N	40m Block 730mL	14.40	31.60	45.50	69.50
O	41mP5 760mL	65.30	52.30	64.60	80.90
P	51-42m Crosscut North 716mL	27.30	28.20	41.90	67.30
Q	34 Imp Bl Store 660mL	23.50	31.90	45.70	69.80
R	42 Imp Main Haulage	15.20	32.10	44.80	71.70
S	19 Imp BL Main Haulage 660mL	8.40	25.40	39.60	64.10
T	41m P5 Crosscut North 775mL	66.50	35.70	55.20	64.70
U	01-01E Imp BL Draw Point 550mL	12.20	44.50	61.30	72.60
V	Subvertical Shafts Hoist Room 500mL	15.60	19.30	39.40	49.00
W	50-51 Access Ramp 880mL	4.70	36.00	44.90	80.10
X	900mL Crusher Station	6.70	31.30	45.60	68.60
Y	51-52m Loop North	3.80	34.30	45.60	75.20
Z	M2 Substation 960mL	4.60	32.10	62.30	51.50

Table 4.9 Continued

AA	01P3 Orepass 500mL	17.70	33.90	43.30	78.30
BB	M2 Shaft Station 880mL	6.50	26.10	58.00	45.00
CC	M1 Shaft Between 880mL -	6.20	25.30	51.50	49.10
DD	23m Main Crosscut North 730mL	27.20	23.80	39.00	61.00
EE	44 Imp Ramp Raise Below 660mL	19.70	23.40	42.50	55.10
FF	30-31 Ramp Raise Below 660mL	18.30	20.10	36.70	54.80
HH	24m Drill Steel Shop 810mL	8.00	28.10	45.50	61.80
II	24m CatShop 810mL	5.80	28.10	45.50	61.80
JJ	26m P7 Crosscut South 880mL	7.20	34.10	60.90	56.00
KK	25m Substation 880mL	5.60	24.90	48.30	51.60
LL	22m Main Haulage West 810mL	7.60	28.00	48.90	57.30
MM	25m Ramp Raise 777-	16.30	34.70	60.50	57.40
NN	26m Main Haulage 810mL	17.60	20.30	31.90	63.60
OO	11 Shaft substation 580mL	43.30	37.80	49.10	77.00
PP	23 Main Haulage 580mL	32.10	26.50	47.60	55.70
QQ	11U5-11U6 Transfer	17.50	22.20	45.20	49.10
RR	11U4-11U5 Transfer Point 805mL	20.50	23.40	40.40	47.90

Table 4.9 Continued

SS	37-38m Ramp Raise 762mL	18.50	25.30	41.70	60.70
TT	30-31m Haulage 730mL	16.00	20.50	31.80	64.50
UU	23Main Haulage 660mL	19.10	21.40	42.50	50.30
VV	12 Shaft Main Cross-cut 550mL	19.10	21.40	42.50	50.30
WW	12 Shaft Station	38.50	42.20	52.90	79.80

Table 4.10 Coal Samples Analysis Results

Sample Identity	Free Silica (% age)	Remarks
1	4.50	All samples were from sections six and seven production stopes
2	4.80	
3	4.50	
4	4.30	
5	5.0	
6	4.20	
7	4.00	

Table 4.11 Stone Dust Samples Silica Analysis Results

Sample Identity	Free Silica (% age)	+350μm(%age)	-350μm (% age)
A	2.50	25.00	75.00
B	2.70	23.50	76.50
C	2.60	22.70	77.30
D	2.80	23.40	76.60

4.2.3 Luanshya Mine

Silica determination of the rock samples was done by means of thin sections viewed under a microscope. The silica contents of the rock from various geological systems of the mine and for settled dust samples are shown in Tables 4.12 and 4.13 respectively. The silica contents for settled dust were determined using chemical and X-ray diffraction methods.

Table 4.12 Rock Samples and Silica Analysis Results

Sample No.	System	Rock type	Total Silica by weight
1	Basement Complex (Lufubu and Muva)	Grey Granite	73.81
2	Katanga (ore formations)	Ore shale (Argillite)	55.46
3	Katanga (Unmineralized rocks)	Foot wall Quartzite	80.10
4	Katanga (unmineralized rocks)	Foot wall conglomerate	66.50

Table 4.13 Settled Dust Samples Silica Results for 18 Shaft

Sample Identity	Sample location	Weight % age Free silica (by XRD)	Weight % age Total silica (by chemical analysis)	Free silica / Total Silica x 100 (% age)
1	1196 Tip/2290-4D	41.40	53.70	77.00
2	1196 Tip/2290-4D	43.70	53.20	82.10
3	1196 Tip/2290 4D	44.20	53.40	82.80
4	1194x/CN 2290-4D	47.50	54.90	86.50
5	1192x/CN/2290-4D	48.30	54.90	87.90
6	1192x/CN/2290-4D	44.80	54.80	81.80
7	2100'1 crusher chamber	35.30	44.70	78.90
8	2100'1 crusher chamber	36.20	46.00	78.70
9	2100'1 crusher chamber	34.40	44.90	76.60

CHAPTER V

RESULTS AND DISCUSSIONS

This chapter includes six parts as follows:

5.1 The free silica content of rock;

5.2 Settled dust and airborne respirable dust results together with mass concentration; the relationship between profusion and large opacities.progression against cumulative dust dose;

5.3 Cumulative exposure to dust in relation to time contributing the exposure for various profusion categories of pneumoconiosis;

5.4 Cumulative total respirable dust dose against Nodule Size by various instruments;

5.5 The comparison of dust concentration measured by gravimetric instruments and the Konimeter;

5.6 Coal workers pneumoconiosis at Wankie Colliery with stage 1 or more.

5.1.1 Silica

Free silica (quartz) values for all rock samples were high (51 -72%) except for Lower Dolomite, Banded Shales Dolomite and Mudseam samples with low silica content of 5, 25 and 39% respectively as shown in Table 4.7. The same applied to the weight percentage of total silica, the former had higher values while the latter had lower values. The free silica content in coal samples was found to be between 4.00 and 5.00% as shown in Table 4.10.

Total silica content of Luanshya rocks ranged between 55.46 and 80.10% as shown in Table 4.12. The analysis of free silica content of the rock was not conducted for Luanshya Mine, but investigations conducted by Lambretchts (61) showed that Mufulira rocks had silica content at an average of 69% while for Luanshya the average was 45%.

Weight percentage quartz (free silica) in the airborne respirable dust was found to be greater than 20% for most of the operations except in sublevel development drilling which showed silica content between 19 and 20 percent as shown in Table 4.8. It was found that the percentage composition (free silica) of the airborne dust was different from the rock samples (parent rocks). This was probably due to the following factors which acted to change the composition: (i) Differential disintegration and (ii) Selective settling of the dispersed dust particles. Under the action of the first, the material may shatter in such a way that one, or more constituents tend to break free as large particles while others are released in the form of minute particles. When all these particles are thrown out in the air, the large ones, because of their higher settling velocity, are rapidly removed from the air.

This leaves in suspension the finer particles, possibly, with a different composition to be inspired by the workers. Selective settling is also affected by the shape of the particles, and for a given size, flat particles will remain longer in suspension than rounding particles, this may further change the percentage composition of the suspended dust.

Settled dust composition is shown in Table 4.9. The average grain size of the 49 samples collected was 18.81 microns while percentage free silica by X-ray Diffraction method was 31.43 ± 2.74 and 41.76 ± 3.72% for Mufulira and Luanshya respectively as shown in Table 5.1. The same Table shows the average total silica compositions for Mufulira and Luanshya mines as 47.88 ± 2.83% and 51.17 ± 3.20% respectively. Generally speaking, Luanshya settled dust is more siliceous than Mufulira dust. This was a contrast from the results found by Lambretchts (61) in rock samples.

5.1.2 Concentration

Crushing operation recorded high mass concentrations of 4.00 mgm^{-3}, 2.60 mgm^{-3} and 1.97 mgm^{-3} when measured by Hexhlet, MRE 1134 and Casella Personal Sampler respectively as shown in Table 5.2.

The exhaust tunnel from the crushing station on the 900m level was always dogged with dust thus rendering the exhaust fans ineffective. At the same time standing instructions regarding a cushion of ground to be left at the crusher fingers to prevent dust being raised by air surges due to tipping above the crusher are ignored. These could be the reasons for high concentrations. Lashing also showed high dust concentrations when measured by the same instruments, this was probably partly due to long forgotten installation of water blasts as stipulated under mining regulation. It was also noted that the mechanical lashing was done without watering the rock in some cases. High concentrations in lashing were also due to unsatisfactory return system especially in mechanised stopes. The auxilliary fresh air intake from draw points on the extraction level is the footwall drive. In a production stope, the draw points are always full of ground, so that air ventilating the draw points return to the footwall drive where it mixes with fresh air. Running the two operations, i.e. watering down and lashing in parallel is not practised, may be because the loader drivers become too wet.

Table 5.1: Settled Dust Samples Grain Size and Silica Results

Mine	Weight Percentage		Average Grain Size (microns)
	by XRD	by Chemical Analysis	
Mufulira	31.43±2.74	47.88±2.83	18.81±4.00
Luanshya	41.76±3.72	51.17±3.20	-

Table 5.2: Respirable Dust Concentrations for Mufulira Mine

Operation	Total Dust Concentration (mgm^{-3})		
	MRE 113A	Casella Personal	Hexhlet
Lashing	2.390±0.670	1.766±0.312	1.369±0.372
Conveying	0.996±0.460	1.173±0.470	0.505±0.476
Crushing	2.600±0.840	1.970±0.400	4.000±1.152
Tramming	1.280±0.338	1.299±0.333	0.763±0.073
Drilling	1.594±0.455	-	1.140±0.323
Tipping	2.410±1.218	-	3.346±2.363
Timbering	-	0.671±0.355	-

Table 5.3: Respirable Dust Concentrations for Luanshya Mine

Occupation	Total Dust Concentration (mgm^{-3}) by MRE 113A
Blasting Workers	1.500 ± 0.465
Drilling workers	2.100 ± 0.643
Conveying workers	0.820 ± 0.090
Mechanical Lashing workers	2.430 ± 0.396
Miscellaneous workers	1.250 ± 0.240
Hand Lashers	0.320 ± 0.073
Crushermen	0.865 ± 0.147

The same Table 5.2, reveals that tipping operation produces substantial amount of dust. This may be due to the fact that the tip station on 730m level is also a dust source in addition to the levels above. The dust due to falling ore from top levels comes to 730m L and gives a combined effect with that from 730m L. The tip attendants at this station have high risk of silicosis. Mechanical lashing workers in Table 5.3 are experiencing high dust concentrations followed by drilling workers (2.43 ± 0.396 and 2.10 ± 0.643 mgm^{-3}, respectively). It was noticed in some circumstances that mechanical lashing was done without watering the muck and this could be one of the factors for the high dust concentration. The crusher chamber at 18 shaft is properly ventilated. The crusher chamber is equiped with exhaust duct and exhaust raise to 2020'L. Similarly at 14 shaft, 1930'L there is an exhaust pipe leading to a return airway. Screening operation showed high dust concentration of 5.90 mgm^{-3}. This kind of operation has very little impact as far as pneumoconiosis prevalence is concerned since there are few people working there and the time of exposure is quite short in a shift.

Virgin rock breakers are exposed to high concentrations of 4.00 mgm^{-3} followed by Coal drill operators with 3.61 mgm^{-3} as shown in Table 5.4. The normal practice at Wankie Colliery is that most mining operations are performed dry.

Table 5.4: Respirable Dust Concentrations for Wankie Colliery

Occupation		Total Dust Concentration (mgm^{-3}) by MRE 113A
Virgin Rock Breakers	Cutting Machine Operator	2.145 ± 0.825
	Production/Development Lashing	4.000 ± 0.675
	Shot firer/Charging crew	2.530 ± 0.653
	Coal Drill Operator	3.600 ± 0.790
Surface Workers	Screening Plant	5.900
	Belt Attendant	2.330
Mine Officials		2.610
Miscellaneous		0.780

5.2 The Relationship between Profusion Progression and Cumulative Doses

The average cumulative total respirable dust dose as well as the average cumulative free silica dose against the stage of pneumoconiosis were investigated and the results are shown in Figure 5.1. The average cumulative dose values used in Figure 5.1 are shown in Table 5.5.

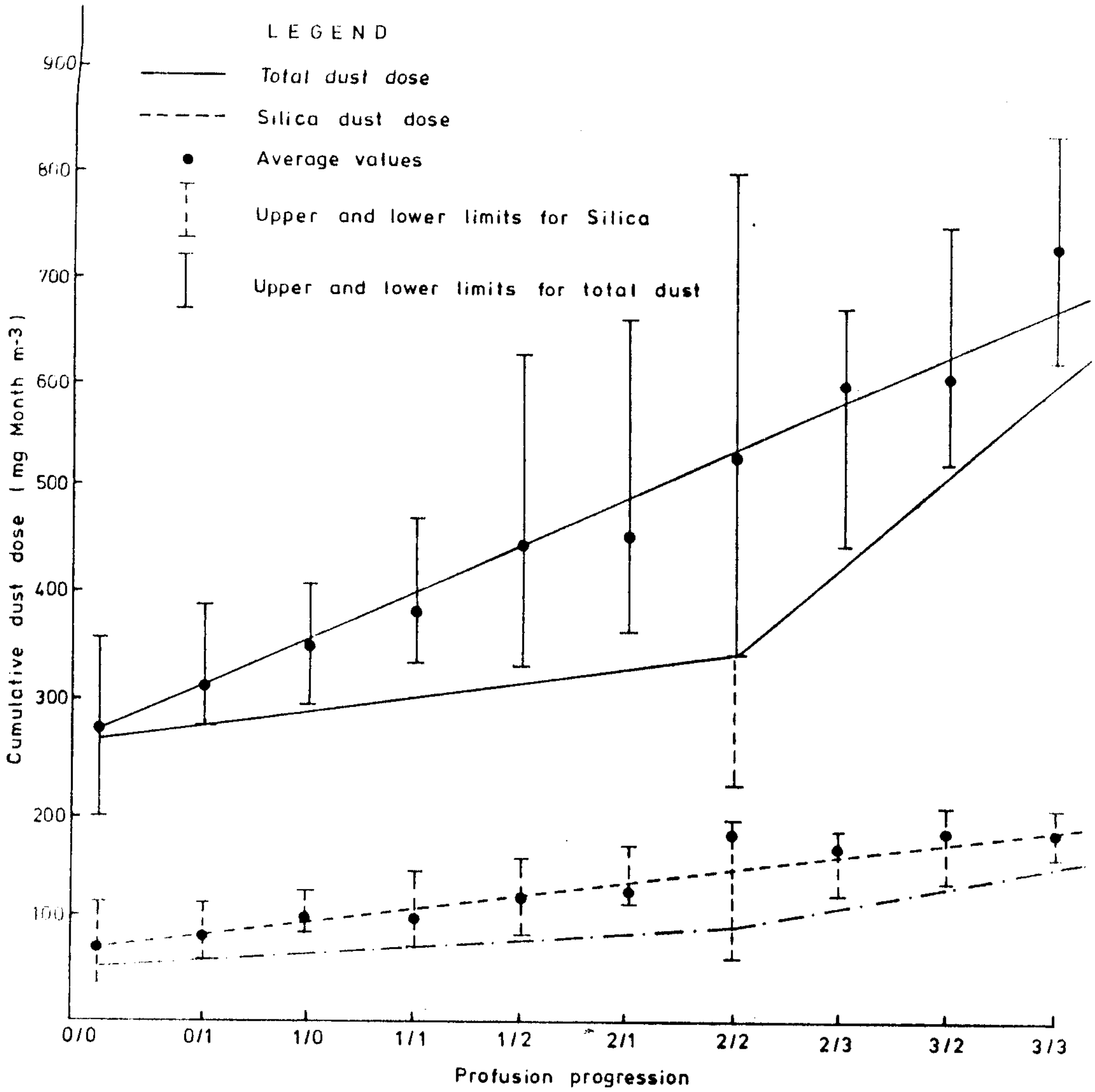

Fig.5.1 THE RELATIONSHIP BETWEEN PROFUSION PROGRESSION AND CUMULATIVE DUST DOSE.

Table 5.5: Mean Values of Indices of Exposure to Profusion Categories

Average cumulative dose (mgmonthm^{-3})	Profusion Category									
	0/0	0/1	1/0	1/1	1/2	2/1	2/2	2/3	3/2	3/3
Average total dust	261.00	315.90	346.70	385.00	441.00	454.70	529.20	596.80	604.00	730.00
Total Dust Dose Fiducial Interval, 95% confidence level	261.10 ±12.50	315.90 ±11.10	346.70 ±12.00	385.00 ±13.10	441.90 ±19.30	454.70 ±13.60	529.20 ±14.40	596.80 ±55.50	604.00 ±35.40	730.00 ±67.20
Average Silica Dust	69.40	85.10	92.50	104.60	117.40	119.10	142.70	169.50	180.20	177.40
Silica Dust Dose Fiducial Interval, 95% confidence level	69.40 ±12.50	85.10 ±4.10	92.50 ±3.90	104.60 ±5.00	117.40 ±5.00	119.10 ±5.21	142.70 ±13.72	169.50 ±13.70	180.20 ±10.90	177.40 ±14.70

The curves show a straight line relationship between the progression of pneumoconiosis and the cumulative dose of total respirable dust or free silica, either of which give a good correlation. The silica content of the respirable dust at Mufulira was fairly high ranging between 19 and 34% of different dust samples with an average of 25.50%. However, more significant than the average dust dose is the lowest cumulative dose at which silicosis is observed. The lowest cumulative total respirable dust dose at which O/1 stage of penumoconiosis is observed is about 275 mg month m^{-3}. The corresponding lowest cumulative free silica doses are 55 mg month m^{-3} and 85 mg month m^{-3}. In Figure 5.2, the lowest cumulative dose at which Stage O/1 of pneumoconiosis is observed is about 285 mg month m^{-3} while that for Stage 2/1 is about 690 mg month m^{-3}. There was only one case with Stage 2/1. Lack of good number of cases leads to deficiency of supporting data in Stage 2/1. For Stage O/O there is a case with cumulative dose of about 695 mg month m^{-3} and cumulative time of 331 months and this case progressed to 2/2 after 193 month of retirement. This single case of 695 mg month m^{-3} may be rejected on grounds of accuracy.

Table 5.6 gives Progressive Massive Fibrosis (PMF) category with Cumulative Total dose as well as cumulative silica dose.

Table 5.6: Large Opacities Progression with Cumulative Dust Dose

Mine	Category A		Category B		Category C	
	Total dust	Free Silica	Total dust	Free Silica	Total Dust	Free Silica
Mufulira	468.220 ±48.400	126.650 ±14.400	580.000	147.000	-	-
Luanshya	695.100	-	256.350 ±110.000	-	399.300	-

Table 5.7: Reliability of Cumulative Dosage of 23 men with Cumulative Dosage equal to 700 mgmonthm^{-3} or above

Description	Cumulative Dosage (mgmonthm^{-3})	Cumulative Time of Exposure (Months)	Average Dust Concentration (mgm^{-3})
Average Indices	821.20	264	3.107
Fiducial Interval, at 95% Confidence level	821.20 ± 61.84	264.± 23.26	3.107 ± 0.275

It was found that the cumulative doses of both total dust and free silica increases with the category of PMF (i.e. the higher the category, the higher the cumulative dose). 468 mg month m^{-3} and 580 mg month m^{-3} were the average cumulative doses for categories A and B respectively while in the case of cumulative free silica about 126 and 148 mg month m^{-3} were found for the same categories. Similarly in the case of Luanshya mine, it was found that about 256 and 399 mg month m^{-3} were the cumulative doses for category A and B respectively, except for one case which showed about 695 mg month m^{-3} for category A. As mentioned earlier on, this case can be rejected since there could be a mistake in reading the radiographs.

Figure 5.3 shows a plot of cumulative total dose against profusion category. Pneumoconiosis stage 0/1 was found at a lower dose of 170 mg month m^{-3} which is contrary to results of Figures 5.1 and 5.2. 2/1 stage of pneumoconiosis is also lower than in Figure 5.1 (corresponding values from Fig. 5.1 are 275 mg month m^{-3} and 300 mg month m^{-3} while for the case of 0/1 in Figure 5.2 is 285 mg month m^{-3}).

The curve in Figure 5.2 was fitted based on the average cumulative dose not on lower dose levels where pneumoconiosis occurs. Figure 5.4 shows a plot of cumulative free silica against Profusion Progression. The levels for 0/1 and 2/1 stages of pneumoconiosis were 45mg month m^{-3} and 51.25mg month m^{-3} (as per lower dose value).

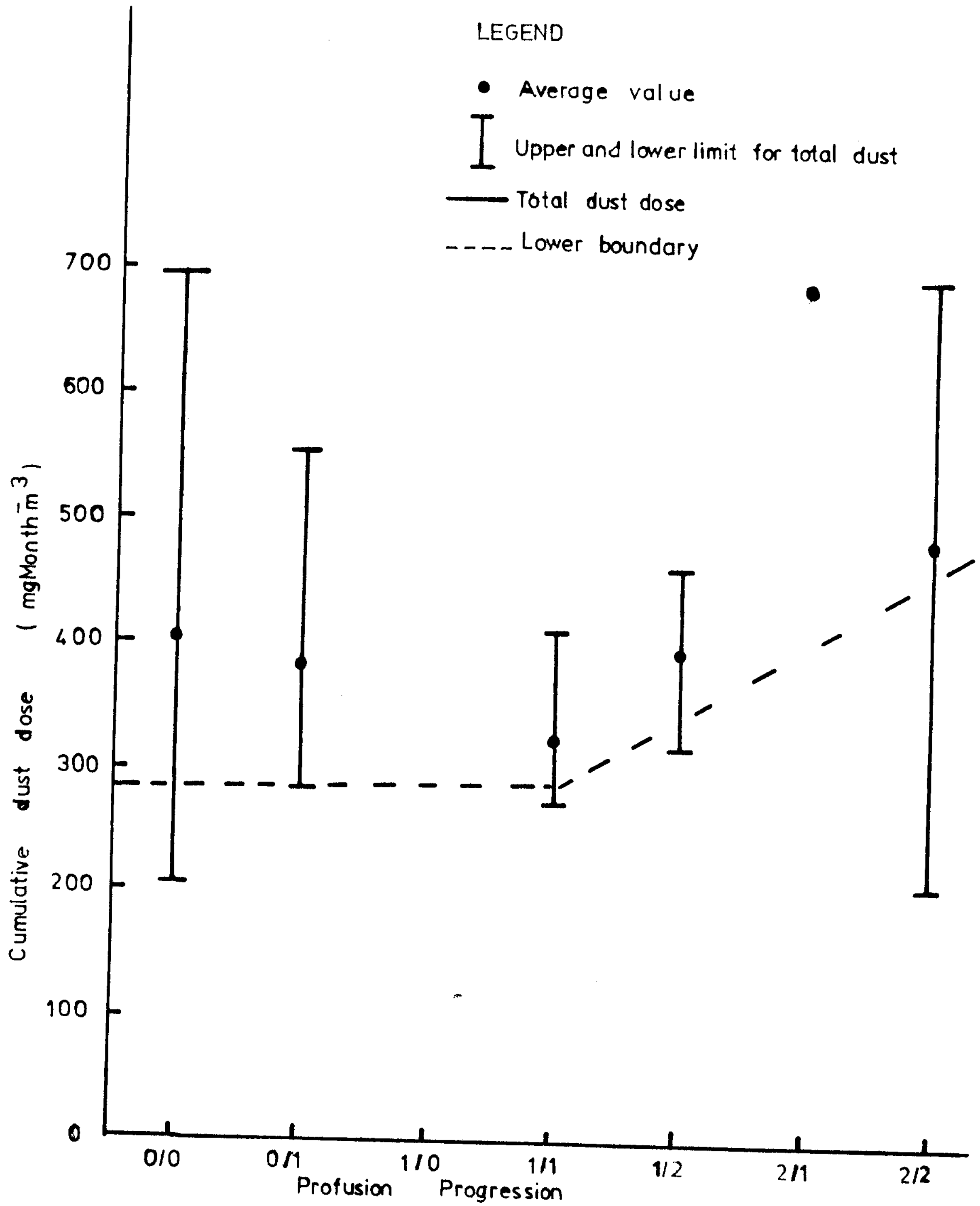

Fig.5.2 THE RELATIONSHIP BETWEEN PROFUSION PROGRESSION AND CUMULATIVE DUST DOSE.

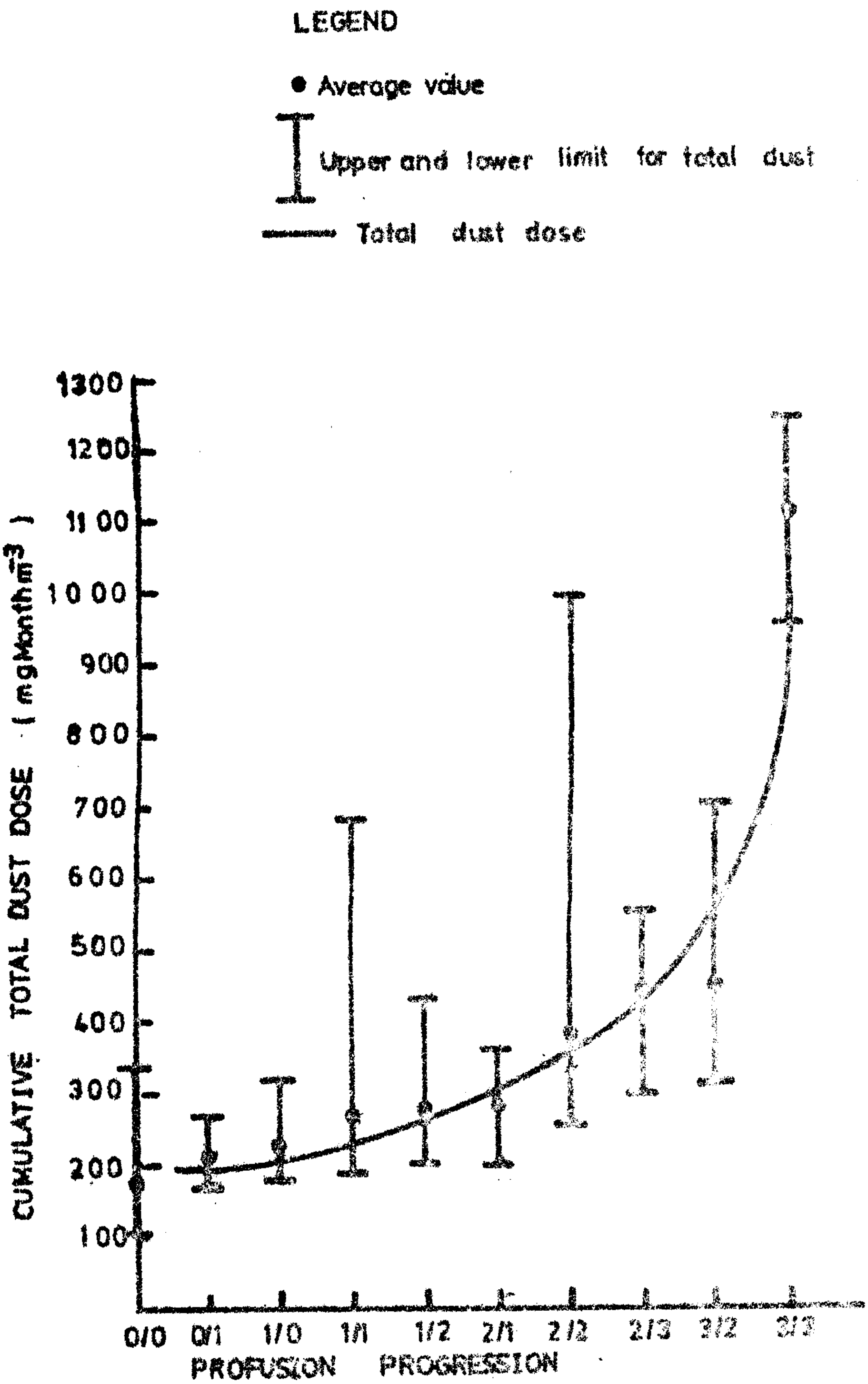

Fig.5.3 THE RELATIONSHIP BETWEEN PROFUSION PROGRESSION AND CUMULATIVE DUST DOSE.

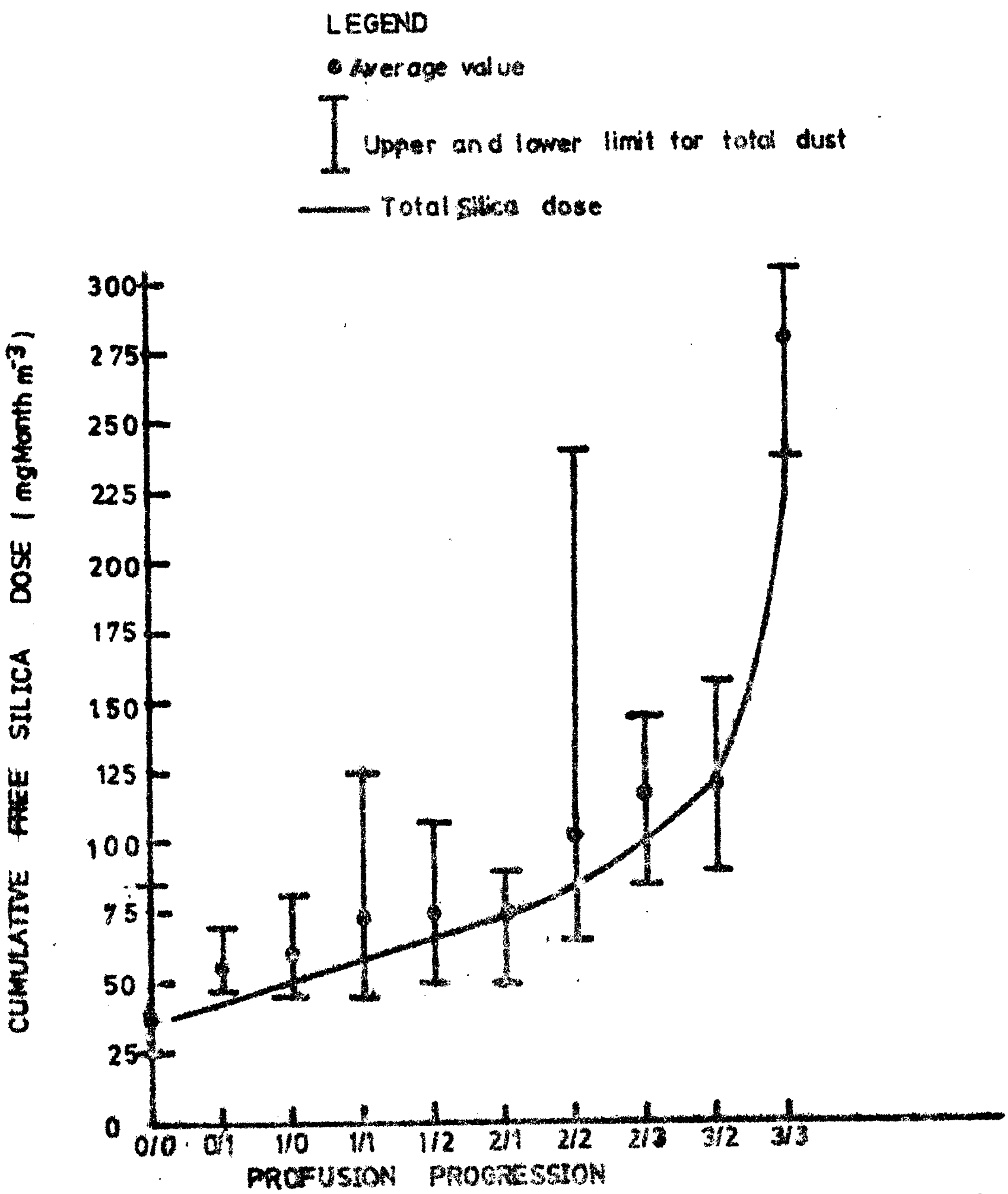

Fig.5.4 THE RELATIONSHIP BETWEEN PROFUSION PROGRESSION AND CUMULATIVE DUST DOSE

The fitted curve shows a level of 45 mg month m^{-3} and 75 mg month m^{-3} for 0/1 and 2/1 stages of pneumoconiosis respectively while the corresponding values from Figure 5.1 were 55mg month m^{-3} and 85 respectively. While cumulative dust dose should be taken as a criterion determining the possibility and progression of pneumoconiosis, dust control measures require a minimum standard to be set in terms of Mass Concentration. Besides, it has been observed by Hurley et al. (46) that for the same cumulative dust dose the progression of pneumoconiosis is higher with longer duration of exposure than with a shorter exposure time.

5.3 Cumulative Exposure to Dust in Relation to Cumulative Time

The average dust concentration to which a person is exposed during his occupational history can be obtained by dividing the cumulative dose by the cumulative time of exposure.

In Fig. 5.5 except for one case which shows stage 2/2 development in three successive lung radiographs at a cumulative dust dose of 225 mg month m^{-3}, it can be generalised that all cases of pneumoconiosis are defined by a lower boundary of cumulative dose ABC. Point B on this boundary corresponds to the highest value of average respirable dust concentration to which a miner can be exposed over a long period without

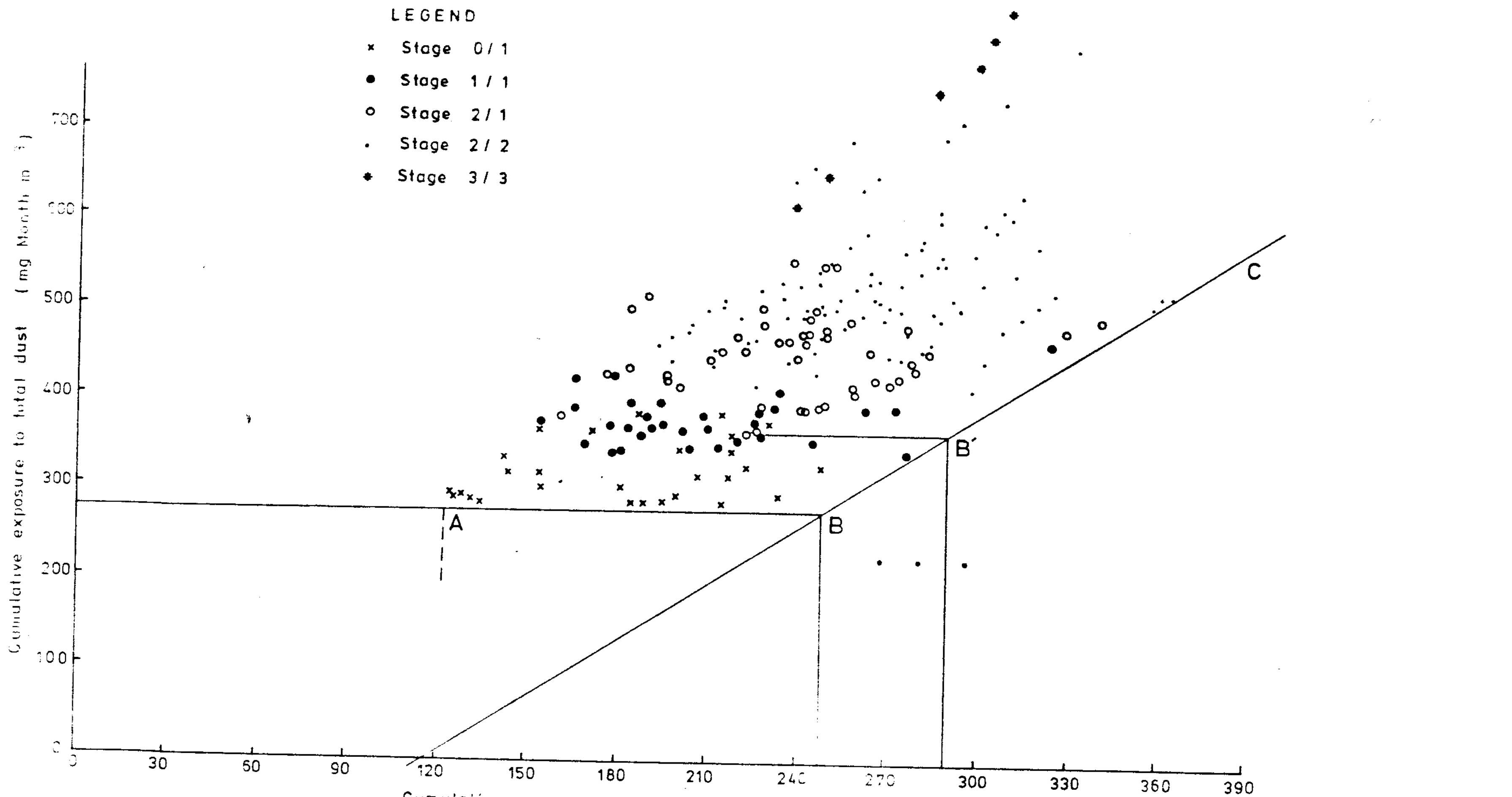

Fig 5.5 CUMULATIVE (LIFE TIME) TOTAL DUST EXPOSURES IN RELATION TO TIME CONTRIBUTING THE EXPOSURES FOR STAGES 0/1, 1/1, 2/1, 2/2 AND 3/3.

contracting pneumoconiosis. This value is obtained by dividing the cumulative dust dose by cumulative time of exposure at point B and is equal to 1.1 mgm^{-3}. An average concentration of 2.25 mgm^{-3} can be tolerated for a shorter period of exposure of 120 months (point A in Figure 5.5). If stage 2/1 is taken as a tolerable limit of disability due to pneumoconiosis, the maximum permissible dust concentration can be raised to 1.28 mgm^{-3} (point B in Figure 5.5). Figure 5.6 gives a plot of cumulative silica dose against cumulative time of exposure. Here also a lower boundary of pneumoconiosis can be defined by ABC. The tolerable average concentration for prolonged exposure (corresponding to Point B) is found to be 0.25 mgm^{-3}. This figure is two and a half times higher than the TLV of 0.1 mgm^{-3} recommended by American Conference of Industrial Hygienists - ACGIH (3). 350 p.p.c.c. has been adopted as a value of concentration of rock dust in intake and face at all working faces on the Zambian Copperbelt. This value was probably worked out on the basis of the 1972 ACGIH publication of Threshold Limit Values. To arrive at 350 particles per cubic centimetre (p.p.c.c.) from the formula, the average quartz content of the respirable fraction of the rock was taken as 20% by weight. Extending this TLV to gravimetric value a further TLV of 0.5 mgm^{-3} can be used.

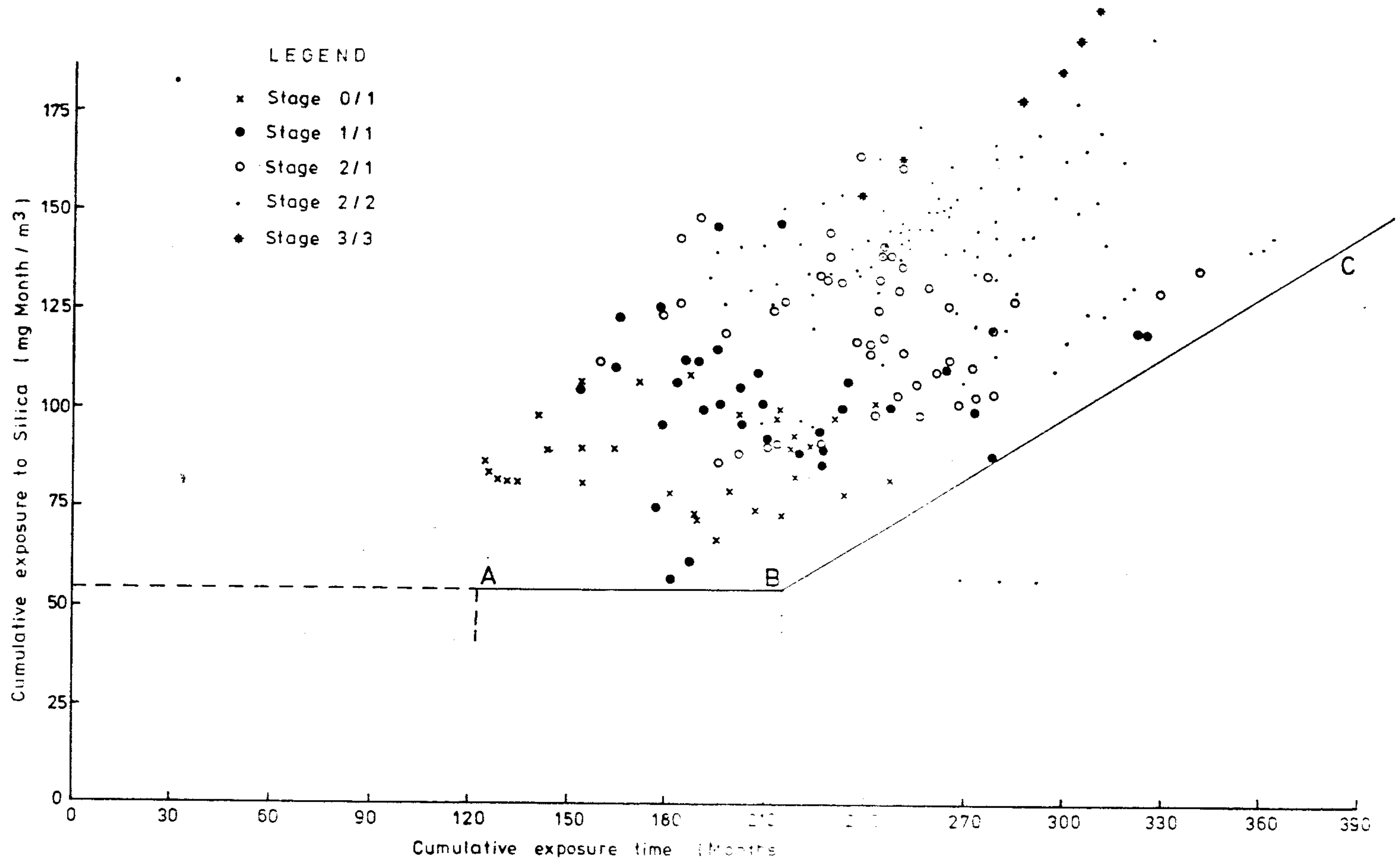

Fig.5.6 CUMULATIVE (LIFE TIME) FREE SILICA EXPOSURES IN RELATION TO TIME CONTRIBUTING THE EXPOSURES FOR STAGES 0/1, 1/1, 2/1, 2/2 AND 3/3.

Assuming 350 p.p.c.c. corresponds to 0.5mgm^{-3} then this value is less than half the average concentration at which silicosis was observed at Mufulira. Even if the exceptional case mentioned earlier is taken into consideration, the permissible concentration falls to 0.76 mgm^{-3} which is higher than the standard adopted on the Copperbelt. At 25.5% free silica, a dust concentration of 0.128 mgm^{-3} which is almost half the concentration at which no silicosis was observed at Mufulira. Figure 5.7 gives a plot of cumulative silica dose against cumulative time of exposure. Here also a lower boundary of pneumoconiosis can be defined by ABC except for three cases of stage 2/2, one which shows development at a cumulative dose of about 209 mgmonth m^{-3}. However, it can be generalised that all cases are defined by the boundary. Point B on this boundary corresponds to the highest value of average respirable dust concentration to which a miner can be exposed over a long period without contracting pneumoconiosis. This value is 285 mg month m^{-3} at a cumulative time of 348 months which is equivalent to 0.82mgm^{-3} for 348 months. An average concentration of 1.60mgm^{-3} can be tolerated for a shorter period of exposure of 180 months (Point A in Figure 5.7). If stage 2/1 is taken as a tolerable limit of disability due to pneumoconiosis, the maximum permissible dust concentration can be raised to 2.10 mgm^{-3} (i.e. 690 mgMonthm^{-3} at 324 months). The results from Fig. 5.7 are comformable with those in Fig. 5.6 and earlier discussion holds also for

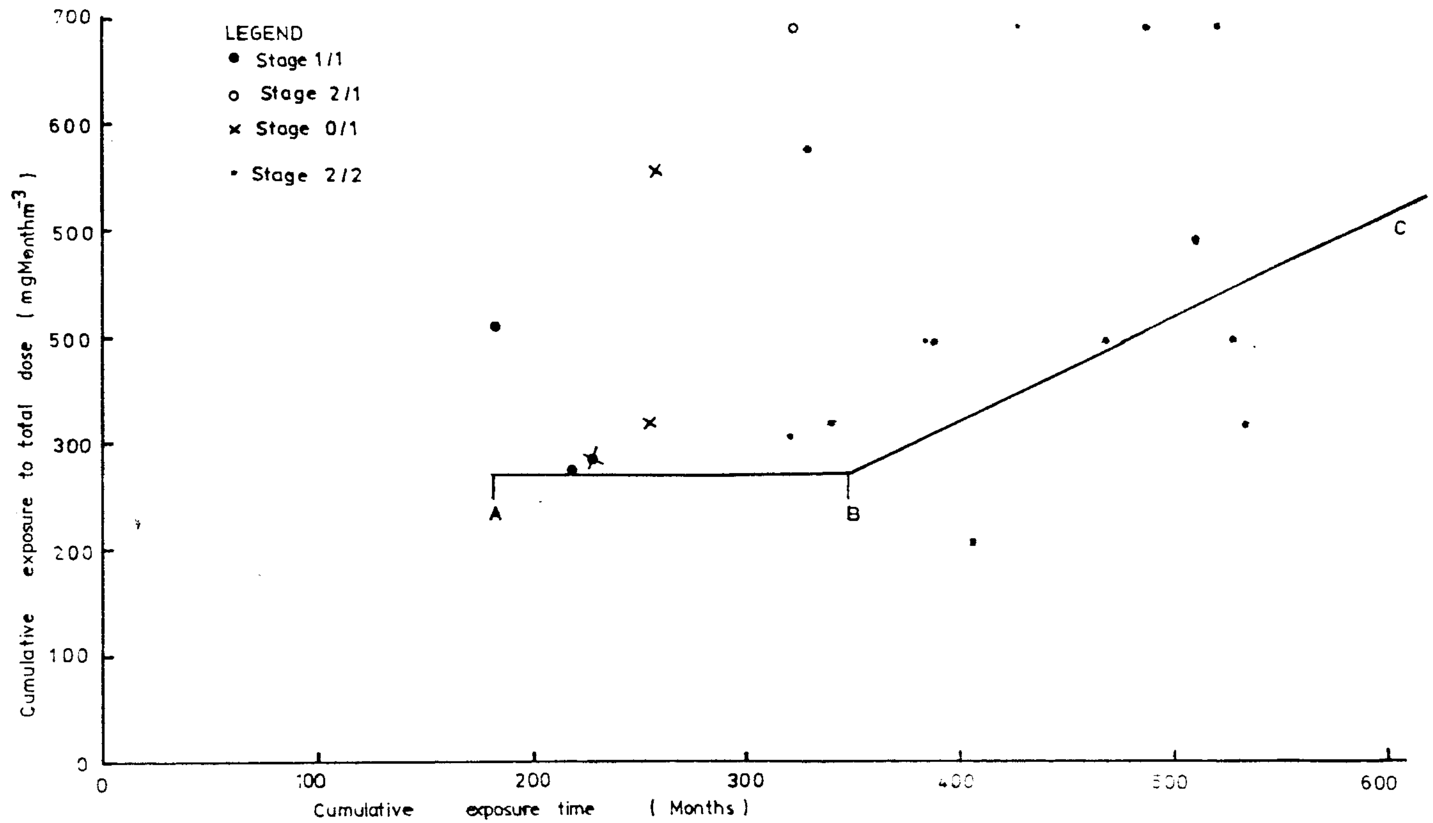

Fig.5.7 CUMULATIVE (LIFE TIME) TOTAL DUST EXPOSURES IN RELATION TO TIME CONTRIBUTING THE EXPOSURES FOR STAGES 0/1, 1/1, 2/1 AND 2/2.

Figure 5.7. A plot of cumulative coal-mine dust dose against time of exposure is given in Fig. 5.8. This figure does not have the detailed extended classification of pneumoconiosis profusion. A lower boundary of cumulative dose is shown in line AB. Boundary AB gives a limit of cumulative dose of 700 mg month m^{-3}. Above this boundary sickness was observed as detailed in Appendix Table D-2 and below this boundary no sickness was noticed. If stage I in this case is taken as a tolerable limit of disability due to pneumoconiosis, then the maximum permissible dust concentration can be 3.10 mgm^{-3} (i.e. 700 mg month m^{-3} at 225 months). This value is higher than that recommended by ACGIH (4) of 2.0 mgm^{-3} for coal dust (silica content 5%). A TLV of 2 mgm^{-3} has been adopted as a value of concentration of coal dust in Zimbabwean Coal mines, this seems to be lower than the level at which no pneumoconiosis was observed at Wankie. Fixing the Threshold Limit Value at 700 mgm^{-3} and fixing dust levels at the adopted concentration of 2.00 mgm^{-3}, 350 months will be required for a man to contract penumoconiosis. The reliability data for cumulative doses of 23 men with doeses greater or equal to 700 mg month m^{-3} is given in Table 5.7.

5.4 Cumulative Total Respirable Dust Dose against Nodule size

investigation regarding the correlation between nodule size and cumulative dust doses was conducted. The nodules were classified accoding to I.L.O. (47) as follows:

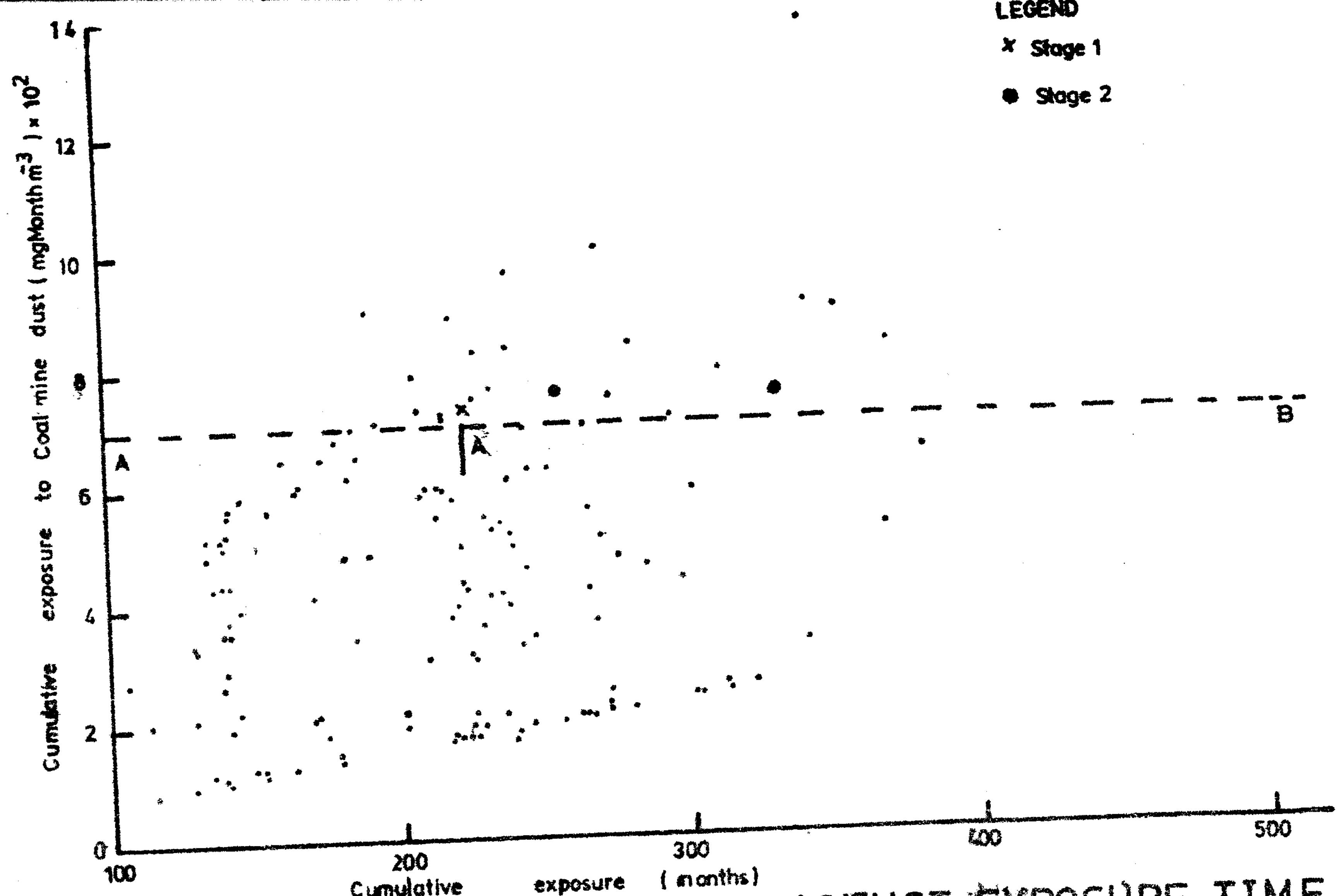

Fig.5.8 CUMULATIVE DOSE AGAINST EXPOSURE TIME.

(i) P=rounded opacities up to the approximate diameter of 1.5 mm.

(ii) m=rounded opacities exceeding about 1.5 mm and up to about 3 mm in diameter.

(iii) n=rounded opacities exceeding about 3 mm and up to 10 mm in diameter.

A plot of cumulative total respirable dust doses against nodule size is given in Figure 5.9. A boundary is defined by a dotted line which cuts the cumulative total dust dose axis at 170 mg month m^{-3} and through a lower dose of about 181 mg month m^{-3} for nodule size P. Nodule size m was found at 199 mg month m^{-3} while n occurs at 203 mg month m^{-3}. Figure 5.10 gives a plot of cumulative free silica dose against nodule size. Here a lower boundary of pneumoconiosis can be defined by the dotted line. The line cossses the cumulative free silica dose at about 56mg month m^{-3}. Pneumoconiosis was found at 67.50, 80.00 and 91.50 mg month m^{-3} for nodule sizes P, m and n respectively. The figure suggests that a dose of 67.50 mg month m^{-3} is a tolerable exposure of free silica. This value is slightly lower than that found to correspond with stage 2/1 of pneumoconiosis in Figure 5.1 In general there is a correlation between cumulative free silica dose with nodule size. Figure 5.11 shows a plot of cumulative total dose against Nodule Size.

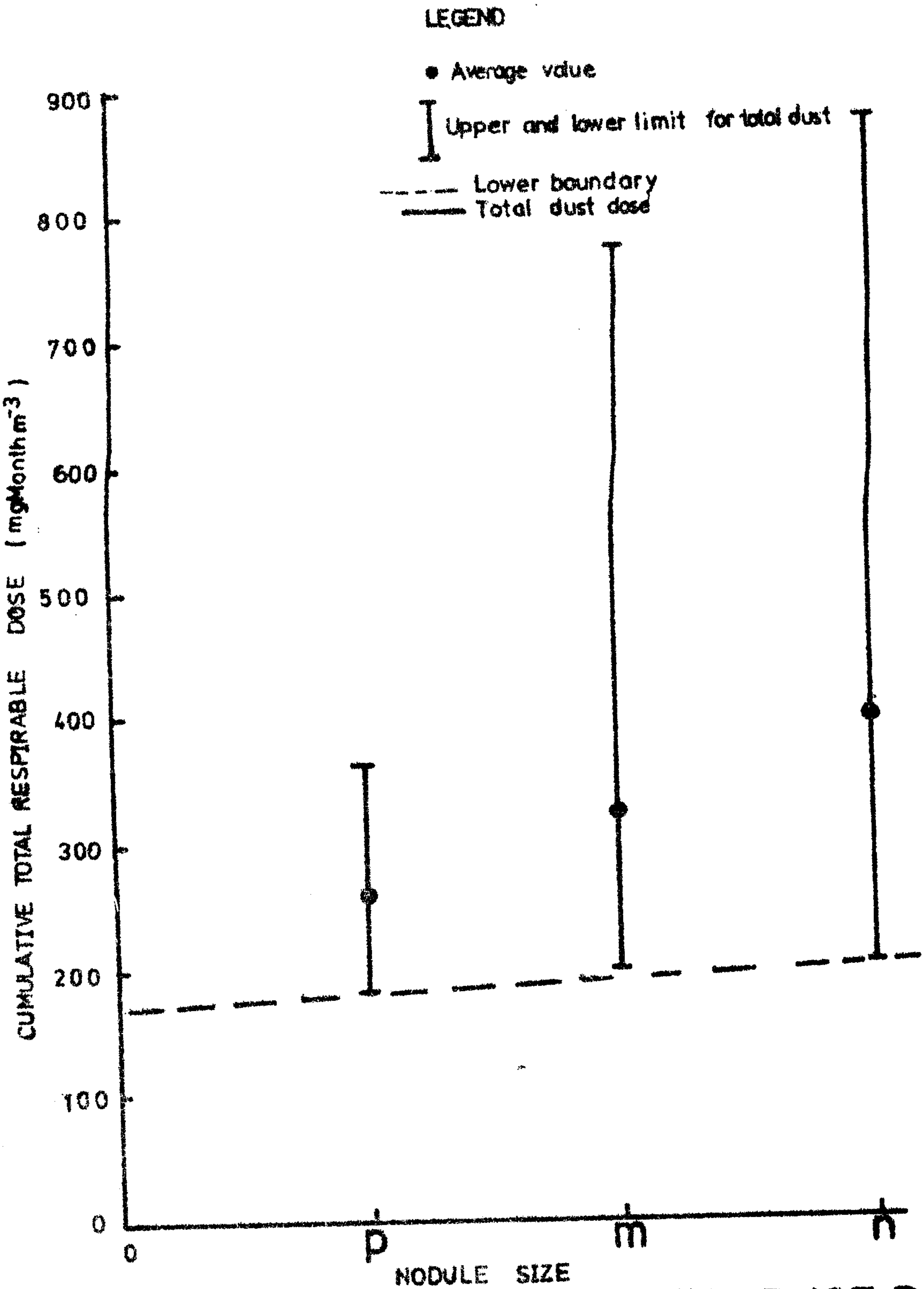

Fig.5.9 CUMULATIVE TOTAL DUST DOSE AGAINST NODULE SIZE BY MRE113A.

The tolerable level is shown by the region below the dotted line. This puts a minimum dose of about 255mg month m^{-3} for nodule size P, 301 and 348mg month m^{-3} for m and n, respectively. These results are absolutely different from those in Figure 5.9. Figure 5.12 gives a plot of cumulative free silica against nodule size. Pneumoconiosis was found at a cumulative dose of about 45mg month m^{-3} for P. This value is lower than that found in Figure 5.10 (67.50mg month m^{-3}). The average values correspond slightly with those in Figure 5.10 (70, 89 and 105 mgmonthm^{-3} for same nodule sizes p, m and n, respectively). Figure 5.13 gives the same plot as in other Figures. The tolerable cumulative dose was fixed by the dotted line at 208 mgmonthm^{-3} for all Nodule Sizes.

Generally speaking, fixing a safe cumulative dose using Nodule Size classification criterion gives a lower tolerable limit value than those profusion category criterion.

5.5 Comparison of Dust Concentrations Sampled by Various Instruments

The correlation of various sampling instruments was determined by running the instruments parallel (parallel sampling). The instruments used for this kind of task were: Hexhlet, MRE 113A, Casella Personal Sampler and Konimeter for Mufulira mine; and MRE 113A and the Konimeter for Luanshya mine.

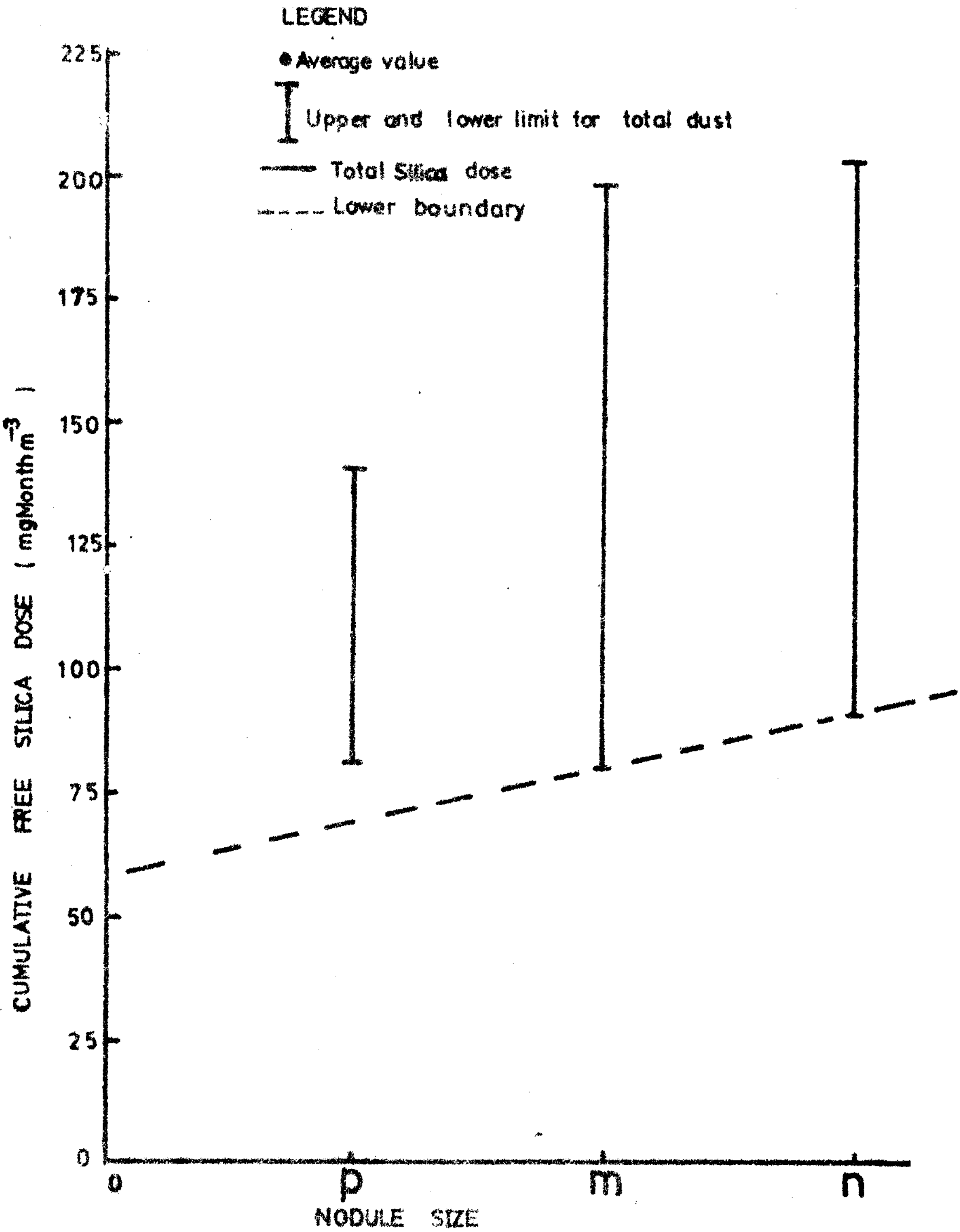

Fig.5.10 CUMULATIVE FREE SILICA DOSE AGAINST NODULE SIZE BY MRE 113A.

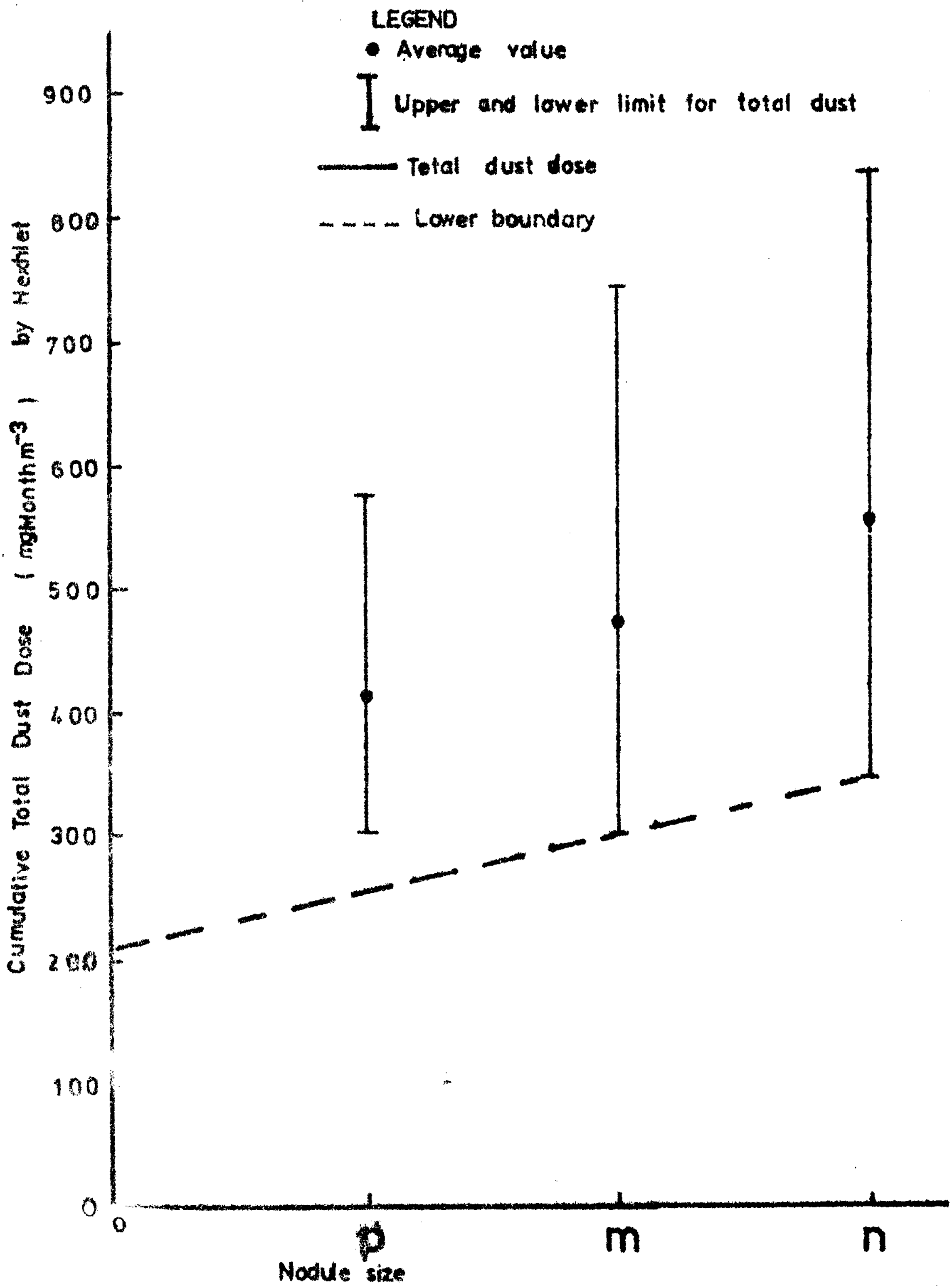

Fig.5.11 CUMULATIVE TOTAL DUST DOSE AGAINST NODULE SIZE.

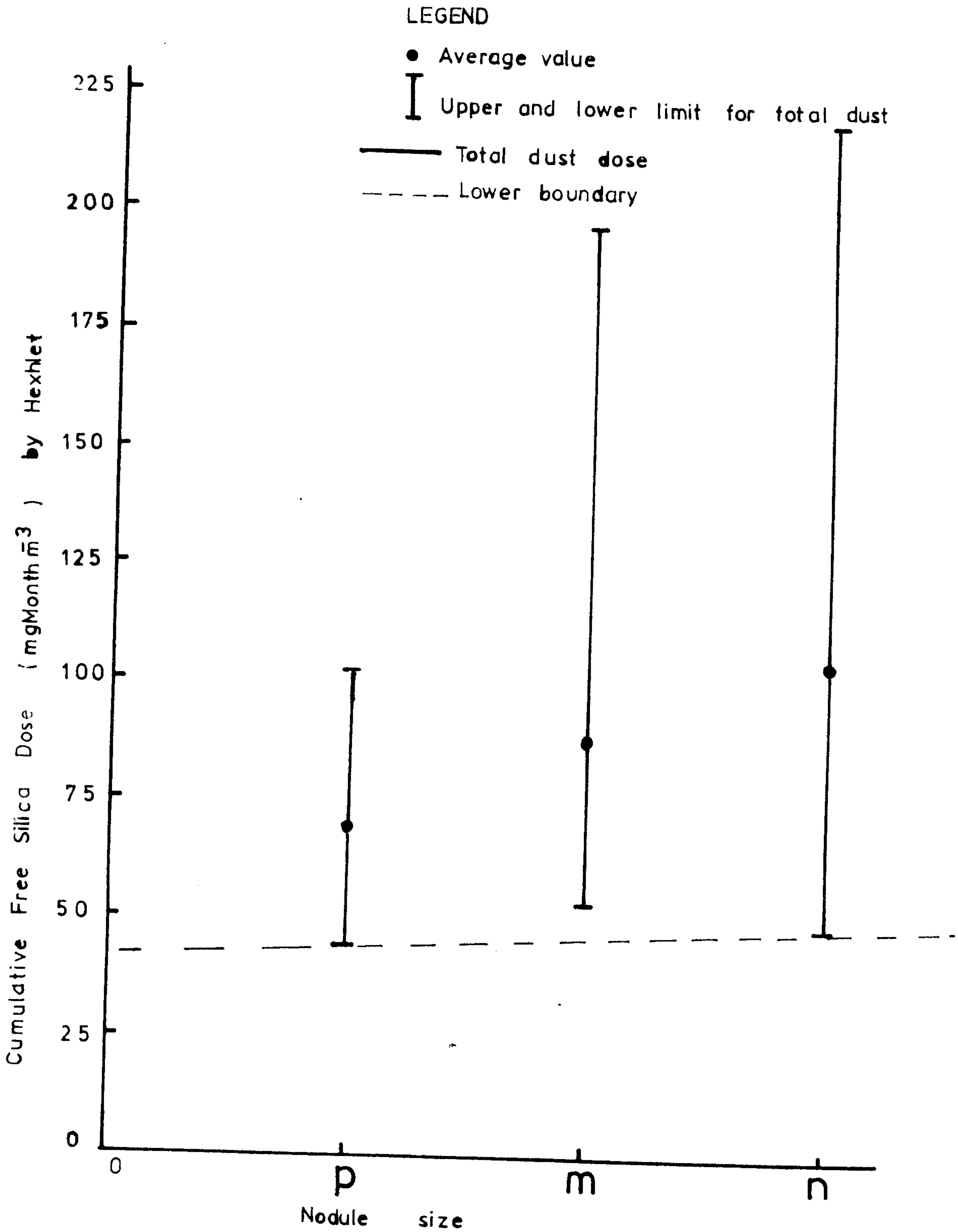

Fig. 5.12 CUMULATIVE FREE SILICA DOSE AGAINST NODULE SIZE.

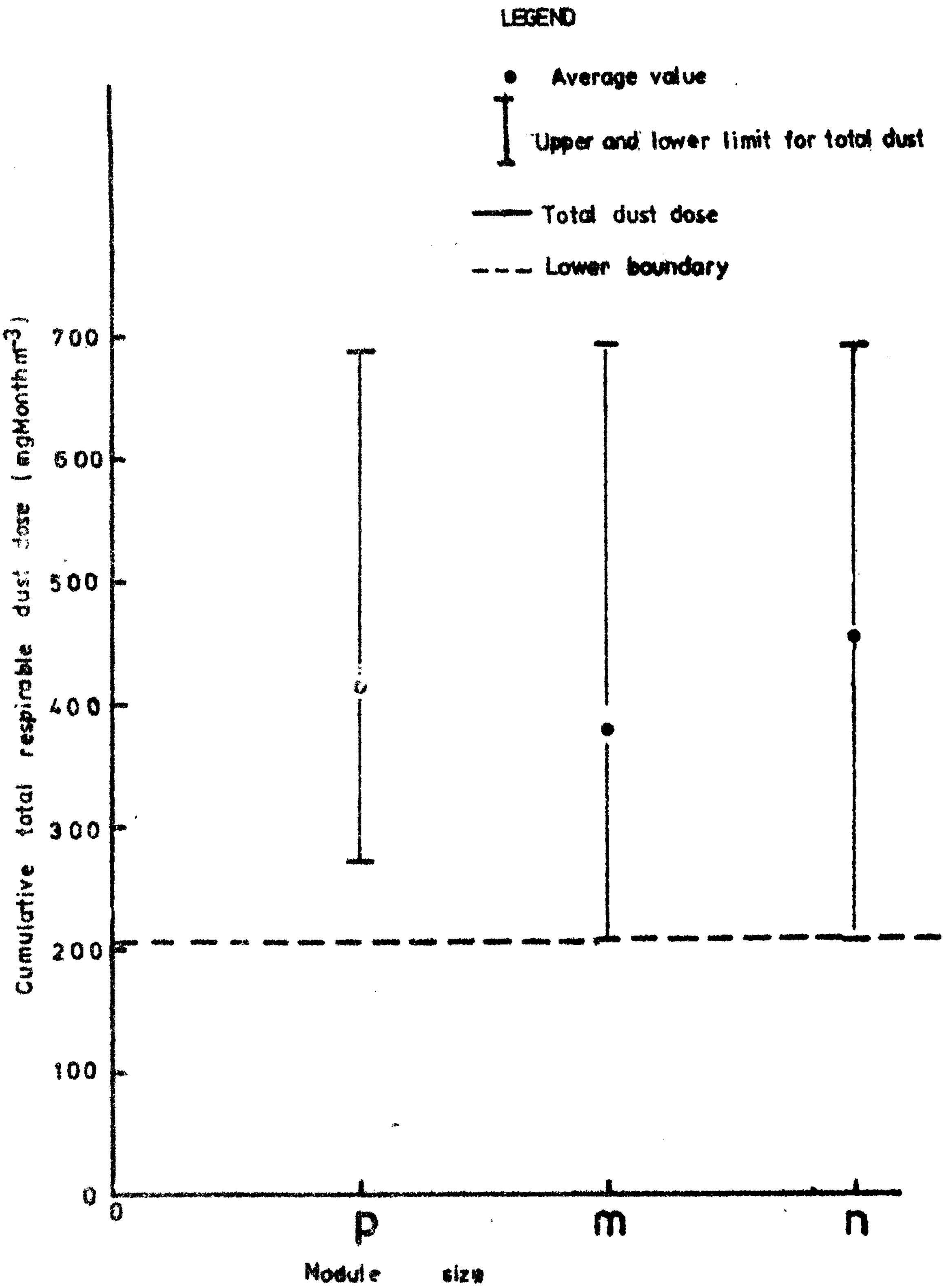

Fig.5.13 CUMULATIVE TOTAL DUST DOSE AGAINST NODULE SIZE BY MRE 113A SAMPLER.

Regression Analysis Technique was used for each MRE 113A and Personal Sampler, 27 konimeter samples were taken while only 6 konimeter samples were taken for each Hexhlet sample. The Konimeter Concentrations were averaged and plotted against the concentration of each gravimetric sample.

5.5.1 <u>MRE 113A, Hexhlet and Casella Personal Samplers</u>

The average respirable dust concentrations as determined by the MRE 113A and the Casella Personal Samplers for four different mining operations are given in Figure 5.14. The average concentrations measured by the two instruments can be related by the following equation with a correlation coefficient r=0.993; $M_A=1.436+2.095M_C$

where M_A = mass concentration by the MRE 113A sampler, and

M_C = mass concentration by Casella personal sampler in mgm^{-3}.

The average respirable dust concentration as determined by the MRE 113A and Casella personal sampler against that determined by Hexhlet is given - Figure 5.15. It is clear from the figure that the Hexhlet over estimates the dust concentration at higher values.

5.5.2 <u>Hexhlet, MRE 113A and Casella Personal Sampler with Konimeter</u>

A comparison of respirable dust concentration as determined by Hexhlet and Konimeter for three mining operations (crushing, drilling and lashing)

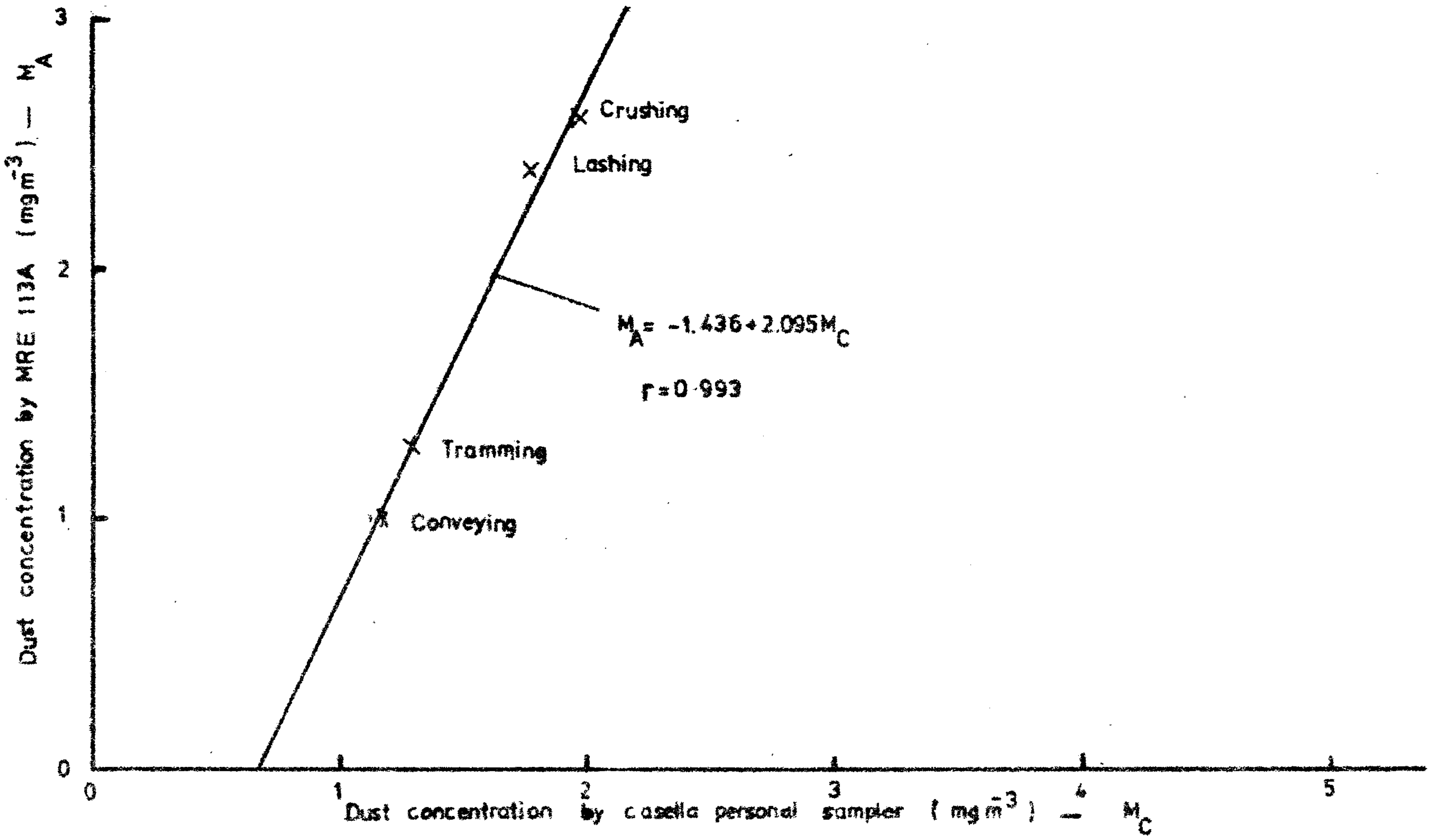

Fig.5.14 COMPARISON OF CONCENTRATION BY CASELLA PERSONAL SAMPLER AND MRE 113A.

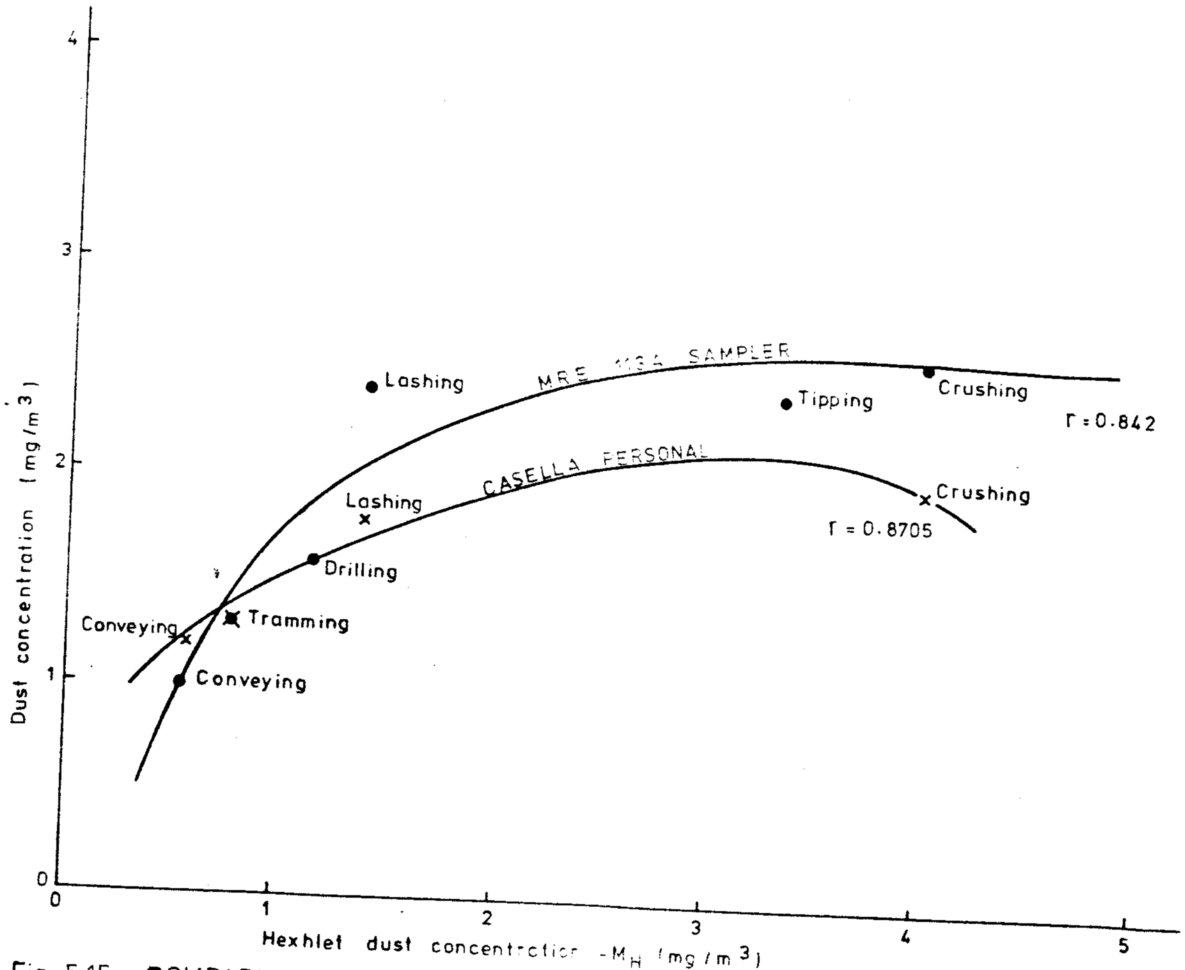

Fig. 5.15 COMPARISON OF DUST CONCENTRATION BY MRE 113A, CASELLA PERSONAL SAMPLER AND HEXHLET.

is shown in Figure 5.16. The concentrations measured by the two instruments can be related by a regression line having the following equation together with a correlation coefficient were:

$r = 0.652$; $M_H = -0.232 + 0.003071\ K$

where M_H = mass concentration by Hexhlet sampler (M_H in mgm^{-3}), and

K = particle number concentration (K in p.c.c.c.).

Similarly, Figure 5.17 shows a plot of respirable dust concentration as determined by MRE 113A and Konimeter, the correlation coefficient and the relationship between Konimeter and MRE 113A were:

$r = 0.734$; $M_A = 0.089 + 0.002184\ K$

where M_A = mass concentration by MRE 113A and K as given in Figure 5.16. Figure 5.18 gives a plot of respirable dust concentrations as determined by Casella personal sampler and Konimeter. A regression line with the following equation $M_C = 0.285920 + 0.001993K$ can be established and the correlation coefficient was found to be poor ($r = 0.33$). While some correlation can be established between concentrations measured by MRE 113A, Hexhlet and the Konimeter, the correlation between Konimeter on one hand and Casella personal sampler on the other is poor.

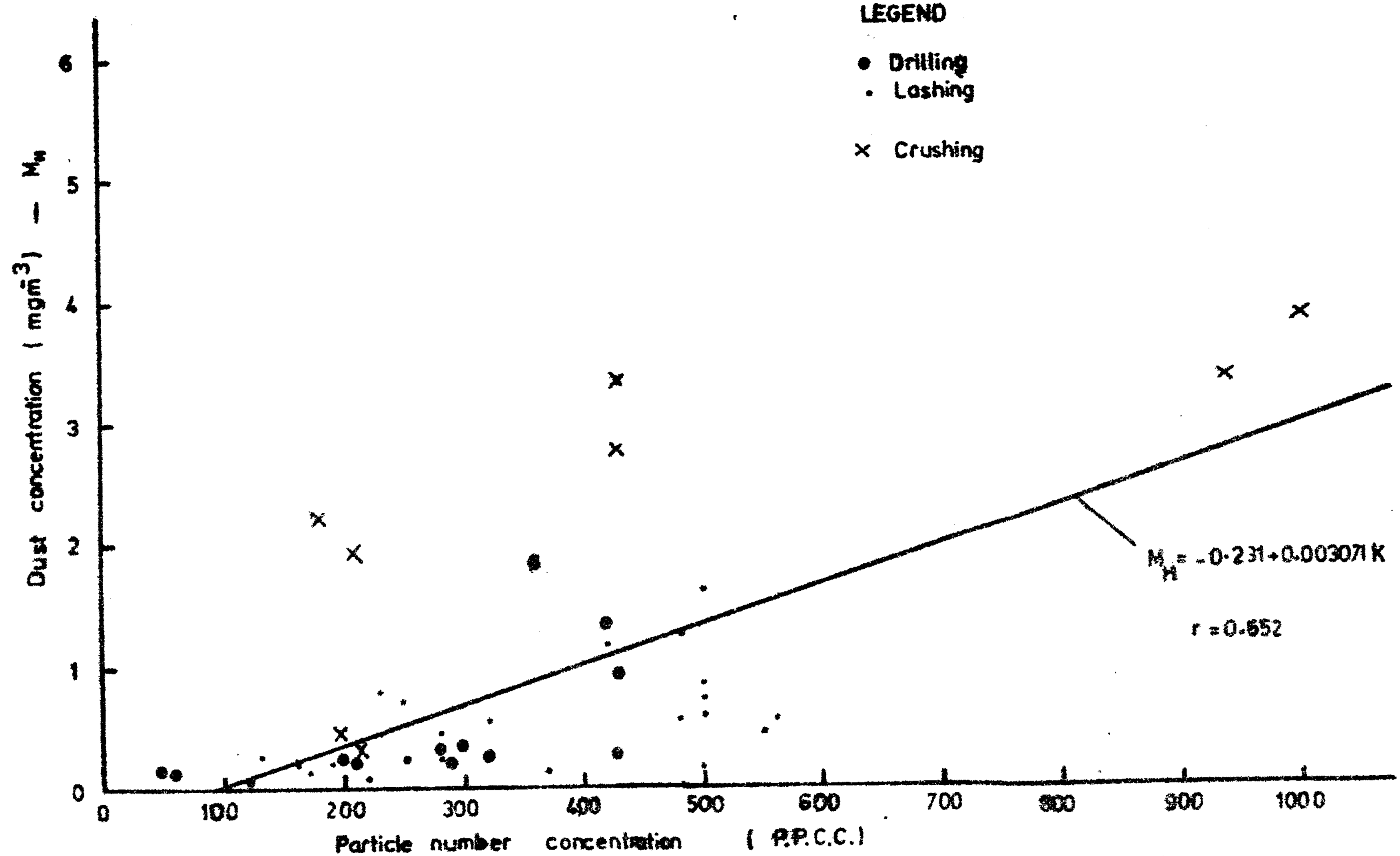

Fig.5.16 COMPARISON OF DUST CONCETRATION BY HEXLET AND KONIMETER.

The number of Konimeter samples for each sample of Hexhlet was rather small and this could contribute to some extent to the correlation established between Hexhlet and Konimeter concentrations. In general, however, it can be said that Konimeter Sampler cannot be relied on to give an accurate estimate of mass concentration of respirable dust.

The equation established between gravimetric sampler concentrations with the Konimeter for various mining operations are given in Table 5.8. The comparison of these concentrations together with the correlation coefficients for the overall operations are shown in Figures 5.16, 5.17 and 5.18.

5.6 Coal Workers' Pneumoconiosis Prevalance at Wankie

In order to establish an exposure limit and pneumoconiosis prevalance, a random sample of 148 miners with exposure duration between 100 and 400 months was taken. The number of men involved in the study and percentage of men classified as stage 1 or more of Coal Workers' pneumoconiosis at Wankie are detailed in Table 5.9. The Table shows that CWP occurs when cumulative dose is about 700 $mgmonthm^{-3}$ and the probability of having CWP of stage 1 or more was found to be 13% (or 0.13).

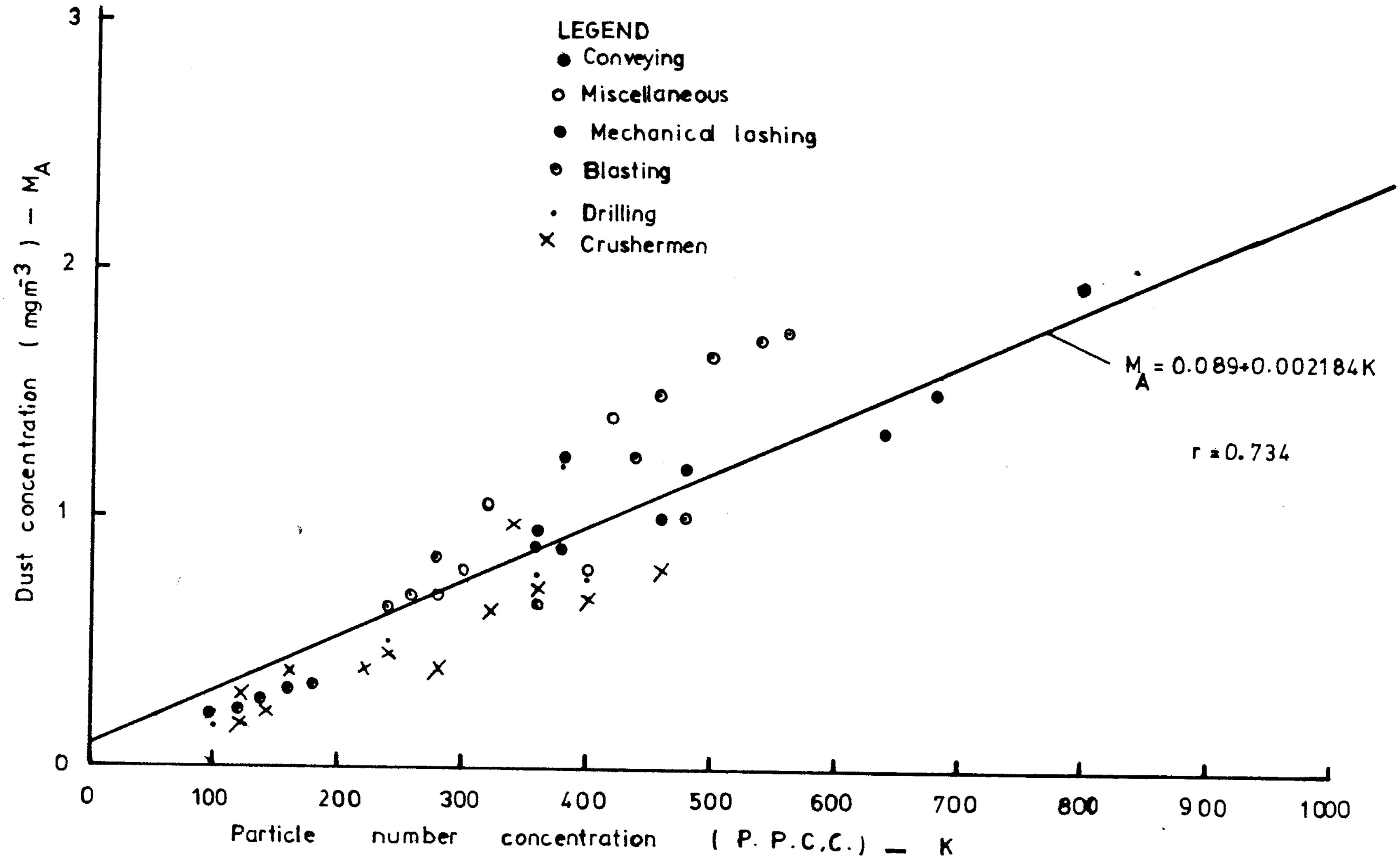

Fig.5.17 COMPARISON OF DUST CONCENTRATION BY MRE 113A AND KONIMETER.

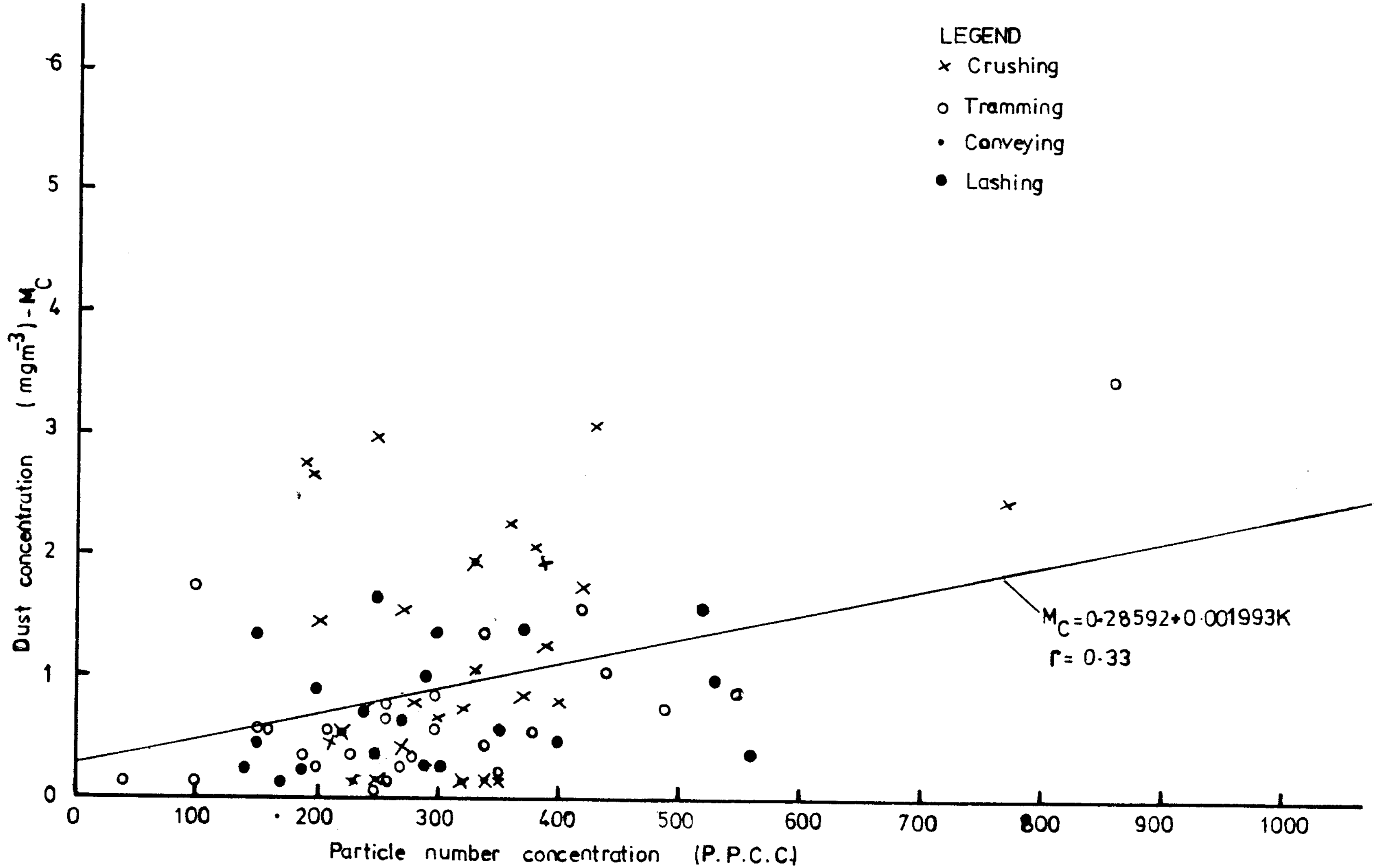

Fig.5.18 COMPARISON OF DUST CONCENTRATION BY CASELLA PERSONAL SAMPLER AND KONIMETER.

Table 5.8: Regression Equations for Gravimetric and Particle Count Concentrations as measured by MRE 113A, Casella Personal Sampler, Hexhlet; and Konimeter

Occupation	Type of Instruments		
	MRE 113A (Fig. 5.17)	Casella Personal (Fig. 5.18)	Hexhlet (Fig. 5.16)
Crushing	M_A=0.0093+0.0019K	M_C=0.589800+0.002195K	M_H=0.96500+0.00296K
Drilling	M_A=-0.0510+0.0025K	-	M_H=0.1089+0.0023K
Lashing	M_A=0.205000+0.002153K	M_C=0.526000+0.000737K	M_H=0.00511+0.00143K
Tramming	-	M_C=-0.18650+0.00293K	-
Conveying	M_A=0.0290+0.0017K	M_C=-0.49510+0.00351K	-
Blasting	M_A=-0.23100+0.00361K	-	-
Miscellaneous	M_A=0.28700+0.00175K	-	-
All Operations	M_A=0.089000+0.002184K	M_C=0.285920+0.001993K	M_H=-0.232000+0.003071K

Table 5.9: Coal Workers' Pneumoconiosis Prevalence at Wankie Colliery

Cumulative Months worked	Cumulative Dust Exposure (mgmonth-3)																		
	≤99	100-149	150-199	200-249	250-299	300-349	350-399	400-449	450-499	500-549	550-599	600-649	650-699	700-749	750-799	800-849	850-899	≥900	All
0-99																			
100-119	1			1	1														3
120-139	1	2		1	1	2		2	1	3									13
140-159		3	2	1	1		4	2		1	4								18
160-179		3	1	2				1			1	3	1						12
180-199						1			2			1	1	1					6
200-219			3	1		1	1	1		1	5			3	1				17
220-239			6	1		2	3	4	1	4		1		2* (50)	1	2	1		28
240-259			3			2			2			2	1		1** (100)			1	12
260-279				7			1	1	1	1	1		1	1				1	15
280-299				1				1	1				2	1		1			7
300-319				3	1					1					1				6
320-339					1									1** (100)					2
340-359			1		1	1											2	1	6
360-379										1						1			2
380-399												1							1
All	2	8	16	18	6	9	9	12	8	12	11	8	6	9	4	4	3	3	148

( ) Percentage classified as Stage 1 or more of Coal Workers' Pneumoconiosis.

*Stage 1

**Stage 2

The population involved in the study aged between 30 and 59 years (standard deviation = 6.50, mean = 48.14 and number of miners = 148) 23 miners were found to have more than 700 $mgmonthm^{-3}$.

CHAPTER VI

6. CONCLUSION AND FURTHER WORK

6.1 Conclusion

It can be concluded from the study that the maximum allowable concentrations of 350 particles per cubic centimeter or 0.5 mgm^{-3} adopted on the Zambian Copperbelt and 2 mgm^{-3} inforce at Wankie Colliery can be considered as adeqaate standards for guarding workers pneumoconiosis provided that the maximum durations of exposure are not exceeded. However, in view of the high silica content of the two Zambian mines, it may be desirable to adopt the free silica standard of 0.1 mgm^{-3} recommended by ACGIH (4).

Simultaneously, it may be desirable to set a standard for the cumulative respirable dust and silica dose. To leave adequate margin of safety and on the analogy of concentration these standards could be set at 275 mgmonth m^{-3} for total dust and the Mufulira dose of 55 mg month m^{-3} for free silica can be extended to Luanshya Mine as well. Beyond these levels, the following steps could then be taken to retard their dust exposure accumulation rate. This could be achieved in a variety of ways such as: reducing the dust levels of their working places, moving them to working places with lower levels, getting them to use dust protective equipment, shortening their underground shift, reducing the number of their underground shifts per week and so on.

For the coal dust a safe level of 700 mg month m^{-3} is suggested. In view of the adopted safe level of 2 mgm^{-3} a miner will take 350 months before experiencing coal workers' pneumoconiosis. Beyond this period a miner should be removed to a non-dusty operation. For comparison of the performance of different dust sampling instruments, the following conclusions can be made:

1. Good correlation can be established between mass concentrations measured by MRE 113A and Casella Personal Samplers, though Hexhlet usually over estimates the concentration at high values.

2. Correlation between particle concentration measured by the Konimeter is poor with the mass concentration measured by the gravimetric dust samplers.

3. Of all the gravimetric samplers, MRE 113A was found to be the most reliable and could be used as long as (over a shift) sampling is done without variation of flow rate. The Casella personal sampler showed diminishing flow rate towards the end of the shift as the filter get clogged. The Hexhlet filters got clogged faster, i.e. within an hour or so owing to the faster rate of sampling but the flow rate remained constant. Besides Hexhlet samples had to be restricted to locations where compressed air supply was available.

From the control point of view MRE 113A should be used as a standard sampler.

The correlation between cumulative dust doses with Nodule sizes the following conclusions can be drawn:

1. Good correlation can be established between nodule size and cumulative concentrations measured by MRE 113A.
2. Correlation between cumulative dust doses (as measured by Hexhlet) and nodule size is poor.
3. Correlation between cumulative dust dose (as measured by Hexhlet) and profusion categories is poor.

Standards or Threshold Limit Values can be based on MRE 113A sampling results and on cumulative dose as related to profusion categories.

6.2 Further Work

The Health-Based Exposure Limit derived from data on Exposure-Effect and Exposure-Response relationships can be extended further into Operational Limits considering environmental conditions.

Further work should be conducted for the formulation of Koniotic index (degree of hazardous) using the results. The dust risk of a working place can be marked using this value which is a function of the concentration of respirable particles, the content of SiO_2 crystals in this concentration, the degree of aggressiveness of the dust in the working place concerned, the degree of ventilation of the operative, and the possibility of retention given by dust dispersal.

A further study on the correlation between Hexhlet, Casella Personal Sampler, MRE 113A and the Konimeter is proposed in order to establish sound instrument factors for the Zambian Copperbelt mining conditions.

REFERENCES

1. AMERICAN CONFERENCE OF GOVERNMENTAL INDUSTRIAL HYGIENISTS TLVS. 1978. Threshold Limit Values for Chemical substances and Physical Agents in the Workroom Environment with Intended Changes for 1978.

2. AMERICAN CONFERENCE FOR GOVERNMENTAL INDUSTRIAL HYGIENISTS. 1983. Change in TLV Proposed in 1983: 364.2.

3. AMERICAN CONFERENCE FOR GOVERNMENTAL INDUSTRIAL HYGIENISTS. 1983 - 1984. Threshold Limit Values for Chemical substance and Physical Agents in the Work Environment with intended Changes for 1983 - 84. pp. 40 - 41.

4. AMERICAN CONFERENCE FOR GOVERNMENTAL INDUSTRIAL HYGIENISTS. 1983 - 84. Threshold Limit Values for Chemical Substance and Physical Agents in the work Environment with Intended Changes for 1983 - 84. pp. 56.

5. ASHE, H.B. and BERGSTROM, D.E. 1964. Twenty-Six Years Experience with dust Control in the Vermont Granite Industry. Ind. Med. Surg., 33: 973 - 978, 1964.

6. AYER, H.E. 1969. Am. Ind. Hyg. Assoc. J. 30: 117

7. BEDFORD, T. and WARNER, E.G. 1943. Chronic Pulmonary disease in South Wales Coal Miners. II. Environmental Studies, B. Physical Studies of the dust hazard and of of thermal environment in certain Coal Mines. Med. Research Council (Brit.) Spec. Rept. Ser. No. 244: 1 - 79.

8. BLOOMFIELD, J.J. and DREESSEN, W.C. 1934. Silicosis Among granite quarriers. Public Health Report. 49: 697.

9. BLOOMFIELD, J.J. and DALIAVALE, J.M. 1935. Determination and Control of Industrial dusts. Public Health Bulletin No. 217: 52.

10. BRA'ZDOVA', O. et al. 1978 Dust Content and Biochemical Composition of Lung Tissue and Bronchi in Simple and Complicated Pneumoconiosis of Coal Miners. Pracov. Le'k., 30: 255 - 260, 1978 (In Czech).

11. CARVER, JAMES. 1975. Respirable dust Regulations in the United Kingdom. International Mine Ventilation Congress (Proc.), Johannesburg, Sept., 1975: 399 - 405.

12. CASSWELL, C. et al. 1971. The Relation of Radiological Appearance in Simple Pneumoconiosis of Coal Workers to Content and Composition of the Lungs. In: Walton, W.H., ed. Inhaled particles, Vol. 2, Old Working Surrey, Unwin Bros., 1971.

13. CHARMAN, J.A. 1973. The Changing picture of the Underground working Environment of the Copper Industry of Zambia, Presented at the 2nd Seminar on Pollution and the Environment held at the University of Zambia. Research Report No. 2/73: 1 - 6.

14. CHUNG, F.H. 1973. A new X-ray Diffraction Method for Quantitative Multi Component Analysis. Advancement in X-ray Analysis. Vol. 17. Sherwin - Williams Research Center, Chicago.

15. CONSTANTINO, J.P. 1981. Health Effects of Respirable Coal Mine Dust: Coal Workers' Pneumoconiosis Mining Congr. Journal, Oct. 1981, 67: 55 - 61.

16. COOPER, W.C. and CRALLEY, L.J. 1958. Pneumoconiosis in Diatomite Mining and Processing. Public Health Service. Pub. No. 601.

17. DAVIDSON, M. 1954. Practical Manual of Diseases of the Chest. pp. 210 - 295, 1954.

18. DAVIS, J.M.G. et al. 1972. The Effect of Quartz and Other Non-Coal Dust in Coal Workers' Pneumoconiosis. In: Walton, W.H., ed. Inhaled Particles, IV. Oxford, Pergamon Press, 1977.

19. DEGUELDRE, G. 1972. Towards a Criterion for measuring the Harmfulness of Mining dust. Proceedings of the Conference on Tech. Measures of dust and suppression in Mines. Luxembourg, 11 - 13 Oct. 1972. pp. 65 - 75.

20. DOBREVA, M. et al. 1977. Characteristics of Lung Dust and Their Relation to Dust Exposure and Pathological Findings in the Lungs. In: Walton, W.H., ed. Inhaled Particles, IV. Oxford, Pergamon Press, 1977.

21. DOYLE, H.N. 1969. Dust Concentration in the Mines. Proceedings of the Symposium on Respirable Coal Mine dust. Washington D.C. Nov. 3 - 4, 1969. Bureau of Mines IC 8458. US. Dept. of the Interior.

22. DOYLE, H.N. 1975. American Experience with Coal Workers' Pneumoconiosis. Inter. Mine Vent. Congr. (Proc.), Johannesburg, Sept, 1975: 389 - 398.

23. DREESSEN, W.C., PAGE, R.T. HOUGH, J.W., et al. 1942. Pub. Health Bull. No. 277. USPHS, Washington, D.C.

24. DREESSEN, W.C., DALLAVALE, J.M. EDWARDS, T.I. et al. 1940. Pub. Health Bull. No. 250. USPHS, Washington, D.C.

25. DRINKER, P. and HATCH, T. 1952. Industrial Dust. Second Edition. McGraw-Hill Publishing Company Ltd. pp. 213 - 229.

26. DUTOIT, R.S.J. 1959. A correlation between silicosis and the Dust Exposure of South African Gold Miners. Journal of the Mine Ventilation Society, Vol. 12, No. 7, July 1959.

27. EINBRODT, H.J. and KLOSTERKÖTTER, W. 1965. The Free Silica Content of Dust Isolated from Lungs as Measure for Silicosis in Man. Ergebuisse auf dem Gebiet der Staub - und Silikosebe kanpfung in Steikohlen Bergbau, 5: 97 - 99, 1965.

28. ENGINEERING AND MINING JOURNAL. 1965. High Silica Lead Mine Eliminates silicosis - (How dust control and preventive Medicine helped a Swedish Mine set a 16 year case - free record). Vol. 166, No. 4: 98 - 99.

29. FAY, J.W.J. 1959. EXPERIMENTS WITH THE HEXHLET DUST SAMPLER IN BRITISH COAL MINES. Annals Occup. Hyg. 1960. Vol. 1: 314 - 323. Pergamon Press Ltd. Printed in Britain.

30. FAY, J.W.J. 1960. Experiments with the Hexhelt Dust Sampler in British Coal Mines. Ann. Occup. Hyg. 1960. Vol. 1, pp. 314 - 323. Pergamon Press Ltd. Printed in Great Britain.

31. FLINN, R.H., DREESSEN, W.C., EDWARDS, T.I. et al. 1939. Pub. Health Bull. No. 244. USPHS, Washington, D.C.

32. FLINN, R.H., BRINTON, H.P., DOYLE, H.N. et al. 1963. USPHS Pub. 1076, USPHS, Washington, D.C.

33. FORBER, J.J., et al. 1950. Physiological Effect of Breathing Dust, Review of Literature on Dust. Bureau of Mines Bulletin 478, Washington. pp. 18 - 57, 1950.

34. GARDNER, L.U. 1942. Annual Report of Saranac Laboratory for the study of tuberculosis. pp. 12. Saranac Lake, N.Y.

35. GARDNER, L.U. From his notes, Courtesy Thomas Durkan, Saranac Laboratories, Saranac, N.Y.

36. GONZALES, A. et al. 1982. The Relation between Pneumoconiosis and Dust Exposure in Spanish Coal Mines with comparative studies of different gravimetric dust samplers. Ann. Occup. Hyg., 26: 789 - 798, 1982.

37. Gravimetric Dust Sampler type 113A, Leaflet 93/10/82.

38. Gravimetric Dust Sampler MRE113A, Instruction leaflet 3104/TN.

39. I.L.O. 1965. Guide to the prevention and suppression of Dust in Mines, Tunnelling and quarries, I.L.O. Geneva, pp. 120 - 133, 1965.

40. GUYAGULER, T. 1982. The Effect of the inherent properties on the Dustability characteristics of the rocks of Zonguldak Coal Basin, Turkey. Ph.D. Thesis, pp.105 - 121. March 1982.

41. HAMLIN, L.E. 1944. Rocky Mountain Med. J. No. 4 (1944).

42. HATCH, R.F. and GROSS, P. 1964. Pulmonary Deposition and Retention of inhaled Aerosols. Academic Press, New York.

43. Hexhlet Instruction Leaflet 3089/TR.

44. HOSEY, A.D., ASHE, H.B. and TRASKO, V.M. 1957. Control of Silicosis in Vermont granite industry. Progress Report. Public Health Publication 557. Washington, U.S. Department of Health, Education and Welfare, 1957.

45. HURLBUT, C.S. and BEYER, D.S. 1934. Sericite in foundry dust. J. Indust. Hyg., 16: 169 1934.

46. HURLEY, J.F., BURNS, J., COPLAND, LIZ., DODGSON, J. and JACOBSEN, M. 1982. Coal Workers' Simple Pneumoconiosis and Exposure to Dust at 10 British Coal Mines. British Journal of Industrial Medicine, 39: 120 - 127, 1982.

47. I.L.O. 1971. ILO/UC International Classification of Radiographs of Pneumoconioses, 1971. Geneva: ILO, 1972. (Occuputional Safety and Health Series No. 22).

48. I.L.O. 1980. Occupational Exposure Limits for Air borne Toxic substances, Second (revised) edition. Occupational Safety and Health Series No. 37. Geneva, I.L.O, 1980.

49. I.L.O. and Central Council of Hungarian Trade Unions. 1967. Course on dust prevention in industry. Budapest, October 1964, Occupational Safety and Health Series, No. 8: 14 - 25.

50. IRVINE, L.G. and SIMSON, F.W. 1943. Memorandum on an Inquiry into the possible prevalence of silicosis on the Mines of the Copperbelt. Northern Rhodesia.

51. JACKSON, M. RAE, S., WALTON. W.H. and ROGAN, J.M. 1970. New dust standards for British Coal Mines, Nature Vol. 227, 445 - 447, August 1,1970.

52. JACOBSEN, M. 1972. The basis for the New Coal dust standards. Mining Engineer, 1972; 131: 269 - 279.

53. JACOBSEN, M. and MACLAREN, W.M. 1982. Unusual Pulmonary Observations and Exposure to Coal Mine Dust: A Case-Control Study. Ann. Occup. Hyg., 26: 753 - 765, 1982.

54. JACOBSEN, M. RAE, S., WALTON, W.H. and ROGAN, J.M. 1970. New dust standards for British Coal Mines. Nature 1970; 227: 445 - 447.

55. JAPANESE ASSOCIATION OF INDUSTRIAL HEALTH. 1982. Additional information for rational for recommendation of permissible concentrations of dust. Japan J. Ind. Health, 24: 548 - 553 (1982) (in Japanese).

56. JONES, W.R. 1933. Silicotic lungs: the minerals contain, J. Hyg., 33: 307, 1933.

57. KNIGHT, G. and COCHRANE, T.S. 1975. Gravimetric Dust sampling with Quartz Analysis and its use in Metal and Mineral Mines. Inter. Mine Vent. Congr. (Proc.) Johannesburg, Sept. 1975: 407 - 414.

58. KNIGHT, G. 1975. Report on Discussions. Inter. Mine Vent. Congr. (Proc.). Johannesburg, Sept. 1975: 423 - 425.

59. KOVALECICH, I.A. Arkiv. Patologii. 8:18 (1957) Abstract in Bulletin of Hygiene No. 34: 53, 1959.

60. LAMBIE, J.S. 1938. Ind. Med. 7: 470

61. LAMBRECHTS, J. DEV. 1945. Report on an investigation into Dust and Ventilation Conditions in the Copper Mines and Broken Hill in Northern Rhodesia with particular reference to silicosis. Govt. Printer, Lusaka. 1945.

62. MALIK, O.P. and VISWANATHAN, P.C. 1980. Measurement of respirable airborne silica by X-ray diffraction (an aid to evaluating the potential silicosis hazard in the work place). Science and Industry. 16: 34 - 36.

63. MAVROGORDATO, A. 1923. Value of the Konimeter, being an investigation into the Methods and results of a dust sampling as at present practised in the Mines of Witwatersrand. S.A. Institute of Medical Research.

64. MAVROGORDATO, A. 1930. Aetiology of silicosis (dust-phthisis). In silicosis, studies and reports. Series F. Industrial Hygiene No. 13: 209. I.L.O. - Geneva.

65. McCRAE, J. 1945. The ash of silocitic lungs. South African Institute of Medical Research, Johannesburg.

66. McDONALD, J.C. and OAKES, C. 1983. Exposure - Response in Miners exposed to silics. In: Proceedings of the VI International Pneumoconiosis Conference, Bochun, 20 - 23 September 1983. Geneva, ILO, in press.

67. MINISTRY OF MINES and MINING DEVELOPMENT. 1970. Annual Report of Mines Department. pp. 15. Lusaka, Zambia.

68. MINISTRY OF MINES and MINING DEVELOPMENT. 1971. Annual Report of the Mines Department. pp. 13. Lusaka, Zambia.

69. MINISTRY OF MINES and MINING DEVELOPMENT. 1972. Annual Report of Mines Department. pp. 11. Lusaka, Zambia.

70. MINISTRY OF MINES and MINING DEVELOPMENT. 1979. Annual Report of Mines Department. pp. 27. Lusaka, Zambia.

71. MOIR, J. 1915. Recent investigations on dust in Mine air, J. chem. Met. Mining Soc. S. Africa, 16:3, 1915.

72. NAEYE, R.L. 1972. Types of fibrosis in coal workers' pneumoconiosis. Ann. N.Y. Acad. Sci., 200: 381 - 400, 1972.

73. NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH. Criteria for a Recommended standard - Occupational Exposure to crystalline silica. HEW Pub. No. (NIOSH) 75 - 120.

74. OAKES, D. et al. 1982. Respiratory effects of prolonged exposure to gypsum dust. Ann. Occup. Hyg., 26: 8330 - 8340, 1982.

75. PARMEGGIAN, L. 1967. Legislative aspects of the prevention of silicosis. Occupational Safety and health No. 8, Geneva, pp. 101 - 105, 1967.

76. POTTER, N.M. and PEPPER, R.B. 1958. Colliery Guard 196: 627.

77. QUILLIAM, J.H. 1975. A Review of dust sampling techniques in South African Gold Mines. Inter. Mine Vent. Congress (Proc.), Johannesburg, Sept. 1975: 419 - 426.

78. RENES, L.E., PAULUS, H.J., MOSEY, A.D. 1939. PHS Pub. No. 31. USPHS, Washington, D.C.

79. RITSON, J.A.S. 1947. A brief introduction to the dust diseases of the lungs (notes and comments) on the Zambian Copperbelt. pp. 22 - 77.

80. ROBOCK, K. 1972. Research on the specific harmfulness of Respirable Dust. Conference on technical measures of dust prevention and suppression in Mines. Luxemburg, 1972.

81. ROSSITER, C.E. 1972. Relation of Lung content to Radiological changes in coal workers. Ann. N.Y. Acad. Sci., 200: 465 - 477, 1972.

82. ROSSITER, C.E. et al. 1967. Dust content, radiology and pathology in simple pneumoconiosis of coal workers (Further Report). In: Davies, C.N., ed. Inhaled Particles and Vapours II. Oxford, Pergamon Press, 1967.

83. RUSSELL, A.E., BRITTEN, R.H., THOMPSON, R.L. and BLOOMFIELD, J.J. 1929. The Health of Workers in Dusty Trades. II. Exposure to siliceous dust (Granite Industry). Public Health Bulletin No. 184. Washington, U.S. Treasury Department, Public Health Service, 1929.

84. RUSSELL, A.E. 1941. The Health of workers in Dusty Trades. VII. Restudy of a Group of Granite Workers. Public Health Bulletin No. 269. Washington, Federal Security Agency, U.S. Public Health Service, 1941.

85. SAYERS, R.R., MERIWETHER, F.V., LANZA, A.J. and ADAMS, W.W. 1933. Silicosis and Tuberculosis among miners of the Tri-state District of Oklahoma, Kansas, and Missouri. U.S. Bureau of Mines, Technical paper No. 545. Government Printing office, Washington, D.C.

86. SAYERS, R.R. BLOOMFIELD, J.J. DALLAVALLE, J.M. 1934. Spec. Bull. No. 41. Pennysylvania Dept. of Labor and Industry.

87. SCHEPERS, G.W.H. 1957. Arch. Industrial Health. 16: 125.

88. SEATON, A. SOUTAR, C.A. and MELVILLE, A.W.T. 1980. Radiological Changes in Coal Miners on leaving the Industry. Br. J. Dis. Chest. 74: 310.

89. SEATON, A., DICK, J.A., DODGSON, J. and JACOBSEN, M. 1981. Quartz and Pneumoconiosis in Coal Miners. The Lancet, Dec. 5, 1981. pp. 1272 - 1275.

90. SEATON, A. 1982. Coal Workers' pneumociniosis in Britain today and tomorrow. British Medical Journal. 28: 1507.

91. SINHA, J.K. and NAIR, P.K. 1983. Industrial Ventilation System and its Application in Pollution Control in Industries. Indian J. Environmental Protection, Vol. 3, No. 4, October 1983. pp. 116.

92. SINHA, J.K. 1984. A new direction for search on cause of pneumoconiosis. Reprinted from The New sketch, issue dated May 7, 1984. pp. 5.

93. SKOCHINSKY, A. and KOMAROV, V. 1969. Mine Dust. MIR publishers, Moscow.

94. SMITH, J.T., BECK, B.D., BRAIN, D.J. HINDS, W.C., BARON, S.G. and WEIL, L. 1982. Prediction of Pneumoconiosis risk by Bioassays of particulate from occupational exposures. Ann. Occup. Hyg. Vol. 26, No. 14: 435 - 448.

95. SMITH, J.V. 1968. CONVERSION table for the Matthews coordinate index to the powder diffraction file. American Society for testing and Materials. pp. 45. 48.

96. SPURNY, K. 1961. Evaluation of Dust hazard according to concentration and silica content. UHLI: 1 - 12.

97. STOBER, W. et al. 1967. Quantitative studies of Dust retention in Animal and Human Lungs after chronic Inhalation. In: Davis, C.N., ed. Inhaled Particles and Vapours II. Oxford, Pergamon Press, 1967.

98. SUHANOV, V,V, 1981. The Prediction of the Safe Period of Work at the Coal Face. Ugol, 1: 51 - 53, 1981. In Russian.

99. TEBBENS, B.C. and BEARD, R.R. 1957. Arch. Industrial Health. 16:55.

100. TEBBENS, B.D., SCHULZ, R.Z. and DRINKER, P. 1945. The potency of silica particles of different size. Ind. Hyg. and Toxicol. Journal. 27: 199.

101. TEBBENS, L.U. and BEARD, R.R. 1957. Arch. Ind. Health 16:55.

102. THERIAULT, J.P.,PETERS, J.M. and FINE Ibid., pp. 18.

103. THERIAULT, J.P.,PETERS, J.M. and JOHNSON, W.M. Ibid., pp. 23.

104. THERIAULT, J.P. and BURGESS, W.A. 1974. Dust exposure in the Vermont granite sheds. Arch. envir. Health, 28: 12 - 17, 1974.

105. THERIAULT, J.P. et al. 1974. Pulmonary Function and Roentgenographic changes in granite dust exposure. Arch. Envir. Health, 28: 23 - 27, 1974.

106. TIMAR MIKLOS.1972. The effects of dust upon man and some Medical aspects of silicosis prevention. Course on dust prevention in Industry. 2nd impression - 1972. Occupational Safety and Health Series No. 8 106 - 125. ILO office Geneva.

107. UNIVERSITY OF BIRMINGHAM (England) 1932. Report of Mining Research laboratory for the year ending 1932.

108. UTIDJIAN, H.M. 1975. Criteria Documents. Recommendations for a Crystalline Silica standard. J. Occup. Med., 17: 775 - 781, 1975.

109. ULRICH, L. and JUCK, A. 1967. Fate of submicronic Inhaled Dust in the Lungs. In: Davies, C.N., ed. Inhaled Particles and Vapours II. Oxford, Pergamon Press, 1967.

110. VEKENY, H. 1983. Some Aspects of the Strategy of Dust Control in Prevention of Pneumoconiosis in Hungarian Coal Mining. In: Proceedings of the VI International Pneumoconiosis Conference, Bochun, 20 - 23 September 1983. Geneva, ILO, in press, (in German).

111. WATKINS - PITCHFORD, W. 1923. Miners' Phthisis. Its cause, nature, incidence and prevention. Med. J. Australia, 2: 394.

112. WATSON, H. H. 1952. Pulmonary Diseases due to dust - Some - physio - physiological conderations. The Heating and Ventilating Engineer and Journal of Air Conditioning, June, 1952., pp. 1 - 6.

113. WHO Evaluation of Exposure to Airborne Particles in the Work Environment. 1984. WHO off set Publication No. 80, Geneva, WHO, 1984.

114. WILSON, R.K. and STEVENS, P.M. 1981. Health Effects of synthetic silica particulates. ASTM STP 732. pp. 185 - 198.

115. ZYAMBO, R.J. 1984. Ventilation Engineer Dust report for Quarter ending 31.03.84. Mining Department, Mufulira Divion, Zambia.

APPENDIX A

Total Dust and Quartz Dust Exposures in Relation to Time Contributing to the Exposure for Various Profusion Categories

Appendix Table A-1 Cumulative (life-time) Total Dust and Quartz Dust Exposures in Relation to Time controbuting to the Exposure for Profusion Category 0/1

Cumulative Total dust dose (mgmonth m^{-3})	Cumulative Silica dust dose (mgmonth m^{-3})	Cumulative time of exposure (months)	Cumulative Total dust dose (mgmonth m^{-3}	Cumulative Silica dust dose (mgmonth m^{-3})	Cumulative time of exposure
288.40	81.04	132	298.80	86.60	125
317.10	89.40	144	310.00	78.10	181
317.20	89.40	154	287.20	73.40	189
317.20	89.40	166	386.10	99.70	214
317.40	89.40	172	281.40	72.10	190
317.50	85.50	178	339.40	98.40	142
348.20	97.70	202	291.60	84.60	126
328.20	82.30	248	388.90	108.10	187
285.40	81.00	135	291.60	84.60	126
280.90	73.50	215	388.90	108.10	187
291.40	78.10	199	280.00	79.90	184

Table A-1 continued

293.20	78.00	234	310.30	87.80	217
287.10	65.90	195	317.30	89.70	218.50
315.80	74.30	207	324.40	91.50	224
344.50	82.60	119	368.10	106.70	172
368.90	106.80	155	438.20	126.90	184
300.40	80.40	155	567.20	164.30	238
361.00	93.60	219	368.90	92.60	226
376.40	97.60	231	390.70	98.20	243
391.70	101.60	243	398.30	100.20	249
290.80	82.40	129			

Appendix Table A-2 Cumulative (life-time) Total Dust and Quartz Dust Exposure in Relation to Time Contributing to the Exposures for Profusion Category 1/1

Cumulative Total dust duse (mg month m^{-3})	Cumulative Silica dust dose (mg month m^{-3})	Cumulative time of exposure (months)	Cumulative Total dust dose (mg month m^{-3})	Cumulative silica dust dose (mg month m^{-3})	Cumulative time of exposure
346.40	57.30	182	427.80	121.30	167
360.70	61.40	188	387.30	85.60	227
355.60	99.50	246	470.80	136.50	197
391.50	109.10	264	468.40	135.90	214
427.80	124.10	178	377.80	73.50	178
347.50	95.40	179	355.50	135.40	170
347.80	95.40	203	393.20	98.50	273
351.00	91.10	213	381.20	92.90	226
363.00	103.00	219	371.30	99.50	191
363.00	104.60	202	376.40	100.80	195

Appendix Table A-2 continued

374.90	107.80	208	396.10	99.60	232
398.40	11.10	186	343.70	88.20	277
414.80	110.10	189	374.50	104.80	155
400.20	114.30	195	392.00	109.10	155
363.70	88.20	227	371.50	106.00	183
355.40	91.30	220			

Appendix Table A-3 Cumulative (life-time) Total Dust and Quartz Dust Exposures in Relation to Time contributing to the Exposures for Profusion Category 2/1

Cumulative Total dust (mgmonth m^{-3})	Cumulative Silica dust dose (mgmonth m^{-3})	Cumulative time of exposure (months)	Cumulative Total dust dose (mgmonth m^{-3})	Cumulative Silica dust dose (mgmonth m^{-3})	Cumulative time of exposure
448.40	113.70	241	472.70	130.30	251
504.30	144.40	219	453.90	126.50	266
456.50	125.00	213	482.60	134.80	278
554.50	160.80	250.	427.10	119.40	198
471.90	132.50	244	455.70	126.40	216
486.20	136.70	250	420.80	85.90	196
405.10	109.90	261	428.50	87.90	202
420.50	110.90	273	441.30	91.30	212
445.80	120.50	279	411.10	99.20	256
453.40	128.90	285	423.10	101.70	268
467.70	116.20	238	429.00	102.90	274

Appendix Table A-3 continued

473.60	117.50	244	435.00	104.20	280
461.80	132.50	233	554.50	160.80	250
490.50	140.80	245	456.50	125.00	213
471.30	134.50	217	504.30	144.40	184
486.70	138.50	229	518.60	148.60	190
480.70	130.70	330	465.00	125.10	243
496.10	135.80	342	492.10	131.70	260
496.10	135.80	342	492.10	131.70	260
503.80	137.80	248	399.40	103.60	249
407.10	105.60	255	429.00	111.40	266
447.00	117.00	241	383.20	111.00	161
426.20	123.50	179			

Appendix Table A-4 Cumulative (life-time) Total Dust and Quartz Dust exposure in Relation to to Time Contributing to the Exposures for Profusion Category 2/2

Cumulative Total dust dose (mg month m^{-3})	Cumulative Silica dust dose (mg month m^{-3})	Cumulative time of exposure (months)	Cumulative Total dust dose (mg month m^{-3})	Cumulative Silica dust dose (mg month m^{-3})	Cumulative time of exposure
639.50	157.30	259	520.40	142.10	361
655.10	161.20	265	512.70	140.10	357
466.00	116.70	301	462.90	120.40	283
481.60	123.60	307	647.30	158.90	237
497.10	124.50	313	661.70	163.10	243
510.10	127.80	318	690.30	171.40	255
523.10	131.00	323	500.30	140.80	246
515.30	131.10	233	514.90	145.00	252
530.90	135.00	239	529.20	149.20	258
546.50	138.90	245	509.10	139.50	269
556.90	141.50	249	540.30	147.30	281
572.50	145.40	225	555.90	155.10	287

Appendix Table A-4 continued

588.10	149.30	261	600.10	162.20	300
438.40	125.40	211	615.70	166.10	306
467.10	133.70	223	631.30	170.00	312
455.90	130.50	212	485.20	140.70	203
470.20	134.70	218	499.50	144.90	209
534.80	153.40	245	509.10	147.20	215
436.60	95.30	224	528.20	151.80	227
567.60	155.30	275	534.20	153.10	233
696.30	164.60	287	459.00	120.20	280
710.70	168.70	293	492.80	129.20	287
739.30	117.10	305	504.80	132.40	293
796.70	193.70	329	540.70	141.90	311
504.80	145.00	251	442.10	125.50	197
533.50	153.30	263	456.50	129.60	206

Appendix Table A-4 continued

571.80	164.40	279	412.80	120.40	244
524.30	143.10	364	470.20	137.00	248
484.50	141.20	254	531.60	134.50	273
598.80	145.40	260	543.20	144.90	279
510.80	148.80	265	614.80	155.30	285
470.80	136.50	197	347.80	94.40	209
485.20	140.70	203	348.00	95.50	220
513.90	149.10	215	494.40	140.50	235
546.60	150.90	262	502.10	142.50	241
589.60	163.30	280	509.70	144.50	247
601.55	166.80	285	517.40	146.50	253
430.70	110.50	244	532.80	150.50	265
465.30	128.70	222	593.70	149.00	304
494.00	135.60	240	609.30	152.90	310

Appendix Table A-4 continued

517.90	142.00	252	455.90	128.10	244
449.30	106.90	269	502.10	139.30	273
411.20	109.10	297	533.30	145.00	273
440.10	128.30	234	504.00	153.00	297
523.70	152.50	269	564.30	164.30	286
458.90	133.10	192	493.40	142.10	219
497.00	139.00	284	511.30	143.10	290
535.20	150.10	300	578.00	162.50	318
449.80	113.10	273	478.50	121.50	275
490.00	124.10	267			

Appendix Table A-5 Cumulative (life-time) Total Dust and Quartz Dust Exposures in Relation to Time contributing to the Exposures for Profusion Category 3/3

Cumulative Total dust dose (mg month m^{-3})	Cumulative Silica dust dose (mg month m^{-3})	Cumulative time of exposure (months)	Cumulative Total dust dose (mg month m^{-3})	Cumulative Silica dust dose (mg month m^{-3})	Cumulative time of exposure
618.50	154.70	238	650.00	162.50	250
743.60	177.90	286	774.80	185.70	298
806.00	193.50	304	837.20	201.30	310

Appendix Table A-6 Cumulative (life-time) Total Dust Exposure in Relation to Time Contributing to the Exposures for profusion Category 0/0 (Luanshya mine)

Cumulative Total Duse Dose (mg month m^{-3})	Cumulative Time of Exposure (months)	Cumulative Total Dust Dose (mg month m^{-3})	Cumulative Time of Exposure (months)	Cumulative Total Dust Dose (mg month m^{-3})	Cumulative Time of Exposure (months)
265.00	212	424.40	211	208.70	278
352.30	248	695.10	331	328.20	219
282.00	171	421.40	214	453.90	241
437.90	215	270.00	216	386.90	215
477.20	278	361.90	231	250.00	255
581.10	279	512.50	258	395.90	222
347.50	193	419.60	220	380.30	230
453.30	228	419.60	236	423.80	252
314.50	143	349.40	247	338.40	236
391.10	276	321.40	253	459.40	253

Appendix Table A-6 continued

361.20	244	362.40	269	474.10	229
471.20	231	379.70	224	505.20	262
458.80	239	485.60	228	320.50	231
420.30	272	363.50	269	413.60	184
598.90	303	343.20	232	438.00	264
405.60	210	466.20	237		

Appendix Table A-7 Cumulative (life-time) Total Dust Exposure in relation to Time Contributing to the Exposures for Profusion Categories 0/1, 1/1, 1/2, 2/1 2/2 (Luanshya mine)

Profusion Category	Cumulative Total Dust Dose (mgmonth m^{-3})	Cumulative Time of Exposure (months)	Cumulative Total Duse Dose (mgmonth m^{-3})	Cumulative Time of Exposure (months)
0/1	551.70	258	285.00	288
	318.80	225	-	-
1/1	272.50	218	285.00	228
	411.20	183	-	-
1/2	463.90	245	318.80	328
2/1	690.30	324	-	-
2/2	300.60	322	399.30	369
	399.30	377	399.30	468
	399.30	529	534.00	315
	567.60	331	208.70	406

Appendix Table A-7 continued

	695.10	427	695.10	487
	695.10	512	695.10	524
2/2	318.80	340	-	-

APPENDIX B

Comparison of Exposure (Cumulative Total Respirable Dust Dose and Cumulative Free Silica Dose) to Profusion Categories and Large Opacities

Appendix Table B-1 Comparison of Exposure (Cumulative total respirable dust dose and cumulative free silica dose) to Profusion Category 0/0

Profusion Category	Cumulative Respirable Dust Dose (mgmonth m^{-3})			
	Total	Free Silica	Total	Free Silica
	241.40	68.50	283.10	77.80
	194.00	34.10	222.10	59.30
	267.70	69.00	234.20	67.90
	240.80	68.10	200.30	52.00
	265.80	72.70	227.20	59.00
	298.80	83.90	240.60	65.40
	200.80	58.20	340.20	98.50
	270.60	77.10	254.10	53.50
0/0	262.40	70.00	258.50	57.60
	277.80	74.00	234.20	67.90
	267.80	41.60	272.30	77.90
	250.20	64.90	235.50	65.20
	271.10	77.10	291.60	84.60
	272.10	77.30	284.10	80.40
	223.60	59.30	222.90	59.20
	223.20	59.30	283.70	70.50
	283.50	82.10	241.90	63.90
	347.90	90.40	345.60	89.60
	359.30	90.10	226.60	64.90
	268.80	69.90	265.30	71.90

Appendix Table B-2 Comparison of Exposure (Cumulative total respirable dust dose and cumulative free silica dose) to Profusion Category 0/1

Profusion Category	Cumulative Respirable Dust Dose (mgmonth m^{-3})			
	Total	Free Silica	Total	Free Silica
0/1	328.10	82.30	386.10	99.70
	285.40	81.00	361.00	93.60
	303.40	57.40	290.80	82.40
	293.20	78.00	280.80	73.60
	298.80	86.70	287.20	73.40
	310.00	78.10	291.40	78.10
	280.00	79.90	300.40	80.40
	310.30	87.80	368.10	106.70
	317.30	89.60	288.40	81.00
	324.40	91.50	317.10	89.40
	291.60	85.60	317.20	89.40
	388.90	108.10	317.30	89.40
	317.40	89.40	317.50	89.50
	339.40	98.40	281.40	72.10
	368.90	106.80	287.10	65.90
	315.80	74.30	344.50	82.60

Appendix Table B-3 Comparison of Exposure (cumulative total respirable dust dose and cumulative free silica dose) to Profusion Category 1/0

Profusion Category	Cumulative Respirable Duse Dose (mgmonth m^{-3})			
	Total	Free Silica	Total	Free Silica
	357.30	87.80	308.50	82.00
	325.10	84.20	316.20	84.00
	327.10	84.70	323.80	86.00
	300.80	80.00	341.80	99.10
	346.90	83.30	399.10	115.80
	349.30	84.00	392.30	99.30
1/0	347.40	95.30	308.00	86.80
	338.70	83.00	319.80	90.00
	405.20	104.30	376.40	97.60
	391.70	101.60	411.40	119.90
	321.50	90.40	356.30	93.20
	300.70	80.50	306.70	82.10
	322.10	86.10	348.20	97.70
	377.60	107.70	348.30	91.50
	362.70	95.70	367.70	102.80

Appendix Table B-4 Comparison of Exposure (cumulative total respirable dust dose and cumulative free silica dose) to Profusion Category 1/1 and 1/2

Profusion Category	Cumulative Respirable Dust Dose (mgmonth m^{-3})			
	Total	Free Silica	Total	Free Silica
	393.10	98.50	355.50	101.40
	387.20	85.50	371.50	106.00
	343.70	119.40	385.80	110.10
	468.50	123.30	400.20	114.30
	381.20	92.90	370.50	104.70
	398.40	111.10	371.30	99.50
	363.70	88.10	376.40	100.80
1/1	347.50	95.30	351.00	91.10
	347.80	95.50	363.00	103.00
	396.10	99.60	367.00	104.60
	374.90	107.80	427.80	124.10
	377.80	73.50	355.60	99.50
	391.50	109.10	470.80	136.50
	355.40	91.30	374.50	104.80
	392.00	109.10	414.80	106.60
	468.40	135.90		

Appendix Table B-4 continued

1/2	424.40	106.30	420.30	114.30
	439.90	110.20	426.70	115.90
	399.10	96.60	446.90	120.50
	405.10	97.90	336.20	89.80
	441.50	126.40	357.90	95.40
	452.30	114.40	365.60	97.40
	483.50	122.20	373.30	99.40
	514.70	130.00	399.20	104.30
	545.90	137.00	445.60	124.90
	577.10	141.70	475.60	136.10
	592.70	145.60	408.70	118.50
	592.70	145.60	408.70	118.50
	608.30	149.50	427.80	123.20
	623.90	153.40	378.00	92.30
	427.80	121.30	435.40	108.90
	428.20	114.70	436.20	123.40
	386.90	111.00	436.50	123.50
	398.80	114.20	436.70	123.50
	442.20	128.20	436.70	123.50
	456.50	132.40	406.50	81.80
	417.50	113.40	423.50	109.00
	398.50	116.30	451.80	124.00
	430.70	110.50	425.70	126.10

Appendix Table B-5 Comparison of Exposure (Cumulative total respirable dust dose and cumulative free silica dose) to Profusion Category 2/1

Profusion Category	Cumulative Respirable Dust Dose (mgmonth m^{-3})			
	Total	Free Silica	Total	Free Silica
2/1	405.10	109.90	465.00	125.10
	420.50	120.50	492.10	131.70
	445.80	128.90	363.90	92.60
	452.40	131.50	390.70	98.20
	461.10	134.50	398.30	100.20
	480.70	130.70	390.70	104.70
	496.10	135.80	448.40	113.70
	503.80	137.80	472.70	130.30
	399.20	88.70	447.00	117.00
	435.10	98.30	471.90	132.50
	444.00	100.50	486.20	136.70
	456.00	103.80	453.90	126.50
	467.90	104.00	482.60	134.80
	411.10	99.80	554.50	160.80
	423.10	101.70	504.30	144.40
	429.00	102.90	518.60	148.60
	435.00	104.20	427.10	119.40
	461.80	132.50	455.70	126.40
	490.50	140.80	470.30	134.50

Appendix Table B-5 continued

	420.80	85.90	486.70	138.50
	428.50	87.90	383.20	111.00
	441.30	91.30	426.20	123.50
	467.70	116.20	438.20	126.90
	399.40	103.60	467.20	164.40
	473.60	117.50	656.50	125.00
	407.10	105.60	429.00	111.40

Appendix Table B-6 Comparison of Exposure (cumulative total respirable dust dose and cumulative free silica dose) to Profusion Category 2/2

Profusion Category	Cumulative Respirable Dust Dose (mgmonth m^{-3})			
	Total	Free Silica	Total	Free Silica
2/2	512.70	140.10	504.80	193.70
	520.40	142.10	533.50	145.00
	524.30	143.10	571.81	153.30
	465.90	116.70	470.80	164.40
	481.60	120.60	485.20	136.50
	497.60	124.50	513.90	140.70
	510.10	127.80	456.60	149.10
	523.10	131.00	474.90	95.30
	515.30	131.10	489.20	130.10
	530.90	135.00	546.60	134.20
	546.50	138.90	589.60	150.90
	572.50	141.50	601.60	163.30
	588.10	145.40	485.20	166.80
	455.90	149.30	499.50	140.70
	470.20	130.50	509.10	144.90
	534.80	134.70	528.20	147.20
	438.40	153.40	534.20	151.80
	467.10	125.40	412.80	153.10
	639.50	133.70	470.20	120.40
	655.10	157.30	484.50	137.00
	442.10	161.20	510.80	141.20

Appendix Table B-6 continued

2/2	656.50	125.50	510.80	145.30
	567.60	129.60	590.90	148.80
	696.30	156.30	611.22	159.20
	710.70	164.60	462.90	163.30
	739.30	168.70	440.10	120.40
	796.70	177.10	523.70	128.30
	647.30	165.10	568.80	162.50
	564.30	152.50	661.70	158.90
	616.90	164.30	690.30	163.00
	449.50	179.60	465.30	171.40
	411.20	106.90	494.00	128.70
	490.00	109.10	519.90	135.60
	531.60	124.10	444.40	142.00
	543.20	134.50	502.10	140.50
	614.80	144.90	509.70	142.50
	509.10	155.30	517.40	144.50
	540.30	139.40	532.80	146.50
	555.00	147.40	449.80	150.50
	600.10	151.10	478.50	113.10
	615.70	162.20	347.80	121.50
	631.30	166.10	348.00	95.40
	459.00	170.00	458.90	95.50
	492.90	120.20	498.40	133.10
	504.80	129.20	500.90	142.10

Appendix Table B-6 continued

	540.80	129.20	500.90	142.10
	500.30	141.90	593.70	145.10
	514.90	140.90	609.30	149.00
	529.20	145.00	455.90	152.90
	497.00	149.20	502.10	128.10
	511.30	139.00	533.30	139.30
	535.20	140.10	564.00	145.00
	578.20	150.10	-	-

Appendix Table B-7 Comparison of Exposure (cumulative total respirable dust dose and cumulative free silica dose) to Profusion Categories 2/3, 3/2 and 3/3

Profusion Category	Cumulative Respirable Dust Dose (mgmonth m^{-3})			
	Total	Free Silica	Total	Free Silica
	479.60	118.80	608.20	169.80
	639.90	171.60	627.30	177.50
2/3	654.20	175.80	646.50	179.10
	668.60	179.90	449.70	179.90
	597.50	173.30	-	-
	522.60	131.20	610.30	176.80
	580.00	147.90	659.20	182.20
	702.00	189.60	668.80	184.50
3/2	725.90	196.60	678.30	186.80
	749.00	202.60	698.30	191.40
	611.80	177.40	687.10	186.80
	683.50	198.20	581.60	168.50
3/3	618.80	154.70	743.60	177.90
	650.00	162.50	774.80	189.70
	650.00	162.50	774.80	189.70
	681.20	162.30	808.00	193.50
	837.20	201.30	-	-

Appendix Table B-8 Comparison of Exposure (cumulative Total Respirable and and Free Silica) to Large Opacities

Large Opacity	Total Respirable Dust Dose (mgmonth m^{-3})	Free Silica Dost (mgmonth m^{-3})
	504.80	132.40
	540.70	141.90
	543.20	144.90
	614.80	155.30
	390.70	104.70
A	498.80	145.30
	510.80	148.80
	479.60	118.80
	522.60	131.20
	456.50	132.40
	470.80	136.60
	485.20	140.70
	513.90	149.10
	581.60	168.50
	610.30	176.80
	242.50	63.90
	242.60	63.90
	242.80	64.00
	456.50	129.60
	456.00	103.80
	567.90	107.00
B	580.00	147.90

Appendix Table B-9 Comparison of Exposure (cumulative Total Respirable Dust Dose) to Large Opacities (Luanshya mine)

Large Opacity Category	Cumulative Total Dust Dose (mgmonth m^{-3})	Cumulative Time of exposure (months)
A	695.10	512
	695.10	524
B	399.30	468
	208.70	406
	208.70	458
	208.70	482
C	399.30	529

APPENDIX C

Comparison of Exposure (Cumulative Total Respirable Dust Dose and Cumulative Free Silica Dose) to Nodule size classifications -p, m and n.

Appendix Table C-1 Comparison of Exposures (cumulative total respirable dust dose and cumulative free silica dose) to Nodule size classification P

Nodule size classification	Cumulative Respirable Dust Dose (mg month m^{-3})			
	Total	Free Silica	Total	Free Silica
	393.10	98.50	420.80	85.90
	424.30	106.30	428.50	87.90
	387.30	85.60	441.30	91.30
	399.20	88.70	456.60	95.30
	435.10	98.30	308.00	86.80
	444.00	100.60	470.80	136.50
	456.00	103.80	485.20	140.70
	467.90	107.00	374.50	91.30
P	357.30	87.80	392.00	116.30
	381.20	92.90	414.80	104.80
	371.50	105.00	391.70	109.10
	385.80	110.10	411.40	106.60
	452.30	114.40	420.30	101.90
	483.50	122.20	306.70	119.90
	514.70	130.00	322.10	114.30
	545.90	137.00	399.20	82.10
	577.10	141.70	447.00	86.10
	370.50	104.70	459.00	104.30
	427.80	121.30	445.60	117.00
	371.30	99.50	471.90	120.20
	376.40	100.80	453.90	124.90

Appendix Table C-1 continued

	351.00	91.10	482.60	132.50
	363.00	103.00	468.40	126.50
	374.90	104.60	408.70	106.70
	386.90	107.80	427.80	118.50
	398.80	111.20	346.90	123.10
	427.80	124.10	349.30	83.30
	363.70	84.00	378.00	88.10
	435.40	92.30	347.50	108.90
	347.80	95.40	436.50	123.40
	436.70	123.50	436.70	123.50
	455.90	128.10	502.10	139.30
	456.50	125.00		

Appendix Table C-2 Comparison of Exposures (cumulative total respirable dust dose and cumulative free silica dose) to Nodule size classification - m

Nodule size	Cumulative Respirable Dust Dose (mgmonth m^{-3})			
	Total	Free silica	Total	Free silica
	405.90	109.90	467.10	125.40
	420.50	120.50	492.70	133.80
	480.70	128.90	608.30	145.60
	496.10	180.70	423.90	149.50
	445.80	135.80	639.50	153.40
	503.80	137.80	655.10	157.30
	512.70	140.10	442.10	161.20
	520.40	142.10	323.90	125.50
M	524.30	143.10	540.30	129.60
	439.90	110.20	462.50	114.70
	465.90	116.70	424.20	123.00
	481.50	120.60	452.90	156.30
	497.10	124.50	567.60	113.10
	343.7o	88.20	461.80	121.50
	468.50	119.40	490.50	132.50
	515.30	123.30	300.60	140.80
	530.90	131.10	308.50	80.00
	399.20	135.00	316.20	82.00
	409.10	96.60	442.20	84.00
	411.10	97.90	618.80	86.00

Appendix Table C-2 continued

	423.10	99.20	681.20	128.20
	429.00	101.70	743.60	154.70
	435.00	102.90	423.50	162.50
	355.00	104.20	467.70	162.30
	441.50	101.40	319.80	177.90
	455.90	126.40	355.60	107.00
	470.20	130.50	391.50	116.20
	400.20	137.70	499.50	90.00
	488.40	153.40	451.80	99.50
M	430.70	109.10	500.30	129.20
	430.70	144.90	514.90	132.40
	399.40	120.40	529.20	141.90
	407.10	137.00	511.30	136.70
	429.00	124.00	535.20	140.80
	462.90	110.50	578.20	145.00
	425.70	103.60	554.50	149.20
	440.10	105.60	568.80	139.00
	523.70	111.40	509.10	143.10
	564.30	120.30	597.50	150.10
	616.90	124.10	611.80	162.50
	426.70	128.30	683.50	135.90
	445.90	152.50	317.50	160.80
	465.00	164.30	348.20	165.00
	492.10	179.60	504.30	173.30
	368.90	115.90	518.60	177.40

Appendix Table C-2 continued

	390.70	120.50	647.30	198.20
	411.20	125.10	398.40	89.50
	448.40	131.70	427.10	87.70
	480.00	109.10	455.70	111.10
	551.60	113.70	471.30	119.40
	449.80	124.70	486.70	126.40
	555.00	134.50	494.40	134.50
	336.20	139.50	502.10	138.50
M	357.90	147.20	502.70	140.50
	492.80	151.10	517.40	142.50
	504.80	162.10	532.80	144.50
	540.70	89.80	383.20	146.50
	486.20	95.40	426.50	150.50
	478.50	110.00	347.80	123.50
	348.00	95.40	458.90	95.50
	498.90	133.10	493.40	142.10
	317.30	98.60	324.40	91.50
	520.90	130.80	578.10	145.10
	533.30	145.00	564.00	153.00

Appendix Table C-3 Comparison of Exposures (cumulative total respirable dust dose and cumulative free silica dose) to Nodule size classification

Nodule size classification	Cumulative Respirable Dust-Dose (mgmmonth m^{-3})			
	Total	Free Silica	Total	Free Silica
	510.10	131.50	580.00	131.20
	523.10	134.50	509.10	147.90
	546.50	127.80	528.20	147.20
	556.90	131.00	543.20	151.80
	572.50	138.90	596.90	141.20
	588.10	141.50	611.20	148.80
	534.80	145.40	398.30	159.20
N	696.30	149.30	499.50	163.30
	710.70	164.60	390.70	171.60
	739.30	168.70	540.30	175.80
	796.70	177.10	614.80	179.90
	504.80	193.70	615.70	189.60
	533.50	145.00	631.30	196.60
	571.80	153.00	365.60	202.60
	456.80	164.40	373.30	104.70
	476.80	132.40	661.70	144.90
	485.20	136.50	690.30	155.30
	513.90	140.70	348.30	166.10
	774.80	149.10	362.60	170.00
	806.80	185.70	465.30	97.40
	837.20	139.50	639.90	99.40

Appendix Table C-3 continued

	474.90	201.30	654.20	91.50
	489.20	130.10	668.60	95.70
	546.60	134.20	702.00	95.70
	589.60	150.90	725.90	128.70
	601.60	163.40	749.00	135.60
N	473.60	166.80	494.00	142.00
	479.60	117.50	517.90	126.90
	522.60	118.80	438.20	124.30
	567.20	168.50	581.60	176.80
	610.20	170.20	608.20	169.80
	627.30	177.50	627.30	179.10
	646.50	179.90	649.60	182.20
	659.20	184.50	668.80	184.80
	678.30	189.10	687.90	191.40
	609.30	149.00		

Appendix Table C-4 Comparison of exposures (Total dust dose and free silica dose) to Nodule size classification n,p,m (Luanshya mine)

Nodule Size classification	Cumulative Total Dust Dose (mgmonth m^{-3})	Cumulative time of exposure (months)
	300.60	322
	399.30	369
	399.30	377
	399.30	468
	399.30	529
	534.00	315
N	567.60	331
	208.70	482
	695.10	487
	695.10	512
	695.10	524
	463.90	245
	318.80	328
	318.80	340
P	272.50	404
	285.00	228
	690.30	324

Appendix Table C-4 continued

M	208.70		406
	208.70		458
	695.10		427
	411.20		183

APPENDIX D

Individuals' Dust Exposure

Appendix Table D-1: Individual's Dust Exposure

Mine No.	Age (years)	Occupation	Occupation Dust Concentration - A_i (mgm^{-3})	No. of Months B_j (months)	Dust Dosage $A_i \times B_j$ ($mgmonthm^{-3}$)	Cumulative Dosage $\Sigma A_i B_j$ ($mgmonthm^{-3}$)	Cumulative Time ΣB_j (months)	Average Dust Concentration $\frac{\Sigma A_i B_j}{\Sigma B_j}$ (mgm^{-3})
10979	53	Lashing	4.00	2	8	8	2	
		Hangon	0.78	133	103.70	111.70	135	0.83
9485	53	Haulage Attendant	0.78	33	25.70	25.70	33	
		Hangon	0.78	77	60.10	85.80	110	0.78
		Track Laying	0.78	68	53.00	138.80	178	
10793	40	Drilling	3.61	12	43.30	43.30	12	
		Coal Cutting	2.145	18	38.60	81.90	30	1.07
		Track Laying	0.78	172	134.20	216.10	202	
10824	43	Track Laying	0.78	139	108.40	108.40	139	0.78
10827	53	Lashing	4.00	74	296.00	296.00	74	
		Roof Bolting	0.78	55	42.90	338.90	129	2.63
10874	39	Lashing	4.00	63	252.00	252.00	63	
		Drilling	3.61	73	263.50	515.50	136	3.80
10678	43	Drilling	3.61	156	563.20	563.20	156	3.61
10783	44	Lashing	4.00	146	584.00	584	146	4.00

Appendix Table D-1 Cont'd

10780	42	Lashing	4.00	87	348.00	348.00	87	
		Barring	0.78	84	65.50	413.50	171	2.42
10007	30	Roof Bolting	0.78	92	71.80	71.80	92	
		Charging	2.53	49	124.00	195.80	141	1.39
10053	52	Coal Cutting	2.145	19	40.80	40.80	19	
		Drilling	4.00	139	556.00	596.80	158	
		Section Ganger	2.61	51	133.10	729.90	209	3.49
10203	43	Lashing	4.00	105	420.00	420.00	105	
		Track Laying	0.78	77	60.10	480.10	182	2.64
10240	48	Track Laying	0.78	146	113.90	113.90	146	
		Rock Bolting	0.78	117	91.30	205.20	263	0.78
10558	34	Lashing	4.00	34	136.00	136.00	34	
		Track Laying	0.78	95	74.10	210.10	129	1.63
10584	43	Drilling	3.61	139	501.80	501.80	139	3.61
10589	42	Lashing	4.00	141	564.00	564.00	141	4.00
10618	48	Lashing	4.00	141	564.00	564.00	141	4.00
10439	40	Lashing	4.00	53	212.00	212.00	53	
		Drilling	3.61	121	436.80	648.80	174	3.73
10455	55	Charging	2.53	246	622.40	622.40	246	2.53

Appendix Table D-1 Cont'd

10467	49	Lashing	4.00	130	520.00	520.00	130	
		Track Laying	0.78	108	84.20	604.20	238	2.54
10488	44	Lashing	4.00	3	12.00	12.00	3	
		Charging	2.53	210	531.30	543.30	213	2.55
10307	46	Charging	2.53	141	356.70	356.70	141	2.53
10360	35	Charging	2.53	140	354.20	354.20	140	2.53
10435	53	Lashing	4.00	200	800.00	800.00	200	
		Supervisor Lashing	4.00	144	576.00	1376.00	344	4.00
9942	57	Production Ganger	2.61	265	691.70	691.70	265	2.61
9941	59	Lashing	4.00	108	432.00	432.00	108	
		Hangon	0.78	9	7.00	439.00	117	
		Track Laying	0.78	116	90.50	529.50	233	2.27
9937	50	Track Laying	0.78	264	208.90	208.90	264	0.78
9250	57	Drilling	3.61	167	602.90	602.90	167	
		Lashing	4.00	26	104.00	706.90	193	3.66
9206	47	Tracks/Hangon	0.78	78	60.90	60.90	78	
		Lashing	4.00	35	200.90	200.90	113	1.78
9435	56	Lashing	4.00	240	960.00	960.00	240	4.00

Appendix Table D-1 Cont'd

9462	56	Hangon	0.78	55	42.90	42.90	55	
		Lashing	4.00	170	680.00	722.90	225	3.21
11044	51	Lashing	4.00	150	600.00	600.00	150	
		Rope Splicing	0.78	74	57.70	657.70	224	
		Barring	0.78	109	85.00	742.70	333	2.23
11549	42	Drilling	3.61	91	328.50	328.50	91	
		Coal,Cutting	2.145	48	108.00	431.50	139	3.10
11686	45	Drilling	3.61	228	823.10	823.10	228	3.61
11682	48	Hangon	0.78	226	176.30	176.30	226	0.78
10986	44	Haulages	0.78	314	244.90	244.90	314	0.78
11064	50	Coal Lashing	4.00	100	400.00	400.00	100	
		Track Laying	0.78	122	95.20	495.20	222	2.23
11084	54	Track Laying	0.78	179	139.60	139.60	179	0.78
11093	47	Lashing	4.00	81	324	324	81	
		Barring	0.78	141	110.00	434	222	1.95
11118	46	Charging	2.53	312	789.40	789.40	312	2.53
11660	53	Barring/Track Laying	0.78	273	212.90	212.90	273	0.78
11559	43	Driller	3.61	149	537.90	537.90	149	
		Track Laying	0.78	67	52.30	590.20	216	2.73

Appendix Table D-1 Cont'd

10122	49	Driller	3.61	190	685.90	685.90	190	
		Hangon	0.78	26	20.30	706.20	216	3.27
11589	51	Hangon	0,78	51	39.80	39.80	51	
		Drilling	3.61	81	292.40	332.20	132	
		Barring	0.78	155	120.90	453.10	287	1.58
11634	55	Hangon	0.78	256	199.70	199.70	256	0.78
10675	41	Lashing	4.00	115	460.00	460.00	115	
		Drilling	3.61	21	75.80	535.80	136	
		Cutting	2.145	30	64.40	600.20	166	3.62
10612	50	Ganger	2.61	191	498.50	498.50	191	
		Haulage	0.78	111	86.60	585.10	302	1.94
10588	54	Shift Boss Messanger	2.61	131	341.90	341.90	131	
		Hangon	0.78	35	27.30	369.20	166	
		Production Ganger	2.61	129	336.70	705.90	295	2.39
10564	58	Lashing	4.00	134	536.00	536.00	134	
		Hangon	0.78	80	62.40	598.40	214	2.80
10528	57	Tracking Laying	0.78	280	170.40	170.40	280	
		Charging	2.53	33	82.50	253.90	313	0.81

Appendix Table D-1 Cont'd

11790	54	Barring/Hangon	0.78	163	127.10	127.10	163	
		Lashing	4.00	58	232.00	395.10	221	1.79
11771	52	Tracks/Hangon	0.78	239	186.40	186.40	239	0.78
10531	50	Track Laying	0.78	153	119.30	119.30	153	0.78
10563	43	Lashing	4.00	3	12.00	12.00	3	
		Hangon/Haulage	0.78	146	113.90	125.90	149	0.84
10621	56	Production Leader	2.61	334	871.70	871.70	334	
		Haulage	0.78	19	14.80	886.50	353	2.51
11592	51	Lashing	4.00	46	184.00	184.00	46	
		Barring/Hangon	0.78	201	156.80	340.80	247	1.38
10649	56	Haulage	0.78	190	148.20	148.20	190	
		Production Ganger	2.61	108	281.90	430.10	298	1.44
11546	56	Lashing	4.00	22	88.00	88.00	22	
		Hangon/Haulage	0.78	149	116.20	204.20	171	1.19
10675	41	Lashing	4.00	114	456.00	456.00	114	
		Drilling	3.61	21	75.80	531.80	135	
		Cutting	2.145	30	64.40	596.20	165	3.61
11527	38	Haulage/Hangon	0.78	128	99.80	99.80	128	0.78
10723	58	Lashing	4.00	63	252.00	252.00	63	
		Hangon/Tracks	0.78	127	99.10	352.10	190	
		Production Ganger	2.61	77	201.00	553.10	267	2.07
11512	55	Drilling	3.61	137	494.60	494.60	137	
		Track Laying	0.78	245	149.10	643.70	382	1.69

Appendix Table D-1 continued

11458	50	Tracks	0.78	105	89.90	81.90	105	
		Charging	2.53	33	83.50	165.40	138	
		Production gauger	2.61	94	245.30	410.70	232	1.77
11161	50	Lashing	4.00	142	568.00	568.00	142	
		Burning	0.78	138	107.60	675.60	280	2.41
11260	52	Timbering	0.78	229	178.60	178.60	229	0.78
11262	50	Lashing	4.00	238	952.00	952.00	238	
		Tracklaying	0.78	33	25.70	977.70	271	3.61
10497	30	Tracks	0.78	115	89.70	89.70	115	0.78
9508	41	Lashing	4.00	74	296.00	296.00	74	
		Drilling	3.61	16	57.80	353.80	90	
		Haulage	0.78	55	42.90	396.70	145	2.78

Appendix Table D-1 continued

9505	46	Drilling	3.61	26	93.90	93.90	26	
		Pumps	0.78	32	25.00	118.90	58	
		Lashing	4.00	78	312.00	430.90	136	3.17
11512	50	Drilling	3.61	140	505.40	505.40	140	
		Tracks	0.78	143	111.50	616.90	183	3.37
11476	53	Hangon	0.78	302	235.60	235.60	302	0.78
11458	53	Tracks	0.78	104	81.10	81.10	101	
		Charging	2.53	31	78.40	159.50	135	
		Production gauger	2.4	84	219.20	378.70	219	1.73
9288	50	Lashing	4.00	170	680.00	680.00	170	
		Hangon	0.78	46	35.90	715.90	216	1.73

Appendix Table D-1 continued

11346	43	Lashing	4.00	1	4.00	4.00	1	
		Hangon	0.78	139	108.40	112.40	140	0.80
11001	52	Haulage	0.78	163	127.10	127.10	163	0.78
11552	46	Drilling	3.61	56	202.20	202.20	56	
		Charging	2.53	1	2.50	204.70	57	
		Hangon	0.78	5	3.90	208.60	62	
		Gauger	2.61	148	386.30	594.90	210	2.83
10771	56	Haongon	0.78	235	183.30	183.30	235	
		Charging	2.53	133	336.50	519.80	268	2.15
11407	52	Lashing	4.00	87	348.00	348.00	87	
		Haulage	0.78	117	91.30	439.30	204	2.15
11091	59	Lashing	4.00	125	500.00	500.00	125	
		Hangon	0.78	94	73.30	473.30	219	2.62

Appendix Table D-1 continued

10804	55	Lashing	4.00	12	48.00	48.00	12	
		Hangon	0.78	190	148.20	196.20	202	0.97
10865	52	Lashing	4.00	57	228.00	228.00	57	
		Haulage	0.78	83	64.70	292.70	140	2.09
10092	54	Lashing	4.00	89	356.00	356.00	89	
		Charging	2.53	152	384.60	740.60	241	
		Hangon	0.78	16	12.50	752.90	257	2.93
11606	55	Bricklaying	0.78	323	251.90	251.90	323	0.78
11477	46	Lashing	4.00	113	452.00	452.00	113	
		Tracks	0.78	117	91.30	543.30	230	2.36
11537	48	Lashing	4.00	93	372	372.0	93	
		Drilling	3.61	114	411.50	783.50	207	3.79

Appendix Table D-1 continued

11700	36	Lashing	4.00	31	124.00	124.00	31	
		Drilling	3.61	110	397.10	521.10	141	3.70
11840	50	Lashing	4.00	79	316.00	316.00	79	
		Drilling	3.61	100	361.00	677.0	179	3.78
11824	46	Lashing	4.00	220	880.00	880.00	220	4.00
11816	52	Tracks	0.78	130	101.40	101.40	130	
		Charging	2.53	146	369.40	470.80	276	1.71
11745	56	Drilling	3.61	49	179.90	179.90	49	
		Track	0.78	161	125.60	305.50	210	1.45
11697	48	Drilling	3.61	216	779.80	779.80	216	
		Roof Bolting	0.78	66	51.50	831.30	282	2.92
11019	42	Lashing	4.00	78	312.00	312.00	78	
		Drilling	3.61	107	386.30	698.30	185	3.77

Appendix Table D-1 continued

11466	44	Tracks	0.78	303	236.30	236.30	303	0.78
10985	57	Production gauger	2.61	159	415.00	415.00	159	
		Tracks	0.78	112	87.40	502.40	271	1.85
10992	47	Lashing	4.00	48	192.00	192.00	48	
		Haulage	0.78	90	70.20	262.20	138	1.90
11483	47	Haulage	0.78	223	173.90	173.90	223	0.78
11310	36	Lashing	4.00	24	96.00	96.00	24	
		Tracks	0.78	147	114.70	210.70	171	1.23
11278	39	Haulage	0.78	218	170.00	170.00	218	0.78
11190	51	Lashing	4.00	108	432.00	432.00	108	
		Barring	0.78	42	32.80	408.20	146	2.80
11143	47	Lashing	4.00	176	704.00	704.00	176	
		Barring	0.78	51	39.80	743.80	227	3.28

Appendix Table D-1 continued

11129	44	Lashing	4.00	116	464.00	464.00	116	
		Charging	2.53	117	296.00	760.00	233	3.26
10158	37	Lashing	4.00	130	520.00	520.00	130	
		Tracks	0.78	78	60.80	580.80	208	2.79
11553	43	Drilling	3.61	134	483.70	483.70	134	3.61
11588	37	Lashing	4.00	27	108.00	108.00	27	
		Drilling	3.61	112	404.30	512.30	139	3.69
10446	48	Cutting	2.145	117	251.00	251.00	117	
		Bricklaying	0.78	142	110.80	361.80	269	134
10535	50	Lashing	4.00	44	176.00	176.00	44	
		Charging	2.53	69	174.60	350.60	113	
		Fitting	0.78	131	102.20	452.80	244	1.86
6145	47	Drilling	3.61	88	317.70	317.70	88	
		Hangon	0.78	134	104.50	422.20	222	
		Charging	2.53	2	5.10	427.30	224	1.91

Appendix Table D-1 continued

10427	50	Lashing	4.00	186	744	744.00	186	
		Hoist Driver	-	88	0	744.00	274	2.72
10149	42	Lashing	4.00	103	412.00	412.00	103	
		Barring	0.78	136	106.10	518.10	239	2.17
10885	40	Lashing	4.00	95	380.00	380.00	95	
		Barring	0.78	145	113.10	493.10	240	2.05
11021	40	Hangon	0.78	245	191.10	191.10	245	0.78
11842	44	Gangleader	0.78	272	212.20	212.20	272	0.78
		Haulage						
10447	47	Haulage	0.78	88	68.60	68.60	88	
		Lashing	4.00	156	624.00	692.60	244	2.84
10599	43	Haulage	0.78	187	145.90	145.90	187	
		Lashing	4.00	39	156.00	301.90	226	1.34

Appendix Table D-1 continued

11456	50	Tracks	0.78	266	207.50	207.50	266	0.78
11100	37	Hangon	0.78	200	156.00	156.00	200	
		Lashing	4.00	43	172.00	328.00	243	1.35
11079	42	Lashing	4.00	66	264	264	66	
		Hangon	0.78	200	156	420	266	1.58
11291	50	Lashing	4.00	64	256.00	256.00	64	
		Fitters	0.78	174	135.70	391.70	238	1.65
9863	47	Lashing	4.00	80	320.00	320.00	80	
		Hangon	0.78	61	47.60	367.60	141	2.610
11412	53	Haulage	0.78	323	251.90	250.90	323	
		Lashing	4.00	18	72.00	323.90	341	0.950
9822	41	Hangon	0.78	266	207.50	207.50	266	0.78

Appendix Table D-1 continued

11629	58	Lashing	4.00	93	372.00	372.00	93	
		Drilling	3.61	99	357.40	729.40	192	
		Cutting	2.145	47	100.80	830.20	239	3.47
10001	56	Hangon	0.78	245	191.10	191.10	245	0.78
9819	52	Lashing	4.00	161	644.00	644.00	161	4.00
10284	42	Lashing	4.00	58	232.00	232.00	58	
		Fitter	0.78	171	133.40	365.40	229	1.60
10288	48	RoofBolting	0.78	255	198.90	198.90	225	0.78
9733	44	Hangon	0.78	70	54.60	54.60	70	
		Driller	3.61	120	433.20	487.80	190	2.57
10974	60	Lashing	4.00	12	48.00	48.00	12	
		Barring	0.78	214	166.90	214.90	226	0.95
11125	43	Lashing	4.00	24	96.00	96.00	24	
		Drilling	3.61	41	148.00	244.00	65	
		Hangon	0.78	41	32.00	276.00	106	2.60

Appendix Table D-1 continued

10910	37	Lashing	4.00	14	56.00	56.00	14	
		Hangon	0.78	160	124.80	180.80	174	1.04
11205	60	Production gauger	2.61	343	895.20	895.20	343	2.61
11161	50	Lashing	4.00	142	568.00	568.00	142	
		Barring	0.78	138	107.60	675.60	280	2.41
11457	44	Tracks	0.78	220	171.60	161.60	220	0.78"
11589	51	Drilling	3.61	81	292.40	292.80	81	
		Barring	0.78	155	120.90	43.30	236	1.75
11771	52	Tracks/Haulage	0.78	240	187.20	187.20	240	0.78
11790	54	Lashing	4.00	63	252.00	252.00	63	
		Hangon	0.78	122	95.20	347.20	185	1.88
11264	59	Haulage	0.78	349	272.20	272.20	349	0.78
10386	40	Lashing	4.00	166	664.00	664.00	166	
		Hangon	0.78	205	159.90	823.90	371	2.22

Appendix Table D-1 continued

10076	52	Hangon	0.78	281	219.20	219.20	281	0.78
10305	55	Charging	2.53	130	328.90	328.90	130	2.53
9931	50	Roof/Botting	0.78	218	170.00	170.00	218	0.78
10416	44	Lashing	4.00	34	136.00	136.00	34	
		Hangon	0.78	110	85.80	221.80	144	1.54
11546	56	Lashing	4.00	42	168.00	168.00	42	
		Hangom	0.78	183	142.70	310.70	225	1.38
11262	52	Lashing	4.00	102	408.00	408.00	102	
		Tracklaying	0.78	39	30.40	438.40	141	3.11
9122	49	Hangon	0.78	254	198.10	198.10	254	
		Charging	2.53	19	48.10	246.20	273	0.90

Appendix
Table D-2: Cases with Cumulative Dust Exposure ≥ 700mgmonthm^{-3}

Mine No	Cumulative dosage (mgmonthm^{-3})	Cumulative time of (months)	Average dust concentration (mgm^{-3})	Stage of Pneumoconiosis
10053	729.90	203	3.49	
10435	1376.00	344	4.00	
9250	706.90	193	3.66	
9435	960.00	240	4.00	
9462	722.90	225	3.21	1
11044	742.70	333	2.23	2
11686	823.10	228	3.61	
11118	789.40	312	2.53	
10122	706.20	216	3.27	
10588	705.90	295	2.39	
10621	886.50	353	2.51	
11262	977.70	271	3.61	
9288	715.90	216	1.73	
10092	752.90	257	2.93	2
11537	783.50	207	3.79	
11824	880.00	220	4.00	
11697	831.30	282	2.95	
11143	743.80	227	3.28	
11129	760.00	233	3.26	
10427	744.00	274	2.72	
11629	830.20	239	3.47	
11205	895.20	343	2.61	
10386	823.9	371	2.22	

APPENDIX E

Occupation Dust Concentration Results for Various Mining Occupations using Various Sampling Instruments

Table E-1: Occupation Dust Concentration Results for Lashing using Casella Personal Sampler

Location	Particle Number (p.p.c.c)	Mineral Oil (mgm^{-3})	Soot Carbon (mgm^{-3})	Incombustible Dust (mgm^{-3})	Total Dust (mgm^{-3})
700mL C73/57-P8 /P9 D.P.L.*	N.D.	1.175	1.17	0.16	2.6225
"	N.D.	1.175	1.17	0.698	3.043
775mL B81/41 P9 Vent Raise	N.D.	0.28	2.12	0.35	2.75
"	N.D.	0.42	0.325	0.525	1.27
"	430	0.41	0.50	4.24	5.15
"	360	0.13	0.82	4.73	5.71
700mL C73/57-P8 D.P.L.	300	0.09	0.03	0.29	0.41
"	320	0.95	0.40	0.06	1.41
"	350	0.14	0.14	0.57	0.85
700mL C73/57 Stope	150	0.01	0.01	0.43	0.45
"	150	NIL	0.109	1.315	1.424
700mL C73/57-P8 /P9 D.P.L.	290	0.61	0.50	1.00	2.11
"	240	0.21	NIL	0.70	0.91
"	270	0.46	0.39	1.38	2.23
"	N.D.	NIL	0.44	0.22	0.66
"	N.D.	0.42	0.21	0.83	1.46
730mL C73/58 Stope	N.D.	1.09	NIL	0.51	1.6
730mL C73/45-46 Slot Raise	240	0.25	0.61	NIL	0.86
810mL C81/48 P8 - D.P.L.	520	0.35	NIL	1.55	1.90
"	150	0.24	0.95	0.02	1.21
730mL C73/49 Stope	40	0.85	2.15	1.23	4.25
"	40	0.97	1.71	0.68	3.36
"	300	0.17	0.05	NIL	0.22

*D.P.L. - Draw Point Loading

Table E-1 Cont'd

730mL C78/49 P6 D.P.L.	200	0.17	0.22	0.90	1.29
"	N.D.	0.605	0.283	0.006	0.896
"	N.D.	0.885	0.933	0.21	2.03
"	N.D.	0.355	0.135	0.52	1.01
730mL"C73/49 P6	"	0.26	0.26	0.418	0.938
DPL "	"	0.37	NIL	0.16	0.57
"	"	0.106	0.638	1.17	1.914
"	"	0.190	0.26	0.68	1.13
"	"	0.42	0.15	0.96	1.54
"	530	0.31	0.32	3.47	4.10
"	250	0.31	0.15	1.67	2.110
"	560	0.28	NIL	0.36	0.64
"	200	NIL	1.34	1.35	2.69
"	270	0.10	0.11	0.63	0.84
"	350	0.46	0.05	2.01	2.52
"	N.D.	0.6424	NIL	0.2677	0.9101
"	"	0.1063	0.4255	0.4255	0.9573
"	"	0.1054	0.4746	0.5801	1.1601
"	"	0.80	0.40	0.75	1.95
"	"	0.59	0.21	0.74	1.54
"	"	0.27	1.99	0.05	2.31
"	190	0.16	0.16	0.21	0.53
865mL C81/24 Block	250	0.24	0.21	0.39	0.84
810mL B81/42 P6 -7 X/cut North	400	0.32	0.31	0.46	1.09
"	140	0.21	0.16	0.21	0.58
"	N.D.	0.9758	1.4934	0.3796	2.8488
810mL B81/49 P6 D.P.L.	90	0.29	0.03	0.92	1.24
"	220	0.24	0.97	3.86	5.07
810mL C73/49 P5 Main Tip	300	0.02	0.01	1.34	1.36
730mL C73/49 Stope	290	0.07	0.59	0.07	0.73
"	170	0.11	0.11	0.13	0.35

Table E-1 Cont'd

730mL B81/42-43, Pl Vent Raise	530	0.41	0.17	0.14	0.72
"	290	0.24	1.60	0.29	2.13
760mL B81/42-43, Pl Vent Raise	100	0.42	1.28	0.06	1.79
"	N.D.	0.678	1.923	0.113	2.714
730mL C73/49 Stope	N.D.	1.0638	1.0638	0.5319	2.6595
"	N.D.	1.186	NIL	0.494	1.68
"	530	0.26	0.20	0.97	1.43
"	170	0.58	NIL	2.24	2.83

Table E-2: Occupation Dust Concentration Results for Crushing using Casella Personal Sampler and Konimeter

Location	Particle Number (p.p.c.c)	Mineral Oil (mgm^{-3})	Soot Carbon (mgm^{-3})	Incombustible Dust (mgm^{-3})	Total Dust (mgm^{-3})
900mL C96/49 crusher	390	0.09	0.09	1.92	2.10
"	370	0.45	0.77	0.82	2.04
"	250	0.25	0.38	0.12	0.75
"	420	0.35	0.35	1.72	2.42
"	270	NIL	NIL	1.54	1.54
"	430	0.04	0.99	3.05	4.08
"	390	0.30	0.30	1.22	1.82
"	280	0.0245	0.0245	0.78	0.87
"	250	0.07	NIL	2.99	3.06
11 Shaft Crusher Station	N.D.**	0.24	0.42	1.73	2.39
"	N.D.	0.24	0.54	1.14	1.92
"	320	0.06	0.28	0.73	1.07
"	380	0.12	0.30	2.02	2.44
"	300	0.20	0.96	0.66	1.82
"	190	0.35	0.98	2.73	4.06
"	196	0.05	0.47	2.66	3.18
"	200	0.25	0.24	1.74	2.23
"	770	0.68	0.10	2.42	4.2
"	360	0.025	0.025	2.26	2.31
"	230	0.06	0.56	0.11	0.73
"	210	0.06	0.06	0.45	0.57
"	400	1.24	0.45	0.79	2.48
"	300	0.06	0.28	1.91	2.25
"	330	0.29	1.03	1.03	2.35
"	340	0.06	0.98	0.130	1.17
"	220	NIL	0.52	0.52	1.04
"	250	0.06	1.08	0.12	1.26
"	270	0.05	0.06	0.40	0.51
"	320	0.17	0.11	0.11	0.39

**N.D. - Not Determined.

TABLE E-3: Occupation Dust Concentration Results for Conveying Using Casella Personal Sampler and Konimeter

Location	Particle Number (p.p.c.c)	Mineral Oil (mgm^{-3})	Soot Carbon (mgm^{-3})	Incombustible Dust (mgm^{-3})	Total dust (mgm^{-3})
790mL-910ml-1144, 1145 & 1146 Conveyors	N.D.	0.06	0.56	0.11	0.73
"	N.D.	0.06	0.06	0.45	0.57
"	N.D.	1.24	0.45	0.79	2.48
"	330	0.00	0.28	1.91	2.25
"	250	0.06	1.08	0.12	1.26
"	220	NIL	0.52	0.52	1.04
"	330	0.29	1.03	0.03	1.35
"	340	0.04	0.98	0.13	1.13
"	270	0.05	0.06	0.40	0.51
"	320	0.17	0.11	0.11	0.39

Table E-4: Occupation Dust Concentration Results for Hoisting (Cage Tender) using Casella Personal Sampler and Konimeter

Location	Particle Number (p.p.c.c)	Mineral Oil (mgm^{-3})	Soot Carbon (mgm^{-3})	Incombustible Dust (mgm^{-3})	Total Dust (mgm^{-3})
430mL - 500mL Lift Shaft	40	0.19	0.19	NIL	0.38
"	40	0.25	NIL	0.14	0.39
"	40	0.13	NIL	0.26	0.39
"	40	0.10	0.10	0.10	0.30
"	260	0.32	NIL	0.13	0.45

Table E-5: Occupation Dust Concentration Results for Timbering using Casella Personal Sampler and Konimeter

Location	Particle Number (p.p.c.c)	Mineral Oil (mgm^{-3})	Soot Carbon (mgm^{-3})	Incombustible Dust (mgm^{-3})	Total Dust (mgm^{-3})
975mL C96/47 -48 Ramp Winze	180	0.09	0.19	1.03	1.31
"	100	0.13	1.18	0.01	1.32
"	70	0.08	0.31	0.69	1.08
"	180	NIL	NIL	0.08	0.08
960mL C96/47 -48 Ramp Winze	180	0.09	1.19	1.03	1.31
"	130	0.19	0.19	0.13	0.51
975mL C96/47 -48 Ramp Winze	100	NIL	0.07	0.28	0.35
500-880mL M3 Shaft	40	NIL	NIL	0.01	0.01
"	150	0.15	0.02	0.35	0.52
730mL Draw Point C73/49 P6	200	0.17	0.05	NIL	0.22

Table E-6: Occupation Dust Concentration Results for Hoisting (Top Lander) using Casella Personal Sampler and Konimeter

Location	Particle Number (P.p.c.c)	Mineral Oil (mgm^{-3})	Soot Carbon (mgm^{-3})	Incombustible Dust (mgm^{-3})	Total Dust (mgm^{-3})
11 Shaft Top Lander	40	0.12	0.30	NIL	0.42
"	40	NIL	0.07	0.15	0.22
"	40	NIL	NIL	0.19	0.19
"	40	0.27	0.13	0.20	0.60
"	40	NIL	NIL	0.13	0.13
"	40	0.30	0.06	0.06	0.42
"	40	NIL	0.07	0.14	0.21

Table E-7: Occupation Dust Concentration Results for Conveying using Casella Personal Sampler and Konimeter

Location	Particle Number (p.p.c.c.)	Mineral Oil (mgm^{-3})	Soot Carbon (mgm^{-3})	Incombustible Dust (mgm^{-3})	Total Dust (mgm^{-3})
81OmL C81/46-47 Loop	250	0.09	0.10	0.06	0.25
"	150	0.26	NIL	0.51	0.77
	100	NIL	NIL	1.71	1.71
"	40	0.28	2.80	1.12	4.20
"	100	0.42	0.69	2.50	3.61
"	40	0.06	0.80	0.12	0.98
"	340	NIL	NIL	1.31	1.31
"	100	0.62	0.62	0.12	1.36
"	40	0.06	0.06	0.57	0.69
"	260	0.03	0.03	0.65	0.71
81OmL C81/37-39 Loop North	440	0.26	0.26	1.06	1.38
"	490	0.21	0.21	0.72	1.14
"	340	0.21	0.32	0.42	0.95
"	500	0.16	0.16	0.86	1.19
"	300	0.39	0.06	0.83	1.28
"	420	0.41	0.23	1.57	2.21
"	860	0.44	0.38	3.45	4.27
"	380	0.50	0.52	0.52	1.54
81OmL C81/42-43 Loop North	190	0.32	0.64	0.32	1.28
"	280	0.67	0.07	0.32	1.28
"	260	NIL	NIL	0.06	0.06
"	270	0.06	0.06	0.26	0.38
"	250	0.06	0.06	0.38	0.50
"	200	0.06	0.32	0.26	0.64
"	230	NIL	2.35	NIL	2.35
"	250	0.19	0.19	0.06	0.44
"	350	0.09	0.09	0.18	0.36
81OmL C81/42-43 Loop North	260	0.32	NIL	0.13	0.43

Table E-7 Cont'd

81OmL C81/26-28 Blocks	N.D.	0.057	0.91	0.51	1.48
"	160	0.16	0.80	0.54	1.50
"	90	0.31	0.42	1.02	1.75
"	140	0.10	0.02	0.02	0.14
"	300	NIL	NIL	0.59	0.59
"	50	0.20	0.18	2.60	2.98
"	240	NIL	0.34	0.78	1.12
"	210	0.11	0.23	0.57	0.91
"	170	0.13	0.37	1.31	1.81
"	230	NIL	NIL	0.33	0.33
81OmL C81/26-28 Block	300	0.41	0.58	0.41	1.40

Table E-8: Occupation Dust Concentration Results for Various Operations using MRE 113A and Konimeter

Location	Operation/ Occupation	Total Dust (mgm^{-3})	Particle Number (p.p.c.c.)
730mL C73/62-63 Loop	Drilling	1.23	67
"	"	1.53	67
"	"	0.63	45
760mL C81/47-P9 X/CN*	"	0.45	41
"	"	2.75	430
"	"	1.55	360
"	"	2.17	430
"	"	1.68	280
"	"	1.02	290
730mL C73/55 P5 Vent Raise	"	2.30	380
"	"	0.76	210
"	"	2.60	ND
"	"	2.80	370
"	"	0.78	70
775mL B81/42 P3 X/CN	"	1.86	320
"	"	2.98	400
"	"	1.88	290
900mL C96/49 crusher	Crushing	1.50	375
"	"	1.21	375
"	"	0.39	90
"	"	1.07	210
"	"	1.29	330
"	"	3.74	410
"	"	3.27	402
11 Shaft Crusher Station	"	4.67	450
"	"	5.086	910
"	"	1.28	1.87
"	"	2.64	209
"	"	3.96	390
"	"	3.02	467
"	"	1.09	198

*X/CN - Cross Cut North

Table E-8 Cont'd

810mL C81/46-47 Loop North	Tramming	1.38	286
"	"	0.37	100
"	"	1.63	310
"	"	0.48	120
"	"	1.42	290
"	"	1.54	300
"	"	1.90	380
"	"	1.70	330
"	"	0.76	280
810mL C81/42-43 Loop North	"	0.87	260
"	"	1.13	239
"	"	0.31	243
"	"	1.39	300
"	"	0.10	110
"	"	2.90	560
"	"	1.48	380
"	"	1.87	190
"	"	1.68	380
790-910mL 1144, 1145 & 1146 Conveyors	Conveying	0.08	38
"	"	0.40	100
"	"	0.34	40
"	"	0.68	40
"	"	0.62	210
"	"	2.30	460
"	"	0.25	58
"	"	0.07	32
"	"	1.20	380
"	"	1.40	360
"	"	2.63	340
"	"	0.98	280
"	"	0.80	110
"	"	2.52	400
"	"	0.67	250
810mL C81/49 P5 Main Tip	Tipping	0.22	40
"	"	2.01	356

Table E-8 Cont'd

810mL C81/49 P5 Main Tip	Tipping	2.67	400
"	"	0.96	160
"	"	1.80	290
730mL C73/49 P5 Main Tip	"	0.44	80
"	"	1.08	90
"	"	6.70	720
"	"	7.67	740
"	"	1.92	296
"	"	0.31	40
810mL C81/49 P5 Main Tip	"	1.96	308
"	"	0.73	120
"	"	4.81	546
"	"	2.72	470
700mL C73/57-P8/P9 D.P.L.	Lashing	0.41	N.D.
"	"	3.03	N.D.
"	"	2.09	200
"	"	2.50	247
700mL C73/57-P8/P9 DPL	"	2.30	240
"	"	1.80	218
"	"	2.79	250
700mL C73/57 Stope	Lashing	2.76	240
"	"	0.84	160
"	"	3.60	390
"	"	2.10	200
"	"	0.21	90
"	"	4.20	520
"	"	4.67	530

Table E-9: Occupation Dust Concentration Results for Various Operations using Hexhlet and Konimete

Location	Operation	Particle Number (p.p.c.c)	Mineral Oil (mgm^{-3})	Soot Carbon (mgm^{-3})	Incombustible Dust (mgm^{-3})	Total Dust (mgm^{-3})
730mL C73/62-63 Loop Development Drive	Drilling	N.D.***	0.10	0.07	0.34	0.51
"	"	N.D.	0.21	0.05	0.26	0.52
760mL B81/41 P9 Vent Raise	"	N.D.	0.07	0.14	0.15	0.36
"	"	N.D.	0.27	0.28	0.15	0.70
"	"	N.D.	0.27	0.21	0.28	0.76
730mL C81/47- P9 X/C	"	N.D.	0.27	0.24	0.29	0.80
730mL C73/57- P9 Tramming	"	N.D.	0.46	0.29	0.17	0.92
"	"	N.D.	0.47	0.29	0.36	1.12
760mL C81/55- P5 Vent Raise	"	360	0.46	0.99	1.84	3.29
"	"	430	0.47	0.91	0.28	1.66
"	"	420	0.86	0.53	1.32	2.71
"	"	430	0.86	1.13	0.91	2.90
775mL C81/37 P5 Vent Raise	"	280	0.12	0.18	0.32	0.62
"	"	210	0.17	0.17	0.29	0.63
775mL B81/42 P3 X/CS	"	200	0.48	0.48	0.27	1.27
"	"	290	0.59	0.16	0.22	0.97
"	"	320	0.52	NIL	0.28	0.80
"	"	300	0.62	0.19	0.36	1.17
"	"	60	0.21	0.21	0.11	0.53

***N.D. - Not Determined

Table E-9 Cont'd

865mL MRA** East	Drilling	50	0.65	0.04	0.19	0.88
"	"	N.D.	0.14	0.13	0.16	0.43
775mL C81/41 P1 Vent X/CS*	"	N.D.	0.71	0.42	0.92	2.05
730mL C73/60- P5 Mining Drive	"	N.D.	0.35	0.40	0.28	1.03
"	"	"	1.39	0.67	0.13	1.19
730mL C73/60- P5 Mining Drive	"	"	0.41	0.17	0.14	0.72
730mL C73/52 P6 D.P.L.	Lashing	500	0.26	0.26	0.81	1.33
"	"	500	0.29	1.89	0.59	2.77
"	"	500	0.49	0.16	0.16	0.81
"	"	500	0.50	2.01	1.60	4.11
760mL C81/52 P6 D.P.L.	"	418	0.32	0.32	1.16	1.80
"	"	483	0.59	0.53	1.20	2.37
760mL C81/43 P1 Vent Raise	"	250	0.50	1.58	0.70	2.78
"	"	500	0.29	0.44	0.73	1.49
"	"	480	0.34	0.65	0.53	1.52
760mL C81/42 P6 X/CN	"	130	0.47	0.04	0.26	0.77
"	"	320	0.44	1.50	0.53	2.47
730mL C73/58 P2 D.P.L.	"	120	0.17	0.44	0.05	0.66
"	"	370	0.02	0.32	0.11	0.45
760mL B81/42 P7 X/CN	"	250	0.23	0.25	0.21	0.69
"	"	320	0.27	0.28	0.22	0.77
760mL B81/42 P6 X/CN	"	280	0.39	0.45	0.42	1.26
"	"	230	0.43	0.53	0.44	1.40
775mL B81/41 P9 Vent Raise	"	220	0.14	0.33	0.08	0.55

**MRA - Main Return Airway

*X/CS - Cross Cut South

Table E-9 Cont'd

775mL B81/41 P9 Vent Raise	Lashing	280	0.20	0.31	0.23	0.74
"	"	550	0.24	0.62	0.42	1.28
"	"	560	0.20	0.58	0.53	1.31
"	"	160	0.20	0.20	0.20	0.60
"	"	170	0.06	0.14	0.14	0.34
"	"	190	0.21	0.20	0.20	0.61
"	"	230	0.53	0.02	0.79	1.34
810mL C81/49 P5 Main Tip	Tipping	N.D.	0.36	9.28	0.41	10.05
"	"	"	0.23	10.72	1.072	12.022
"	"	"	0.12	0.07	0.42	0.61
"	"	"	0.20	0.62	1.62	2.44
810mL C81/49 P5 Main Tip	"	"	0.19	0.01	0.21	0.41
"	"	"	0.09	0.20	0.64	0.93
730mL C73/49 P5 Tip	"	"	0.12	0.02	0.82	0.96
"	"	"	NIL	NIL	0.45	0.45
"	"	"	0.16	0.24	1.35	1.75
"	"	"	0.22	0.10	0.81	1.13
"	"	"	0.23	0.42	0.92	1.57
810mL C81/49 P5 Main Tip	"	"	0.20	5.72	5.00	10.92
"	"	"	0.09	0.62	1.62	2.33
"	"	"	0.20	0.20	0.64	1.04
810mL C81/14 Shaft Crusher	Crushing	179	0.56	0.56	2.22	3.34
"	"	207	0.45	0.45	1.98	2.88
"	"	428	0.86	0.86	2.78	4.50
"	"	211	0.95	0.95	0.37	2.27
"	"	938	0.48	0.48	3.33	4.29

Table E-9 Cont'd

900 C86/46 Crusher	Crushing	196	0.41	0.41	0.47	1.29
"	"	430	0.81	0.81	3.33	4.95
"	"	173	0.50	0.50	4.24	5.24
"	"	218	0.82	0.82	4.76	6.40
810mL C81/14 Shaft Crusher	"	1000	0.97	0.97	3.86	5.80
900mL C96/49 Crusher	"	N.D.	0.41	0.41	0.47	1.29
"	"	N.D.	0.84	0.84	3.38	5.06
810mL C81/43 P8 Loop North	Tramming	280	0.07	0.04	0.53	0.64
"	"	330	0.10	0.02	0.66	0.78
"	"	470	0.17	0.25	0.45	0.87
"	"	500	0.11	0.25	0.40	0.76

Table E-10: Occupation Dust Concentration Results for Miscellaneous using MRE 113A

Location	Mass Concentration (mgm^{-3})
45 East Haulage 1-2 X/cuts	0.99
82 North Ex 14 West Haulage	0.96
65 North Ex 14 West Haulage	1.27
3 South Ex 7 West Haulage 3X/cuts	0.82
21 East Ex 54 South Haulage 21X/cuts	0.83
4 West Ex Main South Haulage	0.46
6 West Ex 40 North Haulage	0.52
16 West Ex 40 North Haulage	0.85
16 East Ex 40 North Haulage	0.72
6 South Ex East Diagonal Haulage	1.39
7 North Ex 18 East Haulage	1.24
18 East Ex 18 North Haulage	1.97
4 West Ex Main South Haulage	0.31
27 East Ex 30 South Haulage	0.55
82 North Ex 14 West Haulage	1.22
65 North Ex 14 West Haulage	1.37
3 South Ex 7 West Haulage 1-2 x/cuts	0.47
22 East Ex 54 South Haulage	0.98
6 West Ex 40 North Haulage	0.87
16 West Ex 40 North Haulage	1.24
11 North Ex 16 West Haulage	0.90
6 South Ex West Diagonal Haulage	1.21
7 North Ex 18 East Haulage	1.24
18 East Ex 18 North Haulage	0.95
65 North Ex 14 West Haulage	1.84
3 South Ex 7 West Haulage	0.49
22 East Ex 54 South Haulage	0.69
7 South Ex West Haulage 7/8 x/cuts	0.72
4 East Ex 7 North Haulage	0.35
7 North Ex 18 East Haulage 6 x/cuts	0.66
18 East Ex 18 North Haulage 8/9 x/cuts	1.44

Key: P/S - Pillar Sliping

Table E-10 Cont'd

13 South Ex 6 West Haulage	0.51
6 West Ex 40 North Haulage 14/15 x/cuts	0.12
16 West Ex 40 North Haulage	0.67
23 East Ex 30 South 4/5 x/cuts	0.29
Section 8 B/C: Haulage	0.40
" 8 B/C: Haulage	0.55
" 8 T/C: Haulage	0.27
" 6 B/C: Haulage	0.13
" 6 B/C: Haulage	0.70
" 3 T/C: Haulage	2.49
" 12 B/C: "	0.12
" 11 B/C: "	1.06
" 4 T/C: "	0.24
" 4 B/C: "	0.14
" 5 B/C: "	0.39
" 9 B/C: "	0.60
" 7 B/C: "	0.88
" 8 B/C: "	1.06
" 8 B/C: "	0.17
" 3 P/S: Haulage 2/3 x/cuts	1.00
" 11 B/C: Haulage	1.60
" 10 B/C: "	1.14
" 12 P/S: Haulage 8/9 x/cuts	0.59
" 4 B/C: Haulage	0.46
" 4 B/C: Haulage	0.13
" 5 B/C: "	1.34
" 7 B/C: "	0.14
" 9 B/C: "	0.50
" 3 26 x/cuts Haulage	0.90
" 4: Haulage	0.16
" 12: "	0.34
" 9: "	0.35
" 7: Haulage	0.50
" 10: "	0.08

Key: B/C - Bottom Coal

Table E-10 Cont'd

Section 5 4 x/cuts Haulage	0.67
" 6 1 x/cut Haulage	0.10
" 1 Belt Road	0.08
" 3: Haulage 25 x/cuts	0.60
" 5: Haulage	0.60
" 4 Belt Road 1 x/cut	0.37
" 1 Belt Road 2 x/cuts	1.20
" 2 Belt Road 8 x/cuts	1.19
Section North Development Belt Road 4/5 x/cuts	1.35
Section 1 Belt Road 1/2 x/cuts	0.30
" 2 Belt Road 7/8 x/cuts	0.62
" 3: Haulage 26 x/cuts	0.23
" 5 Haulages 10m Intake	0.77
Section North Development Belt Road 3/4 x/cuts	0.20
Section 1 Belt Road Intake	0.57
" 2 Belt Road 8/10 x/cuts	0.47
" 4 Belt Road 10 x/cuts	0.41
" 5 Belt Road 1 x/cut	0.63
Section North Development Belt Road 3 x/cut	0.29
Section 8 B/C: Haulage 6/7 x/cuts	1.06
" 8 B/C: Haulage	0.17
" 3 P/C: Haulage 2/3 x/cuts	1.00
" 3 B/C: Haulage	1.6
" 3: 26 x/cuts Haulage	0.90
" 4: 10 in bye	0.16
" 12: 16/18 x/cuts	0.89
" 12: Haulage 10m	0.34
" 9: Haulage 10m	0.35
" 7: Haulage 10m	0.50
" 10: Haulage 10m	0.08
" 5: 4 x/cut Haulage	0.67
" 6: 1 x/cut Haulage	0.10
" 1: Belt Road 10 metres	0.08

Key: T/C - Top Coal

Table E-11: Occupation Dust Concentration Results for Intakes using MRE 113A

Location	Filter No.	Laden Filter Weight (g)	Clean Filter Weight (g)	Total Filter deposit (mg)	Air Volume Sampled (m^3)	Mass Concentration (mgm^{-3})
		B	A	B-A	C	$\frac{B-A}{C}$
16 South Ex W. Diagonal Section 8	32	0.63885	0.63845	0.40	0.224	1.79
"	38	0.65172	0.65020	0.52	0.797	0.65
"	75	0.63085	0.62965	1.20	0.652	1.84
"	74	0.62320	0.62190	1.30	0.652	2.00
14 East Ex 6 South	15	0.62195	0.62120	0.75	0.585	1.28
6 South Ex East Diagonal	14	0.61910	0.61800	1.10	0.704	1.56
Turn off 20 North	76	0.64500	0.64435	0.65	0.534	1.22
North West Development	11	0.63580	0.63540	0.40	0.328	1.22
North West Development	12	0.63180	0.63125	0.55	0.747	0.74
"	23	0.62190	0.62170	0.20	0.219	0.91
22 South Ex West Diagonal	80A	0.64796	0.6470	0.96	0.436	2.20
22 Section 7 West Diagonal	45A	0.64444	0.64321	1.230	0.66	1.86

Table E-12: Occupation Dust Concentration Results for Lashing using MRE 113A

Location	Filter No.	Laden Filter Weight (g)	Clean Filter Weight (g)	Total Filter deposit (mg)	Air Volume sampled (m^3)	Mass Concentration (mgm-3)
		B	A	B-A	C	$\frac{B-A}{C}$
22 South Ex W. Diag. Sect. 7	65	0.62695	0.62375	3.20	0.691	4.63
"	16	0.61930	0.61675	2.55	0.618	4.13
"	31	0.6220	0.61845	3.55	0.753	4.71
"	35	0.62535	0.62300	2.35	0.673	3.50
Section 4	62	0.64195	0.64060	1.35	0.562	2.40
"	58	0.64480	0.64155	3.25	0.675	4.81
"	72	0.65480	0.64950	5.30	0.713	7.43
"	25	0.65940	0.65710	2.30	0.751	3.10
"	10A	0.65200	0.64910	3.10	0.727	4.26
*30 South Ex W. Diag. Sect. 6	2A	0.64362	0.64164	1.98	0.666	2.97
"	9A	0.62470	0.62230	2.40	2.58	
"	42C	0.65882	0.65720	1.62	0.511	3.17
North Main Development	7A	0.65232	0.64981	2.51	0.721	3.48
"	39A	0.65945	0.65720	2.23	0.575	3.88

*Ex - off

W - West

Diag. - Diagonal

N - North

E - East

Sect. - Section

Table E-13: Occupation Dust Concentration Results for Drilling using MRE 113A

Location	Filter No.	Laden Filter Weight (g)	Clean Filter Weight (g)	Total Filter deposit (mg)	Air Volume Sampled (m^3)	Mass Concentration (mgm^{-3})
		B	A	B-A	C	$\frac{B-A}{C}$
14E. Ex 6 South Sect. 5	49	0.62755	0.62405	3.50	0.562	6.23
"	27	0.62475	0.62250	2.50	0.661	3.80
"	33	0.63615	0.63580	0.35	0.174	2.01
"	36	0.63570	0.63410	1.60	0.561	2.85
North West Development	53	0.63245	0.63050	1.95	0.716	2.72
"	61	0.63410	0.63265	1.45	0.641	2.30
"	57	0.6402	0.63725	2.95	0.492	6.00
"	69	0.63980	0.63785	1.95	0.696	2.80
"	24	0.61405	0.61265	1.40	0.447	3.13
North Main Development	52	0.63045	0.62900	1.45	0.653	2.22
"	42A	0.64379	0.64079	3.00	0.425	7.06
"	44B	0.64479	0.64339	1.40	0.397	3.53
"	47A	0.64422	0.64290	1.32	0.320	4.13
Section 4	3A	0.64485	0.64334	1.51	0.620	2.44
"	1A	0.64332	0.64149	1.83	0.671	2.73
"	49A	0.64467	0.64304	1.63	0.436	3.74

Table E-14: Occupation Dust Concentration Results for Coal Cutting using MRE 113A

Location	Filter No.	Laden Filter Weight (g)	Clean Filter Weight (g)	Total Filter deposit (mg)	Air Volume Sampled (m^3)	Mass Concentration (mgm^{-3})
		B	A	B−A	C	$\frac{B-A}{C}$
Section 4	64	0.65050	0.64920	1.15	0.72	1.60
15 South Ex W. Diag. Section 8	19	0.63265	0.62870	3.95	0.657	6.01
"	28	0.63875	0.63685	1.19	0.702	2.71
"	34	0.62920	0.62845	0.70	0.693	1.01
"	54	0.61500	0.64110	0.30	0.591	0.510
"	51	0.63645	0.63640	0.20	0.497	0.40
14 East Ex 6 South Sect. 5	60	0.63040	0.63005	0.25	0.708	0.35
"	56	0.62955	0.62915	0.35	0.647	0.541
"	73	0.63015	0.62870	1.45	0.748	1.94
"	13	0.65050	0.64980	0.65	0.699	1.00
"	22	0.63040	0.63000	0.40	0.587	0.68
Section 4	45C	0.64446	0.64329	1.17	0.695	1.68
"	41B	0.64746	0.64600	1.46	0.706	2.07
"	8A	0.64382	0.64259	1.23	0.707	1.74
"	5A	0.64316	0.64176	1.40	0.694	2.02
"	4A	0.64563	0.64413	1.50	0.752	1.99
North Main Development	40A	0.64490	0.64100	3.90	0.691	5.64
"	44A	0.64726	0.64406	3.20	0.731	4.38
"	81A	0.64919	0.64647	2.72	0.606	4.49

Table E-15: Occupation Dust Concentration Results for Charging using MRE 113A

Location	Filter No.	Laden Filter Weight (g)	Clean Filter Weight (g)	Total Filter deposit (mg)	Air Volume Sampled (m^3)	Mass Concentration (mgm^{-3})
		B	A	B-A	C	$\frac{B-A}{C}$
15 South Ex W. Diag. Sect. 8	50	0.64210	0.63870	3.40	0.691	4.92
"	20	0.63835	0.63715	1.20	0.390	3.10
"	30	0.64135	0.63910	2.25	0.638	3.53
"	37	0.63115	0.62815	3.00	0.775	3.90
Section 4	63	0.62765	0.62655	1.10	0.562	1.96
"	59	0.62835	0.62810	0.25	0.705	0.355
"	66	0.63350	0.63230	1.20	0.661	1.83
"	21	0.61820	0.61755	0.65	0.447	1.45
"	48C	0.64408	0.64336	0.72	0.458	1.57
15 South Ex W. Diag. Sect. 8	43A	0.64349	0.64229	1.20	0.505	2.39
"	43B	0.64488	0.64376	1.12	0.485	2.31
"	40B	0.64497	0.64357	1.40	0.482	2.90
"	6A	0.64491	0.64331	1.60	0.470	3.40
"	41A	0.64569	0.64460	1.09	0.598	1.82

Table E-16: Occupation Dust Concentration Results for Blasting Workers (18 Shaft) using MRE 113A and Konimeter

Location	Konimeter (p.c.c.c)	Incombustible dust (mgm^{-3})	Total dust (mgm^{-3})
1186 Grizzley/2140/2D	240	0.65	0.94
"	260	0.698	0.82
"	560	1.75	2.06
"	460	1.50	1.76
1186 Grizzley/2140/2D	440	1.24	1.46
"	500	1.65	1.94

Table E-17: Occupation Dust Concentration Results for Drilling Workers using MRE 113A and Konimeter

Location	Konimeter (p.c.c.c)	Incombustible dust (mgm^{-3})	Total dust (mgm^{-3})
1152 RIB/2240/10D-18 shaft	400	0.786	1.152
"	460	1.002	2.43
"	360	0.782	2.120
"	240	0.52	1.42
1162 X/CN/2240/2D-18 shaft	840	2.065	3.24
488 STOPE/880L- 14 shaft	380	1.22	3.18
"	160	0.382	1.024
1192 EAST/2290/4D-28 shaft	100	0.181	2.167

Table E-18: Occupation Dust Concentration Results for Conveying Workers using MRE 113A and Konimeter

Location	Konimeter (p.c.c.c)	Incombustible dust (mgm^{-3})	Total dust (mgm^{-3})
1930'L Conveyor-14 shaft	100	0.210	0.645
"	180	0.344	0.947
"	140	0.246	0.726
"	160	0.301	0.922
1930'L Conveyor-14 shaft	180	0.324	0.862
"	160	0.320	0.883
"	120	0.226	0.742

Table E-19: Occupation Dust Concentration Results for Mechanical Lashing Workers using MRE 113A and Konimeter

Location	Konimeter (p.c.c.c)	Incombustible dust (mgm^{-3})	Total dust (mgm^{-3})
1176/2200/2D-18 shaft	380	0.916	1.684
"	800	1.945	3.16
"	680	1.52	2.95
"	640	1.35	2.93
"	360	0.923	1.92
1160 X/CN/2200/4A-18 shaft	540	1.741	2.691
"	480	1.201	1.81
"	380	1.243	2.64
1174 X/CN/2200/4A-18 shaft	360	0.952	2.02

Table E-20: Occupation Dust Concentration Results for Miscellaneous Workers using MRE 113A and Konimeter

Location	Konimeter (p.c.c.c)	Incombustible dust (mgm^{-3})	Total dust (mgm^{-3})
1900'L X/CN-18 shaft	480	1.001	1.497
"	400	0.82	1.225
"	300	0.792	1.286
2200 shaft X/CN-28 shaft	280	0.862	1.0796
2290/4D - 18 shaft	320	1.052	1.430
2240/10D - 18 shaft	260	0.692	0.941
"	360	0.638	0.867
"	420	1.434	1.95
229/4D - 18 shaft	280	0.707	0.962

Table E-21: Occupation Dust Concentration Results for Hand Lashing Workers using MRE 113A and Konimeter

Location	Konimeter (p.c.c.c)	Incombustible dust (mgm^{-3})	Total dust (mgm^{-3})
1228/2350'L/6D-28 shaft	N.D.	0.0508	0.484
"	N.D.	0.0182	0.1733
1158/2240'L/2D-18 shaft	N.D.	0.024	0.2111
"	N.D.	0.023	0.2047
1158/2290'L/2D-18 shaft	N.D.	0.0192	0.344
"	N.D.	0.0270	0.3041
116F/W DRIVE/2240'L/2D -18 shaft	N.D.	0.0167	0.2885
"	N.D.	0.0312	0.3344
"	N.D.	0.0354	0.3672
2200'L SHAFT X/CUT N-28 shaft	N.D.	0.0396	0.4930

Table E-22: Occupation Dust Concentration Results for Crusher men Using MRE 113A and Konimeter

Location	Konimeter (p.c.c.c)	Incombustible dust (mgm-3)	Total dust (mgm-3)
1930'L crusher/14 shaft	160	0.32	0.590
1930'L crusher/14 shaft	120	0.188	0.463
1930'L crusher/14 shaft	140	0.255	0.591
2100'L crusher/18 shaft	ND	0.114	0.657
1930'L crusher/14 shaft	220	0.40	0.736
"	140	0.246	0.631
"	120	0.273	0.591
"	160	0.370	0.664
"	240	0.450	0.88
"	340	0.965	0.965
2100'L crusher/18 shaft	320	0.613	1.313
"	460	0.80	1.44
"	400	0.69	0.69
Surface crusher/14 shaft	260	0.40	0.852
"	360	0.72	1.49
"	ND	0.54	0.97
"	ND	0.52	1.05
"	ND	0.50	0.989