SAFETY IN MINES RESEARCH ADVISORY COMMITTEE

SIMRAC

Draft Final Project Report

Title: PERSONAL GRAVIMETRIC DUST SAMPLING AND RISK ASSESSMENT

Author/s: A D Unsted

Research Agency: CSIR : Division of Mining Technology

Project No.: GAP 046

Date: March 1996

EXECUTIVE SUMMARY

The Government Mining Engineer (GME) introduced a personal gravimetric dust sampling programme for gold mines in 1990 and allowed a two year moratorium period during which anomalies and difficulties encountered were discussed and resolved in committee. The sampling strategy, as prescribed by the GME, was considered, inevitably, to have been based on conservative statistical considerations. It was thus considered to be unnecessarily costly and onerous in terms of the definition of statistical populations, the cost of sample analysis, and the increased organisational workload on mine technical and administrative staff. Experience gained in the statistical determination of health risks in other areas such as heat, noise and biological contamination in South African mines indicated a potential to simplify dust sampling strategies thereby providing scope for cost and effort savings.

In a very general air contamination scenario an atmospheric contaminant is emitted by a source. It may mix with and be diluted by ambient air and it travels to a target person, object or area where it has the potential to exert an effect, usually after being deposited. The physical dimensions involved in this process may be millimetres to kilometres and the times may be milliseconds to virtually years. Air sampling may be performed near the source, in the ambient air, or near the target to characterize the source emission, identify the source, or predict the quality and quantity of contaminant reaching the target. Since the GME's dust sampling programme is aimed only at determining personal exposures, sampling is undertaken only on personnel, i.e. the target receptors. An aerosol consists of particles and the gas in which they are suspended. All aerosols are temporally unstable, i.e. they experience change with the passage of time. Some important aerosol characteristics which can change are: total mass concentration of a contaminant (sum of mass concentrations in the vapour and particle phases), the fraction of a contaminant in the particle or vapour phase, and particle size distribution. Size distribution is of prime importance because the particle size governs the length of time for which the particle will remain suspended in the air, the manner in which it will settle and the air velocity required to remove the particles from the workings.

The unpredictable and somewhat surprising results obtained in this investigation are indicative of a wide variety of aerosol instabilities that may be encountered when sampling for airborne dust. A widely held view that dust concentrations in the workings are homogenous in nature as well as in composition was disproved.

At the outset of gravimetric dust sampling agreement was reached with the GME that mines need only implement personal gravimetric sampling (for risk assessment and the determination of levies) and that exemption from previous statutory requirements - quarterly dust surveys using konimeters - would be granted across the board. In the early stages of implementing the GME's sampling strategy, Industry noted that sampling five percent of the workforce was onerous and that it would be considerably simpler to collect a single sample, at a representative place, in a workplace as an indication of worker exposure. The origins of the project, SIMGAP Project GAP046, were rooted in the Industry's need to establish the viability of such a simplification of sampling procedures.

Extensive investigations were conducted at three underground sites and one surface installation. The first underground site was a highly mechanized, shallow mine, the second site was a shallow mine with conventional mini-longwalls and the third site was a deep mechanized mine. The fourth site was an assay and sample preparation laboratory.

At each location sampling was undertaken over a number of days and all working shifts. Sampling pumps were attached to personnel and the same personnel, as far as possible, were sampled during each investigation. All sampling was conducted for the full working shift. At the same time stationary samples were set up at representative places.

At all the sampling sites extremely large variations in dust concentrations were measured on a day to day and shift to shift basis. Correlation of dust concentrations between personal and stationary samples was very poor as was the correlation between quartz fractions. In addition there was very poor correlation between personal samples in the same area during the same shift. Also, the correlation between dust and quartz concentrations was found to be poor. Thus, the possibility of replacing personal samples with representative, stationary samples could not be justified nor recommended.

As part of this project, but not part of the original proposal, possible reasons for large variations in dust and quartz concentrations were investigated. Regular checks were made with the South African Bureau of Standards (SABS) on analytical results and highly satisfactory agreement in analyses were always obtained. Analyses of in-situ samples were compared with airborne concentrations and little agreement was found.

Sampling pumps were set up to sample in parallel. Pumps of the same make gave very good agreement in dust concentrations but very poor correlation in quartz levels. Although this phenomenon has been noted in overseas literature no satisfactory explanation has been advanced and re-inforced the perception that aerosol behaviour is far from being fully understood or predictable.

Sampling pumps of different types i.e. conventional cassette and cyclone, and rotating sponges yielded different results when set to sample in parallel. The sponge type always gave predictably lower, but extensively scattered, results than the conventional type and this is a cause for concern because it is estimated that approximately 50 percent of the gold, platinum and base metal mines are using this type of sampler and hence results reported would also inadvertently have erred on the low side.

Data from reports submitted by gold mines to the GME were compiled in a data base and examined for trends. Mines were divided into six geographical regions, namely East (Eastern Transvaal), Elsburg, Klerksdorp, North Free State, South Free State and West Wits. Reports of half-yearly results for the period January 1992 to June 1994 were analysed. Results were further classified into three broad activity groups - underground stopes and development, underground roving, and surface.

Large variations in dust concentrations and also in quartz concentrations were found in individual statistical populations, from one statistical population to another and from one sampling area to another for any given six month sampling cycle for a given mine. Furthermore, results differed significantly between successive sampling cycles for a given mine.

Quartz concentration in a given statistical population for five individual samples could vary very little but could also typically vary from 4 to 72 percent, or 17 to 98 percent. It was also found that quartz percentages have been based on the total mass of particulate on filters, no allowance having been made for carbon particles or salts. Reported quartz concentrations are thus likely to have been in error and on an industry basis airborne quartz concentrations reported could inadvertently have been too low.

No significant differences were found in either dust levels or quartz concentrations between the three activity classifications or between the regions, ie all were equally wide in distributions/ranges.

The industry eight-hour Time Weighted Average (TWA) quartz content was found to be in the range 10 - 20 percent. Due to possibly under-reporting an industry level of 20 percent for quartz should be used when evaluating exposures. In this case an eight-hour TWA of 0,5 mg/m^3 would have equated to an Air Quality Index (AQI) of one, and could be adopted as a standard but which would, however, be very difficult to test for compliance. The adoption of this procedure would simplify the evaluation of working place conditions for control purposes as well as provide management with information with regard to likely worker exposure levels with a minimum of delay since the dust samples would not need to be analysed for quartz content. This could represent a significant, but valid, simplification in the risk assessment process.

No detailed analyses of the reports submitted to the GME have been made. However, from the original records the potential exists to extract information pertaining to occupational dust exposure. There is a considerable volume of data which has thus far only been used to calculate levies but which could be put to more meaningful use. Although it would take considerable effort, occupational dust exposure levels could be extracted from these data. Industry at last has the sampling equipment and infrastructure to advance our knowledge in dose/response studies and to eliminate reliance on 40 year old data.

Industry expressed the concern that dust exposure levels and measures instituted to control exposure levels are not adequately reflected in the risk formula as defined at present. It was found that the quartz content of the airborne dust greatly influences the outcome of a risk calculation. It can, however, be shown that if both the quartz and the non-quartz fraction of the airborne dust are incorporated in the risk evaluation the formula would become more equitable. Nevertheless, because of the highly variable and non-repeatable dust and quartz levels, risk assessment, as defined at present, would still be being based on very random variables. This uncertainty would be exacerbated by the inclusion of additional pollutants such as diesel soot, etc.

There is a growing awareness that all dust and not just the toxic fraction can impact on a persons' health.

The so-called nuisance dust or particles not otherwise classified (PNOC) is suspected to contribute to increasing numbers of occupational asthma cases. In addition, the short duration high peak concentrations or transient high peak concentrations of dust are now suspected to play an important role in physiological impairment in conjunction with the average concentration of the dust. These peaks could trigger a physiological response, such as an asthma attack, and also overwhelm the body's natural defence mechanisms thereby leading to a more permanent type of impairment. These transient high peak exposures together with the 8 hour TWA exposures could then constitute the more significant risk.

Risk assessment for levy purposes through the GME's dust sampling programme should be discontinued and levies, which are to pay compensation for past events, should be based on other criteria as defined by the Commissioner for Compensation (COID).

At present, mines are required to implement the GME's gravimetric dust sampling programme to determine personal exposure levels on which a risk levy is calculated. Some mines have abandoned all sampling for engineering control purposes, there being no legal obligation for such sampling. Others, in addition to the gravimetric sampling, have continued with konimeter sampling to identify and rectify unsatisfactory dust concentrations in the workings. There was thus an opportunity to investigate the use of a single set of sampling equipment, viz gravimetric samplers, to fulfill both requirements.

Furthermore, it was noted in the Leon Commission of Enquiry into Health and Safety in Mines[1] that high and unsatisfactory dust concentrations are not being identified and addressed. This remark refers to the eight-hour TWA dust concentrations where high dust concentrations are averaged and therefore go largely undetected and untraceable. Initial trials have indicated the feasibility of using a conventional gravimetric dust sampling pump with a small diameter filter (13mm) for short sampling periods. The small filter gives a superior dust mass/filter mass ratio compared to a bigger filter (25mm diameter). These short duration samples (12 - 15 minutes) have been found to be effective in evaluating workplace conditions and identifying places or operations where high dust concentrations are generated. The results of such sampling can be entered in a standard environmental report form for use by management. It can be assumed that if high dust levels are brought under control then exposure of the workforce to unsatisfactory dust levels will also be controlled. It is correct that there is a delay in obtaining the mass of dust on the filters and that conditions may have altered by the time management receives this report. Nevertheless, this is a common procedure for many occupational hygiene measurements, such as gas samples, that need laboratory evaluation and as such is an internationally practised technique. In any event, delayed results are better than no results and can still alert management to the need for corrective action.

In general, where analyses are required for pollutants other than quartz, it will be necessary to collect two samples since the respirable fraction is used for quartz determination but a total dust sample is needed for other pollutants such as lead. This double sample collection is not considered to be cost effective. Using a conventional sampling system, i.e. filter, cassette, separating cyclone and pump and not a rotating sponge system, both the respirable and non-respirable fractions of the airborne dust are collected separately. After analyses of the respirable fraction, the two fractions could be recombined for a total dust analysis. Trials were held in which weighed thimbles were inserted in the catchpots of the separating cyclones from which the non-respirable fraction could be recovered. However, these trials were discontinued because the thimbles proved to be too difficult to extract from the catchpots. Instead, the residue from the catchpot was carefully deposited onto the already analysed filter through a system of flushing and vacuum deposition. Strict quality controls are necessary to prevent either contamination or loss of sample but, nevertheless, the technique is viable and would make multiple analyses possible, at least where x-ray diffraction is used for analyses. This method is not viable for the rotating sponge samples.

The ultimate objective of dust sampling is to reduce exposure levels to those that may be considered to be in compliance with good health and safety practices. The present programme of sampling has been used only to compute numbers on which dust levies can be based. The strategy is not suitable to gauge the dustiness of working places and individual unsatisfactory exposures remain difficult to detect or trace. This could also be a meaningless exercise if such an attempt were to be made after a lapse of several months. In addition, the present programme provides no useful input to engineering control which would in turn assist with the reduction of personal exposure levels. It is evident that the current sampling programme and strategy should be reviewed as a matter of urgency and that it be replaced by a two pronged approach, one aimed at determining exposure for dose/response and epidemiological studies and the other at engineering control. Both strategies should be viewed in pursuance of an understanding of personal exposure.

PREFACE

A fundamental element of any occupational hygiene initiative of merit is, in terms of Olishifski's well-known definition, the implied logic of evaluating a hazard in a manner conducive to control. It is immaterial if such control is achieved by engineering means (preferably), or by personal protection (last resort), or by a combination of both. The ultimate objective is to reduce exposure to levels consistent with sustained good health and safety. It follows that if this objective cannot be fulfilled, the entire process of hazard anticipation, recognition and evaluation be subjected to serious review.

The present project deals with dust as an occupational health hazard. More realistically it should be regarded as taking stock of the personal (gravimetric) dust sampling programme recently introduced in the South African mining industry. The findings of this study make it eminently clear that, despite the enormous potential of the method to come to grips with this insidious hazard, the specific application reduces the programme to a meaningless exercise: pooled data lack relevance to individual exposure while concurrently providing no useful input to engineering control.

The following extracts from the 'Leon Report' summarise the prevailing situation :
' ---- failure (on the part of mines) to measure actual exposures in the workplace accurately ----' (p40).

The widespread practice of averaging - for example. The average dust level for an entire mine - serves only to confuse '(p60)'

The report also draws attention to several unfounded assumptions, as well as unanticipated problems, for example

- The lack of correlation between dust and quartz,
- The incongruity of compliance testing in highly variable environments,
- The lack of consistency in findings, and consequently 'risk assessment', when using different instruments, and
- The fact that the procedure of combining samples and averaging the results renders the entire programme insensitive to dangerously high personal exposures.

As argued at the outset, the present process of evaluation is not conducive to engineering control or to personal exposure for the purpose of epidemiology. Clearly, a major review is indicated as a matter of priority and in this respect the point of departure should be to obtain a detailed understanding of personal exposure to dust. This, in fact, is the real purpose of the methodology.

A.J. KIELBLOCK
Occupational Hygiene Consultant

CONTENTS

CONTENTS (continued)

CONTENTS (continued)

PART 4

LIST OF TABLES

LIST OF TABLES (continued)

LIST OF FIGURES

PART 1

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

1 INTRODUCTION

Shortly after the introduction of the Government Mining Engineer's (GME) programme of gravimetric dust sampling questions were raised by Industry with regard to an effective means of sampling, for engineering control purposes, possible reduction in sampling effort and reduction in analytical costs. It was also considered that the risk calculated for levy purposes was not equitable and did not accurately reflect any effort made to reduce dust concentrations and thus risk.

The research programme was aimed at addressing the above concerns and extensive data sets were collected at each of three underground test sites, as well as at an assay laboratory where a repeat sampling exercise was conducted several months after the initial survey.

The first underground test site was at a shallow, highly mechanised section of a gold mine in the West Wits Region, the second was a shallow conventional, mini longwall system (Elsburg Region) and the third test site was at a deep mechanised longwall section (Elsburg/Klerksdorp). The fourth test site was an Assay laboratory.

The results of the separate monitoring exercises are set out below.

The investigations were conducted using Gilian pumps. This should be seen as representative of the conventional pump and filter arrangement and not as an endorsement of the product. Rotating sponge type samplers were also used for the sake of completeness since a large number of mines use this system of sampling.

Investigations into analytical techniques were carried out in the CSIR : Mining Technology's (Miningtek) GME approved air quality laboratory. (Now also approved by the Department of Labour).

The possibility of using all pollutants of airborne samples, instead of only quartz, to formulate an Air Quality Index and hence a risk, was also explored with a view to developing a more equitable risk formula.

In-situ quartz concentrations were compared with airborne quartz concentration in investigating reasons for the variations encountered in levels of airborne quartz.

During early 1995 copies of all available gravimetric dust sampling reports (compiled by the mines who are members of the Chamber of Mines) were forwarded to Miningtek by the office of the GME for compilation in a database and analysis to determine if "regional" and "Industry" airborne quartz concentrations could be ascertained with a view to rationalizing these quartz concentrations.

Preliminary trials were carried out using a modified sampling train of standard equipment to collect short duration dust samples that would provide indications of workplace dust concentrations. The results have been very encouraging, and could provide a technique to assist in the evaluation of engineering control methods to limit the liberation of dust into the working environment.

PART 1 COMPARISON OF STATIONARY (AREA) SAMPLES WITH PERSONAL (ROVING) SAMPLES

2 TEST SITE 1 Shallow, highly mechanized section.

2.1 Description of Test Site

The site was located 890 m below surface, approximately 5 km from the main shaft. The orebody was up to 9 m thick. Trackless mining took place in two lower development headings (Stations "A" and "B" in Figure 1), in an upper development heading (extension from "E") and in bord and pillar section "D". Typical dimensions of headings in this section were 8 m wide by 5 m high. In addition, conventional mining took place in a narrow reef mining section located between "B" and "D". The main tip for this mining section was outside the section approximately 0,5 km from "E". The workshop serving the section was 2 km away.

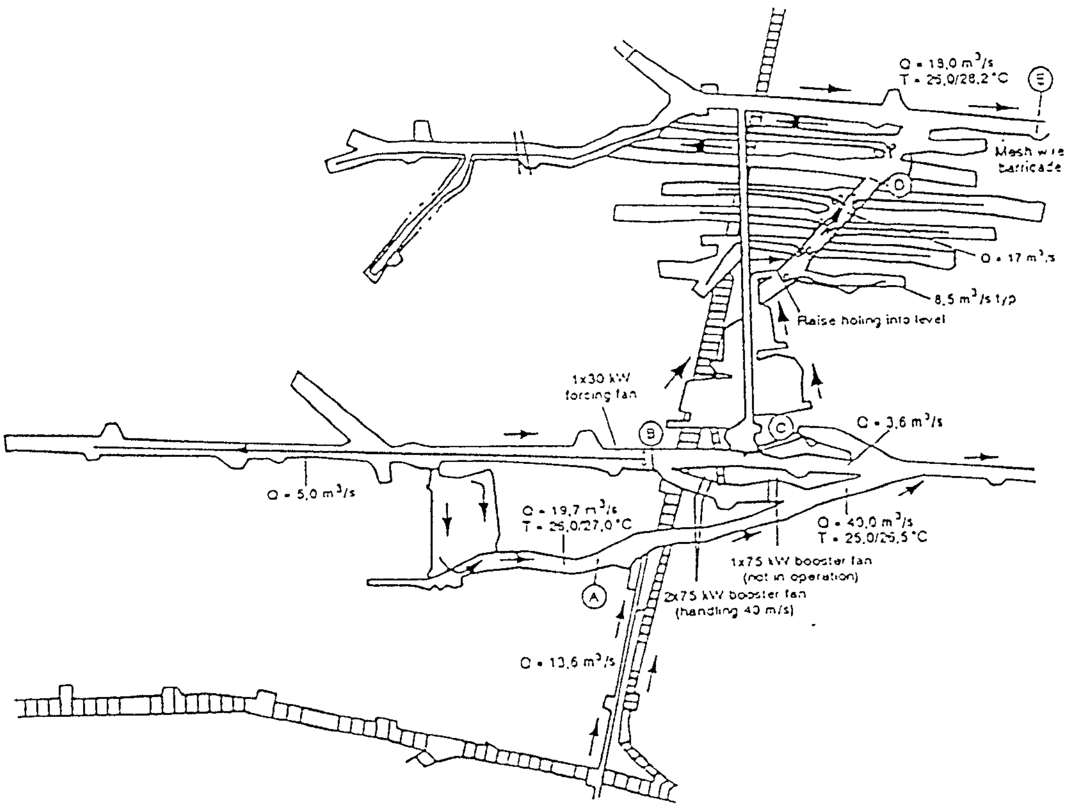

Figure 1 <u>LAYOUT OF TEST SITE (1)</u>

Mining operations were conducted over three shifts every day i.e. morning, afternoon and night shift. The section under consideration was ventilated from a footwall cross-cut via two 75 kW booster fans (next to position "B") delivering 40 m^3/s to the section. This provided the intake air, which was monitored at position "B". Some of this air was used to ventilate the lower development ends (monitored at positions "A" and "C") and some air was passed through the stoping section and a raise bored hole into the bord and pillar section. This air was mixed with some of the return air from the development heading extending from "B". The pollution levels of this air were monitored at position "C". Some of the air from the conventional stoping sections passed via a raise to the upper development end.

The quality of air exiting from the bord and pillar sections was monitored at position "D" (representative place) and the major return was monitored at "E".

Development headings were ventilated by 30 kW fan delivering 10 m^3/s.

2.2 Measurement Strategy

Ideally, every person in the section should have been monitored simultaneously for any given monitoring shift, as well as the fixed stations at inlets, the representative place and the main return. Owing to limitations on available instrumentation and personnel this was not possible and as a next best alternative at least one person from each work category was monitored simultaneously with all the fixed position stations. Once personnel had been selected, the same person was always monitored using the same instruments. The stationary points were monitored using the same instrument for each sampling shift. The purpose of these measurements was to establish whether measurements at fixed point (i.e. representative or main return) would give adequate information on personal exposures in the section, as these fixed point measurements would be easier to implement in any dust sampling strategy and could reduce the monitoring burden.

Ventilation surveys were conducted by mine personnel during each monitoring shift to determine changes in local ventilation conditions, such as at representative place "D", which could be caused by fan stoppages, airway holings, installation of brattices, or partial blocking of airways by blasted rock.

Monitoring was conducted for the full duration of the shift for each of the three shifts worked and each day of the week. The afternoon and night shifts were monitored in one continuous operation to reduce the unproductive set-up time requirements. The data for double shifts were, however, collected and analysed separately. At least two days were allowed between monitoring shifts to allow for down loading of the instruments, recharging of all instrument batteries, calibration checks, etc. The test period extended from the end of October to mid December 1993.

Because the monitoring section had a significant diesel powered vehicle population it was necessary to separate the diesel soot particulate from mineral dust for the purposes of this investigation.

2.3 Instrumentation

The dust sample collection method used was the standard gravimetric dust sampling technique as specified in Guidelines set out by the GME[2]. The technique makes use of pre-weighed 25 mm diameter cellulose nitrate filters, 0,8 µm porosity, for field and control filters. Air is drawn through the filters by a constant volume (1,9 ℓpm) pump and a 10 mm cyclone separator ensures that only the respirable particulates are deposited on the filters for evaluation.

Mineral dust and Diesel Particulate Matter (DPM) were collected on the sampling filters over the full shift. After stabilization the filters were reweighed and checked against the control filters and the total amount of particulate, i.e. mineral dust and DPM was ascertained. DPM was determined using a methodology developed at Miningtek. The method, described below, has been found to be simple and reliable, and can be compared with the one described by Rex and Gardiner[3].

Reweighed field filters are placed in pre-weighed mini platinum crucibles. Each crucible is numbered and has a corresponding numbered lid. When empty, crucibles and lids weigh in the region of 5 000 mg. After the field filter with particulates is placed in the crucible the lid is replaced and the entire ensemble is again reweighed. At this stage a control check is made:

(Crucible + filter (+ dust) + lid) - (crucible (empty) + lid) = filter + dust (weighed separately when filters are returned to the laboratory) .

Discrepancies of five per cent or more resulted in sample rejection.

The loaded crucible is placed in a suitable muffle and the temperature elevated to 200 °C and held for one hour. Thereafter the temperature is further elevated to 600 °C and again held for one hour. This process ensures complete combustion of all combustible matter (DPM + filter) and the lid ensures no loss of non-combustible (mineral) dust. After a suitable cooling period, usually overnight, the crucible and ash are reweighed and simple arithmetic gives the masses of DPM and mineral dust.

2.4 Quartz Determination

Once combustible and non combustible particulate masses had been established, as described above, the ash content (mineral dust) was redeposited on a 25 mm diameter filter and subjected to X-ray diffraction examination to determine the quartz content. This was done for every filter used in the investigation.

2.5 Monitoring Procedures

The following routines were followed: the team, consisting of five to seven engineers and technicians proceeded underground an hour before the working shift (04:00 for the morning shift and 15:00 for the afternoon/night shift) to allow sufficient time to check and set up instrumentation before the arrival of the workforce. During this period all instrumentation for the vehicles to be monitored was installed. As the selected personnel arrived they were equipped with the relevant instrumentation. Thereafter members of the team manned the fixed position or stationary sampling points.

All instrument preparation and control, as well as filter preparation and mass determination were carried out at Miningtek in a GME approved laboratory using GME approved methods. The laboratory has recently also been approved by the Department of Labour.

Quartz determination was performed using a direct on filter technique approved by the South African Bureau of Standards and this equipment was maintained under contract by the manufacturer. Random samples were also sent to the SABS for evaluations.

2.7 Results from and Analysis of Measurements

Measurements were taken during normal mining operations over a period of approximately two months. No attempt was made to control conditions to enable easier interpretation of results nor to obtain a greater volume of useful data, i.e. conditions were monitored as found.

Details of all sampling results are set out in Tables 1 to 4. Table 1 gives data collected for vehicle operators (personal), Table 2 shows results of personal sampling (non vehicle), Table 3 features the results for stationary samples at the inlet position grouped together and Table 4, similarly, the results for the representative place and the main return.

Table 1 SHALLOW MINING SECTION. TRACKLESS MINING TESTS VEHICLES (ROVING)

Date	Test Number	Actual Test Number	LHD 4014 Quartz Content Per Cent	LHD 4014 Mineral Dust Conc mg/m³	LHD 4014 AQI	LHD 4014 Risk Per Cent	DUMP TRUCK 1634 Quartz Content Per Cent	DUMP TRUCK 1634 Mineral Dust Conc mg/m³	DUMP TRUCK 1634 AQI	DUMP TRUCK 1634 Risk Per Cent	SCALER 1514 Quartz Content Per cent	SCALER 1514 Mineral Dust Conc. mg/m³	SCALER 1514 AQI	SCALER 1514 Risk Per Cent	ROOF BOLTER 1026 Quartz Content Per Cent	ROOF BOLTER 1026 Minera l Dust Conc. mg/m³	ROOF BOLTER 1026 AQI	ROOF BOLTER 1026 Risk Per Cent
Morning																		
04/11/93	1	5	2.54	0.035	0.02	0.00	2.65	0.801	0.40	0.64					ND	0.074	0.04	0.01
17/11/93	2	10	47.92	0.441	2.11	17.88	34.19	0.047	0.16	0.10	69.37	0.296	2.05	16.87	11.31	0.113	0.13	0.07
22/11/93	3	11	43.00	0.140	0.61	1.50	49.26	0.047	0.23	0.21	28.64	0.452	1.30	6.71	ND	0.047	0.02	0.00
30/11/93	4	14	65.56	0.383	2.51	25.19	ND	0.125	0.06	0.02		0.204			ND	0.363	0.18	0.13
01/12/93	5																	
Average			39.93	0.250	1.31	11.14	21.53	0.255	0.21	0.24	49.01	0.317	1.68	11.79	2.83	0.149	0.09	0.05
Afternoon																		
27/10/93	6	1		0.701				0.736								0.964		
01/11/93	7	3	37.50	0.902	3.72	55.34	73.50	0.196	1.43	8.19					45.63	0.231	1.05	4.4
09/11/93	8	6	53.97	0.351	1.89	14.33	21.42	0.687	1.47	8.66	35.18	0.260	0.92	3.36	57.84	0.150	0.87	3.03
12/11/93	9	8	37.06	0.769	2.85	32.50	26.42	0.656	1.73	11.97	38.71	0.466	1.81	13.04	28.68	0.656	1.88	14.14
25/11/93	10	12	19.03	0.388	0.74	2.18	68.84	0.240	1.65	10.92	17.50	0.282	0.78	2.41	42.50	0.382	1.62	10.53
Average			36.89	0.640	2.30	26.09	47.55	0.503	1.57	9.94	33.80	0.336	1.17	6.27	43.66	0.477	1.36	8.04
Night																		
27/10/93	11	2														0.158		
01/11/93	12	4	24.01	0.294	0.71	2.00		0.088			33.49	0.560	1.88	14.08	26.47	0.356	0.94	3.55
09/11/93	13	7	53.06	0.460	2.44	23.84	26.59	0.197	0.52	1.09		0.406			12.43	0.245	0.31	0.37
12/11/93	14	9	31.58	0.374	1.18	5.58	11.31	0.125	0.14	0.08	17.13	0.229	0.39	0.61	16.02	0.142	0.23	0.21
25/11/93	15	13	57.89	1.019	5.90	139.16					20.00	0.200	0.40	0.64	29.46	0.947	2.79	31.10
Average			41.64	0.537	2.56	42.64	18.95	0.137	0.33	0.59	23.54	0.349	0.89	5.11	21.10	0.370	1.07	8.81
		Minimum	2.54	0.04	0.02	0.00	ND	0.05	0.06	0.02	17.13	0.20	0.39	0.61	ND	0.05	0.02	0.00
		Maximum	65.56	1.02	5.90	139.16	73.50	0.80	1.73	11.97	69.37	0.56	2.05	16.87	57.84	0.96	2.79	31.10
		Average	39.48	0.49	2.06	26.63	31.42	0.33	0.78	4.19	33.75	0.34	1.19	7.22	22.53	0.34	0.84	5.63
		Std Dev	17.31	0.29	1.56	37.36	24.22	0.28	0.66	4.80	15.11	0.12	0.62	6.12	18.42	0.29	0.84	8.85
		Variance	299.73	0.08	2.43	1395.64	586.46	0.08	0.44	23.09	228.24	0.01	0.39	37.42	339.47	0.09	0.70	78.26

ND : Less than detection limit of 20 μg

Table 2 SHALLOW MINING SECTION. TRACKLESS MINING TESTS PERSONNEL (ROVING)

			TEAM LEADER				MINER'S ASSISTANT				CONSTRUCTION ASSISTANT			
Date	Test Number	Actual Test Number	Quartz Content Per Cent	Mineral Dust Conc. mg/m³	AQI	Risk Per Cent	Quartz Content Per Cent	Mineral Dust Conc. mg/m³	AQI	Risk Per Cent	Quartz Content Per cent	Mineral Dust Conc. mg/m³	AQI	Risk Per Cent
Morning														
04/11/93	1	5	21.36	0.081	0.17	0.12	9.44	0.404	0.38	0.58	30.65	0.438	1.34	7.22
17/11/93	2	10	49.70	0.463	2.30	21.17	39.54	0.391	1.55	9.56	55.05	0.401	2.21	19.53
22/11/93	3	11	3.90	0.252	0.13	0.06	50.13	0.537	2.69	28.96	9.62	0.348	0.33	0.45
30/11/93	4	14	45.00	0.311	1.40	7.81	32.92	0.407	1.34	7.18	9.20	0.420	0.39	0.60
01/12/93	5						50.62	0.237	1.20	5.76				
Average			29.99	0.277	1.00	7.29	36.53	0.395	1.43	10.41	26.13	0.402	1.07	6.95
Afternoon														
27/10/93	6	1		0.596								0.332		
01/11/93	7	3	63.40	0.337	2.13	18.23					51.60	0.281	1.45	8.44
09/11/93	8	6	16.15	0.164	0.26	0.28					25.15	0.254	0.64	1.63
12/11/93	9	8	17.15	0.269	0.46	0.85					12.18	0.313	0.38	0.58
25/11/93	10	12	26.87	0.262	0.71	1.99					18.89	0.148	0.28	0.31
Average			30.89	0.326	0,89	5.34					26.96	0.265	0.69	2.74
Night														
27/10/93	11	2		0.421								0.402		
01/11/93	12	4	96.35	0.292	2.81	31.64					85.91	0.147	1.26	6.39
09/11/93	13	7	40.46	0.440	1.78	12.68					25.74	0.276	0.71	2.03
12/11/93	14	9	10.23	0.173	0.18	0.13					ND	0.035	0.02	0.00
25/11/93	15	13	ND	0.102	0.05	0.01					ND	0.026	0.01	0.00
Average			36.76	0.286	1.21	11.12					27.91	0.177	0.50	2.11
		Minimum	ND	0.08	0.05	0.01	9.44	0.24	0.38	0.58	ND	0.03	0.01	0.00
		Maximum	96.35	0.60	2.81	31.64	50.62	0.54	2.69	28.96	85.91	0.44	2.21	19.53
		Average	32.55	0.30	1.03	7.91	36.53	0.40	1.43	10.41	27.00	0.27	0.75	3.93
		Std Dev	26.73	0.14	0.95	10.23	15.10	0.10	0.74	9.73	24.57	0.13	0.64	5.54
		Variance	714.66	0.02	0.91	104.71	227.89	0.01	0.55	94.70	603.58	0.02	0.42	30.66

ND : Less than detection limit of 20 μg

Table 3 SHALLOW MINING SECTION. TRACKLESS MINING TESTS FIXED STATIONS : INTAKE

Date	Test Number	Actual Test Number	STATION "A" Quartz Content Per Cent	STATION "A" Mineral Dust Conc. mg/m³	STATION "A" AQI	STATION "A" Risk Per Cent	STATION "B" Quartz Content Per Cent	STATION "B" Mineral Dust Conc. mg/m³	STATION "B" AQI	STATION "B" Risk Per Cent	STATION "C" Quartz Content Per cent	STATION "C" Mineral Dust Conc. mg/m³	STATION "C" AQI	STATION "C" Risk Per Cent
Morning														
04/11/93	1	5	53.19	0.066	0.35	0.49	30.80	0.100	0.31	0.38	2.07	0.412	0.21	0.17
17/11/93	2	10	37.89	0.081	0.31	0.37	8.28	0.050	0.04	0.01	ND	0.159	0.08	0.03
22/11/93	3	11	28.54	0.099	0.28	0.32	ND	0.162	0.08	0.03	40.02	0.970	0.39	0.61
30/11/93	4	14	ND	0.177	0.09	0.03	ND	0.028	0.01	0.00	ND	0.258	0.13	0.07
01/12/93	5	15	ND	0.106	0.05	0.01	ND	0.149	0.07	0.02	ND	0.132	0.07	0.02
Average			23.92	0.106	0.22	0.24	7.82	0.098	0.10	0.09	8.42	0.386	0.18	0.18
Afternoon														
27/10/93	6	1		0.369				0.313				0.295		
01/11/93	7	3	5,63	0.167	0.09	0.04	3.55	0.129	0.06	0.02	ND	0.148	0.07	0.02
09/11/93	8	6	8.52	0.232	0.20	0.16	42.89	0.128	0.55	1.21	25.75	0.258	0.66	1.76
12/11/93	9	8	ND	0.182	0.09	0.03	8.52	0.188	0.16	0.10				
25/11/93	10	12	51.54	0.211	1.09	4.73	ND	0.160	0.08	0.03	33.33	0.192	0.64	1.64
Average			16.42	0.232	0.37	1.24	13.74	0.184	0.21	0.34	19.69	0.223	0.46	1.14
Night														
27/10/93	11	2		0.220				0.401				0.278		
01/11/93	12	4	2.76	0.284	0.14	0.08	25.58	0.124	0.32	0.40	ND	0.093	0.05	0.01
09/11/93	13	7	21.83	0.307	0.67	1.80	4.24	0.432	0.22	0.19	4.85	0.372	0.19	0.14
12/11/93	14	9	ND	0.83	0.04	0.01	ND	0.105	0.05	0.01				
25/11/93	15	13	26.36	0.332	0.87	3.06	ND	0.241	0.12	0.06	ND	0.211	0.11	0.04
Average			12.74	0.245	0.43	1.24	7.46	0.260	0.18	0.17	1.62	0.239	0.12	0.06
		Minimum	ND	0.07	0.04	3.00	ND	0.03	0.01	0.00	ND	0.09	0.05	0.01
		Maximum	53.19	0.37	1.09	4.73	42.89	0.43	0.55	1.21	40.02	0.97	0.66	1.76
		Average	18.17	0.19	0.33	0.86	9.53	0.18	0.16	0.19	9.64	0.29	0.24	0.41
		Std Dev	19.07	0.09	0.33	1.41	13.68	0.11	0.15	0.32	14.71	0.22	0.22	0.63
		Variance	363.48	0.01	0.11	2.00	187.24	0.01	0.02	0.10	216.50	0.05	0.05	0.40

ND : Less than detection limit of 20 µg

Table 4 SHALLOW LONGWALL MINING SECTION. TRACKLESS MINING TESTS FIXED STATIONS : RETURNS

Date	Test Number	Actual Test Number	STATION "D"				STATION "E"			
			Quartz Content Per Cent	Mineral Dust Conc. mg/m^3	AQI	Risk Per Cent	Quartz Content Per Cent	Mineral Dust Conc. mg/m^3	AQI	Risk Per Cent
Morning										
04/11/93	1	5	10.16	0.302	0.31	0.38	18.03	0.382	0.69	1.90
17/11/93	2	10	40.10	0.163	0.65	1.70				
22/11/93	3	11	72.16	0.433	3.13	39.06	53.35	0.414	2.21	19.53
30/11/93	4	14	75.77	0.392	2.97	32.27	45.00	0.241	1.09	4.72
01/12/93	5	15	58.95	0.285	1.68	11.31	33.12	0.239	0.79	2.51
Average			51.43	0.315	1.75	17.54	37.38	0.319	1.20	7.17
Afternoon										
27/10/93	6	1		1.425				1.686		
01/11/93	7	3	48.95	1.308	6.40	163.84	97.85	0.662	6.48	168.05
09/11/93	8	6	25.76	0.281	0.72	2.09	27.49	0.282	0.78	2.41
12/11/93	9	8	38.71	90.692	2.68	28.70	17.18	0.609	1.05	4.38
25/11/93	10	12	52.79	0.994	5.25	110.23	38.57	0.904	3.49	48.62
Average			41.55	0.940	3.76	76.22	45.27	0.829	2.95	55.87
Night										
27/10/93	11	2		0.215				0.359		
01/11/93	12	4	17.08	0.214	0.37	0.54	67.29	0.198	1.33	7.09
09/11/93	13	7	39.83	0.475	1.89	14.31	49.30	0.388	1.91	14.62
12/11/93	14	9	6.69	0.155	0.10	0.04	46.86	0.062	0.29	0.34
25/11/93	15	13	55.26	1.070	5.91	139.88	44.44	0.508	2.26	20.41
Average			29.72	0.426	2.07	38.69	51.97	0.303	1.45	10.62
		Minimum	6.69	0.16	0.10	0.04	17.18	0.06	0.29	0.34
		Maximum	75.77	1.43	6.40	163.84	97.85	1.69	6.48	168.05
		Average	41.71	0.56	2.47	42.10	44.87	0.50	1.86	24.55
		Std Dev	21.20	0.42	2.11	55.09	21.16	0.39	1.63	45.18
		Variance	449.33	0.17	4.44	3034.52	447.68	0.15	2.66	2041.05

Shown in the Tables are the actual sampling dates and the order that the samples were collected. However, for convenience, all the morning shifts have been grouped together. This has also been done for the afternoon and night shifts. Averages are shown for the three different shifts separately and averages, minimum, maximum, standard deviation and variance are shown for all variables for all shifts in a given category.

2.7.1 Comparison of representative place samples and main return samples, stationary samplers and roving samplers and between roving samplers

If a single stationary monitoring site can be used as an indicator of worker exposure within the section then some agreement could at least be expected between results obtained at possible representative sites.

The results of the comparison between dust loads monitored at the main return, Station E, and at the representative place, Station D, are shown in Figure 2. In this instance there is some agreement and an equation can be fitted to the data as follows:

Dust load for Station D = 0.78 (dust load for Station E) $^{0.92}$

The coefficient of correlation is 0.86.

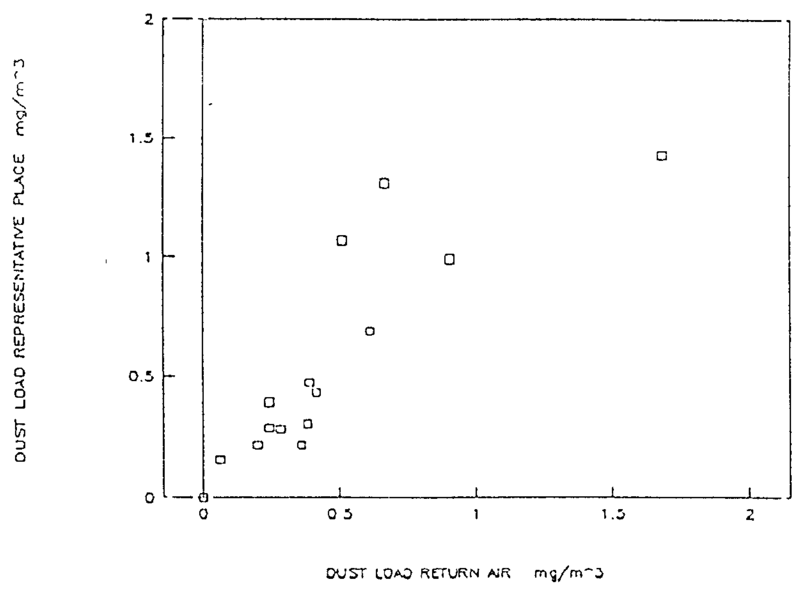

Figure 2 COMPARISON OF DUST LOADS, RETURN AIR AND REPRESENTATIVE PLACE

However, reference to Table 4 shows that over the measuring period the average dust concentration at Station E was 0,5 mg/m^3 with a standard deviation of 0,39 mg/m^3 (78 per cent of the average value). Similarly, for Station D (representative place) the average dust concentration was found to be 0,56 mg/m^3 with a standard deviation of 0,42 mg/m^3 (75 per cent of the average value). The scatter in the data is illustrated in Figure 3*. So, although the correlation in readings appeared to be good, there was a large variation in dust levels with large standard deviations. Although 15 samples had been averaged, it would be necessary to collect many more samples to obtain a representative dust concentration.

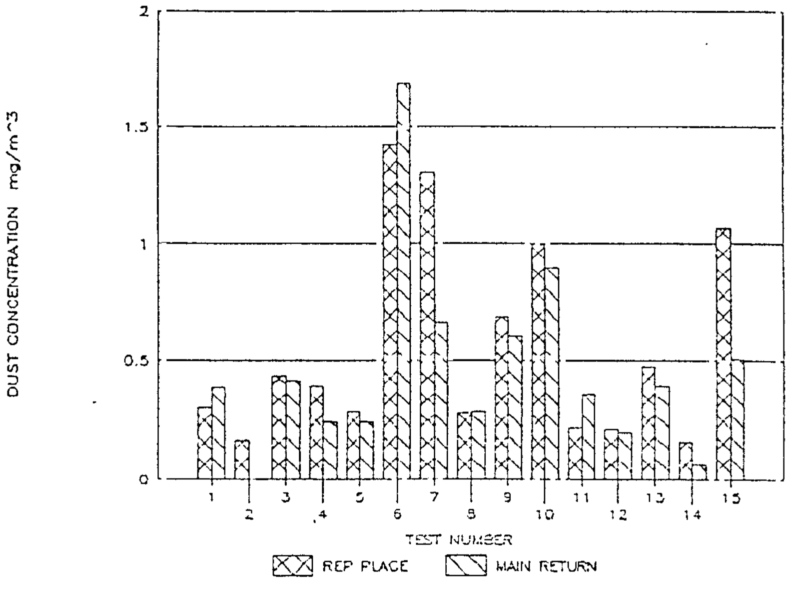

Figure 3 COMPARISON OF AREA SAMPLERS : DUST CONCENTRATIONS AT REPRESENTATIVE PLACE AND MAIN RETURN

* Where shifts are shown on the x-axis the first five shifts are the morning shift results, the next five shifts are afternoon shift results and the last five shifts refer to the night shifts results.

A comparison of dust concentrations at an intake air source and the representative place and main return is shown in Figure 4. Dust concentrations in the intake air are seen to be lower than those measured at the other two localities, but this was to be expected as intake air is supposed to be uncontaminated.The comparison is made in order to establish if any deviation in dust concentrations could be ascribed to mining activities, and not to contaminated intake air on any given day.

An additional comparison is made in Figure 5 for all intake air sources, i.e. Stations A, B and C, and the representative place (Station D) and the main return (Station E). There were differences between intake air dust levels and for some shifts the samples collected at the representative place and the main return were higher than those of the intakes. The differences in dust concentrations between the representative place and the main return recorded for some shifts can be clearly seen. Without a thorough investigation and the collection of a large number of samples the selection of a representative intake position, or representative return air position, would not be readily feasible.

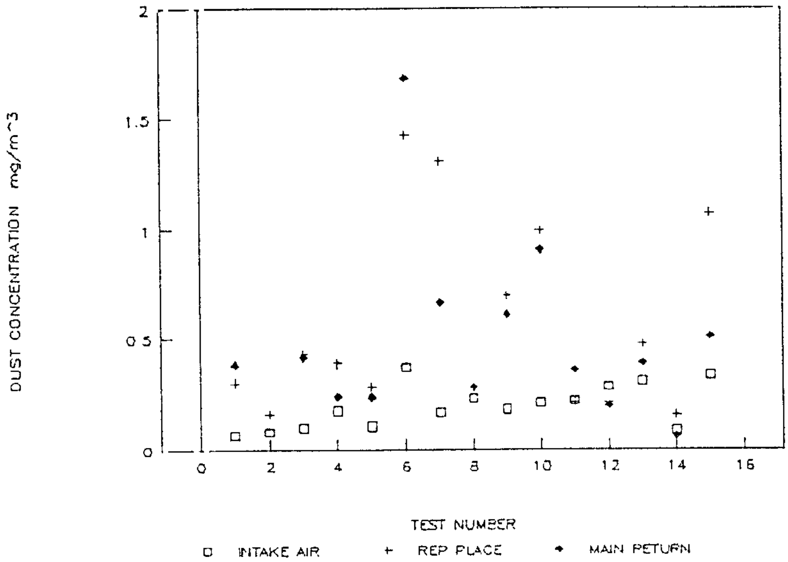

Figure 4 COMPARISON OF INTAKE AND RETURN AIR DUST CONCENTRATIONS - INTAKE REPRESENTATIVE PLACE, MAIN RETURN

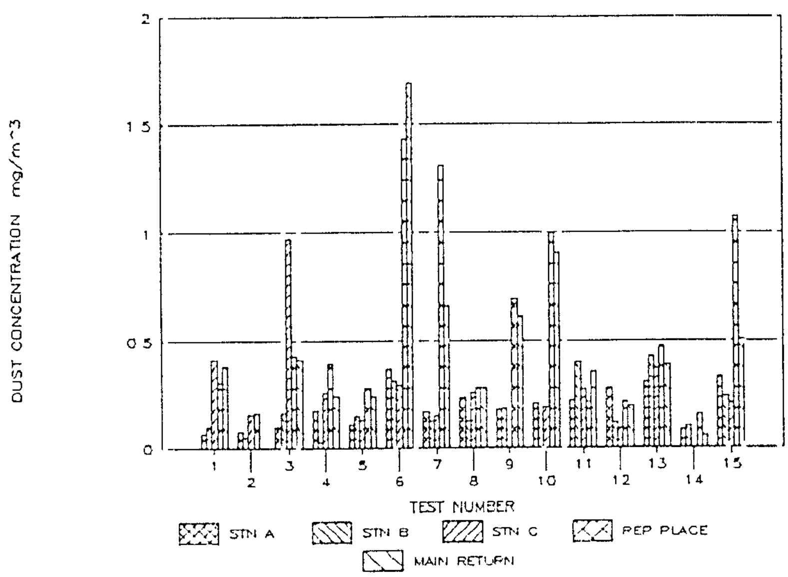

Figure 5 COMPARISON OF INTAKE AND RETURN AIR DUST CONCENTRATIONS : ALL INTAKES, REPRESENTATIVE PLACE, MAIN RETURN

Changes in quartz content, on a shift-wise basis, are illustrated in Figure 6 where the quartz content is plotted for each monitoring shift at the representative place. A large scatter in quartz concentration was encountered: minimum 6,7 per cent, maximum 75,8 per cent with an average value of 41,7 per cent and a standard deviation of 21,2 per cent. Shift-wise fluctuations were unpredictable, large and unexplained.

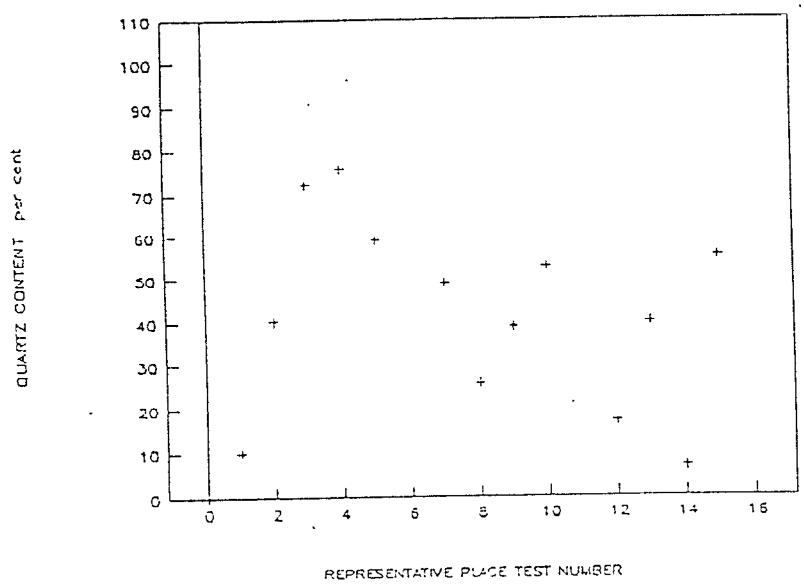

Figure 6 VARIATION IN QUARTZ CONTENT - REPRESENTATIVE PLACE

An investigation into any possible relationship between actual dust concentration and quartz content revealed no acceptable correlation, as seen in Figure 7.

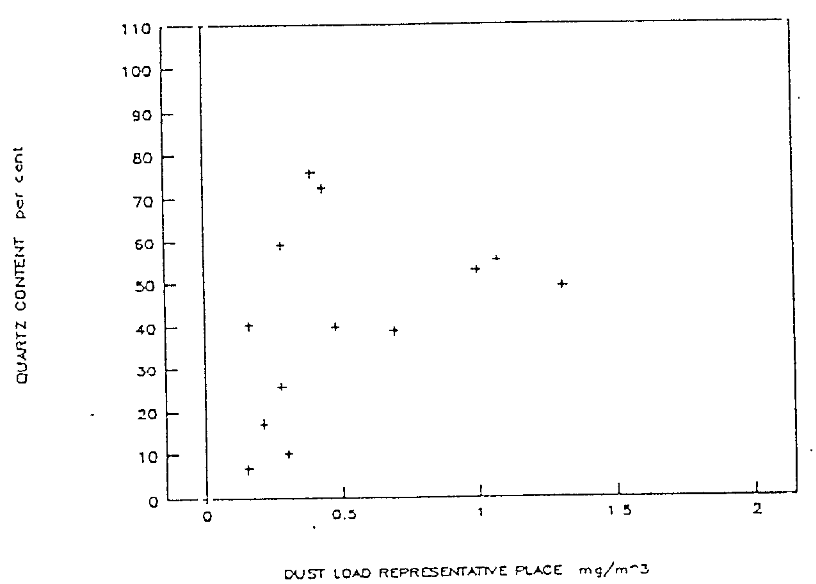

Figure 7 DUST LOAD AND QUARTZ CONTENT - REPRESENTATIVE PLACE

Although an acceptable correlation was found between dust concentrations measured at the representative place and main return (Figure 2) the same conclusion could not be drawn for a comparison of quartz concentrations evaluated for these two measuring stations. This is illustrated in Figure 8 and large variations and scatter are evident.

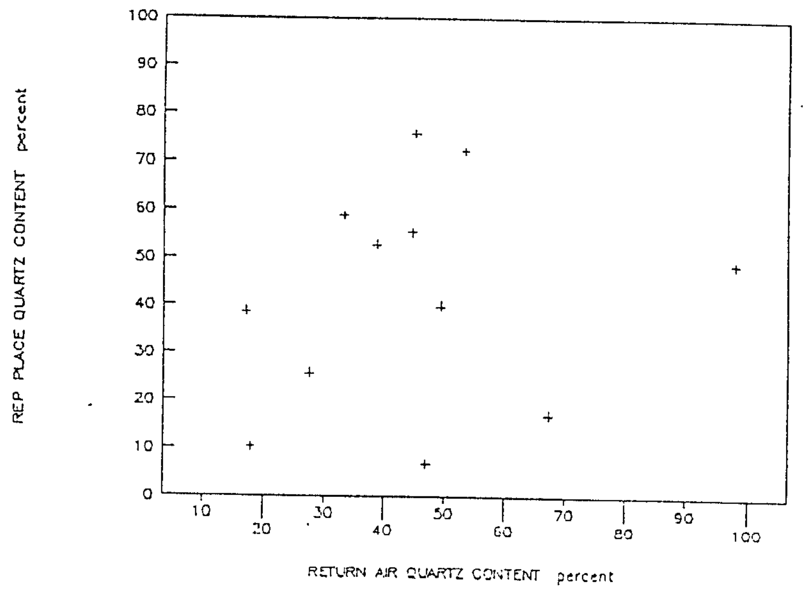

Figure 8 <u>COMPARISON OF QUARTZ CONTENT - RETURN AIR AND REPRESENTATIVE PLACE</u>

One of the main reasons for this intense investigation was to establish if personal sampling could be replaced by area sampling. In Figure 9 the relationship between dust samples collected at the representative place are compared with those collected on a sampler attached to a team leader who roved throughout the mechanised section. As can be seen, dust concentrations for the team leader fall within a narrow range, 0,1-0,6 mg/m^3 and those for the representative place in the range 0,1-1,5 mg/m^3. The correlation is poor in that a single dust concentration at the representative place could correlate with two or three concentrations for the team leader.

Similarly, Figure 10 shows a poor correlation between dust levels at the representative place and those to which a construction worker in the section were exposed. In Figures 11 and 12 quartz concentrations of airborne dust at the representative place were compared with those evaluated for samples collected on filters carried by the team leader and construction worker respectively. No correlations can be seen in these comparisons.

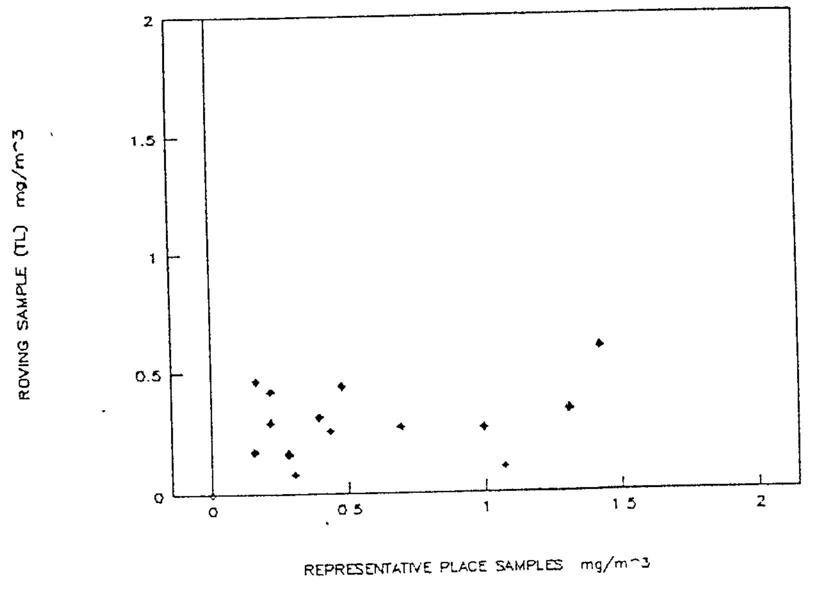

Figure 9 STATIONARY AND ROVING SAMPLES - DUST AT REPRESENTATIVE PLACE, TEAM LEADER

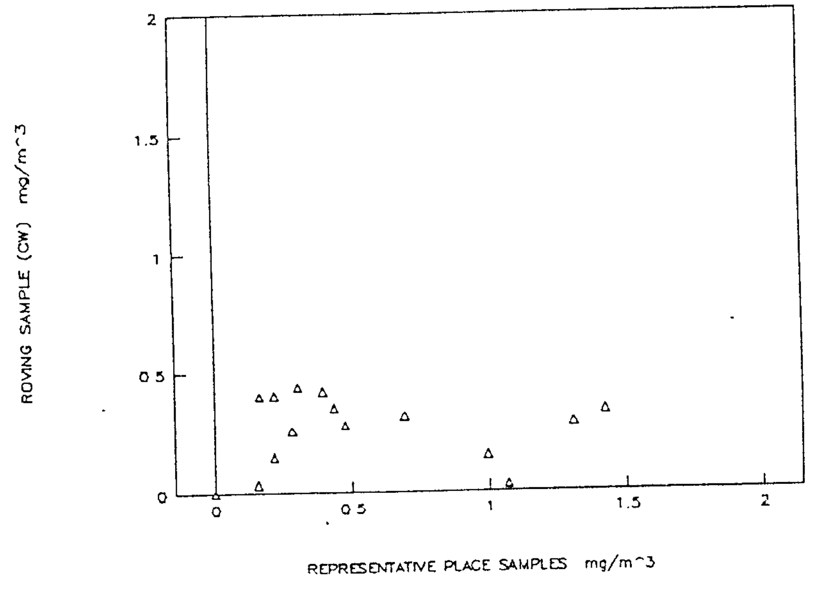

Figure 10 STATIONARY AND ROVING SAMPLES - DUST AT REPRESENTATIVE PLACE, CONSTRUCTION WORKER

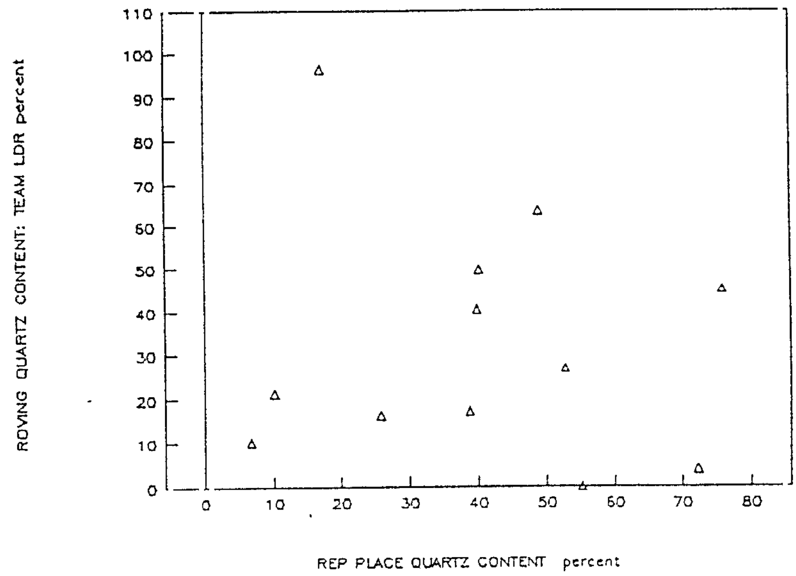

Figure 11 COMPARISON OF QUARTZ CONTENT - REPRESENTATIVE PLACE, TEAM LEADER

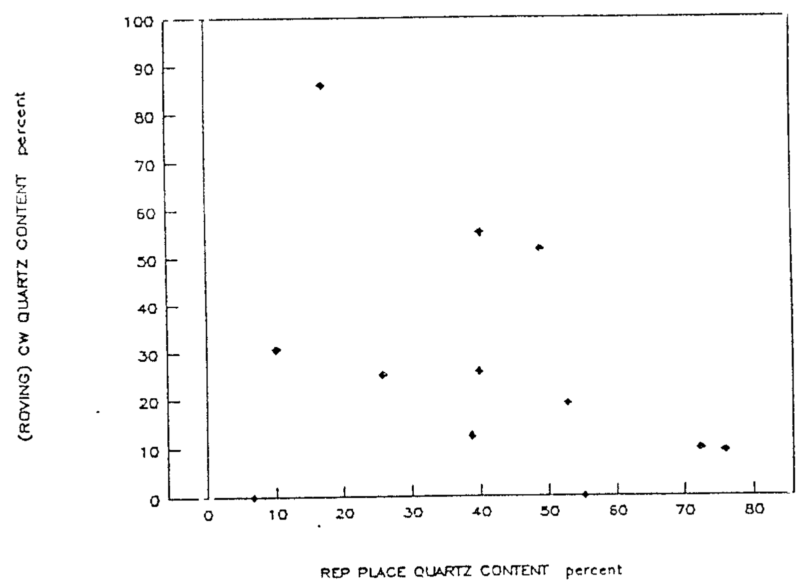

Figure 12 COMPARISON OF QUARTZ CONTENT - REPRESENTATIVE PLACE, CONSTRUCTION WORKER

Because a good correlation was found between dust concentrations measured at the main return and the representative place, it can also be concluded that if results from the main return had been used, instead of those from the representative place, no meaningful correlations between stationary and roving samplers would have emerged for any of the comparisons discussed above.

Ultimately, in the Government Mining Engineer's gravimetric dust sampling programme, dust and quartz concentrations are used to calculate an Air Quality Index (AQI) and "Risk" for each Statistical Population in a mine's sampling strategy. The AQI is calculated as follows:

$$AQI = \left(\text{Per cent Quartz X } \frac{\text{dust concentration}}{100} \right) \text{ x } 10^{-1}$$

In effect the quartz fraction of the mineral dust is compared to a Threshold Limit Value (TLV) of 0,1 mg/m^3 . The TLV is considered to be a concentration to which most persons can be exposed for eight hours a day for five days a week without experiencing harmful effects over a working life time.

Any AQI greater then a value of one should attract attention and an action level is considered to be half the TLV. The AQI may be considered to be a better measure of conditions than individual dust and quartz measurements since it incorporates both dust and quartz concentrations in the Index.

Risk has been defined by the GME as 4 $(AQI)^2$ and is used in calculations of dust levies.

A plot of AQI evaluated for each monitoring shift at the representative place is shown in Figure 13. Very large shift-wise fluctuations are seen as well as a very large scatter in the data. Of the 13 valid data sets eight had AQIs in excess of unity. However, the scatter in the results, as seen in Table 4, shows that values varied from 0,1 to 6,4 with an average of 2,5 and a standard deviation of 2,1 (84 per cent of average). A comparison of AQIs for the main return (Station E) and the representative place (Station D) is illustrated in Figure 14. Once again, although it was seen in Figure 2 that a good correlation existed for dust concentrations measured at these two localities, no such correlation could be found for the AQIs calculated for these two monitoring stations. Against this criterion results from these two stationary samples' positions are no longer seen to be interchangeable.

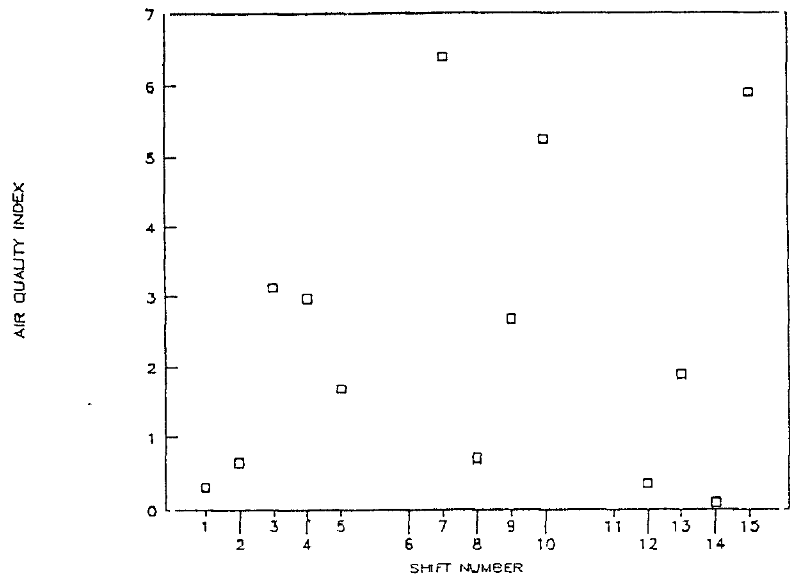

Figure 13 AIR QUALITY INDEX : REPRESENTATIVE PLACE "D"

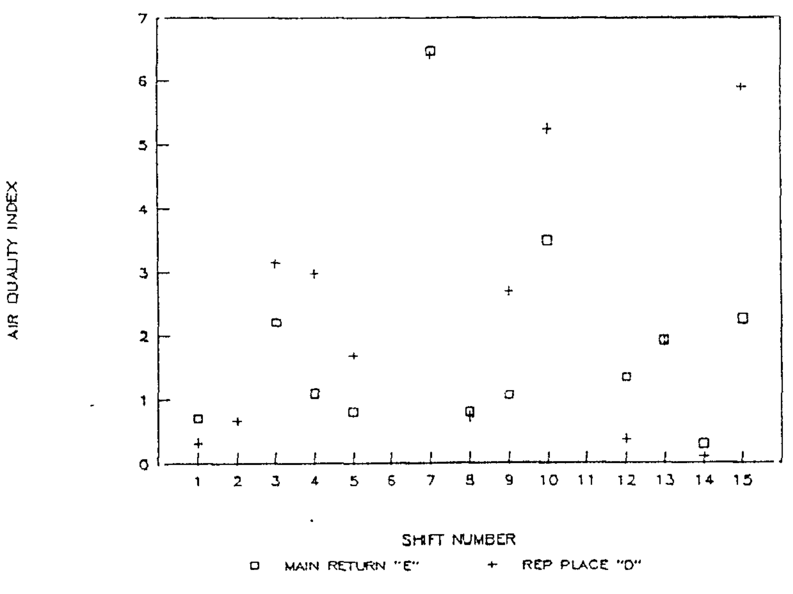

Figure 14 AQI : COMPARISON OF FIXED SAMPLERS : MAIN RETURN "E" AND REPRESENTATIVE PLACE "D"

A comparison for a stationary or fixed sampler (Station D) with a personnel (roving) sampler worn by the team leader is shown in Figure 15. No real correlation can be observed and a poor correlation is observed when AQIs for the representative place are compared with those of other roving samplers namely the dump truck driver (Figure 16) and the Load Haul Dump (LHD) driver (Figure 17).

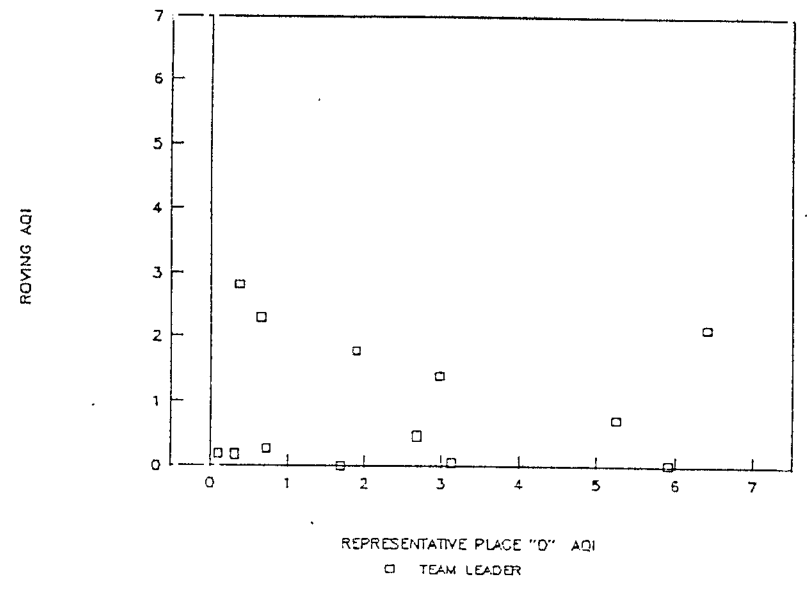

Figure 15 AQI : COMPARISON : FIXED TO ROVING SAMPLES : REPRESENTATIVE PLACE "D" AND TEAM LEADER

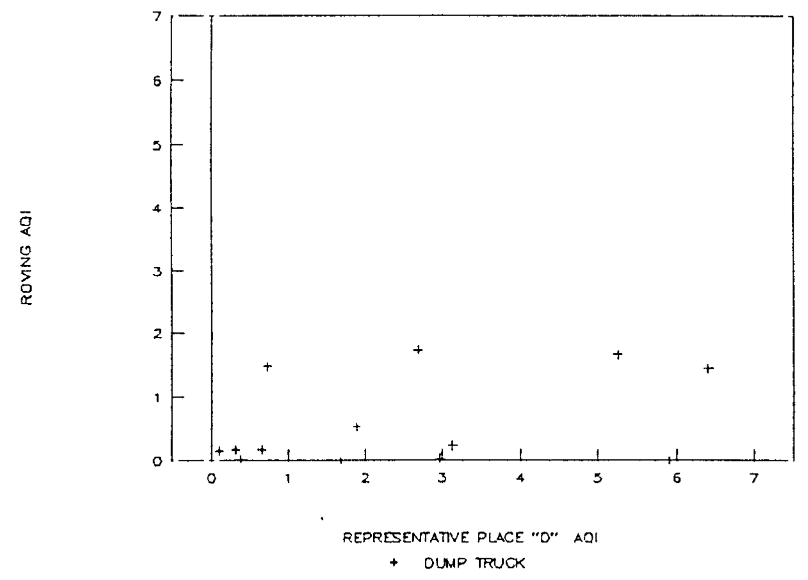

Figure 16 AQI : COMPARISON FIXED TO ROVING SAMPLES REPRESENTATIVE PLACE "D" AND DUMP TRUCK

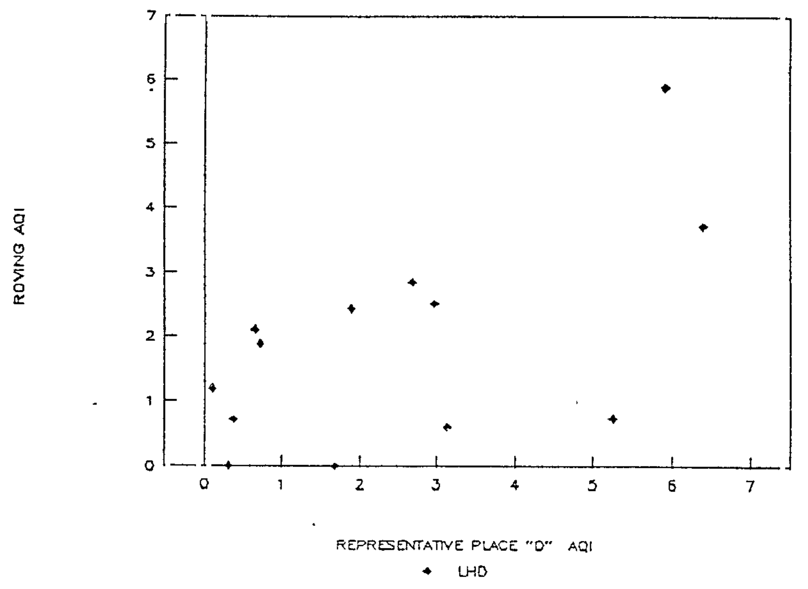

Figure 17 AQI : COMPARISON FIXED TO ROVING SAMPLES REPRESENTATIVE PLACE "D" AND LHD

Figure 18 shows the last three comparisons on a single plot.

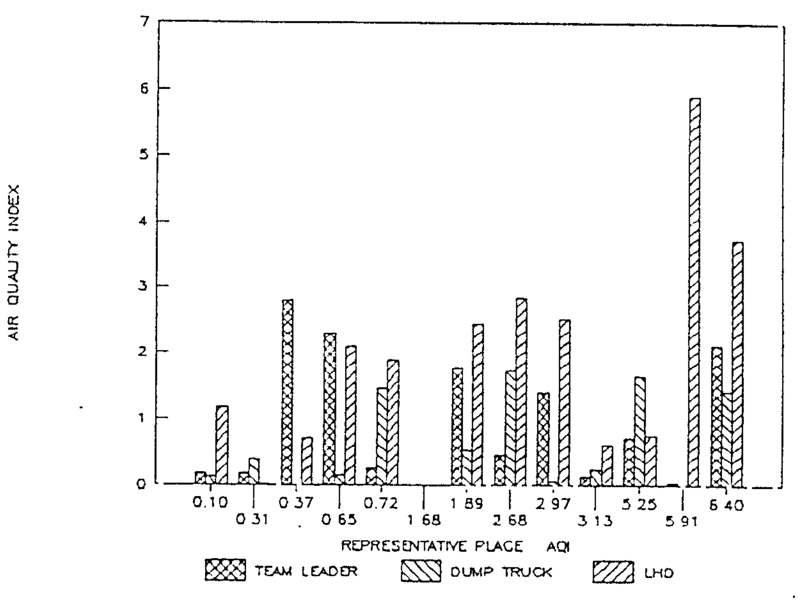

Figure 18 AQI : COMPARISON FIXED TO ROVING SAMPLES REPRESENTATIVE PLACE, TEAM LEADER, DUMP TRUCK, LHD

Comparisons of exposures experienced by roving personnel were also evaluated. These are all persons engaged in the same working area, and, to some degree similarity in dust exposures could have been anticipated. Furthermore, if correlation proved to be good it may be possible to only sample one person and then be able to obtain representative exposure levels for other workers in this area. Potentially, this could save on sampling costs. In Figure 19 dust levels experienced by the scaler and roof bolter operators are compared and large shift-wise and individual differences were found. The range of dust concentrations measured for the scaler operator was found to be 0,2 to 0,56 mg/m^3 with an average value of 0,34 mg/m^3 and a standard deviation of 0,12 mg/m^3 (35 per cent of the average). Although the average exposure for the roof bolt operator was also found to be 0,34 mg/m^3 the scatter of dust concentrations was much higher and lay in the range 0,05 - 0,96 mg/m^3 with a standard deviation of 0,29 mg/m^3 (85 per cent). Dust loads for the team leader and construction worker are depicted in Figure 20, where once again it is seen that two persons working in the same section can experience different dust exposures which are largely unrelated. This is further illustrated in Figures 21 to 23 which compares dust exposures for the LHD operator with those of the team leader,as well as with those of the dump truck driver respectively.

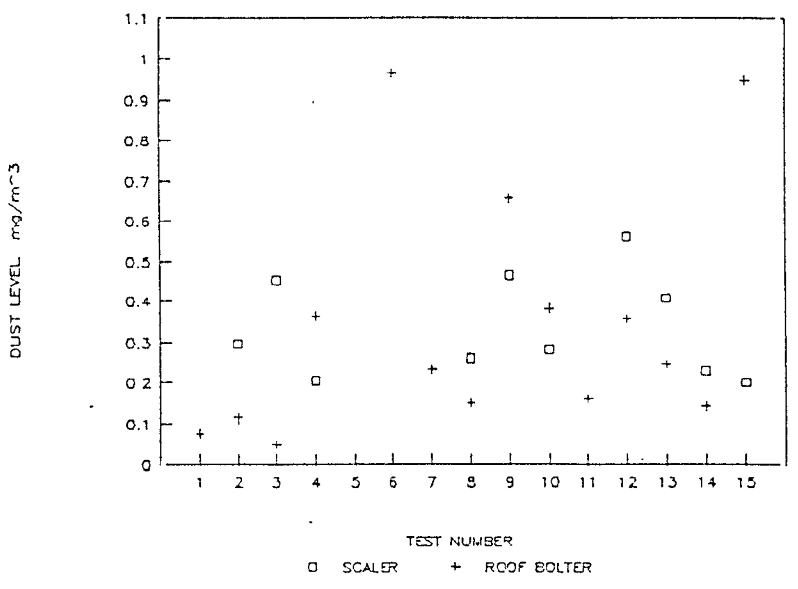

Figure 19 VARIATION IN DUST EXPOSURE - SCALER AND ROOF BOLTER

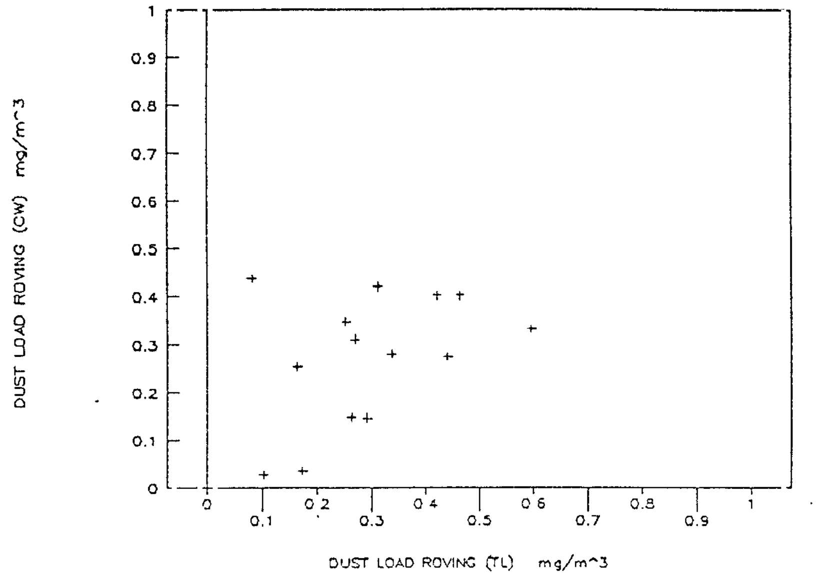

Figure 20 COMPARISON OF DUST LOADS - ROVING : TEAM LEADER AND CONSTRUCTION WORKER

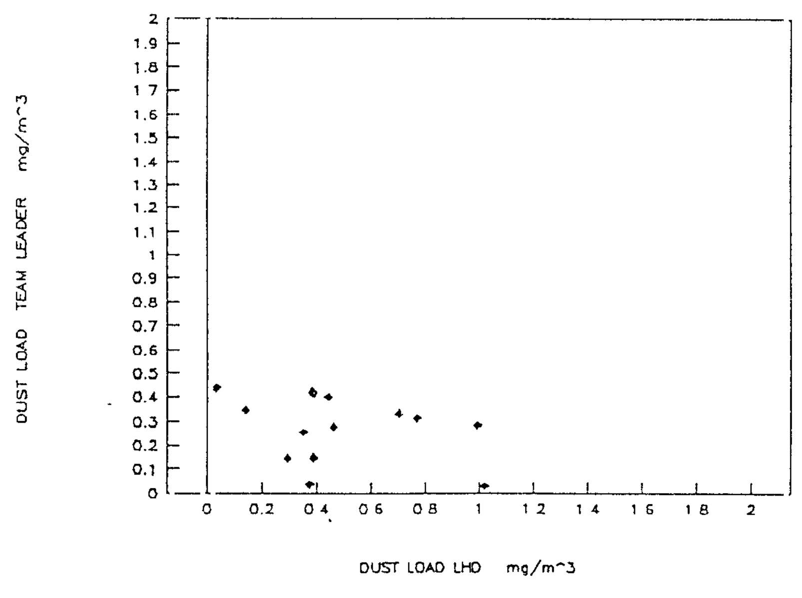

Figure 21 COMPARISON OF DUST LOADS - ROVING : LHD AND TEAM LEADER

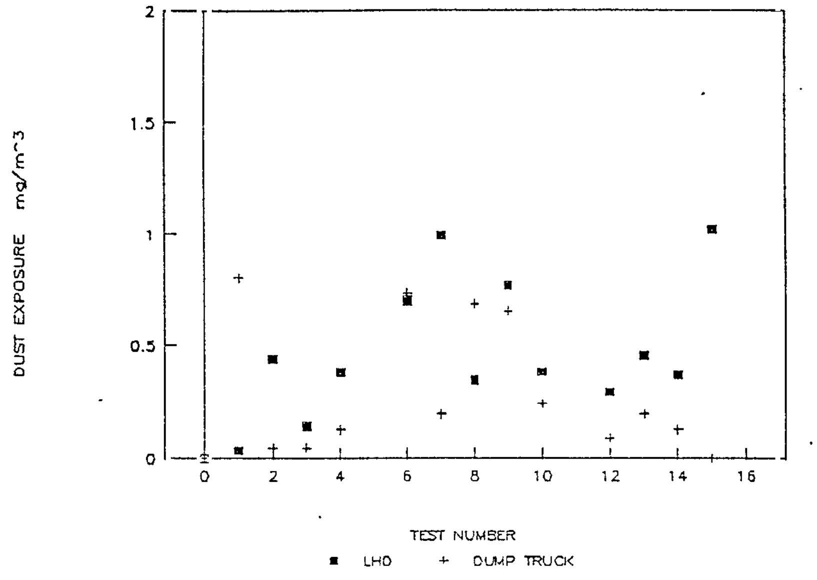

Figure 22 VARIATION IN DUST EXPOSURE - ROVING : LHD AND DUMP TRUCK

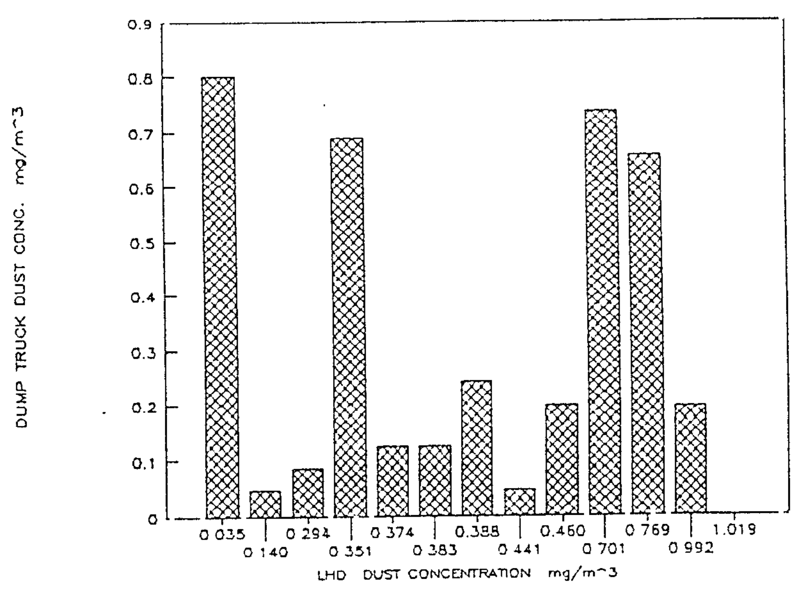

Figure 23 COMPARISON OF ROVING SAMPLERS : LHD AND DUMP TRUCK

The quartz content of airborne dust was also compared for roving samplers and some of the results are shown in Figures 24 to 26 where they are set out for the team leader, the construction worker and the LHD operator respectively.

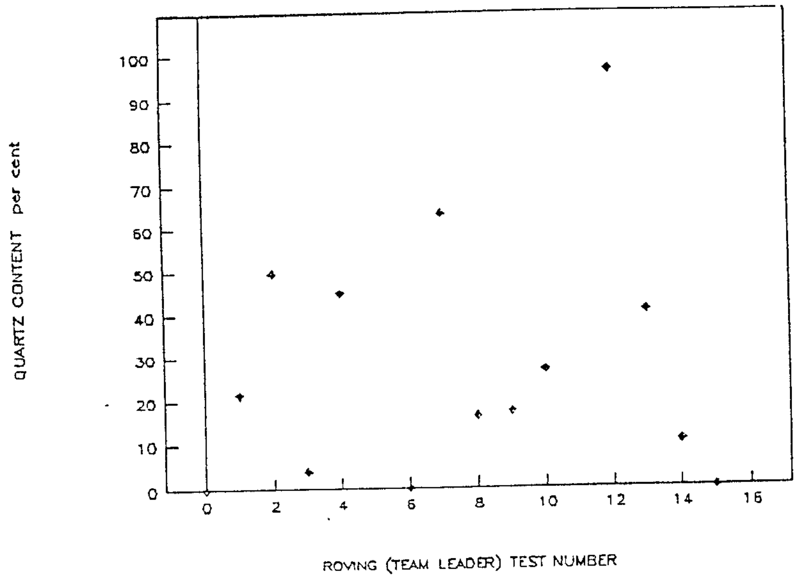

Figure 24 VARIATION IN QUARTZ CONTENT - ROVING : TEAM LEADER

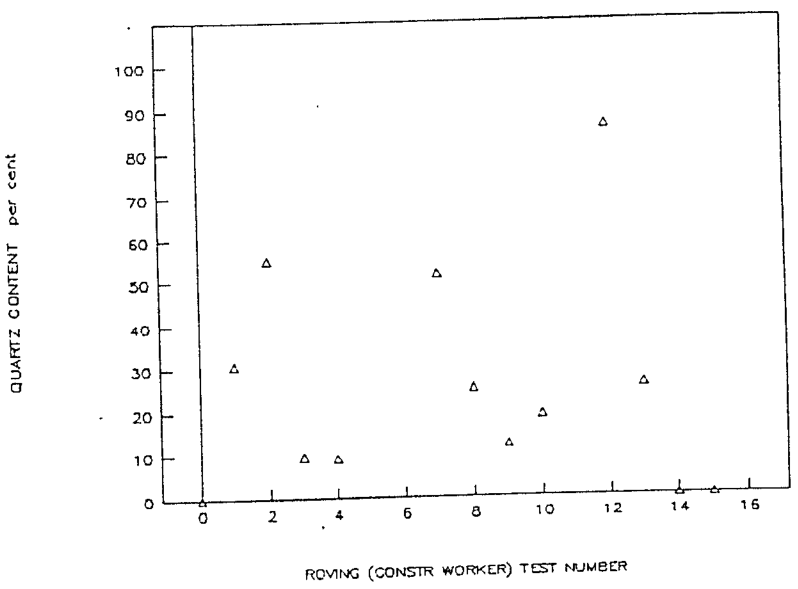

Figure 25 VARIATION IN QUARTZ CONTENT - ROVING : CONSTRUCTION WORKER

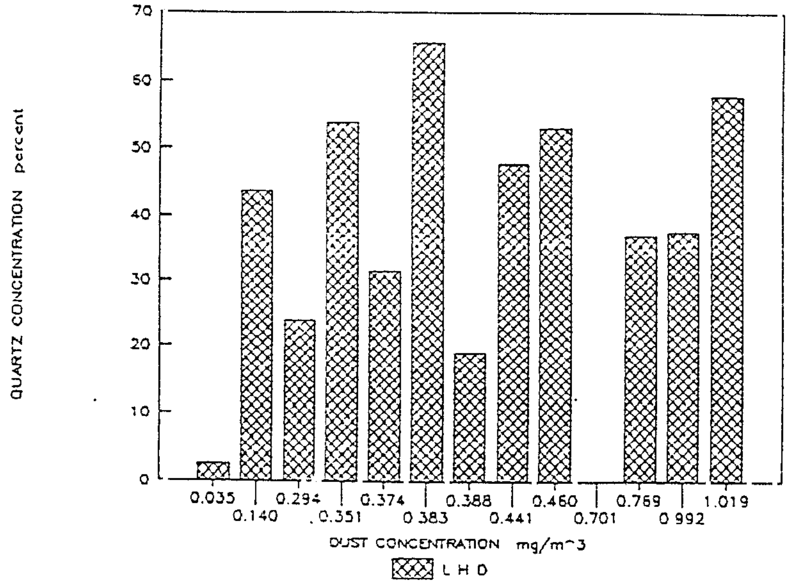

Figure 26 VARIATION IN DUST AND QUARTZ LEVELS : ROVING - LHD

Again, large shift-wise and individual fluctuations were found. A direct comparison of the quartz content of airborne dust experienced by the team leader and construction worker, respectively, is shown in Figure 27. Although there is a reasonable correlation in quartz content as seen in Figure 20 there was little agreement in dust concentrations, and consequently, large variations in AQI occurred (see Table 2). As in Figure 7, where the dust load was compared to the quartz concentration for a stationary sampler (representative place), the comparison is now made for roving samplers, namely, the team leader (Figure 28) and the construction worker (Figure 29). Once again no correlation was found.

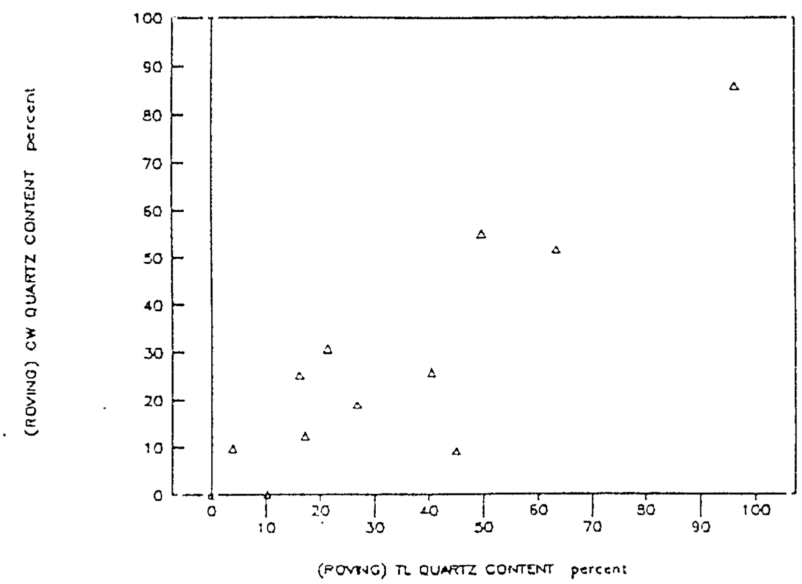

Figure 27 COMPARISON OF QUARTZ CONTENT ROVING : TEAM LEADER AND CONSTRUCTION WORKER

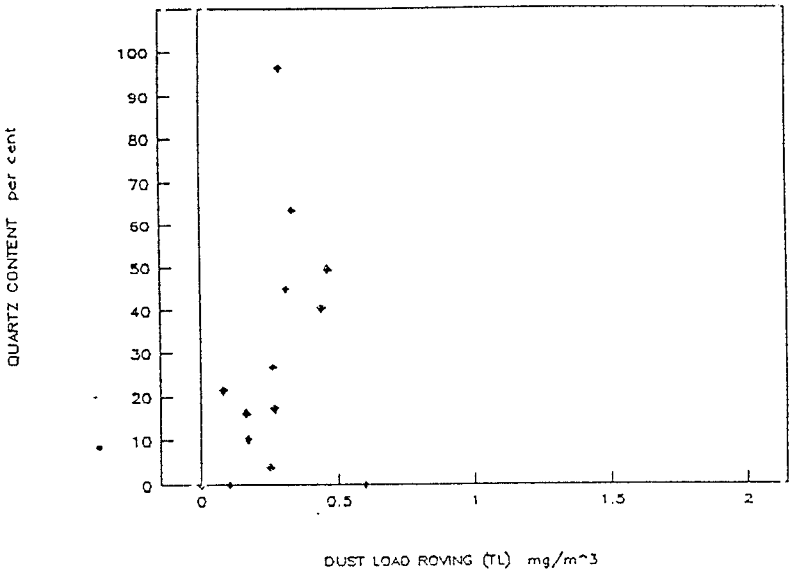

Figure 28 DUST LOAD AND QUARTZ CONTENT - ROVING : TEAM LEADER

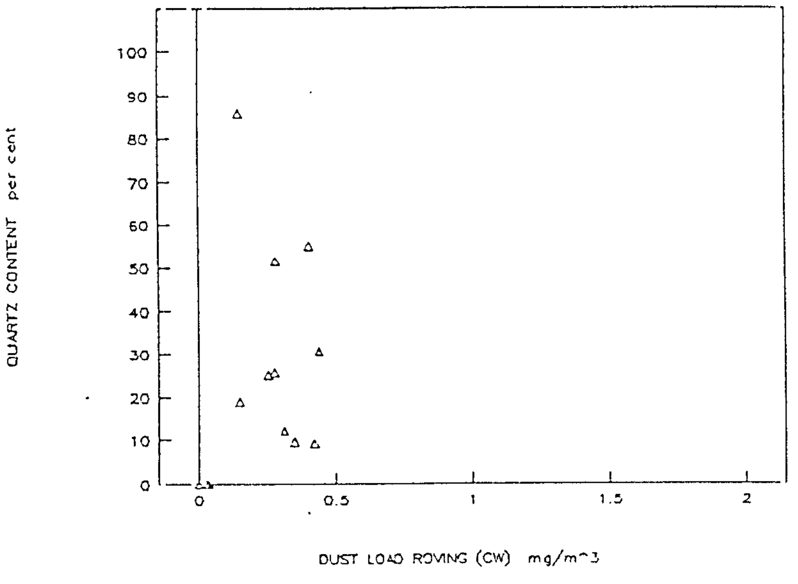

Figure 29 DUST LOAD AND QUARTZ CONTENT - ROVING : CONSTRUCTION WORKER

The AQIs were investigated for roving samplers within the section. Figure 30 shows the variation in AQI levels observed for the team leader and Figure 31 shows the results obtained for the dump truck driver. The large shift-wise variations of AQI for the LHD operator are depicted in Figure 32 and a comparison of AQIs for the dump truck and LHD operators is shown in Figure 33.

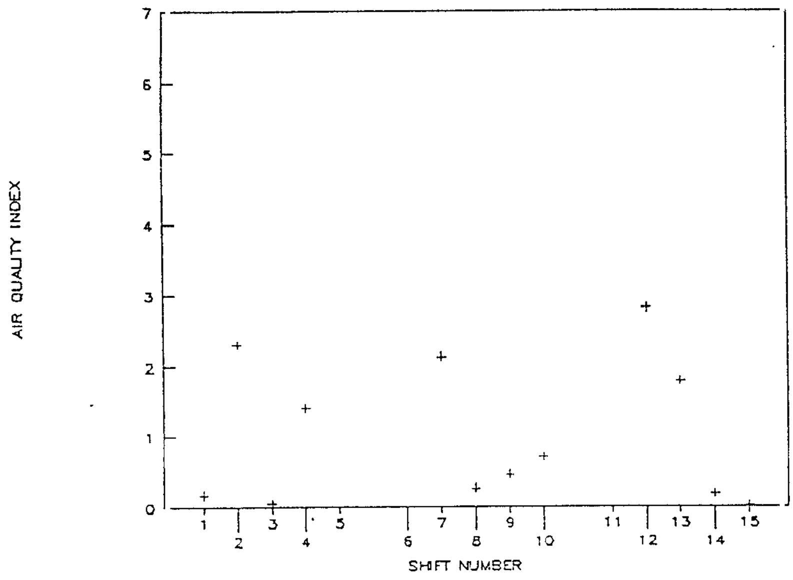

Figure 30 AIR QUALITY INDEX - ROVING : TEAM LEADER

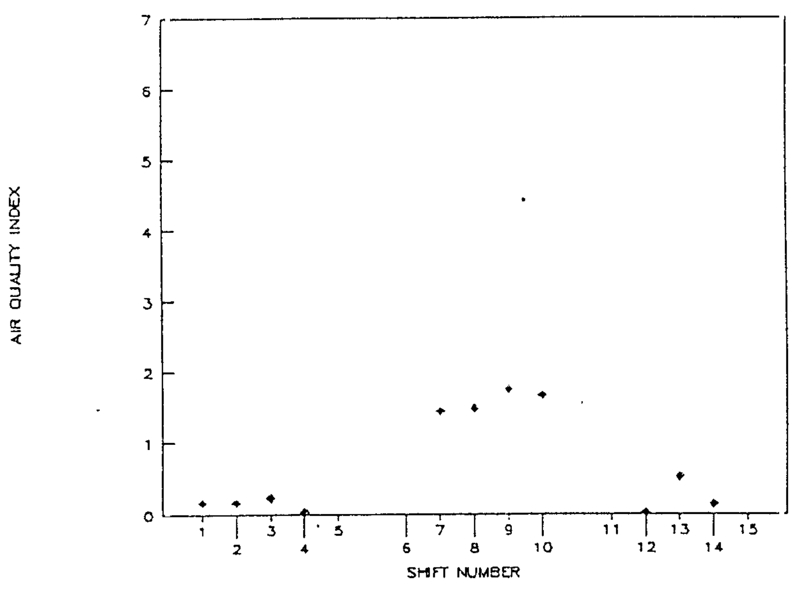

Figure 31 AIR QUALITY INDEX - ROVING : DUMP TRUCK

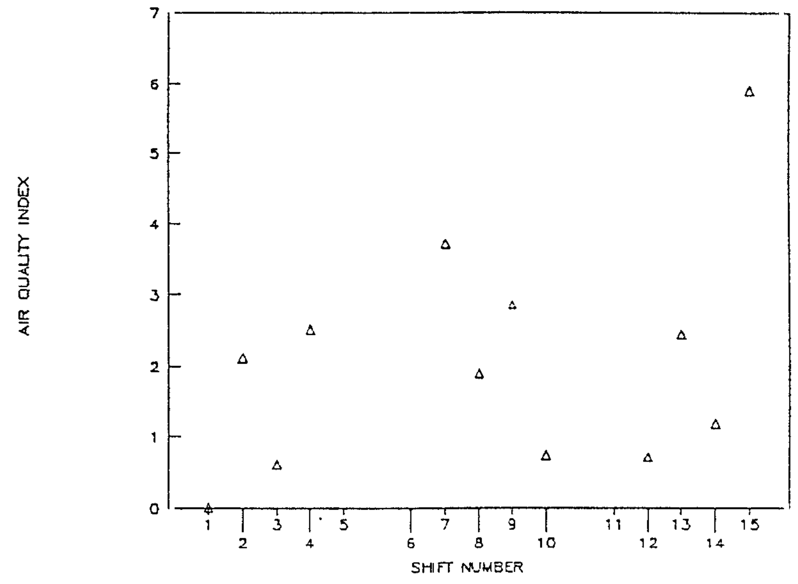

Figure 32 AIR QUALITY INDEX - ROVING : LHD

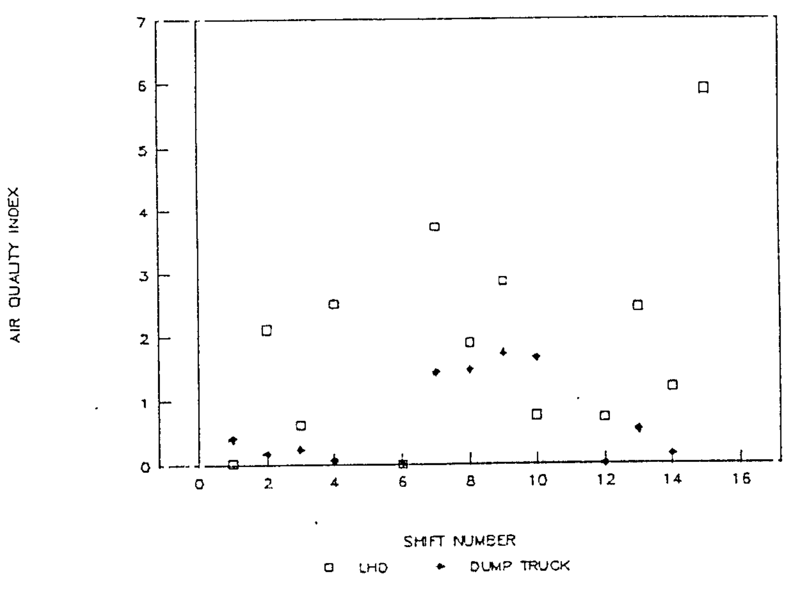

Figure 33 COMPARISON OF AQI - ROVING : LHD AND DUMP TRUCK

Figure 34 shows a similar comparison but includes the results obtained for the team leader as well. A study of these Figures shows large shift-wise and individual fluctuations with little or no correlation.

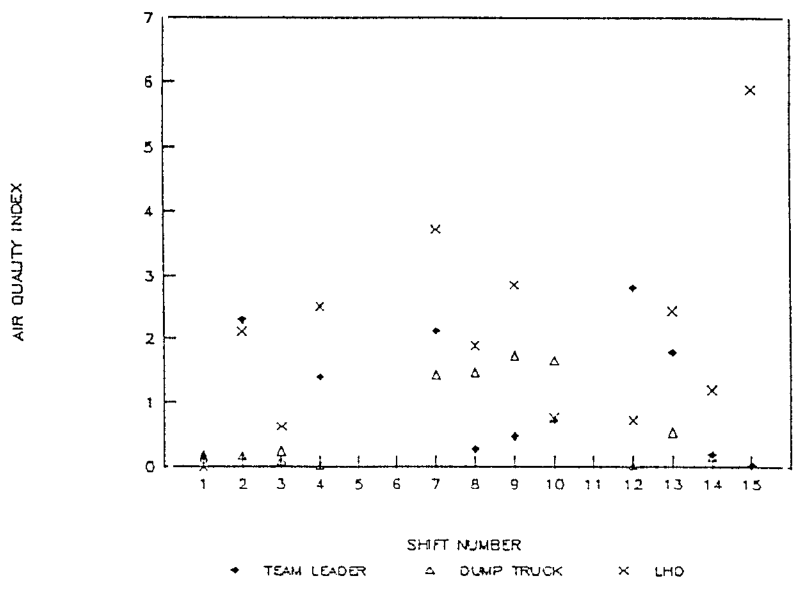

Figure 34 AQI COMPARISON OF ROVING SAMPLERS : TEAM LEADER, DUMP TRUCK, LHD

Discussion on these findings will be presented under this heading when the results of all the investigations have been set out.

3 TEST SITE 2 Shallow mine - conventional "mini" longwall section.

3.1 Description of Test Site

This monitoring site was located approximately 1 100 m below surface and very close to the shaft. The stoping width was 1,2 m. Mining took place over ten panels - five on the west and five on the east side of the original raise with the panels designated 1W, 2W etc. (See Figure 35). The stoping dip distance was about 200 m and the angle of inclination about 25°. Approximately 12 m^3/s entered the footwall cross-cut on 8 level, passed up a cross raise and was joined with 15 m^3/s from the stoping section below to provide the ventilating air for the site under investigation. After passing through the test site 14 m^3/s passed to the stoping section above and 13 m^3/s

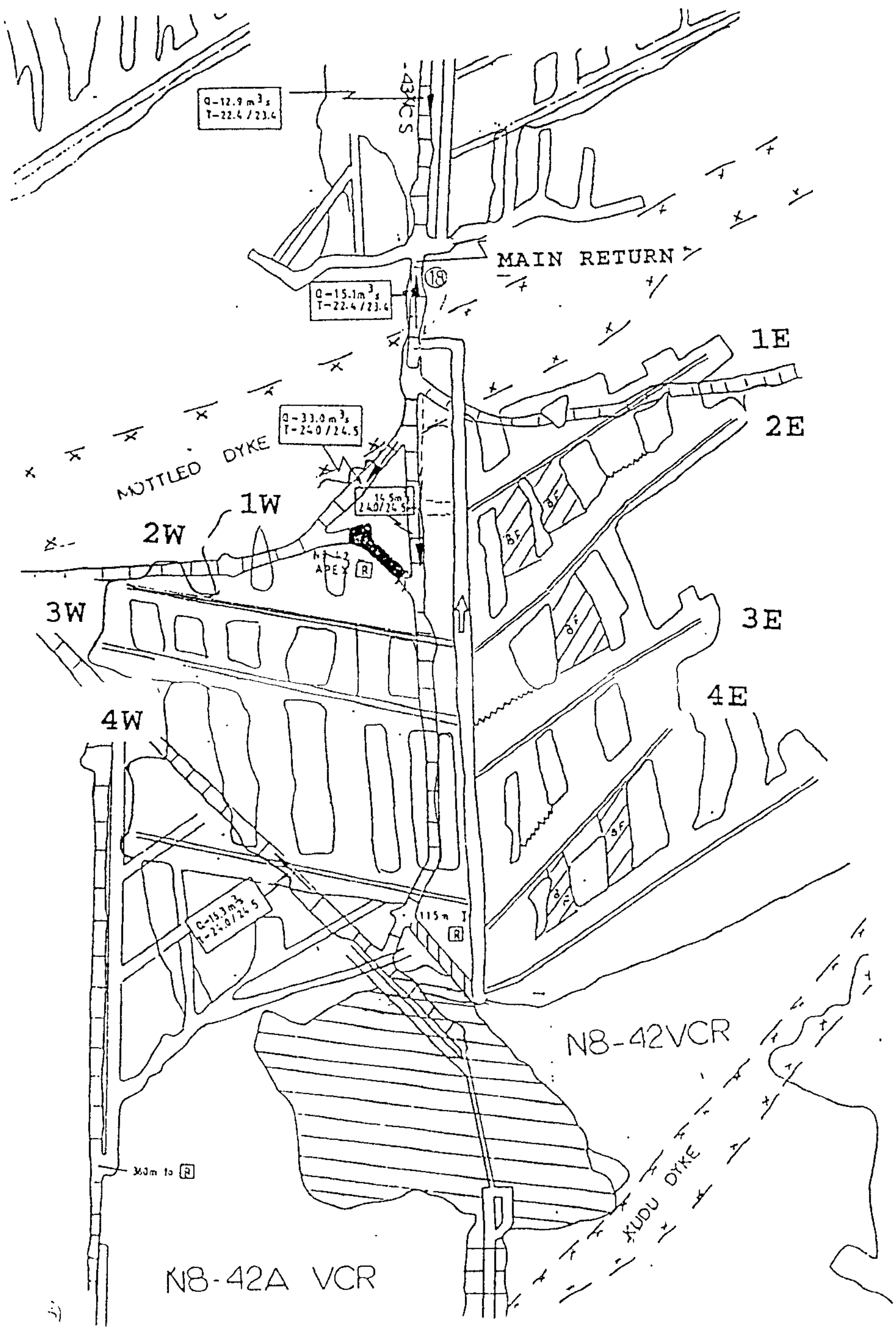

Figure 35 LAYOUT OF TEST SITE (2)

returned on 6 level. A day shift and a cleaning shift were in force and dust samples were collected over both shifts for the full duration of the shift. Personnel involved during morning shift operations totalled 58 and during the night (cleaning) 32.

3.2 Measurement Strategy

Research personnel proceeded to the test site approximately one hour before commencement of mining activities to check instrumentation and set up the stationary monitors.

Fixed position monitoring stations were established in the main return and at the top of 1W and 1E panels respectively. These latter two monitoring positions were considered to be representative places and the same sampling pumps were always used in the same localities for these three sampling positions.

As far as was possible pumps were attached to personnel in each working panel but the same panels were not always being worked. Due to different work allocation it was, therefore, not always possible therefore to always monitor the same personnel.

Two Gilian pumps were placed at each of the fixed positions in very close proximity for each shift to sample at each of the fixed positions. Later it was possible to operate samplers with rotating sponges in parallel with the Gilian pumps. Each of the personnel selected for a given shift also carried two sampling pumps. This was done to test results for parallel personal sampling as well as for stationary sampling.

Ventilation surveys and parallel dust sampling was carried out by mine environmental control personnel during each of the monitoring shifts.

The purpose of all the measurements was to again compare results from stationary monitors with those obtained for personal or roving monitors. In addition, the performance and results of instruments sampling in close proximity to each other could be compared.

Data were collected over the period 21 December 1993 to 21 February 1994 over 14 shifts.

3.3 Instrumentation, Monitoring Procedures and Quality Control

These have all been described in Section 2.

3.4 Results from and Analysis of Measurements

Details are set out in Tables 5 to 7.

Table 5 CONVENTIONAL LONGWALL SECTION PERSONNEL (ROVING)

Date	Test Number	1W Quartz Content Per Cent	1W Mineral Dust Conc. mg/m³	1W AQI	1W Risk Per Cent	2W Quartz Content Per Cent	2W Mineral Dust Conc. mg/m³	2W AQI	2W Risk Per Cent	3W Quartz Content Per Cent	3W Mineral Dust Conc. mg/m³	3W AQI	3W Risk Per Cent	4W Quartz Content Per Cent	4W Mineral Dust Conc. mg/m³	4W AQI	4W Risk Per Cent
21/12/93	1	ND 4.47	0.676 0.760	0.34 0.38	0.46 0.58					2.71 4.13	0.884 0.824	0.44 0.41	0.78 0.68				
28/12/93	2	3.87 ND	0.620 0.638	0.31 0.32	0.38 0.41					6.30 8.91	0.587 0.539	0.37 0.48	0.55 0.92				
05/01/94	3	12.85 8.83	0.677 0.657	0.87 0.58	3.03 1.35					17.27 ND	0.724 0.428	1.25 0.21	6.25 0.18				
07/01/94	4	9.24 8.67	0.768 0.830	0.71 0.72	2.01 2.07	18.58	1.572	2.92	34.11								
11/01/94	5																
19/01/94	6	9.21 3.61	0.521 0.830	0.48 0.42	0.92 0.69												
24/01/94	7	5.67 0.19	0.600 0.523	0.34 0.26	0.46 0.27												
28/01/94	8	ND ND	0.318 0.839	0.16 0.42	0.10 0.70					9.32 2.84	1.341 0.952	1.25 0.48	6.25 0.91				
01/02/94	9													ND ND	0.533 0.592	0.27 0.30	0.28 0.35
04/02/94	10													ND ND	0.763 0.880	0.38 0.44	0.58 0.77
09/02/94	11																
14/02/94	12													ND ND	0.699 0.442	0.35 0.22	0.49 0.20
17/02/94	13													ND 1.10	0.890 1.092	0.45 0.55	0.79 1.19
21/02/94	14													1.10 1.17	0.908 0.858	0.45 0.43	0.82 0.74
	Minimum Maximum Average Std Dev Variance	ND 12.85 4.76 4.24 17.98	0.32 0.84 0.66 0.14 0.02	0.16 0.87 0.45 0.19 0.04	0.10 3.03 0.96 0.82 0.67					ND 17.27 6.44 5.97 25.67	0.43 1.34 0.78 0.27 0.07	0.21 1.25 0.61 0.38 0.14	0.18 6.25 2.07 2.43 5.89	ND 1.17 0.34 0.52 0.27	0.44 1.09 0.77 0.19 0.04	0.22 0.55 0.38 0.09 0.01	0.20 1.19 0.62 0.29 0.08

ND : Less than detection limit of 20 µg

Table 6 CONVENTIONAL LONGWALL SECTION PERSONNEL (ROVING)

		5W				1E				4E				5E			
Date	Test Number	Quartz Content Per Cent	Mineral Dust Conc. mg/m³	AQI	Risk Per Cent	Quartz Content Per Cent	Mineral Dust Conc. mg/m³	AQI	Risk Per Cent	Quartz Content Per Cent	Mineral Dust Conc. mg/m³	AQI	Risk Per Cent	Quartz Content Per Cent	Mineral Dust Conc. mg/m³	AQI	Risk Per Cent
21/12/93	1																
28/12/93	2																
05/01/94	3																
07/01/94	4					12.71	1.031	1.31	6.86								
11/01/94	5																
19/01/94	6					ND ND	0.632 0.483	0.316 0.242	0.40 0.23								
24/01/94	7						0.581										
28/01/94	8																
01/02/94	9	2 84 3 81	0.810 0.761	0.41 0.38	0.66 0.58												
04/02/94	10													ND ND	0.884 0.791	0.44 0.40	0.78 0.63
09/02/94	11	3.18 ND	0.880 1.268	0.44 0.63	0.77 1.61									ND 1.58	1.210 1.586	0.61 0.79	1.46 2.52
14/02/94	12													ND 1.42	0.952 0.917	0.48 0.46	0.91 0.84
17/02/94	13													ND ND	0.773 0.776	0.39 0.39	0.60 0.60
21/02/94	14									1.26 ND	0.795 0.832	0.40 0.42	0.63 0.69				
	Minimum Maximum Average Std Dev Variance	ND 3.81 2.46 1.46 2.13	0.76 1.27 0.93 0.20 0.04	0.38 0.63 0.46 0.10 0.01	0.58 1.61 0.90 0.41 0.17		0.48 1.03 0.68 0.21 0 04							ND 1.58 0.38 0.65 0.42	0.77 1.59 0.99 0.26 0.07	0.39 0.79 0.49 0.13 0.02	0.60 2.52 1.04 0.62 0.38

ND : Less than detection limit of 20 µg

Tables 5 and 6 show the results obtained for personal monitoring conducted in panels 1W, 2W, 3W, 4W, 5W, 1E, 4E and 5E. As far as possible maxima, minima, averages, standard deviations and variances have been calculated. Table 7 sets out the results for the representative samples and the main return samplers. The results of these monitoring exercises indicate that the range in dust concentrations and quartz concentrations were much lower than those obtained at the first test site. Nevertheless, standard deviations of up to 35 per cent of average values were calculated and, once again, these are much lower than those calculated for the first test site.

A comparison of dust concentrations at Station 1W (representative place) and the main return, as shown in Figure 36, indicates no meaningful correlation. This result is totally different from that obtained at the first site where correlation was found to be good and could be expressed in a mathematical relationship. When the results of dust levels obtained for a representative place are compared with those for a personal sampler (roving) (1W), once again no meaningful correlation can be found. (Figure 37). Furthermore, a comparison of dust levels at the main return with those of representative place 1W (Figure 38) also displays no correlation.

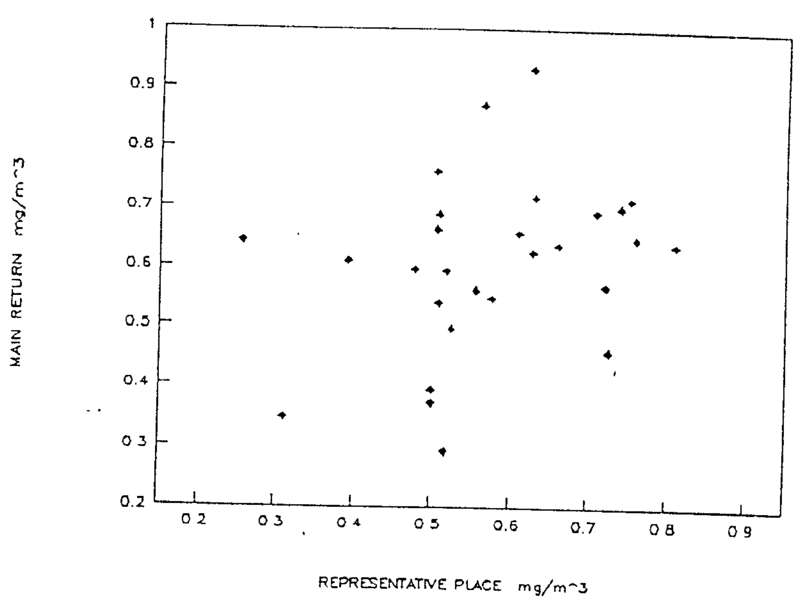

Figure 36 COMPARISON OF STATIONARY SAMPLERS : REPRESENTATIVE PLACE AND MAIN RETURN (DUST)

Table 7 <u>CONVENTIONAL LONGWALL SECTION FIXED STATIONS : REPRESENTATIVE PLACES</u>

Date	Test Number	1E				1W				MAIN RETURN			
		Quartz Content Per Cent	Mineral Dust Conc. mg/m³	AQI	Risk Per Cent	Quartz Content Per Cent	Mineral Dust Conc. mg/m³	AQI	Risk Per Cent	Quartz Content Per Cent	Mineral Dust Conc. mg/m³	AQI	Risk Per Cent
21/12/93	1	ND	0.810	0.41	0.66	NC	0.640	0.32	0.41	4.60	0.630	0.32	0.40
		ND	0.760	0.38	0.58	5.23	0.650	0.34	0.46	ND	0.590	0.30	0.35
28/12/93	2	ND	0.660	0.33	0.44	ND	0.640	0.32	0.41	ND	0.670	0.34	0.45
		ND	0.630	0.32	0.40	2.78	0.720	0.36	0.52	ND	0.640	0.32	0.41
05/01/94	3	4.06	0.517	0.26	0.27	11.45	0.594	0.68	1.85	6.02	0.482	0.29	0.34
		ND	0.507	0 25	0.26	10.14	0.690	0.70	1.96	ND	0.469	0.23	0.22
07/01/94	4	5.92	0.708	0.42	0.71	6 91	0.695	0.48	0.92	13.20	0.742	0.98	3.84
		4.79	0.752	0.38	0.57	7.97	0.715	0.57	1.30	9.12	0.702	0.64	1.64
11/01/94	5	ND	0.562	0.28	0.32	ND	0.672	0.44	0.76	ND	0.895	0.45	0.80
		ND	0.624	0.31	0.39	2.46	0.934	0.47	0.87	ND	0.882	0.44	0.78
19/01/94	6	ND	0.609	0.30	0.37	4.25	0.659	0.33	0.43	ND	0.618	0.31	0.38
		ND	0.627	0.31	0.39	4.15	0.626	0.31	0.39	ND	0.458	0.23	0.21
		ND	0.690	0.35	0.48	ND	0.556	0.28	0.31	ND	0.668	0.33	0.45
		ND	0.664	0.33	0.44	3.85	0 624	0.31	0.39	ND	0.658	0.33	0.43
24/01/94	RS	ND	0.143	0.07	0 02	ND	0.126	0.06	0.02	ND	0.080	0.04	0.01
	7	ND	0 476	0.24	0 23	4.36	0.596	0.30	0.36	ND	0.539	0.27	0.29
		ND	0.391	0.20	0.15	ND	0 611	0.31	0.37	ND	0.567	0.28	0.32
		ND	0.450	0.23	0.20	ND	0.749	0.37	0.56	4.74	0.549	0.27	0.30
	RS	ND	0 569	0.28	0.32	ND	0 409	0.20	0.17				
		ND	0 205	0.10	0.04	ND	0.231	0.12	0.05	ND	0.383	0.19	0.15
28/01/94	RSM									ND	0.307	0.15	0 09
	8	ND	0.555	0.28	0 31	ND	0.562	0.28	0.32	ND	0.590	0.30	0.35
		ND	0.575	0.29	0 33	ND	0 549	0.27	0.30	ND	0.558	0.28	0.31
		ND	0.663	0.33	0.44					ND	0.565	0.28	0.32
		ND	0 567	0.28	0 32	ND	0 615	0.31	0.38	ND	0.602	0.30	0.36
	RS	ND	0 016	0.01	0 00	ND	0 011	0.01	0.00	26.14	0.088	0.23	0.21
01/02/94	9	ND	0 499	0 25	0.25	ND	0 372	0 19	0.14	ND	0.416	0.21	0.17
		ND	0 310	0.16	0.10	ND	0.347	0.17	0.12	ND	0.445	0.22	0.20
		ND	0.520	0 26	0 27	ND	0.584	0.29	0 34	ND	0.489	0.24	0.24
		ND	0.587	0 29	0.34	ND	0 414	0.21	0.17	ND	0.498	0.25	0.25
	RS	ND	0 146	0.07	0.02	ND	0.251	0.13	0.06	ND	0.244	0.12	0.06
04/02/94	RSM									ND	0.250	0.13	0.06
	10	ND	0.517	0.26	0 27	ND	0.292	0.15	0.09	ND	0.605	0.30	0.37
		ND	0 499	0.25	0 25	ND	0 395	0 20	0.16	ND	0.779	0.39	0.61
		ND	0 622	0.31	0.39	ND	0.297	0.15	0.09	ND	0.828	0.41	0.69
	RS	ND	0.571	0 29	0 33	ND	0.458	0.23	0 21	ND	0.777	0.39	0 60
		ND	0 462	0 23	0 21	ND	0.294	0 15	0.09	ND	0.441	0.22	0.19
09/02/94	RSM	ND								4.44	0.968	0.48	0.94
	11	ND	0 524	0 26	0 27	ND	0.497	0.25	0.25	ND	0.416	0.21	0.17
		ND	0 725	0.36	0 53	ND	0.460	0 23	0 21	ND	0.428	0.21	0.18
		ND	0 516	0 26	0 27	ND	0 595	0 30	0 35	ND	0.521	0.26	0.27
			0.574	0.29	0.33	ND	0 595	0 30	0.35	ND	0.499	0.25	0.25
14/02/94	12	ND	0 740	0.37	0.55	ND	0.703	0 35	0.49	ND	0.535	0.27	0 29
		ND	0 255	0 13	0 07	ND	0 643	0.32	0.41	ND	0.562	0.28	0.32
		ND	0.506	0 25	0 26	ND	0 804	0.40	0.65	ND	0.619	0.31	0.38
		ND	0.494	0.25	0.24	ND	0 668	0.33	0 45	ND	0.709	0.35	0.50
17/02/94	13	ND	0.720	0.36	0.52	ND	0 570	0 29	0.32	ND	0.731	0.37	0.53
		ND	0.507	0 25	0.26	ND	0 540	0 27	0 29	ND	0.697	0.35	0.49
		ND	1.090	0 55	1.19	ND	0 759	0.38	0.58	ND	0.679	0.34	0.46
		ND	0.805	0.40	0.65	ND	0.704	0 35	0.50	ND	0.700	0.35	0.49
	RS	22.05	0.168	0.08	0 03	ND				6.66	0.150	0.10	0.04
21/02/94	RSM									ND	0.375	0.19	0.14
	14	ND	0 505	0.25	0.26	ND	0 664	0.33	0.44				
		ND	0 503	0 25	0.25	ND	0.761	0.38	0 58				
		ND	0.483	0 24	0 23	ND	0 542	0 27	0 29	ND	0.506	0.25	0.26
		ND	0.518	0 26	0 27	ND	0 614	0.31	0.38	ND	0.805	0.40	0.65
	RS	ND	0.414	0 21	0.17	ND	0 358	0 18	0.13	ND	0.470	0.24	0.22
	RSM									ND	0.277	0.14	0.08
	Minimum	ND	0 26	0 13	0 07	ND	0.29	0 01	0 00	ND	0.42	0.21	0.17
	Maximum	5.92	1 09	0 55	1 19	11 45	0 93	0 70	1 96	13.20	0.90	0.98	3.84
	Average	0.32	0 59	0 30	0 38	1.41	0 60	0 30	0 43	0.88	0.61	0.33	0.50
	Std Deviation	1.23	0 18	0 09	0 25	2 85	0 14	0 13	0 39	2 66	0.12	0.13	0.57
	Variance	1.52	0 03	0.01	0 06	8 13	0 02	0 02	0.15	7.07	0.02	0.02	0.33

ND : Less than detection limit of 20 μg

RS : Rotating Sponge Sampler

RSM : Rotating Sponge Sampler - Mine sample

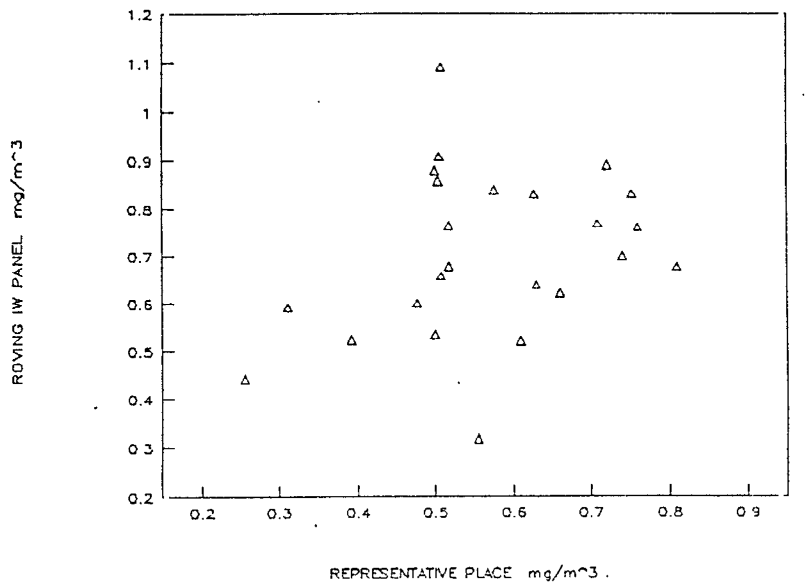

Figure 37 STATIONARY SAMPLERS VS ROVING (DUST) REPRESENTATIVE PLACE AND ROVING 1W

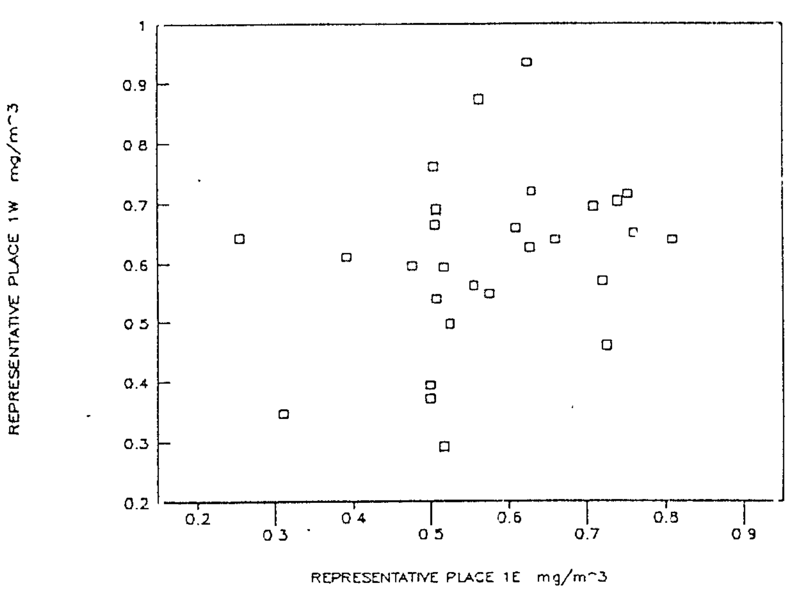

Figure 38 COMPARISON OF REPRESENTATIVE PLACES (DUST) REPRESENTATIVE PLACE 1E AND REPRESENTATIVE PLACE 1W

In Figure 39 dust levels for the main return are compared with dust levels of a personal sampler (1W). This comparison also shows no correlation.

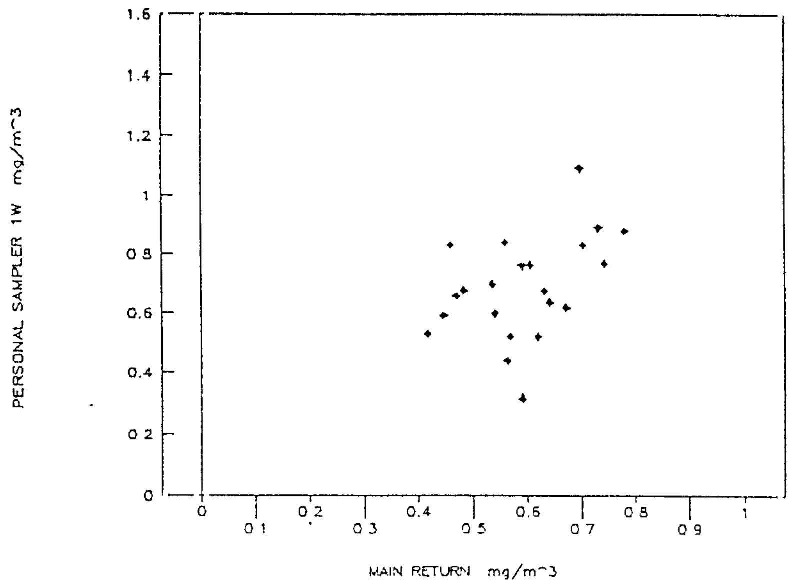

Figure 39 COMPARISON : STATIONARY AND ROVING (DUST) : MAIN RETURN AND PERSONAL 1W

The results of comparing monitoring results for the different matched pairs of instruments are discussed later in this report.

4 TEST SITE 3 Deep mine, mechanized section.

4.1 Description of Test Site

Data were collected in a deep level mining operation which used LHD vehicles in roadways (reef drives) to move broken rock from the stope face to a boxhole tip.

The site comprised a 5 500 tons/month production stope in Ventersdorp Contact Reef (VCR), 2 500 m below surface. The stoping width was 1,3 m and the dip of the reef 25° (similar to test Site 2). For reasons of ground control five of the six stopes were mined up-dip and the bottom stope was mined on breast. The distance between roadways in which the LHDs operated was 30 m.

Diagonal access connections between roadways enabled vehicles to move to the various roadways. The general layout of this test site is shown in Figure 40. The site had a labour complement of 40 persons per shift. Seven LHDs were available of which five to six were in operation. During the mining shift the LHDs were mainly used for the transport of materials to the stope face, and, during the night shift broken rock was transported either from the footwall development ends or from the stope face to the stope tips.

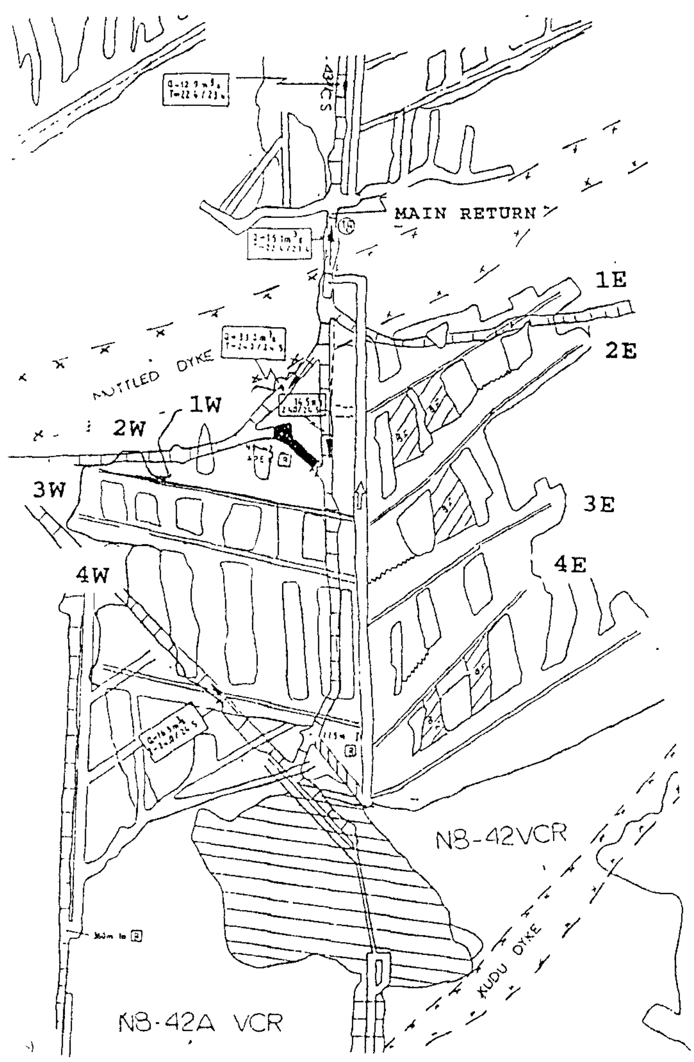

Figure 40 LAYOUT OF SITE (3)

When not in use the vehicles were parked in the two workshops serving the site. The test site was ventilated by refrigerated intake air being supplied via two 55 kW booster fans forcing the cooled air into the section at Station D. In the bottom footwall drive airflow was split, allowing some air to ventilate the footwall drive while most of the air was directed towards the stope face, some was also directed via a diagonal access way to the upper roadways. Airflow rates and directions are shown in Figure 40. The airflow in the connection between the bottom of the section and the first roadway was controlled by means of a curtain. Fifty per cent of the air supplied was exhausted via two fans at the top access of the stope into Return Airway : F.

A particular feature of this test site was the difference in airflow rates at the various locations, aggravated by many uncontrollable leakage paths.

4.2 Measuring Strategy and Procedures

The quality of the intake air was monitored at Station D. Other fixed positions or stationary monitoring positions, were the bottom entry to the stopes; G, return positions at E and F and an important intermediate return at H. Stations K and J were entrances to stopes and used for comparison with worker exposure in the stopes. Sampling trains were also fitted to three LHDs operating in the lower part of the stope and a sampling pump was sometimes fitted to an LHD operating in the uppermost part of the section and sometimes to the team leader. Once again the same instruments were used for any given sampling position for each shift. Personnel from the mine environmental control department assisted with manual determination of airflow rates.

4.3 Results from and Analysis of Measurements

Results are tabulated in Tables 8, 9 and 10. As was found at test site 2, a conventional mini-longwall, no correlation could be found between dust concentrations measured at representative places and returns, or between the different representative places and different returns. This is shown in Figure 41. Also seen in this bar chart plot are the fluctuations in dust concentrations at these localities on a shift-wise basis.

Table 8 DEEP LEVEL TRACKLESS SECTION. TRACKLESS MINING TESTS. VEHICLES (ROVING)

		LHD T41				LHD T30				LHD T27				LHD T28			
Date	Test Number	Quartz Content Per Cent	Mineral Dust Conc. mg/m³	AQI	Risk Per Cent	Quartz Content Per Cent	Mineral Dust Conc. mg/m³	AQI	Risk Per Cent	Quartz Content Per Cent	Mineral Dust Conc. mg/m³	AQI	Risk Per Cent	Quartz Content Per Cent	Mineral Dust Conc. mg/m³	AQI	Risk Per Cent
24/03/94	1	9.70	0.181	0.18	0.12	9 80	0.164	0.16	0.10	9.43	0.374	0.35	0.50				
29/03/94	2	7.10	0.159	0.11	0.05	5.40	0.187	0.10	0.04	4.30	0.110	0.06	0.01	15.02	0.390	0.59	1.37
11/04/94	3	5.56	0.224	0.12	0.06					8.46	0.154	0.13	0.07	10.21	0.254	0.26	0.27
15/04/94	4	4.58	0.092	0.05	0.01	11.30	0.114	0.13	0.07	8 70	0.096	0.08	0.03	4.78	0.185	0.09	0.03
21/04/94	5	3.35	0.130	0.07	0.02	6.08	0.123	0.07	0.02	5.94	0.123	0.07	0.02				
02/05/94	6	7.19	0.148	0.11	0.05	13.89	0 097	0.13	0.07	10.58	0.105	0.11	0.05	7.46	0.192	0.14	0.08
05/05/94	7	3.51	0.157	0.08	0.02					11.70	0.103	0.12	0.06	10.36	0.352	0.36	0.53
	Minimum	3.35	0.09	0.05	0.01	5.40	0.10	0.07	0.02	4.30	0.10	0.06	0.01	4.78	0.19	0.09	0.03
	Maximum	9.70	0.22	0.18	0.12	13.89	0.19	0.16	0.10	11.70	0.37	0.35	0.50	15.02	0.39	0.59	1.37
	Average	5.86	0.16	0.10	0.05	9.29	0.14	0.12	0.06	8.44	0.15	0.13	0.10	9.57	0.27	0.29	0.46
	Std Deviation	2.12	0.04	0.04	0.04	3.19	0.03	0.03	0.03	2.38	0.09	0.09	0.16	3.41	0.08	0.18	0.49
	Variance	4.51	0.00	0.00	0.00	10.18	0.00	0.00	0.00	5.66	0.01	0.01	0.03	11.63	0.01	0.03	0.24

Table 9 DEEP LEVEL TRACKLESS STOPING SECTION. TRACKLESS MINING TESTS. STATIONARY SAMPLERS : INTAKE

		STATION D				STATION G				STATION K				STATION J			
Date	Test Number	Quartz Content Per Cent	Mineral Dust Conc. mg/m³	AQI	Risk Per Cent	Quartz Content Per Cent	Mineral Dust Conc. mg/m³	AQI	Risk Per Cent	Quartz Content Per Cent	Mineral Dust Conc. mg/m³	AQI	Risk Per Cent	Quartz Content Per Cent	Mineral Dust Conc. mg/m³	AQI	Risk Per Cent
24/03/94	1	10.50	0.167	0.18	0.12	9.41	0.153	0.14	0.08	11.29	0.180	0.20	0.17	6.40	0.191	0.12	0.06
29/03/94	2	11.20	0.179	0.20	0.16	7 70	0.101	0.08	0.02	5.50	0.161	0.09	0.03	4.70	0.199	0.10	0.04
11/04/94	3	8.00	0.193	0.15	0.10	6.70	0.184	0.12	0.06	6.50	0.162	0.11	0.04	4.20	0.146	0.07	0.02
15/04/94	4	10.08	0.123	0.12	0.06					6.37	0.100	0.06	0.02	7.04	0.086	0.06	0.01
21/04/94	5	10.75	0.016	0.02	0.00	5.62	0.119	0.07	0.02	8.13	0.099	0.08	0.03	11.07	0.134	0.15	0.09
02/05/94	6	22.18	0.138	0.31	0.37	8.89	0.083	0.07	0.02	10.47	0.080	0.08	0.03	11.07	0.134	0.15	0.09
05/05/94	7	12.70	0.132	0.17	0.11	7.41	0.091	0.07	0.02	5.88	0.082	0.05	0.01	9.20	0.169	0.16	0.10
	Minimum	8.00	0.02	0.02	0.00	5.62	0.08	0.07	0.02	5.50	0.08	0.05	0.01	4.20	0.09	0.06	6.01
	Maximum	22.18	0.19	0.31	0.37	9.41	0.18	0.14	0.08	11.29	0.18	0.20	0.17	11.07	0.20	0.16	0.10
	Average	12.20	0.14	0.16	0.13	7.62	0.12	0.09	0.04	7.73	0.12	0.10	0.05	7.01	0.15	0.10	0.05
	Std Deviation	4.28	0.05	0.08	0.11	1.27	0.04	0.03	0.03	2.14	0.04	0.05	0.05	2.24	0.04	0.04	0.03
	Variance	18.28	0.00	0.01	0.01	1.62	0.00	0.00	0.00	4.59	0.00	0.00	0.00	5.03	0.00	0.00	0.00

Table 10 DEEP LEVEL TRACKLESS STOPING SECTION. TRACKLESS MINING TESTS. FIXED STATIONS : RETURNS

		STATION E				STATION H : MAIN RETURN			
Date	Test Number	Quartz Content Per Cent	Mineral Dust Conc. mg/m³	AQI	Risk Per Cent	Quartz Content Per Cent	Mineral Dust Conc. mg/m³	AQI	Risk Per Cent
24/03/94	1	10.33	0.165	0.17	0.12	6.80	0.183	0.12	0.06
29/03/94	2	5.90	0.077	0.05	0.01	6.70	0.152	0.10	0.04
11/04/94	3	5.50	0.082	0.05	0.01	3.80	0.167	0.08	0.03
15/04/94	4	8.26	0.121	0.10	0.04	6.73	0.169	0.11	0.05
21/04/94	5	7.63	0.053	0 04	0.01	8.47	0.075	0.06	0.02
02/05/94	6	7.27	0.107	0.08	0.02	9.94	0.044	0.04	0.01
05/05/94	7	9.16	0 091	0 08	0 03	7.07	0.091	0 06	0 02
	Minimum	5.50	0 05	0.04	0.01	3.80	0.04	0.04	0.01
	Maximum	10.33	0.17	0.17	0.12	9.94	0.18	0.12	0.06
	Average	7.2	0 10	0.08	0 03	7.07	0.13	0.09	0.03
	Std Deviation	1.59	0.03	0 03	0 04	1.74	0.05	0.03	0.02
	Variance	2.52	0.00	0 00	0.00	3.03	0.00	0.00	0.00

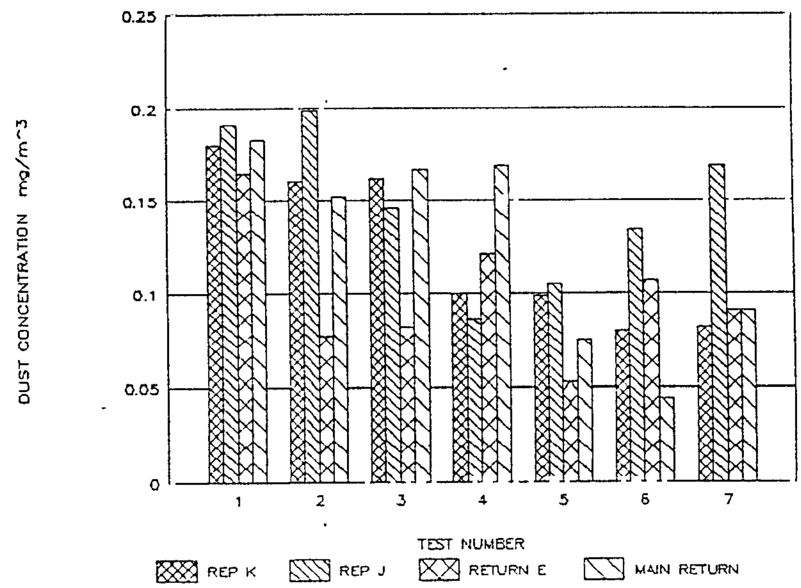

Figure 41 COMPARISON OF REPRESENTATIVE PLACES AND RETURN (DUST)

The bar chart, Figure 42, shows the relationship between dust concentrations monitored at LHD operators compared with each other and also with levels obtained at the main return. No clear correlation can be observed and the shift-wise fluctuations are again very evident, up to 400 per cent in some cases.

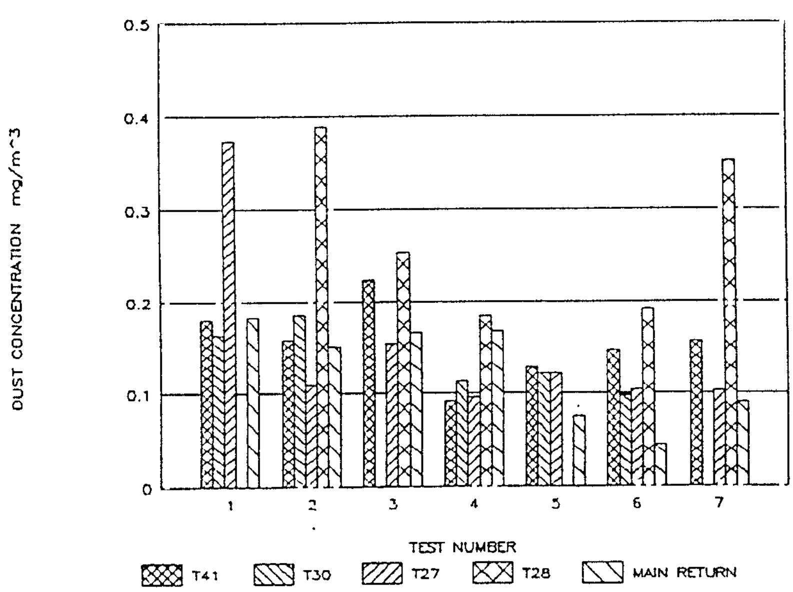

Figure 42 COMPARISON OF LHDs AND RETURN (DUST)

A typical variation in dust levels and quartz concentrations for these particular exposures is shown in Figure 43 for an LHD operator. A similar comparison is made for a stationary sampler, at main return H, and is illustrated in Figure 44. Whereas the dust concentration remained quite steady for the first four shifts the associated quartz concentrations did not. The highest quartz concentration was measured on shift six and is associated with the lowest dust level. The AQIs were all low owing to low dust concentrations and relatively low quartz content. Nevertheless, as assessed at the first two test sites, dust and quartz levels varied independently of each other on a shift-wise basis and no meaningful correlations could be found between dust/quartz concentrations measured at stationary samplers and those measured at roving samplers, nor between samplers in the same categories, e.g. stationary.

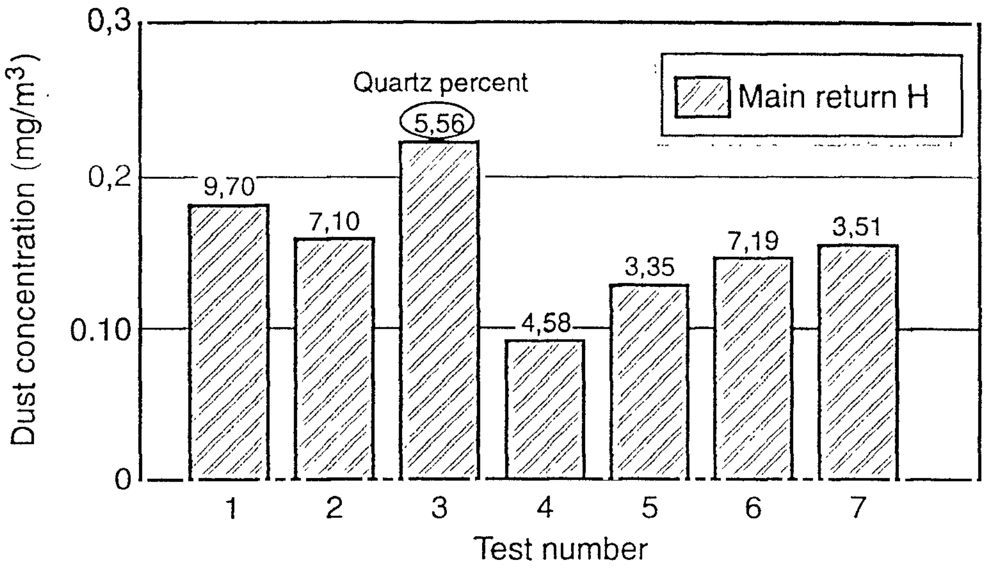

Figure 43 VARIATION OF DUST AND QUARTZ LEVELS LHD T41

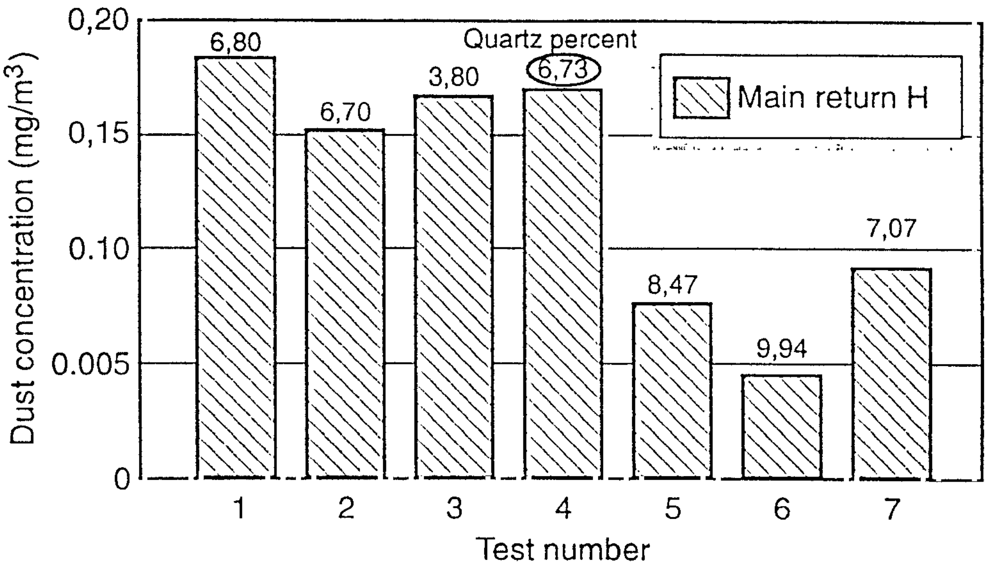

Figure 44 VARIATION OF DUST AND QUARTZ LEVELS MAIN RETURN H

5 TEST SITE 4 Surface locality

5.1 Assay Laboratory and Sample Preparation

Gravimetric dust sampling is implemented in surface operations as well as underground operations. It was therefore considered appropriate to investigate results obtained in a typical surface installation and dust sampling was conducted in an assay laboratory/sample preparation operation. There were obvious difficulties in selecting an effective representative place or stationary sampling position in an "open" reduction works, where wind currents could substantially influence results, and it is also possible that personal samplers would also have been affected in this way. It was therefore considered that a dust sampling exercise conducted in an enclosed environment was more likely to yield useful data and hence an investigation was conducted in an assay laboratory/sample preparation operation.

Dust control equipment and appliances in the laboratory were operational during both tests.

5.2 Measuring Strategy and Procedures

In all, ten stationary (representative) sampling positions were selected in the different work areas. These are shown in Figure 45 and denoted by S1, S2 etc. Corresponding personal samples, P1, P2 etc., were collected in these work areas although persons being sampled did not spend the entire shift in the area only. All samples were collected over the full eight hour shift. Standard sampling pumps and 25 mm diameter cellulose nitrate filters with 10 mm diameter separating cyclones were used to collect the samples.

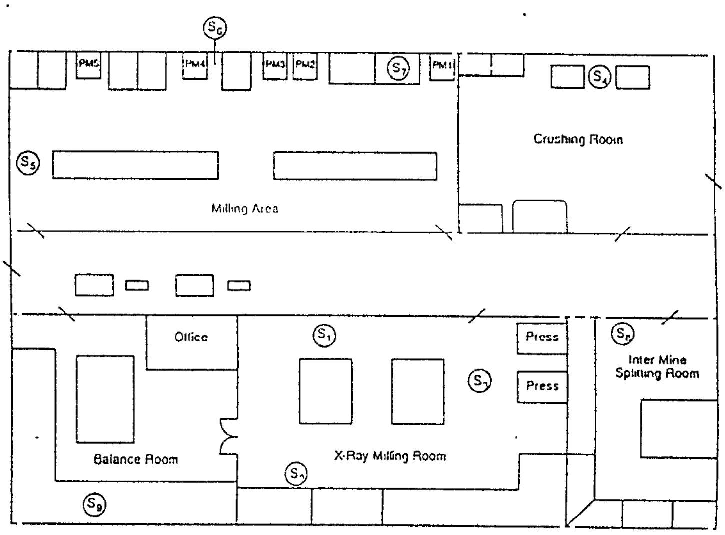

Figure 45 ASSAY LABORATORY AND SAMPLE PREPARATION

5.3 Results from and Analyses of Measurements

Results of the two investigations carried out are set out in Tables 11 and 12.

Table 11 ASSAY LABORATORY DUST SAMPLING - FIRST SURVEY

	Personal Reference	Dust Conc. mg/m³	Per Cent Quartz	AQI	Stationary Reference	Dust Conc. mg/m³	Per Cent Quartz	AQI
X-Ray Milling	P1 P2 P3	0.415 0.343 0.274	23.5 ND 15.6	1.0 0.2 0.4	S1 S2 S3	0.142 0.534 0.279	11.3 19.0 11.6	0.2 1.0 0.3
	AV	0.344	13.03	0.5	AV	0.318	13.97	0.5
Crushing	P4	6.274	23.5	14.7	S4	3.302	34.1	11.3
Milling	P5 P6 P7	0.326 0.512 2.513	36.6 1.4 32.2	1.2 0.3 8.1	S5 S6 S7	0.078 0.151 0.155	ND 23.6 10.3	0.0 0.4 0.2
	AV	1.117	23.73	3 2	AV	0.128	11.30	0.2
Splitting	P8	0.272	8.1	0.2	S8	0.11	ND	0.1
Balance					S9	0.106	ND	0.1

ND: Less than detection limit of 20 µg

Table 12 ASSAY LABORATORY DUST SAMPLING - SECOND SURVEY

	Personal Reference	Dust Conc. mg/m³	Per Cent Quartz	AQI	Stationary Reference	Dust Conc. mg/m³	Per Cent Quartz	AQI
X-Ray Milling	P1 P2 P3	0.340 1.150 0.240	25.1 38.6 34.3	0.9 4 4 0 8	S1 S2 S3	0 090 0.190 0.190	13.9 53.1 18.2	0.1 1.0 0.3
	AV	0.577	32.7	2.0		0.157	28.4	0.5
Crushing	P4	0.770	27.9	2.1	S4	0.200	10.0	0.2
Milling	P5 P6 P7	0.500 0 270 0.310	15.3 18.3 29.4	0.8 0.5 0.9	S5 S6 S7	0.070 0.110 0 110	28.5 18.2 18.2	0.2 0.2 0.2
	AV	0 360	21.0	0.7	AV	0.097	21.6	0.2
Splitting	P8	0.230	25.3	0 6	S8	0.160	25 6	0.4
Balance					S9 S10	0.090 0.120	22.2 16.7	0.2 0.2
	AV					0.11	19.5	0.2

The relationship between stationary samples and corresponding personal samples is shown in Figure 46 for the first investigation. Figure 47 shows the results obtained in the second exercise at this establishment. In both cases correlation was found to be poor and, thus, similar to results obtained for the underground investigations. Although actual dust concentrations were found to be lower in the second exercise at the assay laboratory, the scatter in results is still evident.

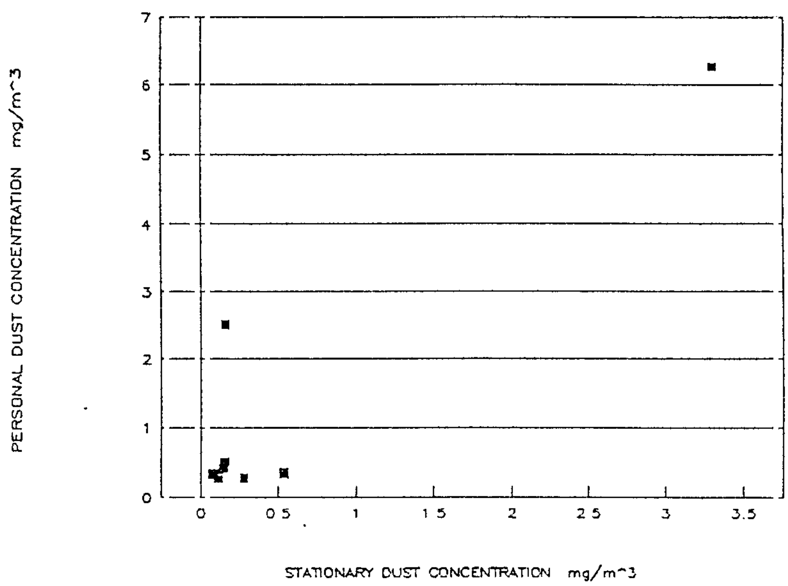

Figure 46 STATIONARY VS PERSONAL SAMPLES (DUST) : TEST 1

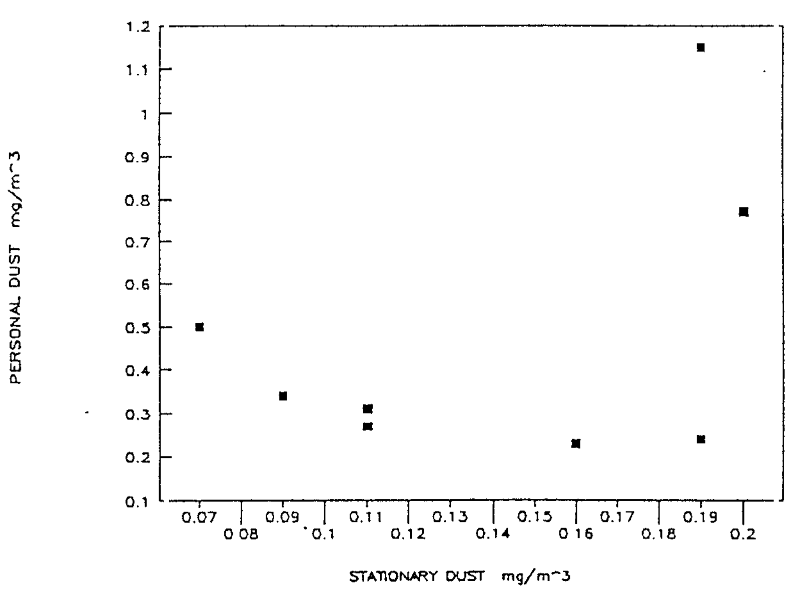

Figure 47 STATIONARY VS PERSONAL SAMPLES (DUST) : TEST 2

In the first investigation airborne quartz concentrations were found to vary from less than the detectable limit of 20 µg to 36,6 per cent for personal samples and up to 34,1 per cent for stationary samples, although these maxima occurred in different parts of the building. In fact, the maximum personal quartz exposure correlated with the minimum stationary concentration. In the second survey quartz concentrations ranged from 15,3 per cent to 38,6 per cent for personal samplers and from 10 per cent to 53,1 per cent for stationary samplers.

The relationship between personal dust and quartz concentrations, stationary dust and quartz concentrations and stationary and personal quartz concentrations are shown in Figures 48 to 50 respectively.

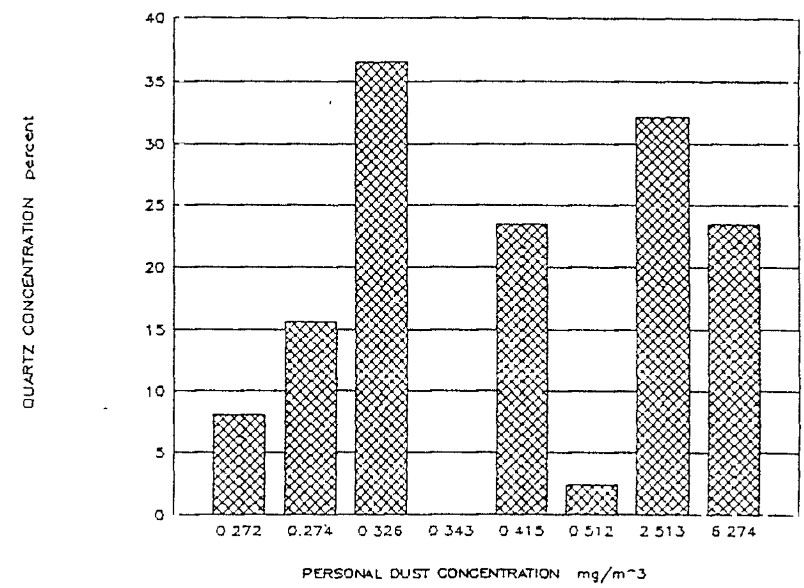

Figure 48 QUARTZ CONCENTRATIONS : PERSONAL SAMPLES - TEST 1

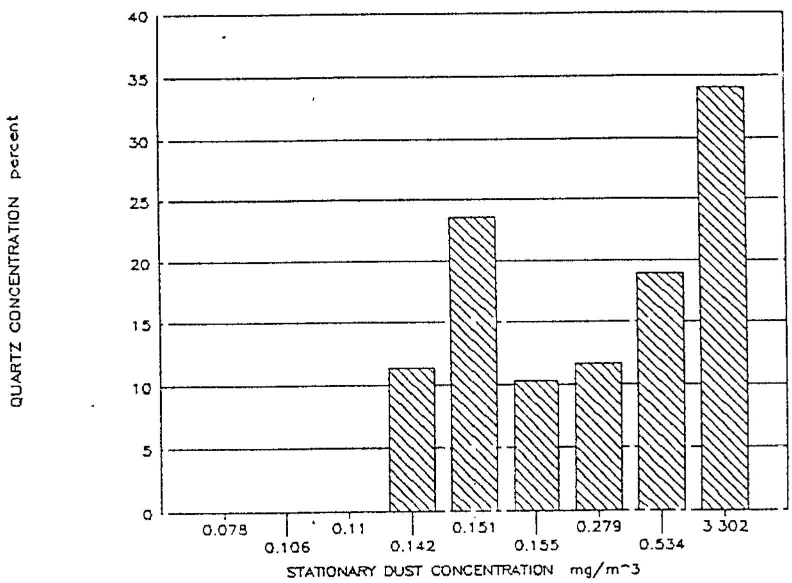

Figure 49 QUARTZ CONCENTRATIONS : FIXED SAMPLERS - TEST 1

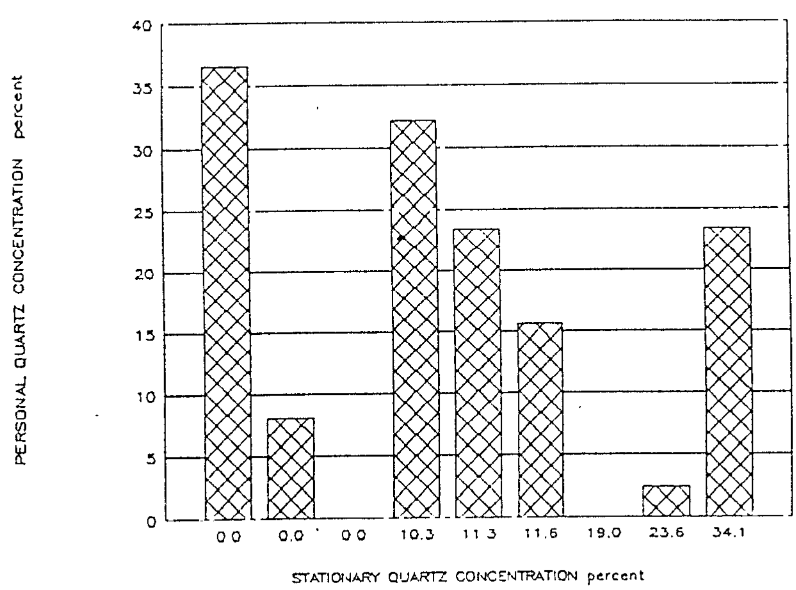

Figure 50 FIXED VS PERSONAL QUARTZ CONCENTRATIONS - TEST 1

These same aspects were examined for the second dust survey conducted at the assay laboratory and are presented in Figures 51 to 53 respectively. Although dust levels generally appeared to be lower for personal samplers during the second survey, quartz concentrations were, if anything, higher.

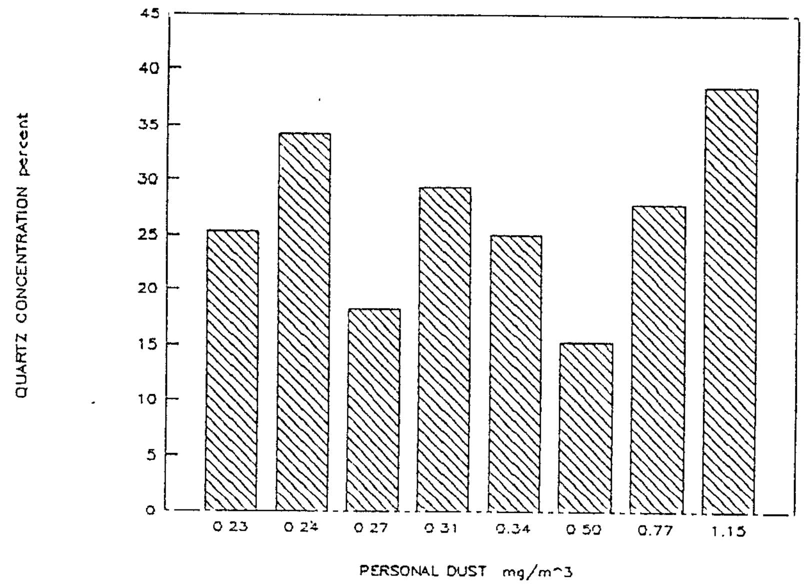

Figure 51 QUARTZ CONCENTRATIONS : PERSONAL SAMPLES - TEST 2

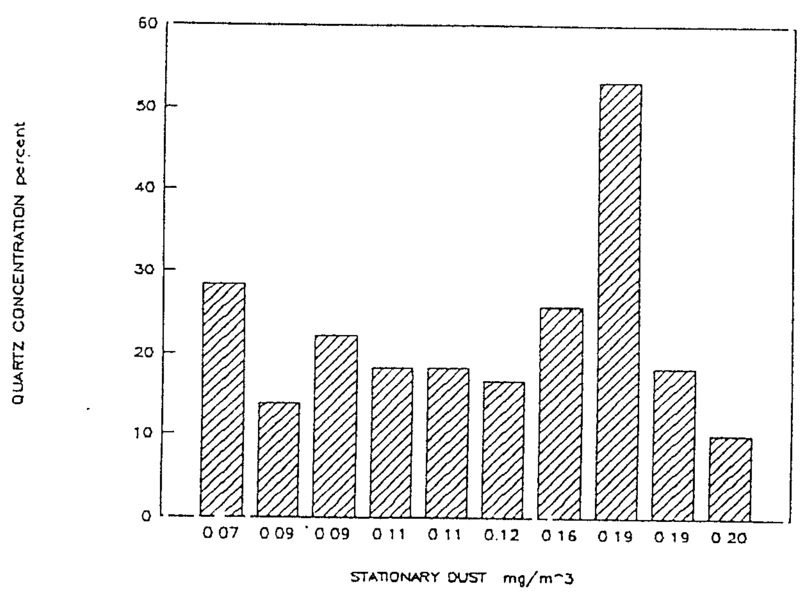

Figure 52 QUARTZ CONCENTRATIONS : FIXED SAMPLERS - TEST 2

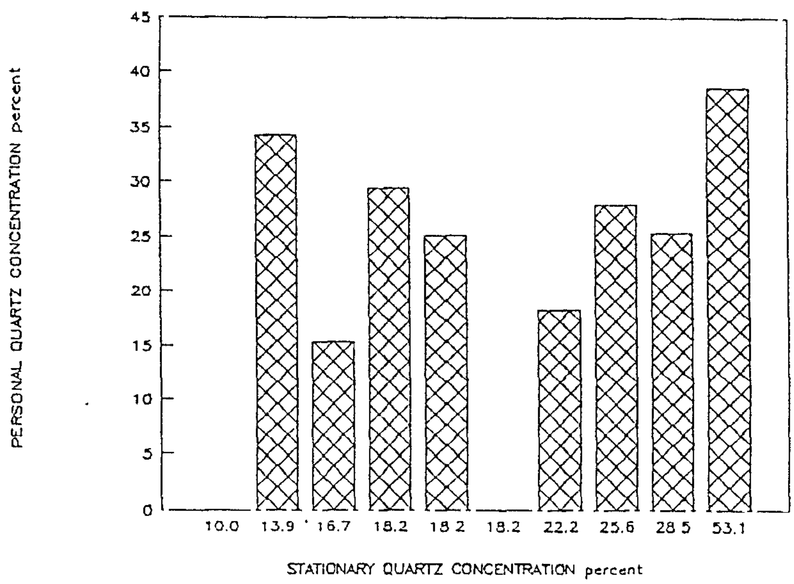

Figure 53 FIXED VS PERSONAL QUARTZ CONCENTRATIONS

The same comments appear to hold for the second survey as noted for the first.

The two surface surveys have displayed the same behaviour patterns for dust and quartz concentrations as was found in the underground surveys. Several very high, and thus unacceptable, AQIs were found during the first survey but these were not repeated in the second survey.

6 DISCUSSION

6.1 Personal vs Stationary Samples

One of the major aspects of this research was to establish if personal sampling could be reduced or even entirely replaced by stationary (fixed) or area samplers thereby reducing both sampling effort and costs. At all four test sites investigated, i.e. three underground and one laboratory, there was strong evidence that correlation between dust levels obtained at fixed positions samplers and personal samplers was very poor. This means that it would not be possible to only collect dust samples at fixed position sites, either main returns or representative places, and expect to be able to obtain results that could represent exposure levels of personnel working in the area. At three of the four test sites no correlation could be found between dust levels measured at main returns and those measured at representative places.

Figures 54 and 55 below show the relationship between dust concentrations measured at stationary sampling positions and those obtained for some of the roving personnel at test Site 1. A comparison of dust levels for the major stationary and personal samplers is shown in Figure 56.

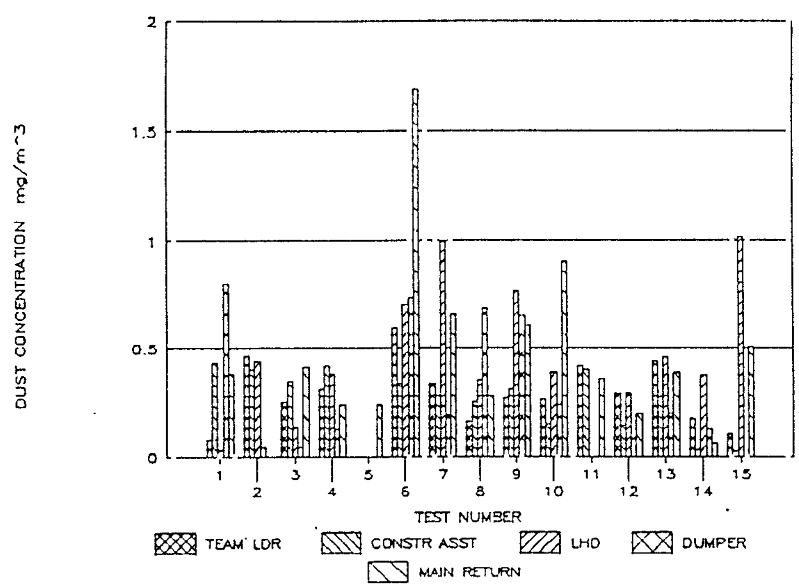

Figure 54 COMPARISON OF ROVING AND AREA SAMPLERS

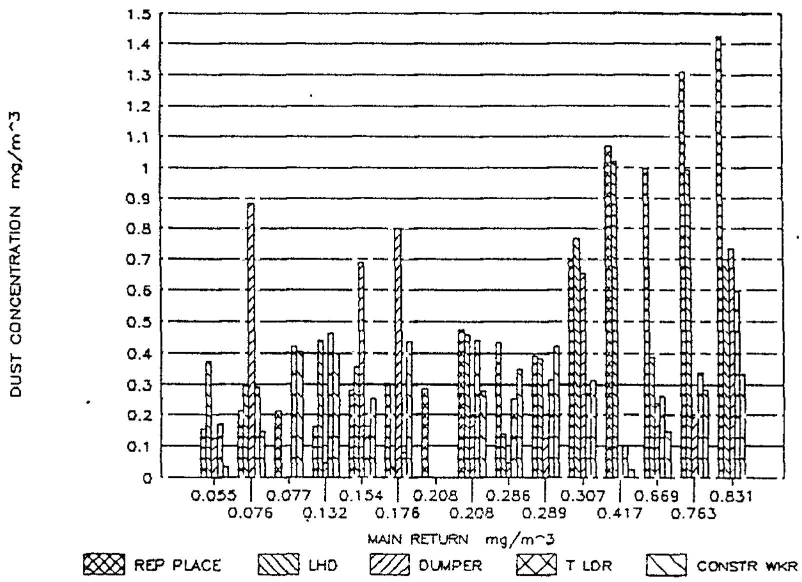

Figure 55 COMPARISON OF DUST LEVELS : TWO STATIONARY AND FOUR PERSONAL

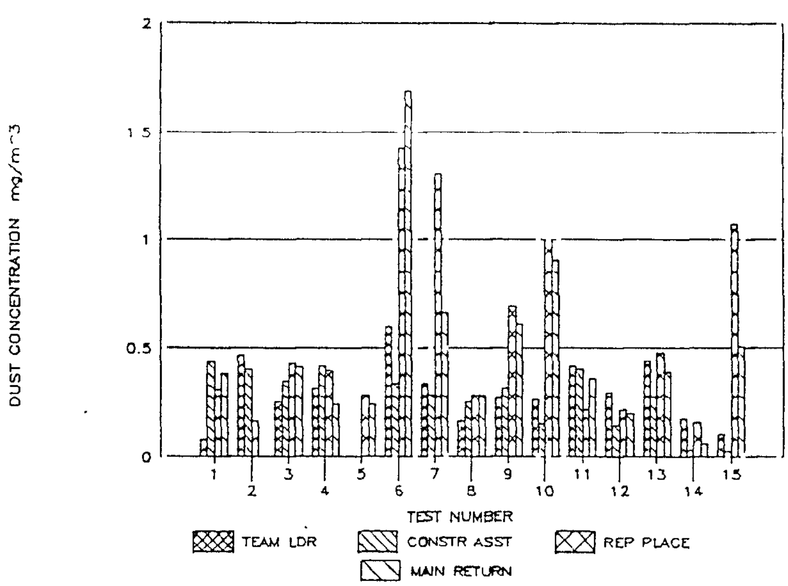

Figure 56 COMPARISON OF ROVING AND AREA SAMPLERS

Comparisons of dust levels with the return air station levels are shown in Figures 57 to 60 for a team leader, construction worker, LHD and dump truck drivers respectively.

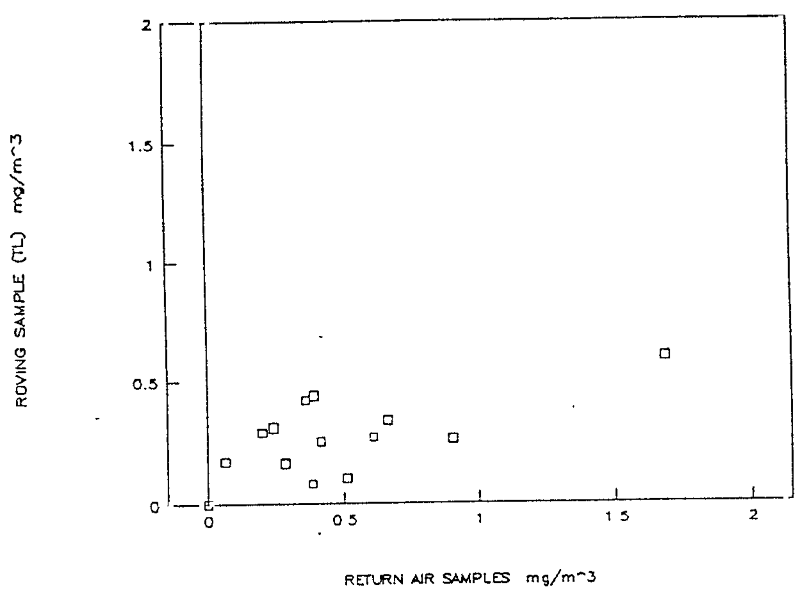

Figure 57 STATIONARY AND ROVING SAMPLES (TEAM LEADER)

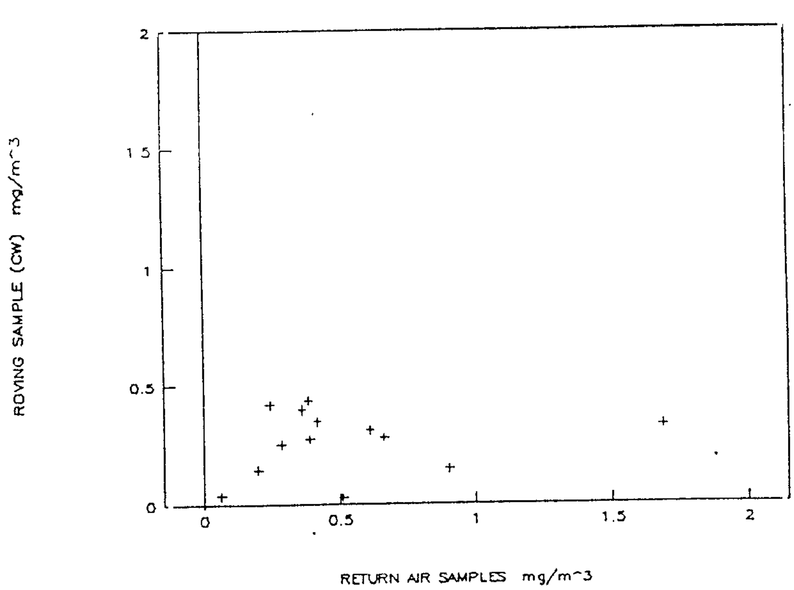

Figure 58 STATIONARY AND ROVING SAMPLES (CONSTRUCTION WORKER)

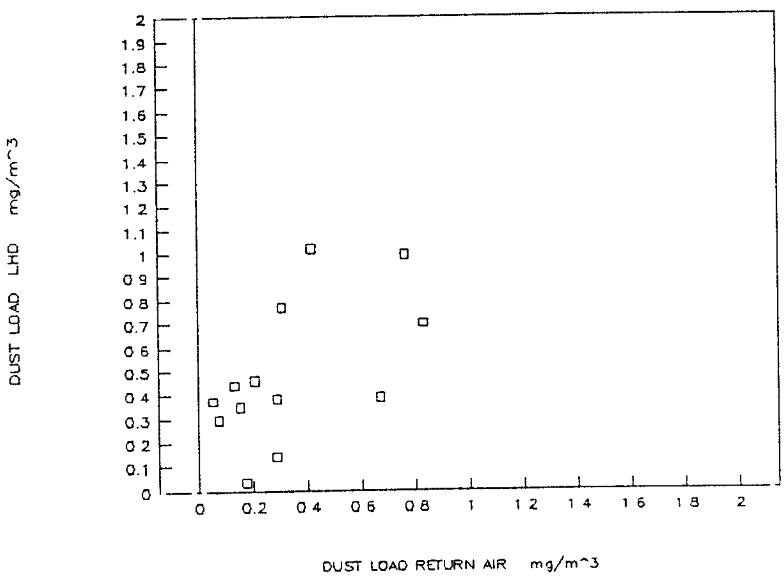

Figure 59 COMPARISON OF DUST LOADS (LHD)

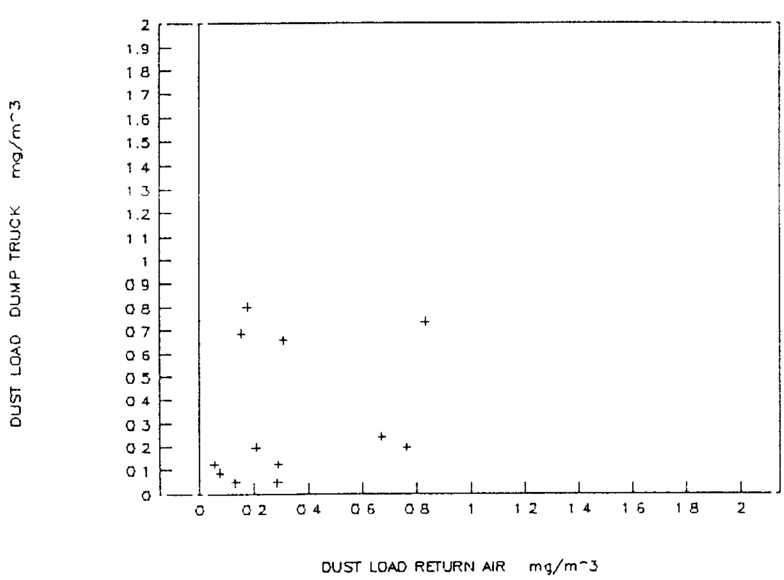

Figure 60 COMPARISON OF DUST LOADS (DUMP TRUCK)

6.2 Variations in Dust Concentrations

It was also found that dust concentrations varied from day to day as illustrated in Figure 61, which is also based on data from test site 1. Very often substantial differences in dust levels were found from shift to shift. For example, referring to Figure 61, shift 11 followed immediately after shift 6, and shift 12 followed immediately after shift 7 since, as explained, the night shifts were mónitored back to back with the afternoon shifts. These shift-wise changes in dust levels were observed at all the test sites and at test site 4, the laboratory, and considerable differences in dust levels were measured from one monitoring exercise to the next, which were months apart. This is in agreement with results reported by mines and also in agreement with the literature[4].

Comparisons of all vehicle operators' exposure levels with each other and the main return are shown in Figure 62. The shift-wise variations are very apparent.

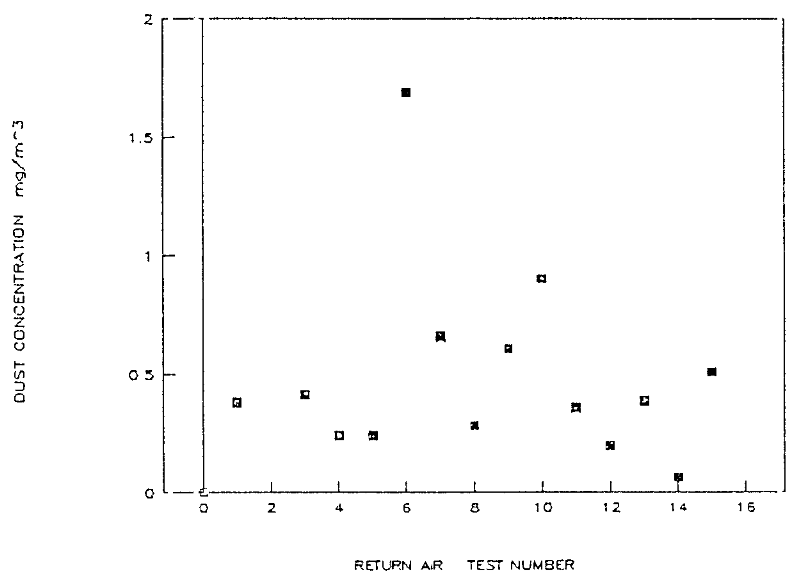

Figure 61 VARIATION IN DUST EXPOSURE (RETURN AIR) : SHIFT TO SHIFT BASIS

6.3 Variations in Quartz Concentrations

In addition to shift-wise variations in dust levels, quartz concentrations for the dust samples also varied on a shift-wise basis and was evidenced at all the test sites. A typical example is shown in Figure 63. Dust and quartz levels are shown together for this monitoring station and quartz concentrations are seen to vary from 17 to 98 per cent. Dust and quartz levels are shown together for this monitoring station and the randomness of quartz levels with respect to dust levels is clearly seen in Figure 64.

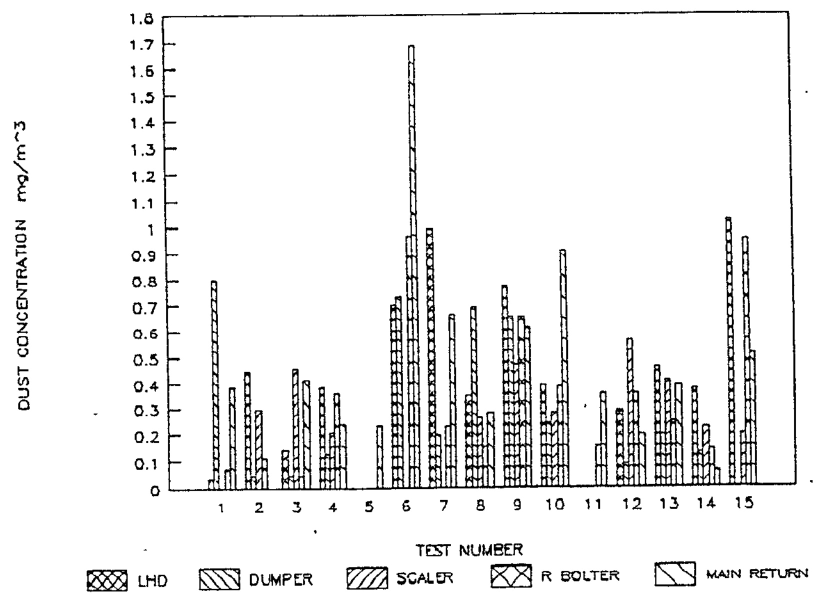

Figure 62 <u>COMPARISON OF ROVING AND AREA SAMPLERS (ALL VEHCILE DRIVERS)</u>

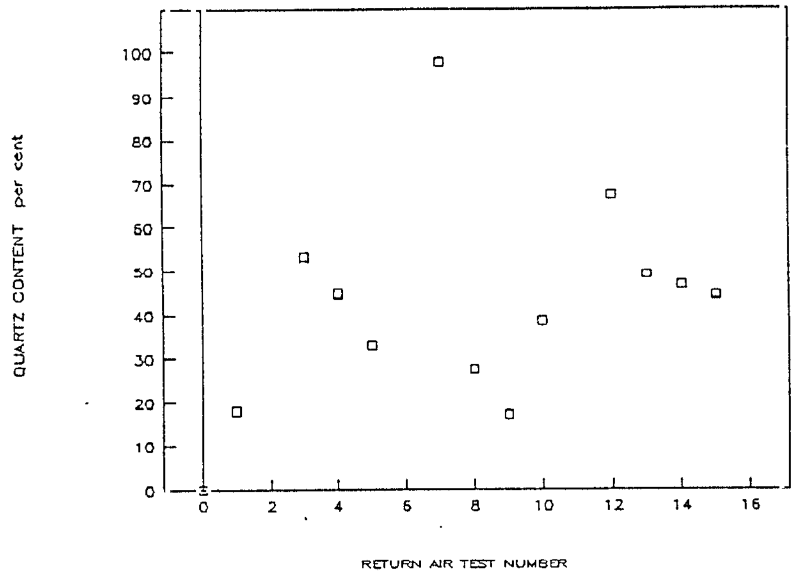

Figure 63 <u>VARIATION IN QUARTZ CONTENT (RETURN AIR)</u>

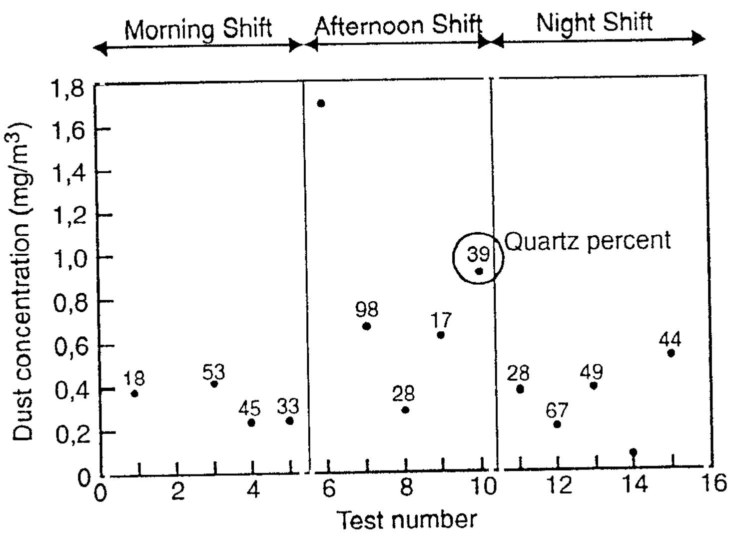

Figure 64 STATIONARY SAMPLING POSITION (MAIN RETURN) : DUST AND QUARTZ LEVELS

6.4 Correlation Between Dust and Quartz Levels

No correlation between dust levels and quartz concentrations could be found in any of the samples collected and analysed for this research project.

A typical relationship is shown in Figures 65 and 66.

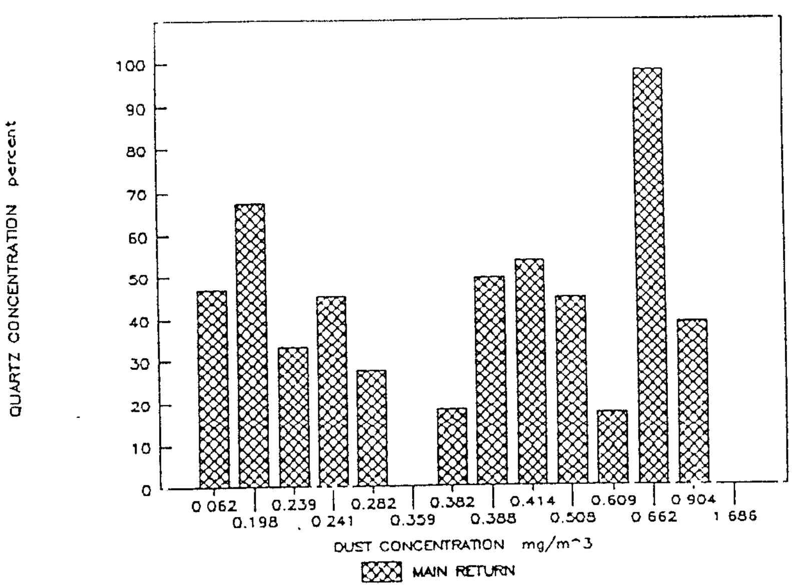

Figure 65 VARIATION IN DUST AND QUARTZ LEVELS (MAIN RETURN)

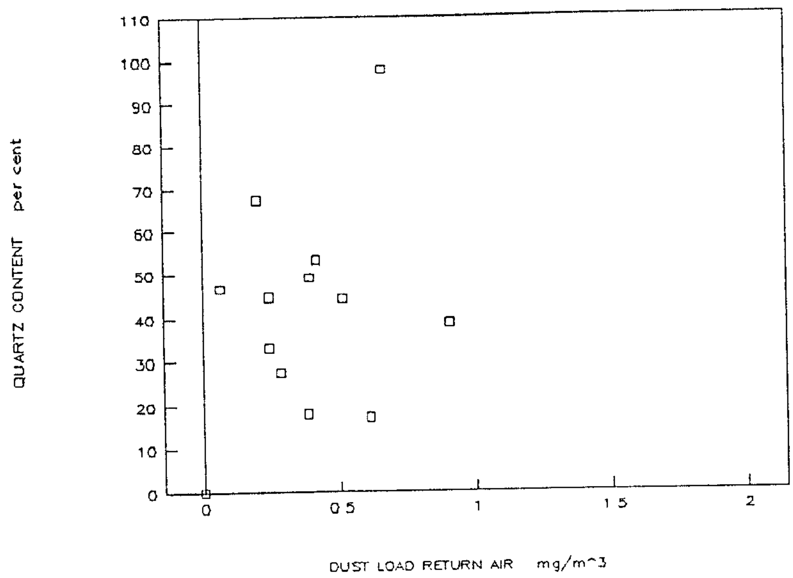

Figure 66 DUST LOAD AND QUARTZ CONTENT (RETURN AIR)

6.5 Air Quality Index

Dust samples are analysed to compile an Air Quality Index (AQI) which should provide a measure of the relative toxicity of a sample. It is therefore predictable that if dust and quartz concentrations vary on a shift-wise basis the AQI will also do so as shown in Figure 67. (An AQI greater than unity would be regarded as unsatisfactory).

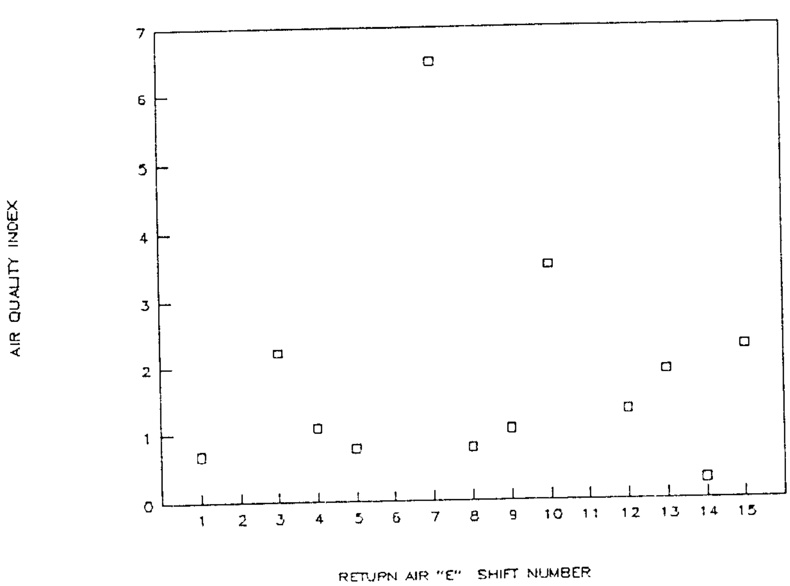

Figure 67 AIR QUALITY INDEX (RETURN AIR "E")

Reference to Figure 54 shows that little correlation was found between dust concentrations measured at personal samplers, but for different occupations within a working section this can be regarded as an expected result.

6.6 Personal Samplers : Quartz, Quartz and Dust, AQIs

In none of these investigations was a correlation found for personal samplers between quartz concentrations, quartz concentrations and dust levels, and AQIs. Furthermore the tables of results indicate large differences in standard deviations and minima/maxima observations, ***which collectively indicates a need for a large number of samples to be collected to more accurately characterize typical or mean exposure values*** for the different work categories or even stationary sampling positions. This is not practical and defeats an objective of this project, namely to reduce the sampling effort.

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Fixed Point, stationary or area samplers do not provide accurate or comparable Time Weighted Averages, quartz content, Air Quality Index or risk to be able to use data collected at such monitoring stations to substitute for personal samples. Variations in these parameters have been observed on a shift, daily, weekly and monthly basis. Results reported are very dependent on the day and the shift that is being sampled for the person being sampled. These are thus random results.

7.2 Very large ranges in quartz concentration have been observed in five samples of a given Statistical Population and even bigger ranges have been detected in a large working section. Furthermore, although Gilian pumps sampling in parallel yielded very similar dust loadings, the quartz concentrations were uncorrelated. Overseas tests have confirmed this anomaly without offering any explanation.

7.3 Unpredictable variations in dust and quartz levels and, consequently, variations in AQI and risk, as well as the unexplained characteristics of quartz in suspension in the working atmosphere should be very carefully considered before any standards are set, i.e. legally required dust concentrations and AQI. Testing for compliance could require large numbers of samples and prove to be costly.

7.4 High dust counts and high quartz concentrations are lost in the permissible averaging system, and unsatisfactory personal exposures are difficult to trace and act upon because a quartz fraction is required before an AQI can be calculated. Often these calculations will only be performed at the conclusion of a sampling cycle when any action is meaningless. Thus, at present, when the dust concentration of a sample is determined there are no indications on whether or not the result is acceptable. Moreover, the results of dust sampling, which are all of a personal nature, are not reported on any environmental assessment report, nor is this required.

Any high "peak" dust concentrations during a shift cannot be identified by present sampling practices, and the shift average and Statistical Population average further conceals these aberrations.

7.5 The fact that quartz concentrations for parallel dust samples have not been found to be compatible is an indication that the quartz distribution within a moving airstream is not as homogeneous as had been assumed in the past. A bedrock of non-homogeneous nature, a variable rock breaking mechanism and different rock moving processes could all contribute to these differences. This can compound difficulties in testing for compliance with a set standard.

7.6 Poor correlation in sampling results obtained for different types of instruments must cast doubt on a large percentage of results submitted to the GME for risk assessment, since it is estimated that at least half of the gold mines, members of the Chamber of Mines, use rotating sponge type instruments for sampling.

7.7 It is apparent that there has been a misconception on the way in which airborne dust behaves, how it is liberated and the non-homogeneity of the composition of dust. These factors all contribute towards making the prediction of dust levels for given conditions all but impossible. There is a strong indication that considerably more research is needed to advance the understanding of dust, its behaviour and the minimum number of samples required to be able to certify acceptable representation both for personal and control samples.

PART 2

8 ASSESSMENT OF GRAVIMETRIC DUST SAMPLING DATA FROM SIX SAMPLING CYCLES SUBMITTED BY GOLD MINES, MEMBERS OF THE CHAMBER OF MINES, TO THE GOVERNMENT MINING ENGINEER.

8.1 Methodology

Following a project report back meeting in November 1994, in which attention was drawn to variable dust and quartz concentrations encountered in extensive monitoring exercises, Miningtek was requested to investigate the feasibility of regional and/or an industry average quartz concentration for airborne dust.

Individual dust sampling reports for six sampling cycles submitted by gold mines, members of the Chamber of Mines, to the Government Mining Engineer, were compiled in a database for analysis. In addition, dust sampling reports compiled by Miningtek were studied in detail and, where appropriate, used in the analyses.

Mines were grouped into geographical areas for purposes of compiling regional dust (eight hour Time Weighted Average) and quartz concentrations. The regions were defined as East (Transvaal), Elsburg, Klerksdorp, Northern Free State, Southern Free State and West Wits. All data were used for Industry analyses. The mines in the different regions were as follows:

East	:	Leslie, Winkelhaak, Kinross, Grootvlei, ERPM.
Elsburg	:	Randfontein Estates, Western Areas, Durban Deep.
Klerksdorp	:	Buffelsfontein, Hartebeestfontein, Vaal Reefs West, Vaal Reefs East, Vaal Reefs South.
Northern Free State	:	Free State Geduld, Western Holdings, Freddies, Loraine, Harmony, President Brand, President Steyn, Free State Saaiplaas.
Southern Free State	:	H J Joel, Beatrix, Oryx, Unisel, St Helena.
West Wits	:	Leeudoorn, Libanon, West Driefontein, Elandsrand, East Driefontein, Deelkraal, Doornfontein, Western Deep Levels, Blyvooruitzicht, Kloof.

Furthermore, the results were separated, for each region, into categories of underground stoping and development, underground roving (i.e. other than stoping and development) and surface.

For any meaningful results to emerge it became apparent that simple averages could not be used. Consequently, all TWAs and quartz concentrations were weighted according to the numbers of persons exposed to specific levels (as reported in data for Statistical Populations in the returns submitted). A full understanding of TWAs is complicated because different sampling pumps were used throughout Industry and, as will be shown, different pumps did not produce compatible results.

8.2 Results

8.2.1 Overall industry results

Overall industry results are presented in Tables 13 to 17 for eight-hour Time Weighted Averages broken down into stoping and development, underground roving, surface, total underground and overall (underground and surface). Data for all six sampling cycles are presented.

TABLE 13 INDUSTRY STOPING AND DEVELOPMENT POPULATION TWA DUST DISTRIBUTION

Dust Conc.	Persons	Persons	Persons	Persons	Persons	Persons
Grouping (mg/m^3)	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6
0-0,2	3264	3349	4876	5700	7720	7329
0,2-0,4	28973	28175	46230	53789	60732	46340
0,4-0,6	42786	40568	42326	40530	43208	51099
0,6-0.8	25433	21982	22331	22050	17230	17044
0,8-1,0	11910	14892	6609	1724	3085	4559
1,0-1,2	2569	6365	1520	1354	942	1430
>1,2	3744	2252	656	286	821	508

TABLE 14 INDUSTRY UNDERGROUND ROVING POPULATION TWA DUST DISTRIBUTION

Dust Conc.	Persons	Persons	Persons	Persons	Persons	Persons
Grouping (mg/m^3)	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6
0-0,2	7294	5711	9390	9353	17896	14790
0,2-0,4	40510	38098	43964	45621	43698	50905
0,4-0,6	24353	28132	27749	21426	22143	23785
0,6-0,8	10013	12349	5134	10076	12229	10249
0,8-1,0	4852	1855	3262	3551	4952	3611
1,0-1,2	2267	1069	149	515	1071	2318
>1,2	1268	686	0		311	1366

TABLE 15 INDUSTRY SURFACE POPULATION TWA DUST DISTRIBUTION

Dust Conc.	Persons	Persons	Persons	Persons	Persons	Persons
Grouping (mg/m^3)	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6
0-0,2	3843	3835	4714	5376	9594	3798
0,2-0,4	6960	8110	9034	10712	12274	8509
0,4-0,6	7761	4770	7044	4667	7084	6276
0,6-0,8	2167	2679	2815	1931	2991	2277
0,8-1,0	2046	1482	744	642	1269	803
1,0-1,2	331	401	824	723	381	120
>1,2	1377	865	327	615	847	920

TABLE 16 INDUSTRY TOTAL UNDERGROUND POPULATION TWA DUST DISTRIBUTION

Dust Conc.	Persons	Persons	Persons	Persons	Persons	Persons
Grouping (mg/m^3)	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6
0-0,2	10558	9060	14266	63142	25616	22119
0,2-0,4	69483	66273	90194	86151	104430	97245
0,4-0,6	67139	68700	70075	43476	65351	74884
0,6-0.8	35446	34331	27465	11800	29459	27293
0,8-1,0	16762	16747	9871	4905	8037	8170
1,0-1,2	4836	7434	1669	801	2013	3748
>1,2	5012	2938	656	0	1132	1874

TABLE 17 INDUSTRY OVERALL TWA DUST DISTRIBUTION

Dust Conc.	Persons	Persons	Persons	Persons	Persons	Persons
Grouping (mg/m^3)	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6
0-0,2	14401	12895	18980	68518	35210	25917
0,2-0,4	76443	74383	99228	96863	116704	105754
0,4-0,6	74900	73470	77119	48143	72435	81160
0,6-0,8	37613	37010	30280	13731	32450	29570
0,8-1,0	18808	18229	10615	5547	9306	8973
1,0-1,2	5167	7835	2493	1524	2394	3868
>1,2	6389	3803	983	615	1979	2794

Data for stoping and development are presented graphically in Figures 68 and 69, where Figure 69 is a statistically smoothed curve of Figure 68 and shows actual numbers of persons not percentage of the working population. Based on data submitted by mines the largest percentage of underground workers in this category are exposed to dust concentrations in the range 0,2-0,4 mg/m^3 although in the last sampling cycle analysed there was an upward shift whereby the majority of workers in this category were exposed to dust concentrations in the range 0,4 to 0,6 mg/m^3. The significance of this shift will be discussed later. There is a positive skewness for the frequency distribution which may be considered to be normal[5].

In Figures 70 and 71 the results of the analyses for the underground roving population (industry) are presented and it is clear that the exposure levels for the majority of the workers in this category are in the range 0,2-0,4 mg/m^3. Once again positive skewness is displayed.

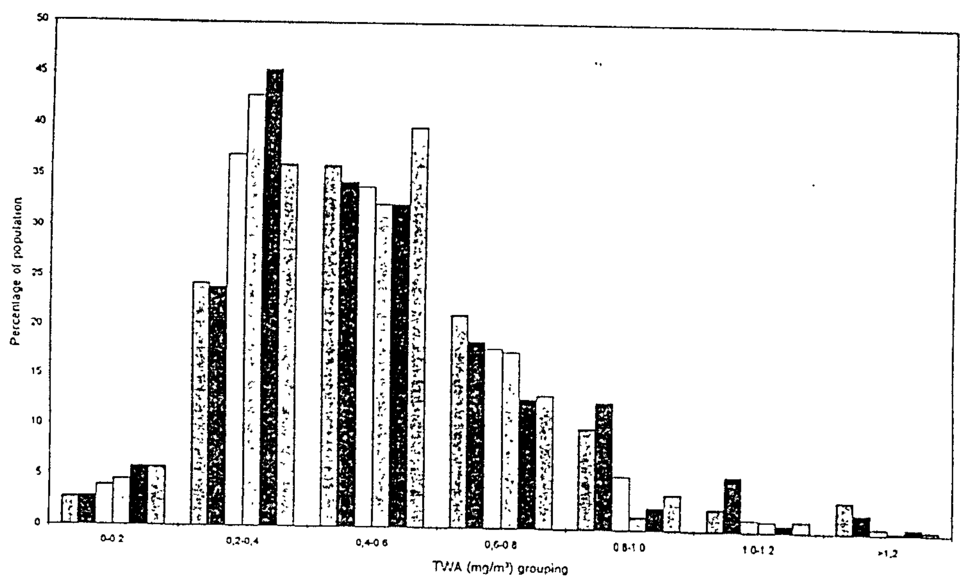

Figure 68 INDUSTRY STOPING AND DEVELOPMENT POPULATION TWA DUST DISTRIBUTION (HALF YEARLY CYCLES JANUARY TO JUNE 1994)

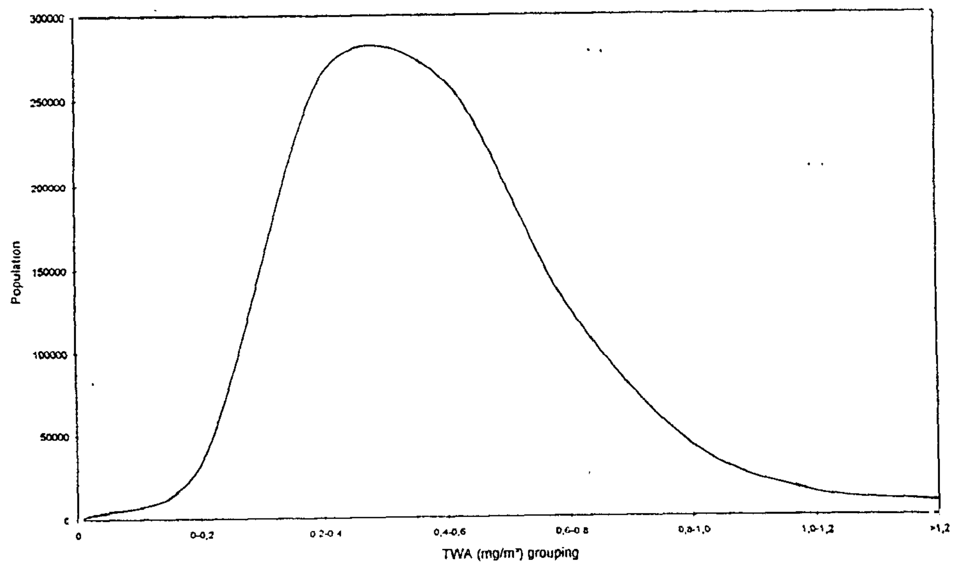

Figure 69 INDUSTRY TOTAL STOPING AND DEVELOPMENT POPULATION TWA DUST DISTRIBUTION

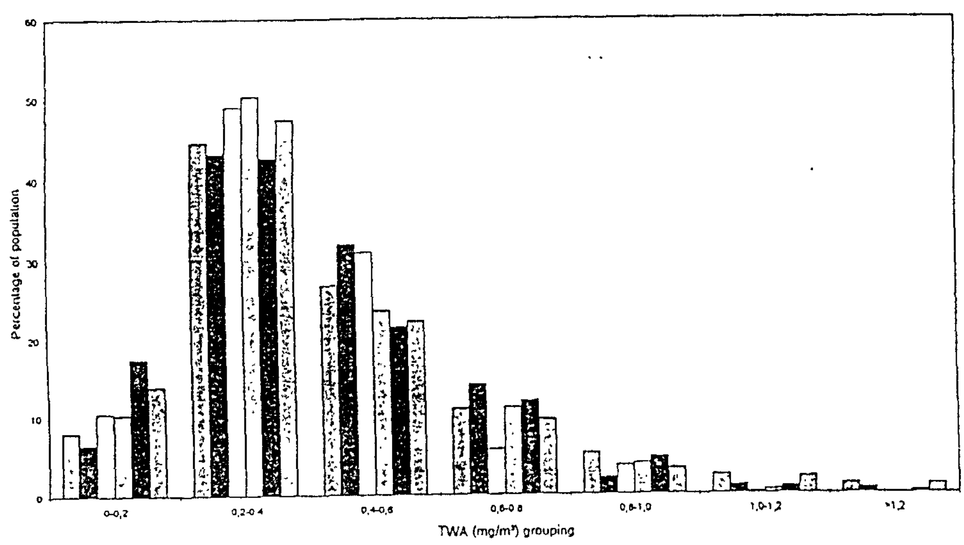

Figure 70 INDUSTRY UNDERGROUND ROVING POPULATIONS TWA DUST DISTRIBUTION (HALF YEARLY CYCLES JANUARY 1992 TO JUNE 1994)

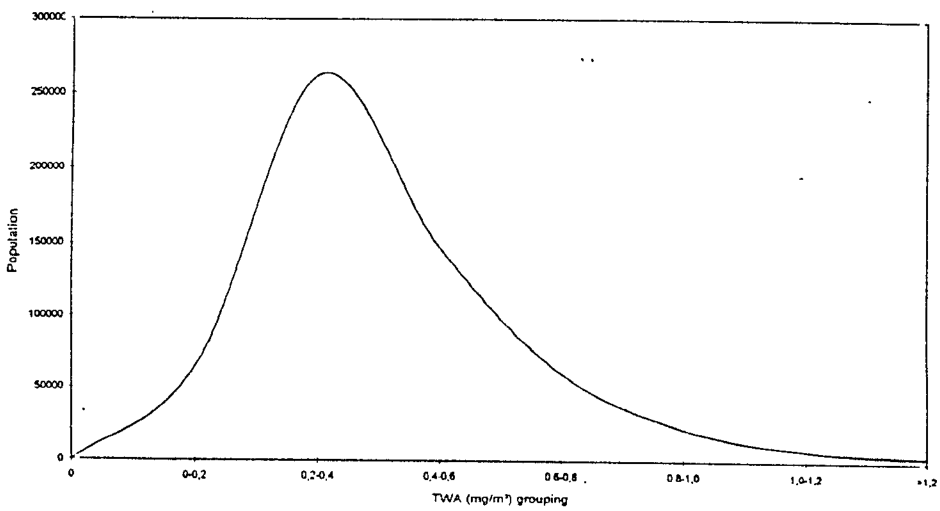

Figure 71 INDUSTRY TOTAL UNDERGROUND ROVING POPULATION TWA DUST DISTRIBUTION

Data collected for surface workings are presented in Figures 72 and 73 and although the mean exposure level remains in the range 0,2-0,4 mg/m^3 it is also evident that a larger proportion of this particular sector of the workforce is exposed to dust concentrations in excess of 1,2 mg/m^3 than was found for the two underground categories. This aspect will also be discussed later. Positive skewness is again displayed.

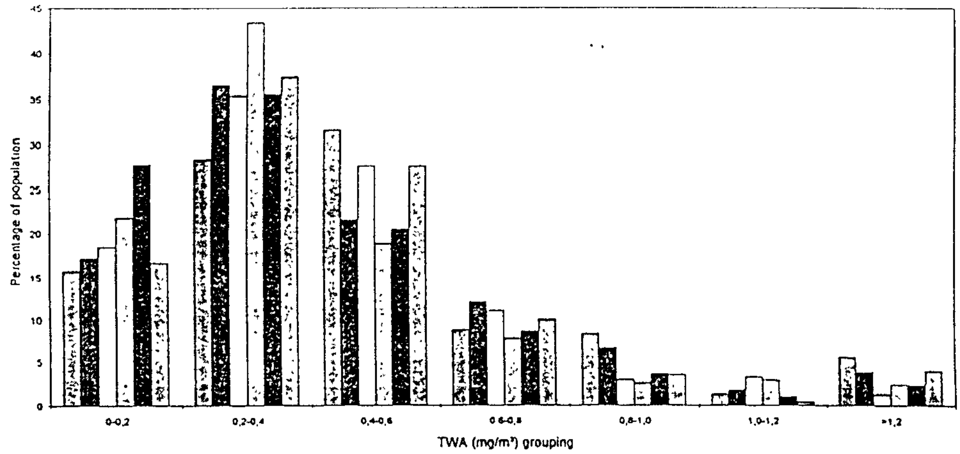

Figure 72 INDUSTRY SURFACE POPULATION TWA DUST DISTRIBUTION (HALF YEARLY CYCLES JANUARY 1992 TO JUNE 1994)

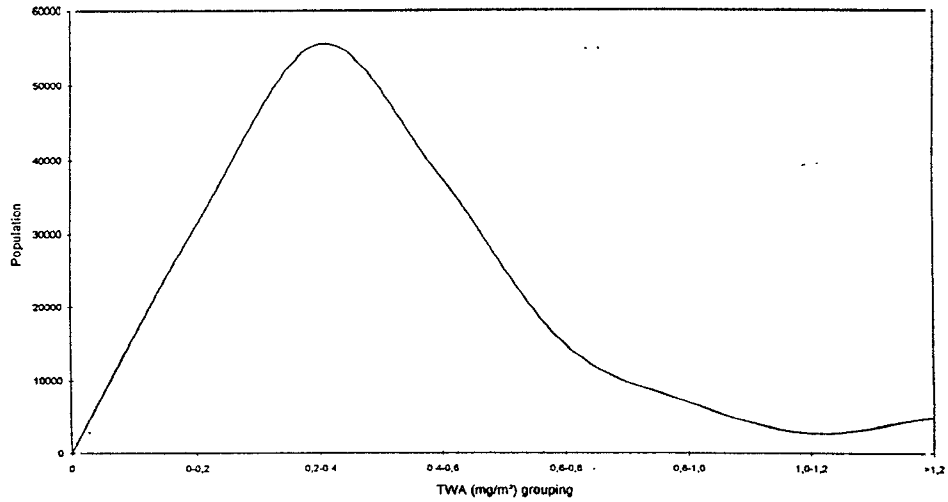

Figure 73 INDUSTRY TOTAL SURFACE POPULATION TWA DUST DISTRIBUTION

The results for all underground work categories were grouped and the analyses are shown in Figures 74 and 75.

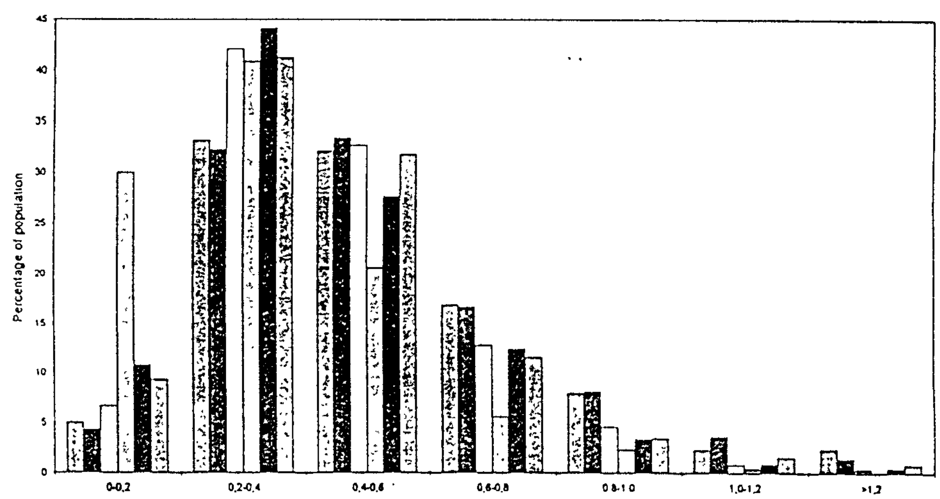

Figure 74 INDUSTRY TOTAL UNDERGROUND POPULATION TWA DUST DISTRIBUTION (HALF YEARLY CYCLES JANUARY 1992 TO JUNE 1994)

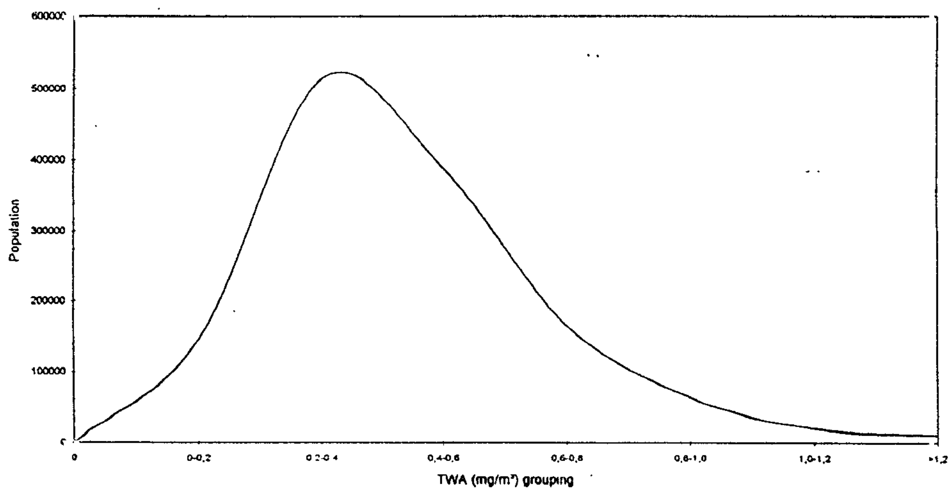

Figure 75 INDUSTRY TOTAL UNDERGROUND POPULATION TWA DUST DISTRIBUTION

Positive skewness is displayed and the mean exposure levels are seen to lie in the range 0,2-0,4 mg/m^3.

Once the surface results are added to those just presented the picture is found to remain unchanged except for the elevation of the number of persons exposed to dust concentrations greater than 1,2 mg/m^3.

Shown in Figures 76 and 77 are the overall (surface plus underground) TWA distributions and the overall industry population TWA distribution. Taking into account the surface and underground results, the majority of the workforce is seen to be exposed to dust concentrations in the range 0,2-0,4 mg/m^3.

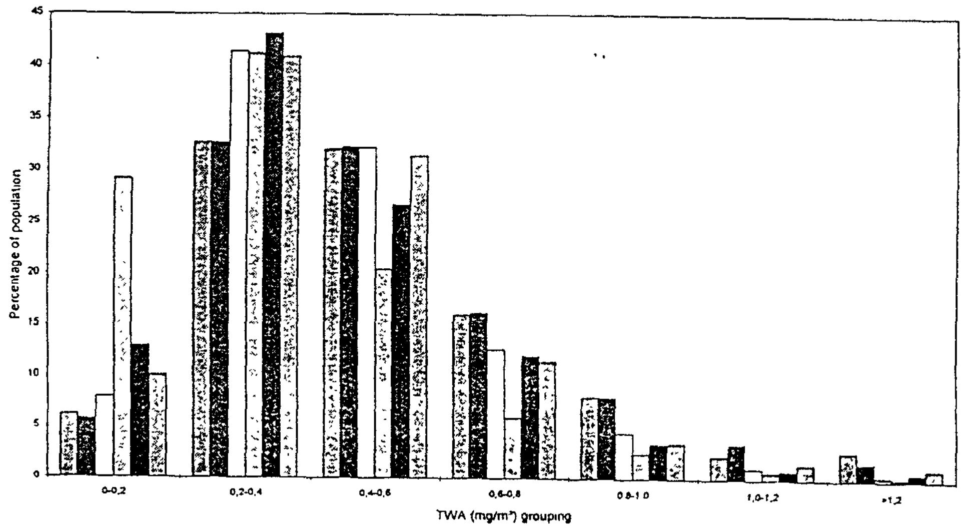

Figure 76 INDUSTRY OVERALL POPULATION TWA DUST DISTRIBUTION (HALF YEARLY CYCLES JANUARY 1992 TO JUNE 1994)

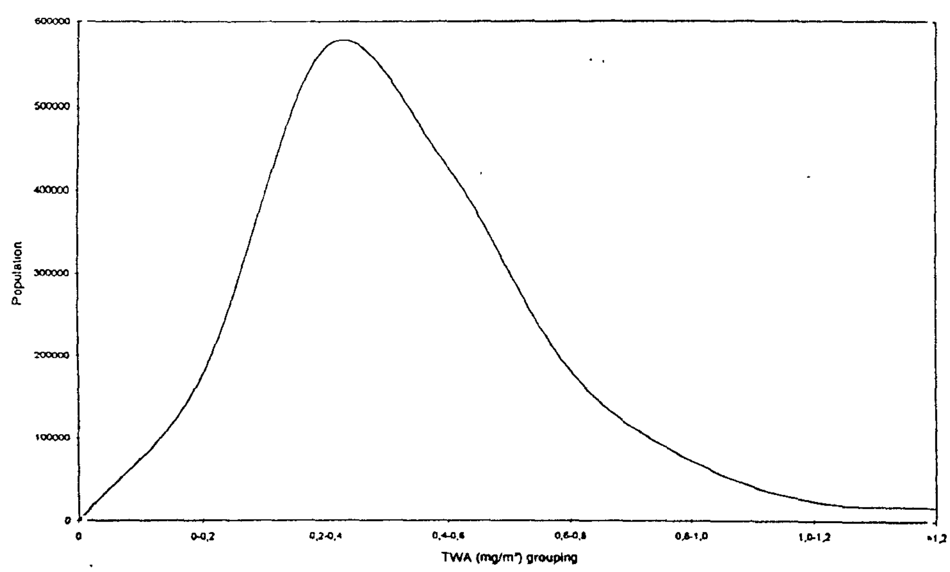

Figure 77 INDUSTRY OVERALL POPULATION TWA DUST DISTRIBUTION

8.2.2 Overall industry quartz analyses

Overall industry quartz analyses are set out in Tables 18 to 22 in which are the quartz concentrations for stoping and development, underground roving, surface, total underground population and industry overall (surface and underground) are shown.

TABLE 18 INDUSTRY STOPING AND DEVELOPMENT POPULATION QUARTZ PER CENT DISTRIBUTION

Quartz	Persons	Persons	Persons	Persons	Persons	Persons
Grouping (%)	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6
0-5	5259	4550	5287	8194	7709	8188
5-10	15225	14639	27865	23926	23959	38612
10-15	32708	34274	44410	37218	41606	38389
15-20	31866	32351	22560	31209	30494	32079
20-25	19159	17443	11794	7066	14405	6869
25-30	4476	6610	7231	8501	7094	2163
30-35	3704	2080	2826	2684	3394	1738
35-40	3456	3747	1944	1260	925	249
>40	1824	1897	1316	1602	353	475

TABLE 19 INDUSTRY UNDERGROUND ROVING POPULATION QUARTZ PER CENT DISTRIBUTION

Quartz	Persons	Persons	Persons	Persons	Persons	Persons
Grouping (%)	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6
0-5	9112	10018	12474	11811	13998	17332
5-10	19550	18555	28309	28794	29212	32365
10-15	24745	24730	22038	24082	29493	31126
15-20	17165	19716	12932	13158	19695	18761
20-25	7874	8898	7224	7425	5465	3395
25-30	3809	3393	4111	3012	2662	1966
30-35	3817	4281	647	685	288	230
35-40	1843	1795	1086	287	165	181
>40	2680	2802	885	740	1151	766

TABLE 20 INDUSTRY SURFACE POPULATION QUARTZ PER CENT DISTRIBUTION

Quartz	Persons	Persons	Persons	Persons	Persons	Persons
Grouping (%)	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6
0-5	4619	4143	5422	5708	6233	6120
5-10	5042	4719	7857	7205	6098	7064
10-15	6520	5487	5945	6278	6634	4658
15-20	3253	3359	2570	2680	4804	1586
20-25	2396	2313	1713	683	1639	2529
25-30	1406	1036	1337	1009	1397	910
30-35	178	203	625	426	769	397
35-40	87	39	85	146	77	192
>40	1227	1122	251		130	135

TABLE 21 INDUSTRY TOTAL UNDERGROUND POPULATION QUARTZ PER CENT DISTRIBUTION

Quartz	Persons	Persons	Persons	Persons	Persons	Persons
Grouping (%)	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6
0-5	14371	14568	17761	20005	21707	25520
5-10	34775	33194	56174	52720	53171	70977
10-15	57453	59004	66448	61300	71099	69515
15-20	49031	52067	35492	44367	50189	50840
20-25	27033	26341	19018	14491	19870	10264
25-30	8285	10003	11342	11513	9756	4129
30-35	7521	6361	3473	3369	3682	1968
35-40	5299	5542	3030	1547	1090	430
>40	4504	4699	2201	2342	1504	1241

TABLE 22 INDUSTRY OVERALL QUARTZ PER CENT DISTRIBUTION						
Quartz	Persons	Persons	Persons	Persons	Persons	Persons
Grouping (%)	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6
0-5	18990	18711	23183	25713	27940	31640
5-10	39817	37913	64031	59925	59269	78041
10-15	63973	64491	72393	67578	77733	74173
15-20	52284	55426	38062	47047	54993	52426
20-25	29429	28654	20731	15174	21509	12793
25-30	9691	11039	12679	12522	11153	5039
30-35	7699	6564	4098	3795	4451	2365
35-40	5386	5581	3115	1693	1167	622
>40	5731	5821	2452	2342	1634	1376

Figures 78 to 87 show the graphical analyses of the above. All graphs, with the exception of underground roving, indicate mean quartz concentrations in the range 10-15 per cent. Underground roving results display a mean of between 5 to 10 per cent for airborne quartz, but with a shift to a higher range (10-15 per cent) for the last two sampling cycles. All graphical analyses display positive skewness with a detectable population being exposed to dust concentrations where quartz levels are greater than 40 per cent.

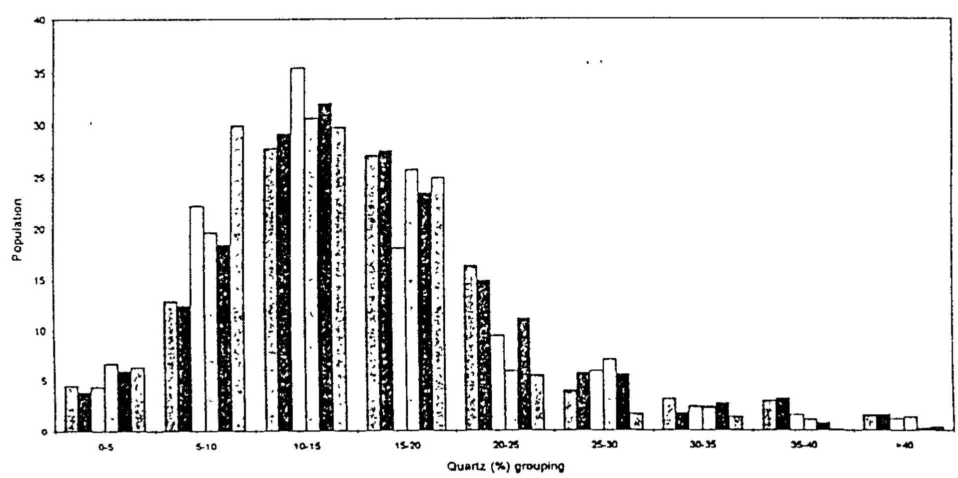

Figure 78 INDUSTRY STOPING AND DEVELOPMENT POPULATION QUARTZ PER CENT DISTRIBUTION (HALF YEARLY CYCLES JANUARY 1992 TO JUNE 1994)

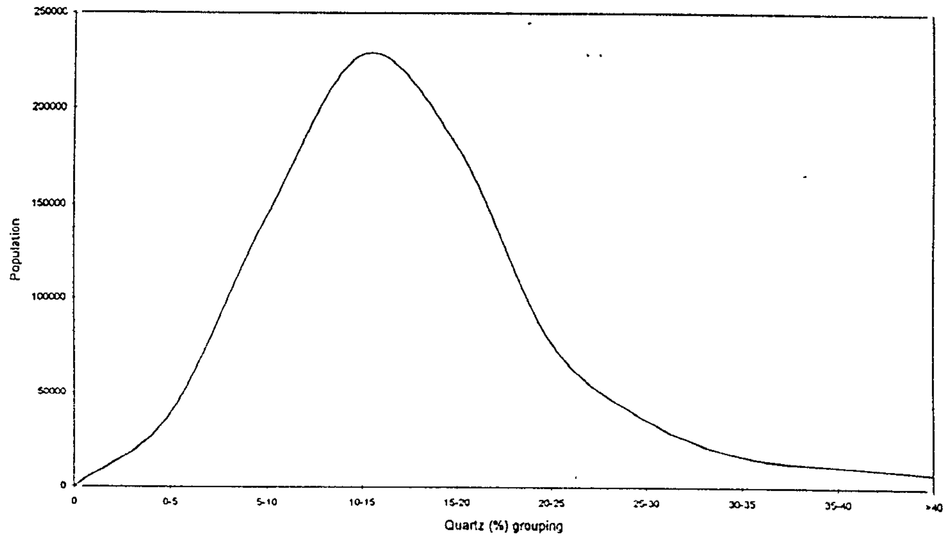

Figure 79 INDUSTRY STOPING AND DEVELOPMENT POPULATION QUARTZ PER CENT DISTRIBUTION

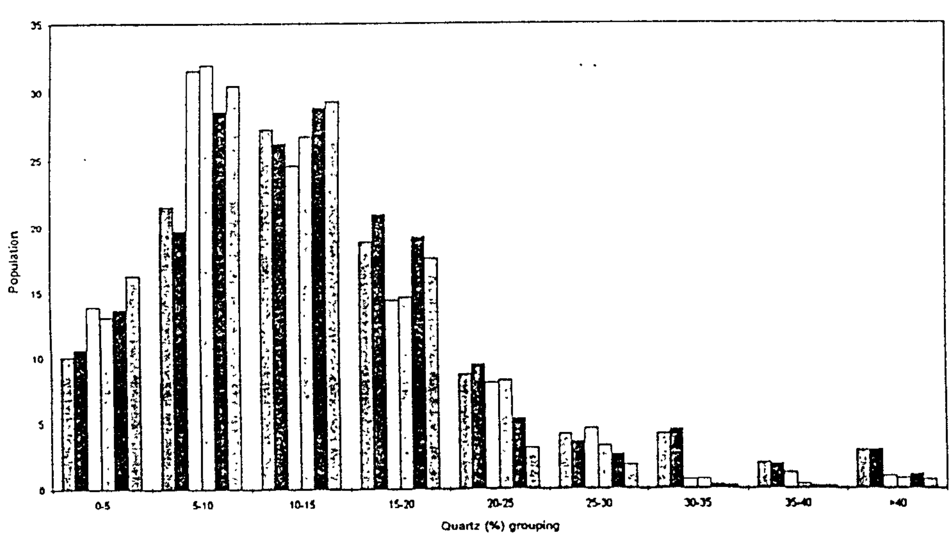

Figure 80 INDUSTRY UNDERGROUND ROVING POPULATION QUARTZ PER CENT DISTRIBUTION (HALF YEARLY CYCLES JANUARY 1992 TO JUNE 1994)

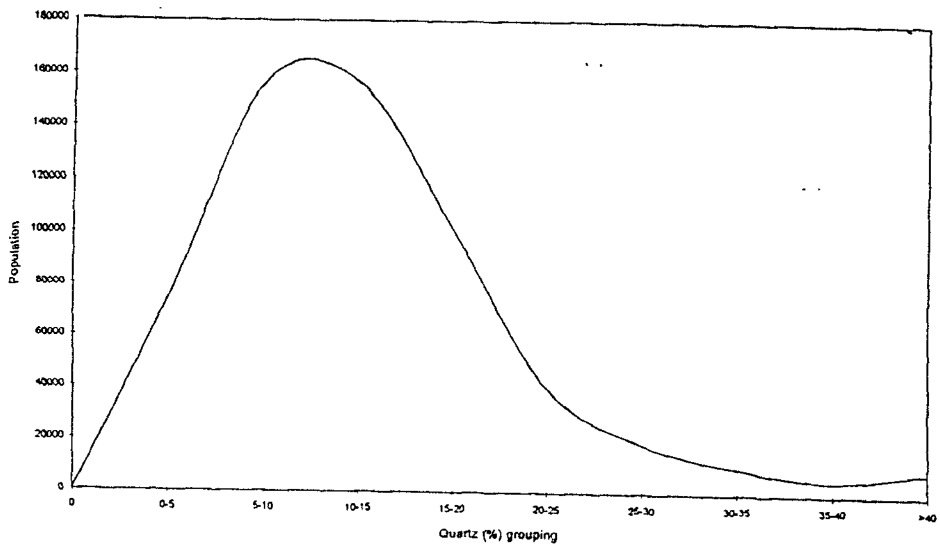

Figure 81 INDUSTRY UNDERGROUND ROVING POPULATION QUARTZ PER CENT DISTRIBUTION

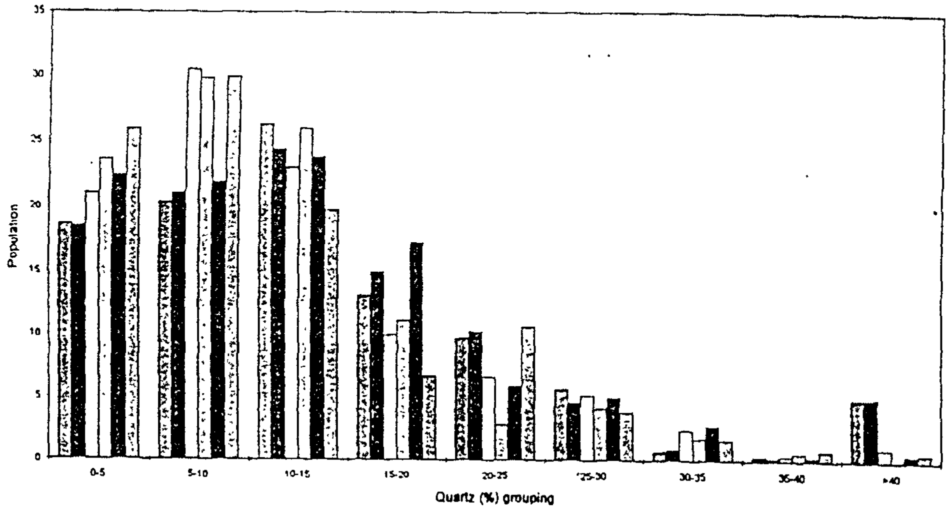

Figure 82 INDUSTRY SURFACE POPULATION QUARTZ PER CENT DISTRIBUTION (HALF YEARLY CYCLES JANUARY 1992 TO JUNE 1994)

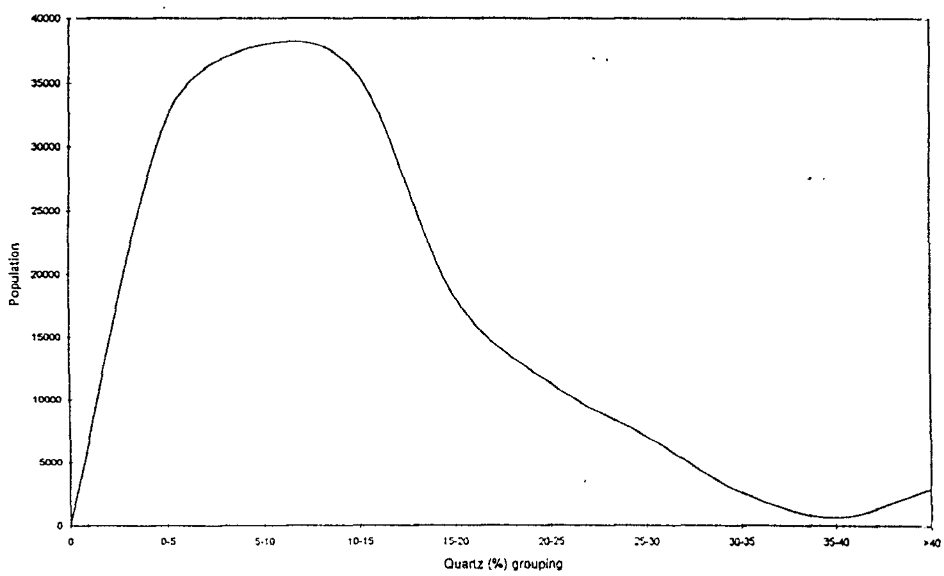

Figure 83 INDUSTRY SURFACE POPULATION QUARTZ PER CENT DISTRIBUTION

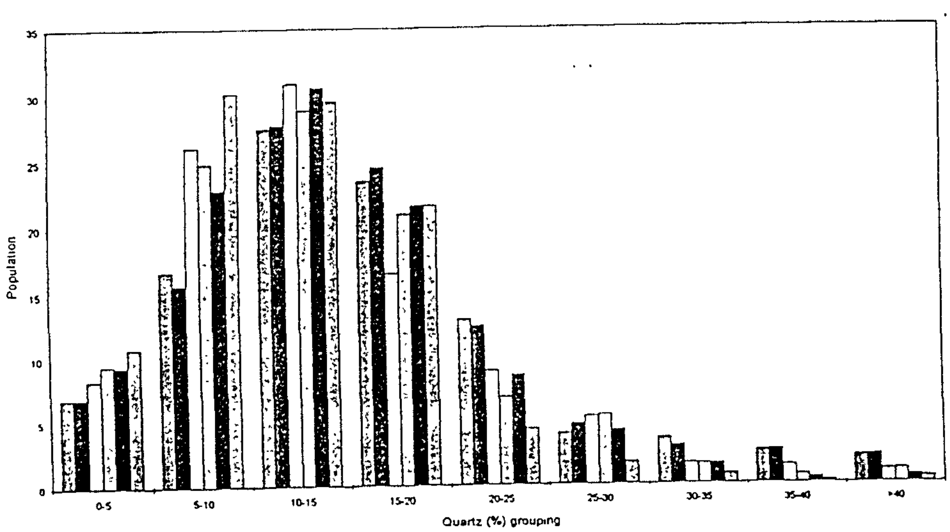

Figure 84 INDUSTRY TOTAL UNDERGROUND POPULATION QUARTZ PER CENT DISTRIBUTION (HALF YEARLY CYCLES JANUARY 1992 TO JUNE 1994)

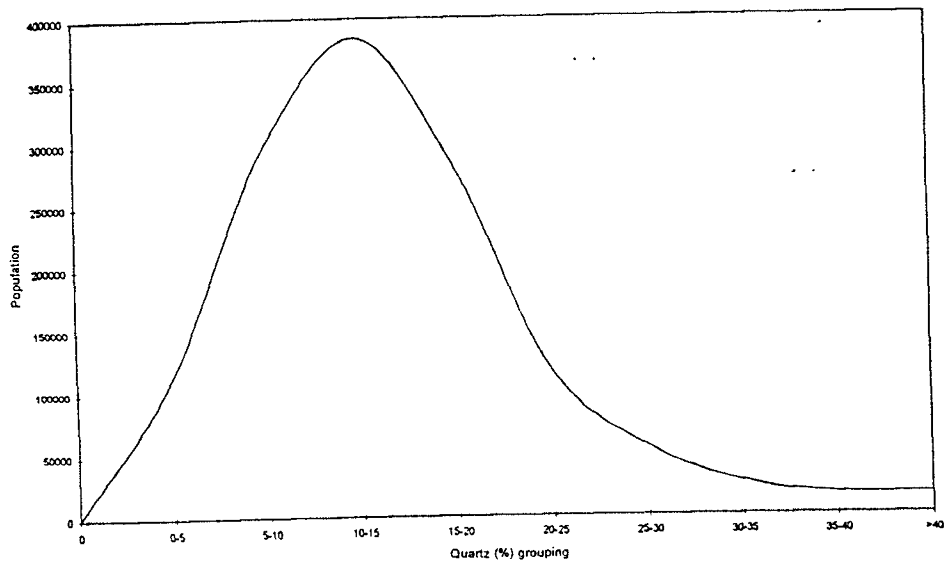

Figure 85 INDUSTRY TOTAL UNDERGROUND POPULATION QUARTZ PER CENT DISTRIBUTION

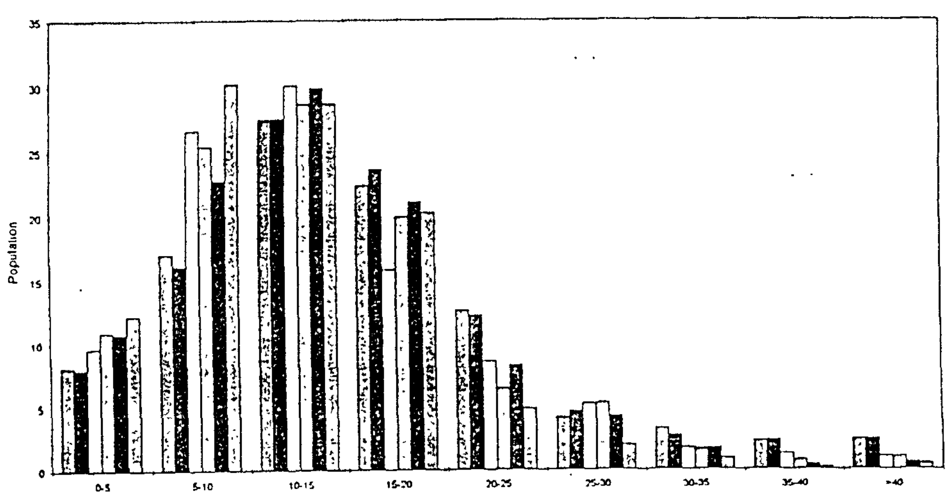

Figure 86 INDUSTRY OVERALL POPULATION QUARTZ PER CENT DISTRIBUTION (HALF YEARLY CYCLES JANUARY 1992 TO JUNE 1994)

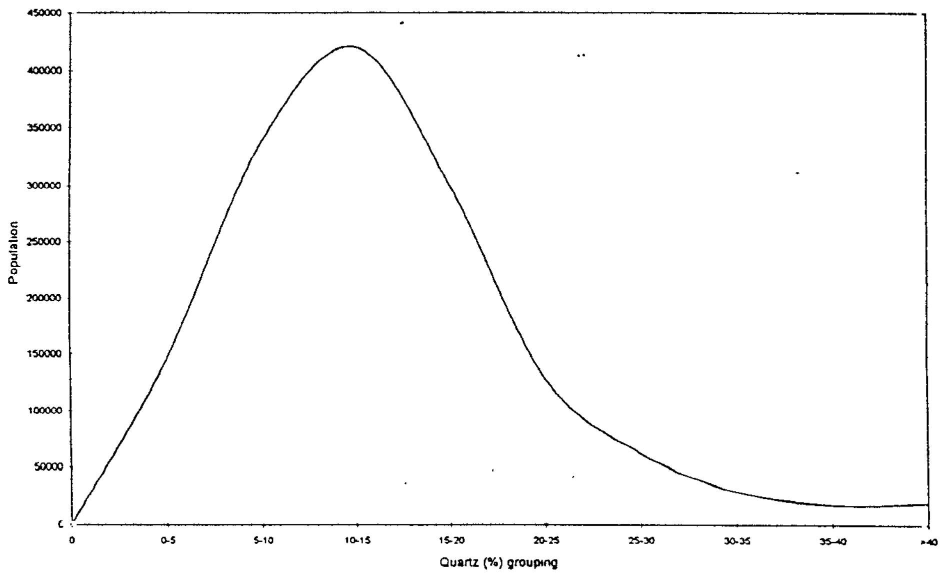

Figure 87 INDUSTRY OVERALL POPULATION QUARTZ PER CENT DISTRIBUTION

8.2.3 Overall industry population dust exposure

Overall trends in Industry Time Weighted Averages are summarised in Tables 23 to 25 and graphically interpreted in Figures 88 to 90. These trends indicate that an increasingly greater percentage of the mine workforce is being exposed to increasingly lower levels of dust. The fraction of the workforce exposed to dust concentrations less than 0,4 mg/m^3 has increased by approximately 15 per cent, while the fraction of the workforce exposed to dust concentrations greater than 0,6 mg/m^3 has decreased by approximately the same amount over the six dust sampling cycles evaluated.

TABLE 23 INDUSTRY OVERALL TWA DISTRIBUTION, 0 TO 0,4 mg/m^3 (Dust)

Dust Conc. Grouping (mg/m^3)	Persons Cycle 1	Persons Cycle 2	Persons Cycle 3	Persons Cycle 4	Persons Cycle 5	Persons Cycle 6
0-0,2	14401	12895	18980	68518	35210	25917
0,2-0,4	76443	74383	99228	96863	116704	105754

TABLE 24 INDUSTRY OVERALL TWA DISTRIBUTION, 0,4 TO 0,6 mg/m³ (Dust)						
Dust Conc.	Persons	Persons	Persons	Persons	Persons	Persons
Grouping (mg/m³)	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6
0,4-0,6	74900	73470	77119	48143	72435	81160

TABLE 25 INDUSTRY OVERALL TWA DISTRIBUTION > 0,6 mg/m³ (Dust)						
Dust Conc.	Persons	Persons	Persons	Persons	Persons	Persons
Grouping (mg/m³)	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6
0,6-0,8	37613	27010	30280	13731	32450	29570
0,8-1,0	18808	18229	10615	5547	9306	8973
1,0-1,2	5167	7835	2493	1524	2394	3868
1,2+	6389	3803	983	615	1979	2794

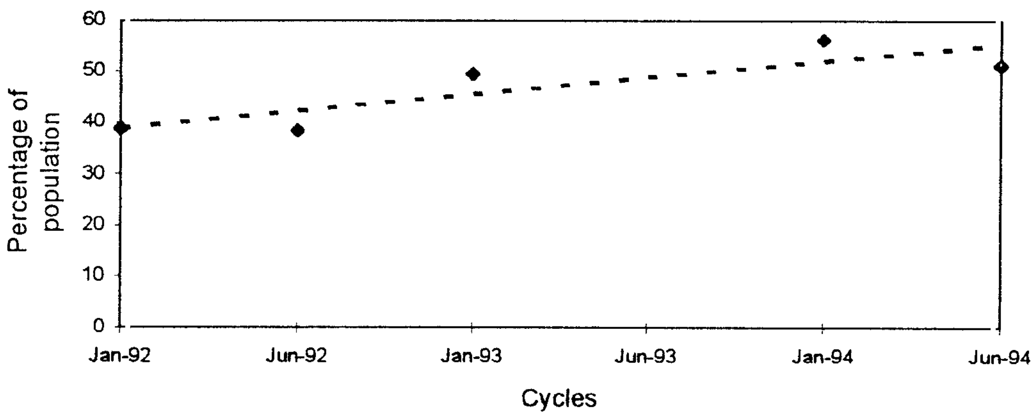

Figure 88 PERCENTAGE OF TOTAL POPULATION EXPOSED TO TWA DUST LEVELS BELOW 0,4 mg/m³

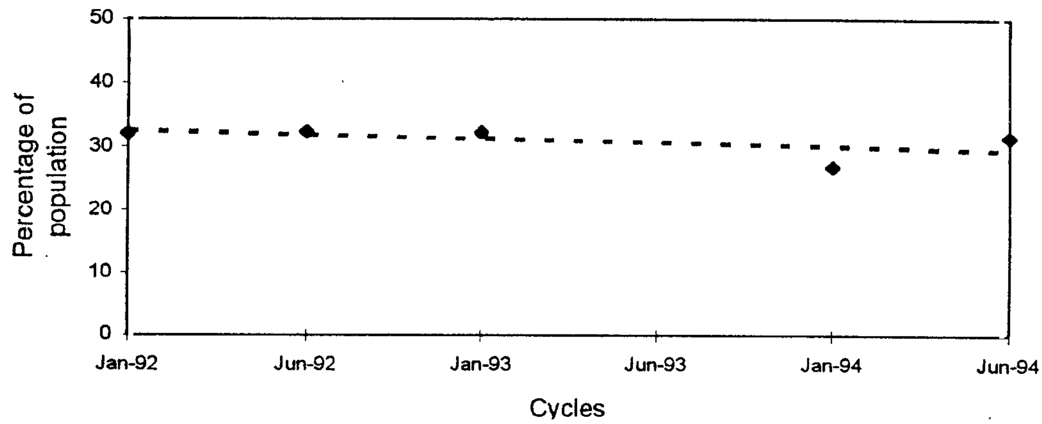

Figure 89 PERCENTAGE OF TOTAL POPULATION EXPOSED TO TWA DUST LEVELS BETWEEN 0,4 AND 0,6 mg/m^3

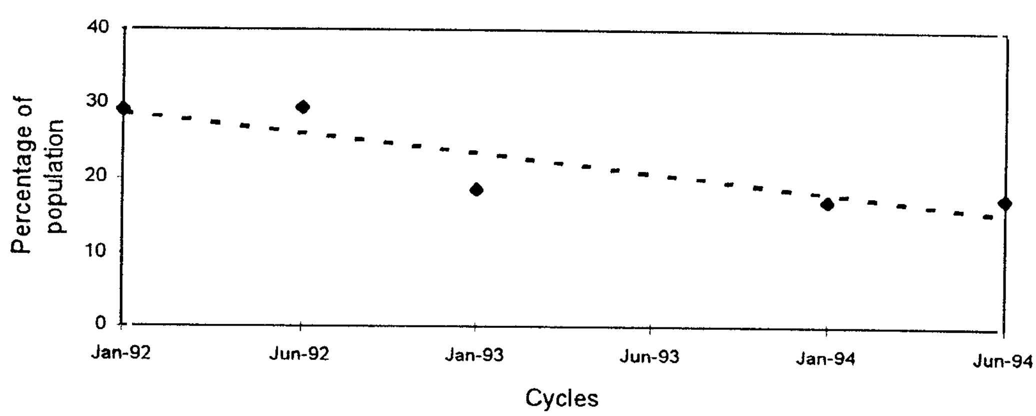

Figure 90 PERCENTAGE OF TOTAL POPULATION EXPOSED TO TWA DUST LEVELS GREATER THAN 0,6 mg/m^3

8.2.4 Industry trends in quartz concentrations

A similar analysis was performed to examine industry trends in quartz concentrations to which the working population is exposed. These results are shown in Tables 26 to 28 and Figures 91 to 93. There is a shift towards exposure to lower quartz concentrations.

TABLE 26 INDUSTRY OVERALL QUARTZ DISTRIBUTION, 0 TO 10 PER CENT

Quartz Grouping (%)	Persons Cycle 1	Persons Cycle 2	Persons Cycle 3	Persons Cycle 4	Persons Cycle 5	Persons Cycle 6
0-5	18990	18711	23183	25713	27940	31640
5-10	39817	37913	64031	59925	59269	78041

TABLE 27 INDUSTRY OVERALL QUARTZ DISTRIBUTION, 10 TO 20 PER CENT

Quartz Grouping (%)	Persons Cycle 1	Persons Cycle 2	Persons Cycle 3	Persons Cycle 4	Persons Cycle 5	Persons Cycle 6
10-15	63973	64491	72393	67578	77733	74173
15-20	52284	55426	38062	47047	54993	51426

TABLE 28 INDUSTRY OVERALL QUARTZ DISTRIBUTION, >20 PER CENT

Quartz Grouping (%)	Persons Cycle 1	Persons Cycle 2	Persons Cycle 3	Persons Cycle 4	Persons Cycle 5	Persons Cycle 6
20-25	29429	28654	20731	15174	21509	12793
25-30	9691	11039	12679	12522	11153	5039
30-35	7699	6564	4098	3795	4451	2365
35-40	5386	5581	3115	1693	1167	622
>40	5731	5821	2452	2342	1634	1376

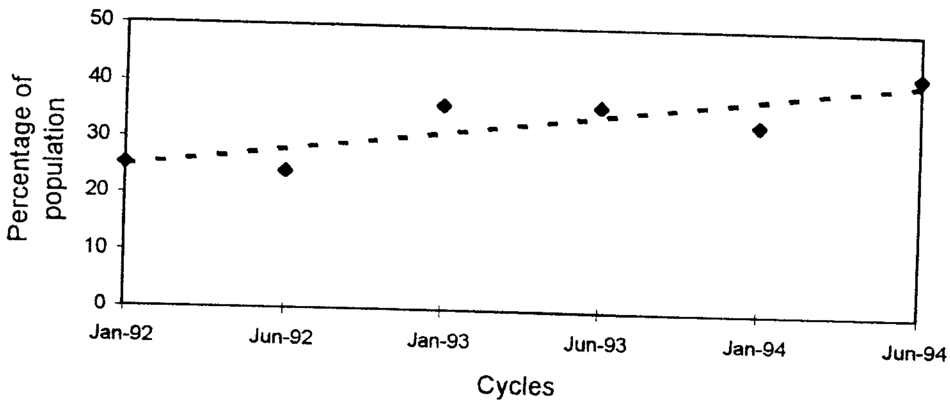

Figure 91 PERCENTAGE OF TOTAL POPULATION EXPOSED TO QUARTZ LEVELS BETWEEN 0 AND 10 PER CENT

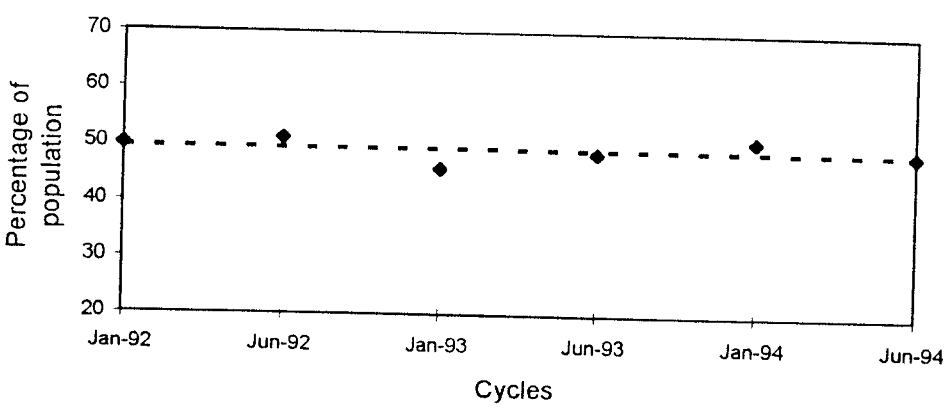

Figure 92 PERCENTAGE TOTAL POPULATION EXPOSED TO QUARTZ LEVELS BETWEEN 10 AND 20 PER CENT

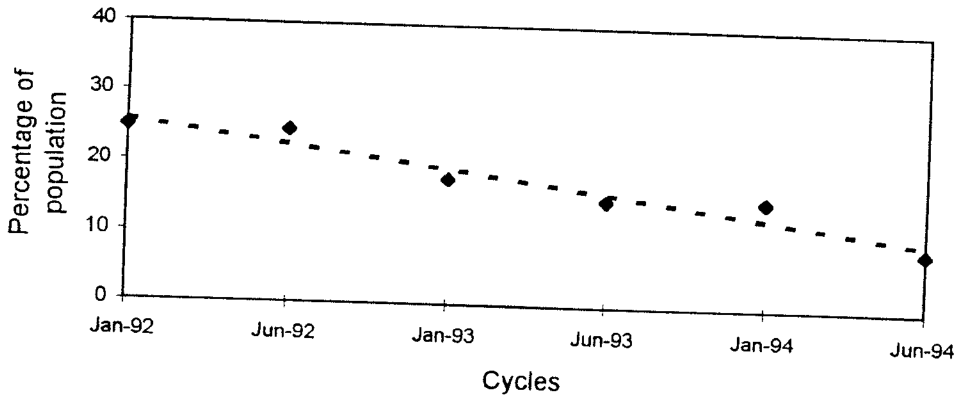

Figure 93 PERCENTAGE OF TOTAL POPULATION EXPOSED TO QUARTZ LEVELS GREATER THAN 20 PER CENT

The reason for the shifts to lower dust concentrations and for more persons to be exposed to lower concentrations of airborne quartz is not clear. As seen in Part 1 no relationship was found between dust levels and quartz concentrations.

8.2.5 Regional and industry average dust concentrations

Regional and Industry average dust concentrations, both simple arithmetic and person weighted, are presented in Table 29 and corresponding graphs in Figures 94 to 100.

Table 29 SIMPLE ARITHMETICAL AND PERSON WEIGHTED CYCLIC AVERAGE DUST EXPOSURE LEVELS (TWA) (EXCLUDING SURFACE RESULTS)

East Simple Ave mg/m^3	Std Dev	Weighted Ave mg/m^3	Elsburg Simple Ave mg/m^3	Std Dev	Weighted Ave mg/m^3
0.52	0.34	0.54	0.54	0.26	0.55
0.55	0.28	0.59	0.45	0.22	0.54
0.54	0.25	0.55	0.46	0.24	0.58
0.57	0.25	0.58	0.50	0.22	0.72
0.53	0.25	0.51	0.47	0.25	0.51
0.58	0.26	0.57	0.57	0.22	0.63
Klerksdorp Simple Ave mg/m^3	Std Dev	Weighted Ave mg/m^3	NOFS Simple Ave mg/m^3	Std Dev	Weighted Ave mg/m^3
0.59	0.29	0.64	0.37	0.16	0.48
0.59	0.23	0.61	0.43	0.21	0.55
0.50	0.21	0.53	0.39	0.17	0.46
0.48	0.18	0.49	0.37	0.18	0.44
0.50	0.25	0.53	0.35	0.17	0.41
0.39	0.19	0.43	0.38	0.18	0.45
SOFS Simple Ave mg/m^3	Std Dev	Weighted Ave mg/m^3	W Wits Simple Ave mg/m^3	Std Dev	Weighted Ave mg/m^3
0.61	0.30	0.62	0.54	0.71	0.51
0.52	0.25	0.64	0.44	0.26	0.46
0.49	0.21	0.50	0.39	0.18	0.38
0.51	0.27	0.46	0.39	0.19	0.38
0.44	0.21	0.43	0.37	0.21	0.36
0.63	0.20	0.63	0.40	0.30	0.41
Industry Total Simple Ave mg/m^3	Std Dev	Weighted Ave mg/m^3			
0.50	0.46	0.54			
0.48	0.25	0.54			
0.43	0.21	0.46			
0.41	0.20	0.46			
0.41	0.22	0.43			
0.43	0.25	0.46			

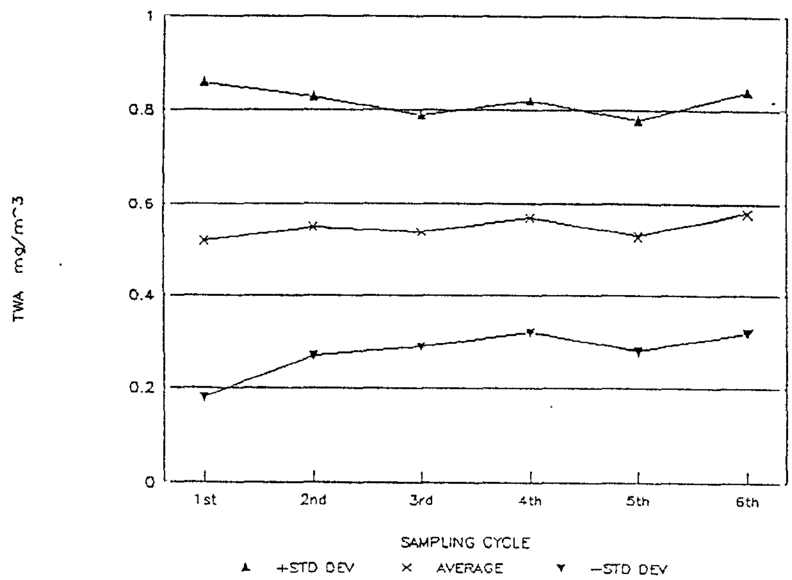

Figure 94 EAST REGION DUST AVERAGES

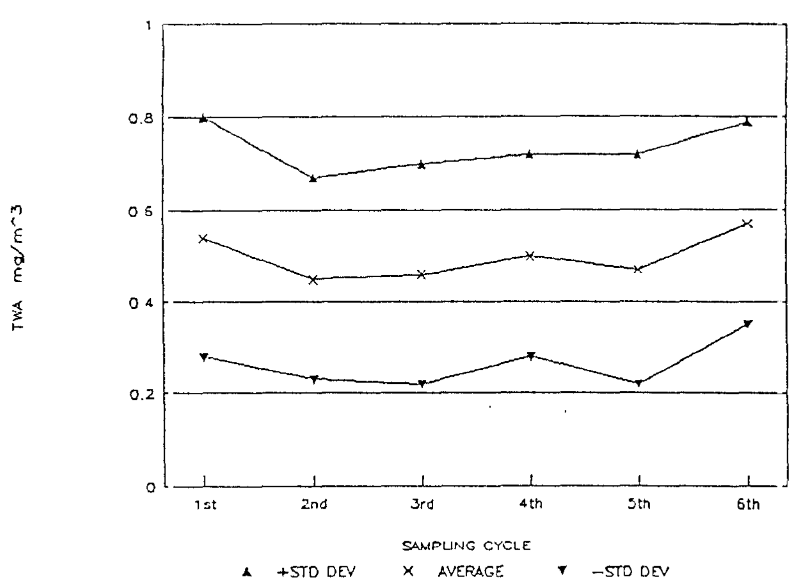

Figure 95 ELSBURG REGION DUST AVERAGES

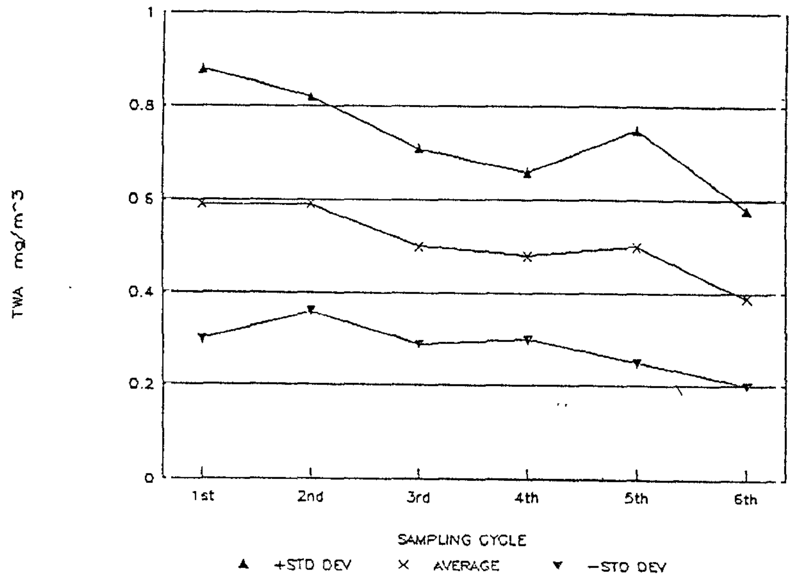

Figure 96 KLERKSDORP REGION DUST AVERAGES

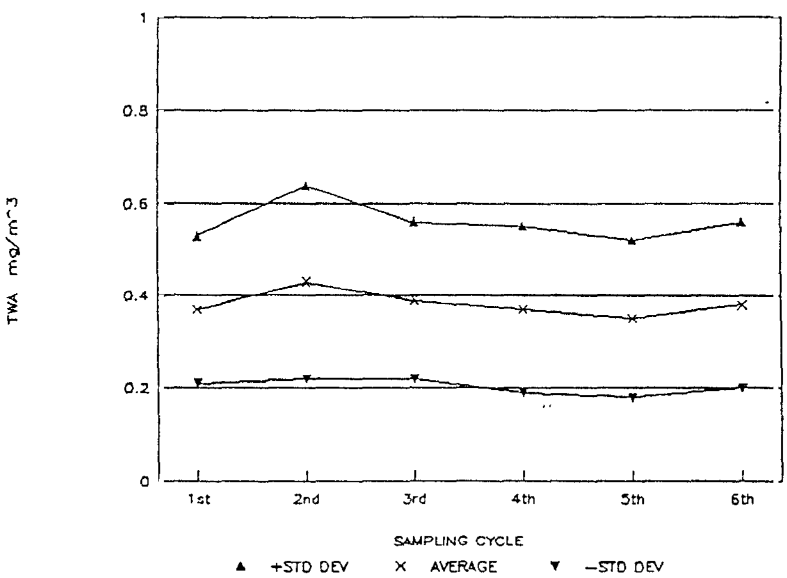

Figure 97 NORTH FREE STATE REGION DUST AVERAGES

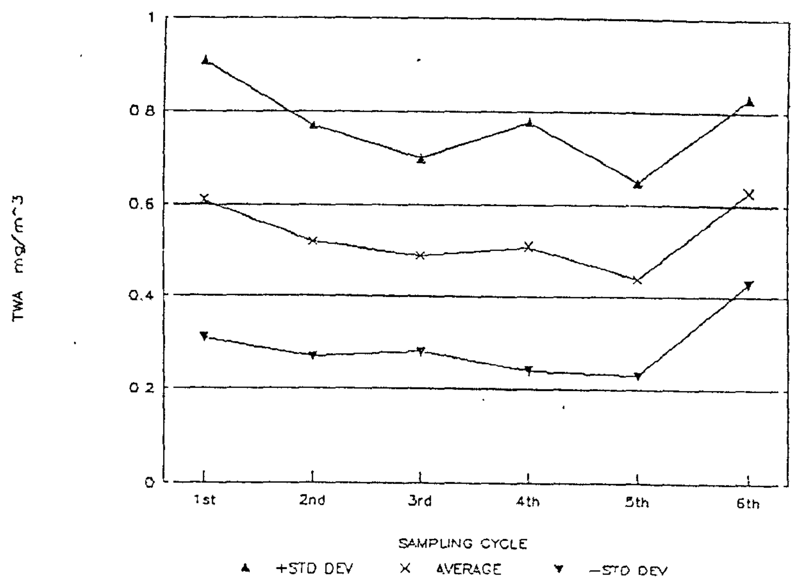

Figure 98 SOUTH FREE STATE REGION DUST AVERAGES

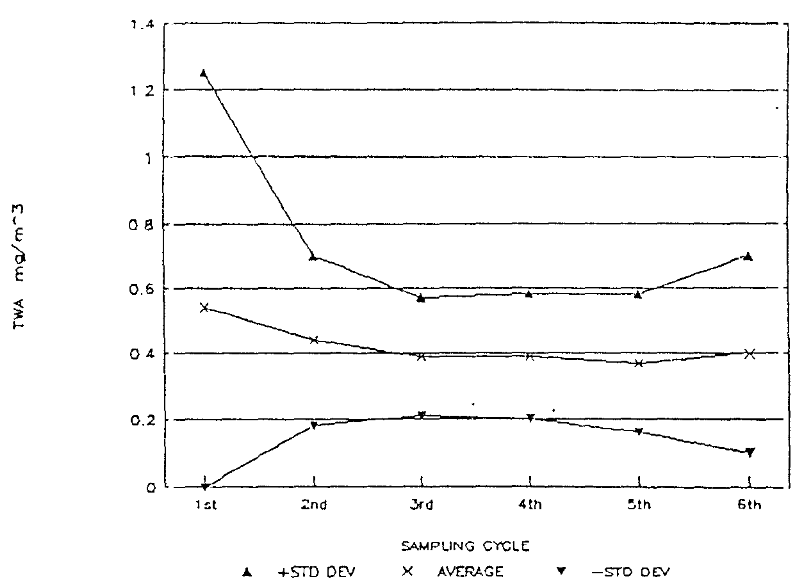

Figure 99 WEST WITS REGION DUST AVERAGES

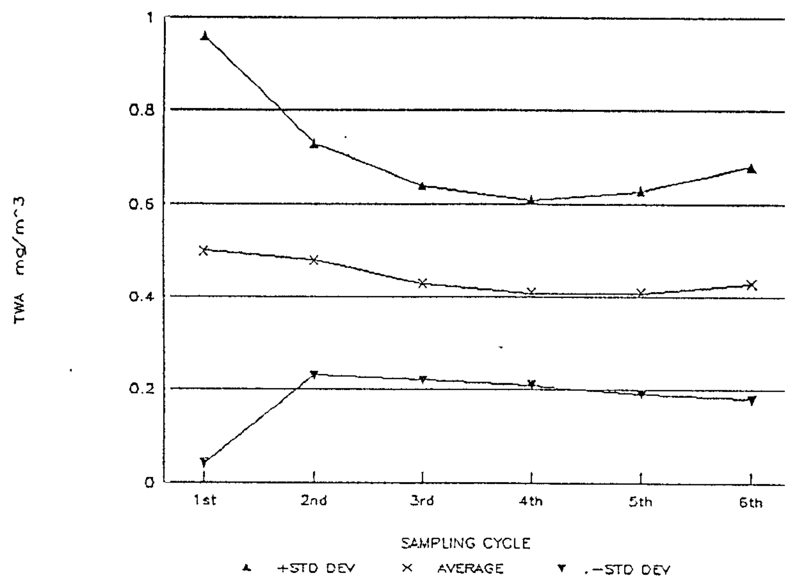

Figure 100 INDUSTRY DUST AVERAGES

Exposure levels in the East and Elsburg regions appear to be similar, as do levels in the Klerksdorp, West Wits and Northern Free State regions. The Southern Free State region apparently has the highest average exposures. However, when comparisons between regions are made, no statistical differences in results obtained for the different regions could be demonstrated and an industry average of 0,4 mg/m^3 is indicated.

8.2.6 Regional and industry quartz concentrations

In a similar fashion regional and industry quartz concentrations, simple and person weighted, were compiled and are set out in Table 30. The graphic interpretations are shown in Figures 101 to 107.

In recognition of the variability of airborne quartz concentration and its unpredictability, Industry requested available data to be examined to determine what single value could be used, representatively, either for each region or for Industry in general. The system of report compilation wherein averages are averaged, with possible compounded errors and masking of high values, precludes any possibility of determining statistical differences in quartz concentrations in the various regions. However, an industry average of 10 to 20 per cent is indicated.

Table 30 SIMPLE ARITHMETICAL AND PERSON WEIGHTED CYCLIC AVERAGE QUARTZ CONCENTRATIONS (EXCLUDING SURFACE RESULTS)

East Simple Ave Per Cent	Std Dev	Weighted Ave Per Cent	Elsburg Simple Ave Per Cent	Std Dev	Weighted Ave Per Cent
15.52	7.98	15.56	14.88	8.50	16.08
15.61	8.00	14.64	14.77	9.05	15.91
9.36	4.65	10.28	14.30	7.48	16.77
10.32	5.99	10.98	14.67	7.62	16.02
11.06	6.72	11.23	15.63	10.73	16.61
8.79	3.93	8.89	13.34	6.37	16.62
Klerksdorp Simple Ave Per Cent	Std Dev	Weighted Ave Per Cent	NOFS Simple Ave Per Cent	Std Dev	Weighted Ave Per Cent
19.23	7.65	18.98	14.22	7.29	14.99
19.37	7.75	19.36	14.20	7.30	15.61
19.46	8.74	19.15	13.22	8.00	15.29
17.68	5.89	18.06	13.30	7.60	15.65
16.12	7.16	16.84	12.90	5.69	13.94
12.89	7.13	13.82	11.69	5.01	12.52
SOFS Simple Ave Per Cent	Std Dev	Weighted Ave Per Cent	W Wits Simple Ave Per Cent	Std Dev	Weighted Ave Per Cent
9.29	3.84	9.31	15.52	20.20	16.80
9.70	3.82	9.72	14.69	9.61	16.60
9.31	3.09	9.69	10.97	6.06	10.96
9.77	6.12	9.30	11.64	6.43	11.98
11.25	5.08	10.50	11.30	6.63	11.94
9.05	6.91	8.36	11.91	8.78	11.85
Total Industry Simple Ave Per Cent	Std Dev	Weighted Ave Per Cent			
15.41	13.36	16.21			
15.22	8.52	16.37			
13.05	7.80	14.37			
12.89	7.14	13.75			
12.87	8.82	13.69			
11.71	6.90	12.42			

In the above two analyses surface data were excluded.

Actual TWA and quartz concentration data for the East, Elsburg, Klerksdorp, North Free State, South Free State and West Wits Regions are appended in Appendix A in Tables 1 to 12 and Figures 1 to 72.

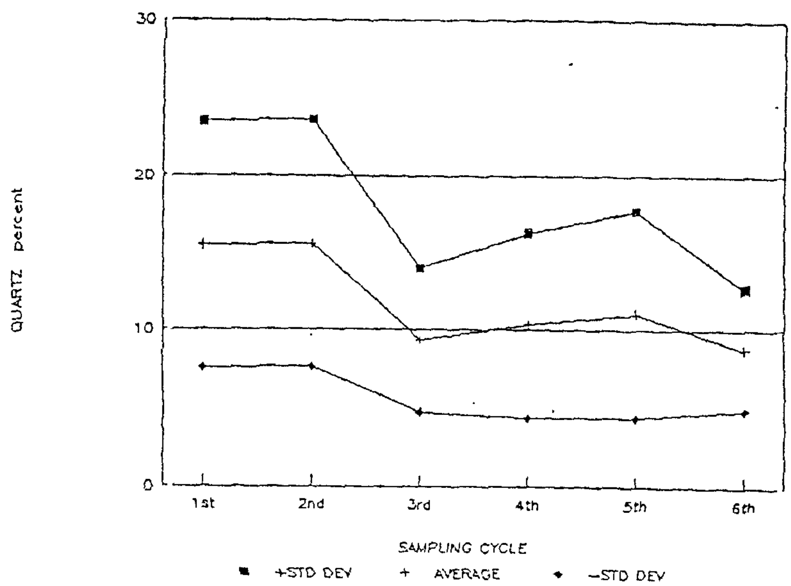

Figure 101 EAST REGION QUARTZ AVERAGES

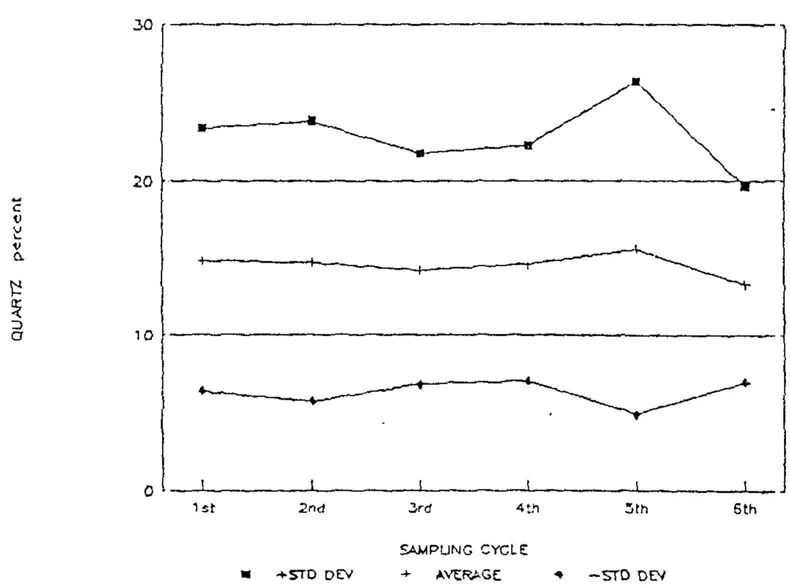

Figure 102 ELSBURG REGION QUARTZ AVERAGES

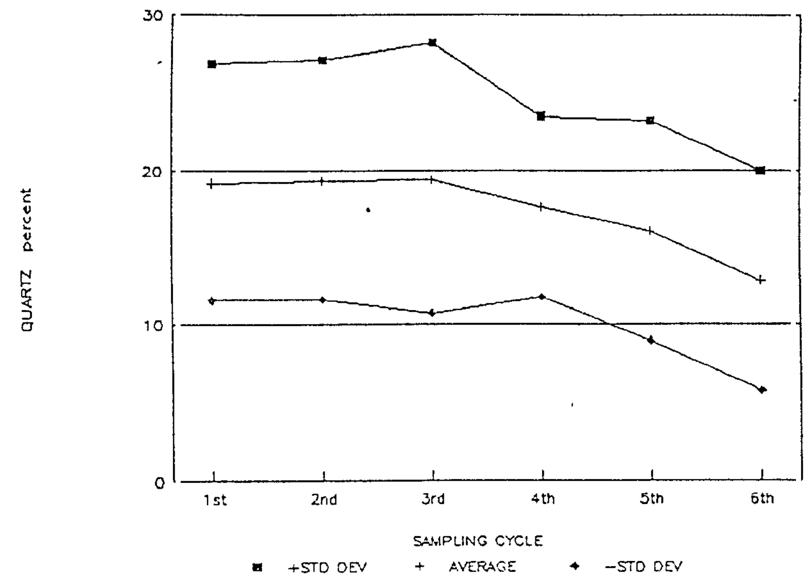

Figure 103 KLERKSDORP REGION QUARTZ AVERAGES

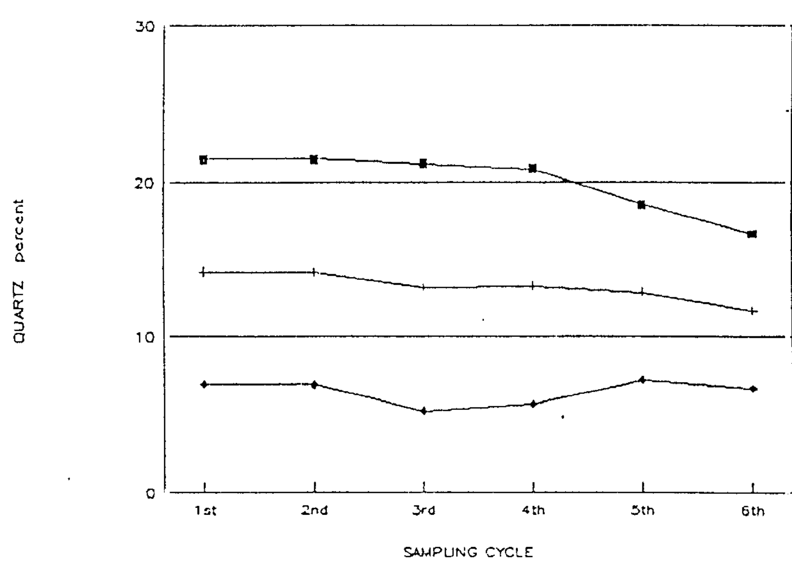

Figure 104 NORTH FREE STATE REGION QUARTZ AVERAGES

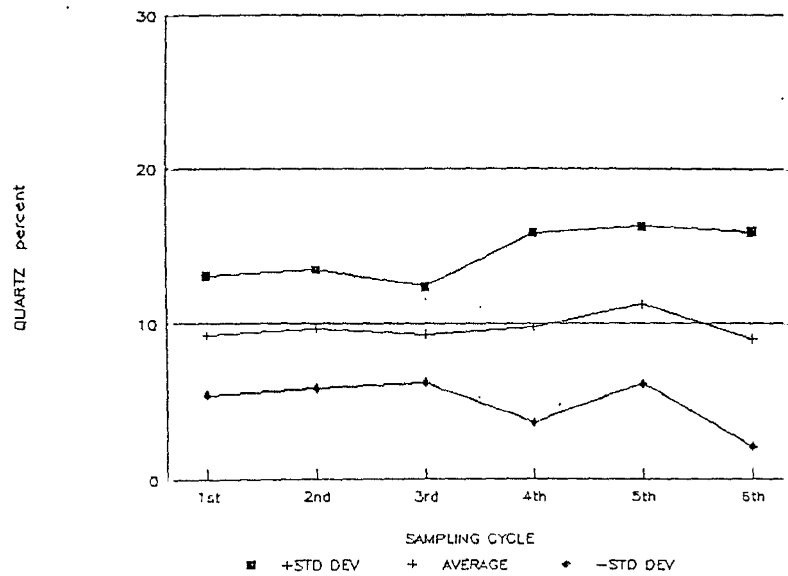

Figure 105 SOUTH FREE STATE REGION QUARTZ AVERAGES

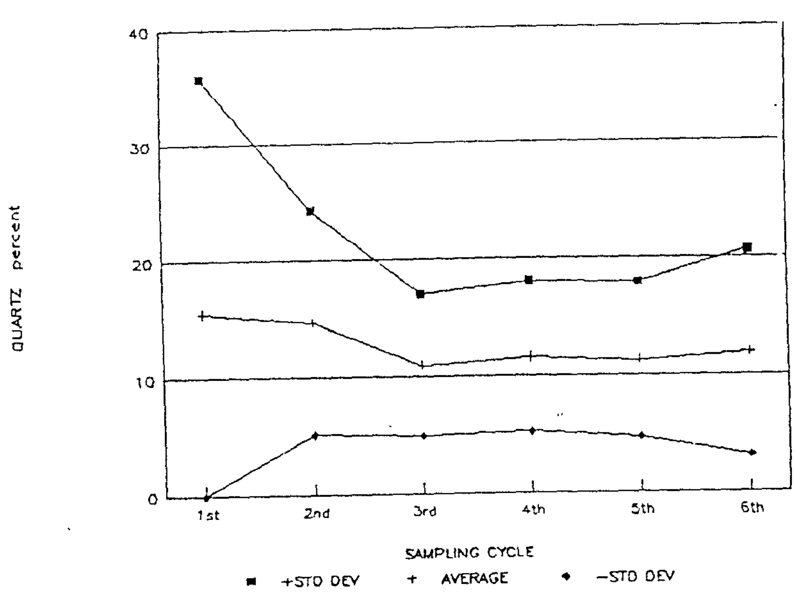

Figure 106 WEST WITS REGION QUARTZ AVERAGES

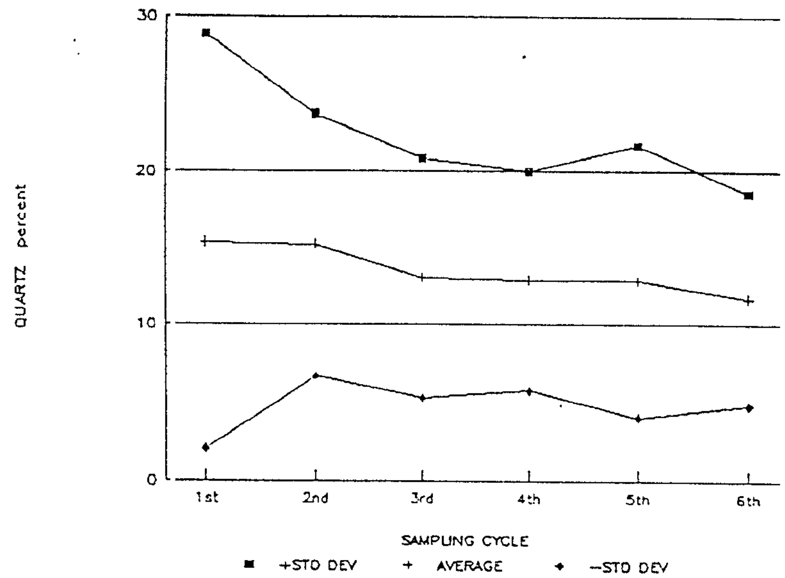

Figure 107 INDUSTRY QUARTZ AVERAGES

9 DISCUSSION

9.1 Results Submitted to the GME

An inspection of the results forwarded to the GME by mines shows not only large variations in dust concentrations from one Statistical Population to another in a given sampling area for a mine, but also large variations in quartz content for these Statistical Populations. Typical examples are shown in Figure 108. In addition, the quartz concentration for a given Statistical Population can also vary from one sampling cycle to the next (Figure 109).

In terms of the GME's guidelines for gravimetric dust sampling it is permissible to combine up to five samples of a Statistical Population for a single analysis. It is also only required to analyse for quartz once a year. The quartz concentrations thus reported are from combined analyses and still display wide variations. For research purposes each individual sample was analysed and typical variations of quartz concentrations for five individual samples are shown in Figure 110. An average value is meaningless with such large variations, and the reporting system is such that the very high individual quartz concentrations will go undetected and the person exposed to the high quartz concentration will not be identified. As reported above quartz concentrations in a working section, not necessarily a Statistical Population, have shown variations from 17 to 98 per cent.

Dust concentrations greater than the mean could be indicative of specific occupations or work places giving rise to high or unsatisfactory dust levels. This has not been investigated in the current report or in the reporting system. Industry statistics tend to mask workplaces and work categories, where attention should be focused for action. There are obviously work categories and workplaces where exposure to dust should be of concern.

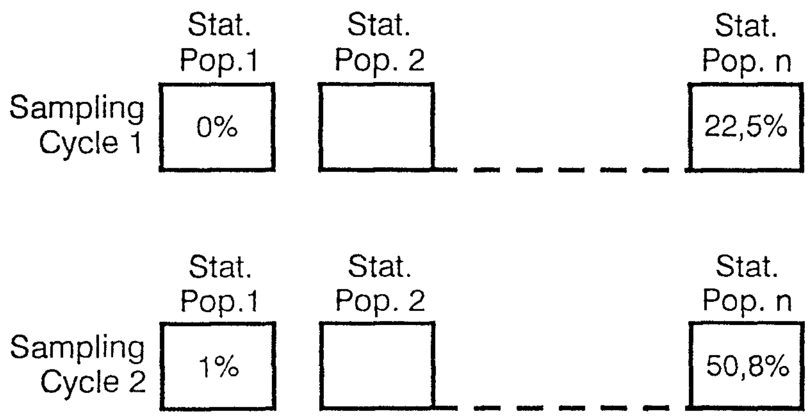

Figure 108 VARIATION IN QUARTZ CONCENTRATION BETWEEN STATISTICAL POPULATIONS

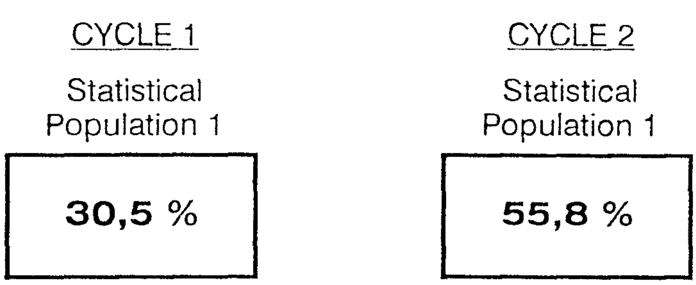

Figure 109 VARIATION IN QUARTZ CONCENTRATION BETWEEN SAMPLING CYCLES

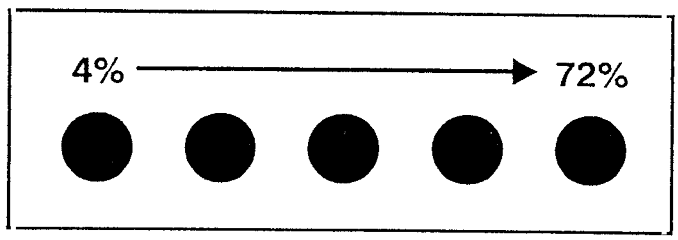

Figure 110 INDIVIDUAL QUARTZ CONCENTRATION IN A STATISTICAL POPULATION

Depicted in Figure 111 are typical ranges in Risk from one Statistical Population to the next for a mine for sampling cycle A and for the next sampling cycle, B, after mass and quartz analyses. These are very large changes, but, because of the permissible averaging system in reporting, personnel exposed to unsatisfactory dust and quartz levels cannot readily be identified, and at best these levels could only be detected at the end of a sampling cycle once quartz analyses have been completed. This system is ineffective in timeously identifying unsatisfactory conditions with a view to implementing controls.

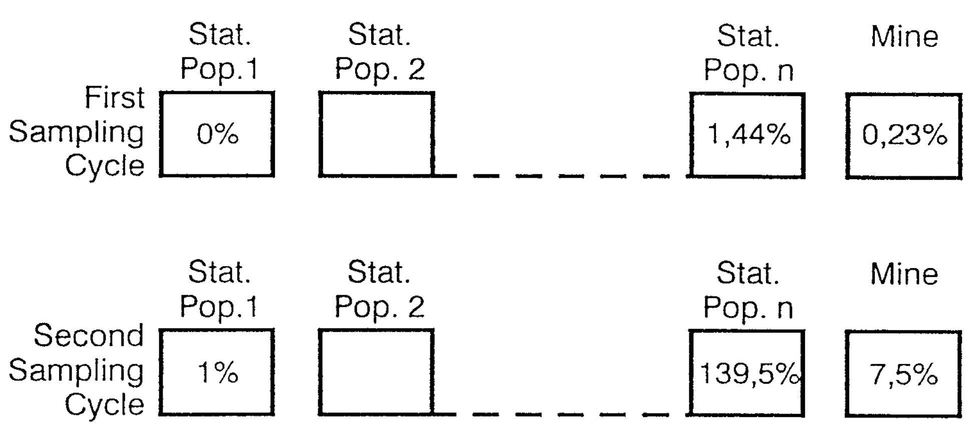

Figure 111 VARIATION IN RISK BETWEEN STATISTICAL POPULATIONS

9.2 Impact of Quartz Content on Risk

Table 31 shows the results of typical returns from a mine.

Table 31 THE INFLUENCE OF QUARTZ CONCENTRATION ON RISK

	TWA mg/m^3	SiO_2 %	AQI	Risk %
Cycle 1	5,0	7,0	3,5	49,0
Cycle 2	1,5	30,0	4,5	81,0

During the first cycle a "high" TWA was reported for a low quartz concentration which resulted in an AQI of 3,5 and a risk of 49 per cent. During the next cycle dust exposure levels had reduced substantially, which should inherently produce better working conditions, but because of a more than 400 per cent increase in quartz content, something which no mine can control, the resulting AQI increased to 4,5 and the risk to 81 per cent. This system of evaluation must be considered to be flawed when airborne dust concentrations have been reduced but a mine is likely to be penalized for a risk based on a factor over which it has no control. Furthermore, in sampling only to produce results for risk calculations, remedial actions are unlikely to be implemented timeously.

9.3 Risk

The way risk is presently defined and assessed does not adequately reflect any measures taken to reduce concentrations of airborne dust, and mines may be penalised for something over which they have no control, namely the quartz content of the airborne dust.

In a recent study[8] the author suggests that attention should be paid to occupational asthma which is defined by the American Lung Association as a disease in which the airways overreact to dusts, vapours, gases or fumes. When these irritants are inhaled, the airway muscles tighten, the tissues swell, and excess mucous is produced, all of which make breathing difficult. It is also suggested that eight-hour TWA exposure limits may not be appropriate for controlling asthma resulting from irritant exposures, as the asthma may be induced by ***transient peak exposures*** rather than by sustained exposure levels[10].

Furthermore, the study points to important evidence of the role that all dusts, not just specific dusts such as silica, play in the causation of occupational disease.

Table 32 THE EFFECT OF QUARTZ CONTENT ON AQI AND RISK AND PROPOSED CHANGES TO RISK EVALUATION

TWA mg/m³	SiO_2 %	PI	PNOC mg/m³	PI PNOC	AQI	RISK
5,0	7	3,5	-	-	3,5	49,0
1,5	30	4,5	-	-	4,5	81,0
PROPOSED CHANGE : INCLUDE PNOC IN ASSESSMENT						
5,0	7	3,5	4,65	0,93	4,43	78,5
1,5	30	4,5	1,05	0,21	4,71	88,7

PI : Pollutant Index (Pollutant Content/Threshold Limit Value)

PNOC : Particles Not Otherwise Classified (Non Respirable Dust)

PI PNOC : Pollutant Index for Non Respirable Dust

The old concept was that there were nuisance dusts that didn't matter too much and therefore they were regarded as harmless as they did not have specific effects like silica or asbestos. However, this concept needs to be re-evaluated. Global exposure, the importance of everything inhaled, not just individual agents, is an important concept to recognize.

In South African mines the present risk calculation does not take into account the non-quartz fractions or Particles Not Otherwise Classified (PNOC).

Table 32 illustrates the impact of including PNOC in the risk calculation. Although the risks for both situations would increase, the disparity between taking PNOC into account, which can be justified as pointed out above, or by totally omitting it (as done at present) is considerably reduced.

This approach would make risk assessment more equitable but the risk would still largely be based on "random" quartz concentrations, which would still be unacceptable.

If diesel soot is to be included in any risk calculation, it could be taken into account by dividing the soot fraction (obtained as described in Part 1) by a TLV. A TLV for soot has not yet been set for South African mines, but in a separate study[7] soot levels were also shown to fluctuate considerably and this may, in turn, exacerbate the evaluation.

9.4 Investigation of Quartz Variations

The anomalies and large variations in dust and quartz levels were reported at a progress meeting and Miningtek was asked to investigate possible reasons for large differences in airborne quartz. This was a deviation from the original research proposal.

Consequently, several working places were visited and rock samples were chipped from the hangingwall, working face and footwall, and, during the in-situ sampling airborne samples were collected. The in-situ samples were pulverized and analysed for quartz and the airborne samples were X-rayed for quartz content. The results are presented in Figure 112. No correlation could be found between in-situ quartz concentrations and airborne quartz concentrations.

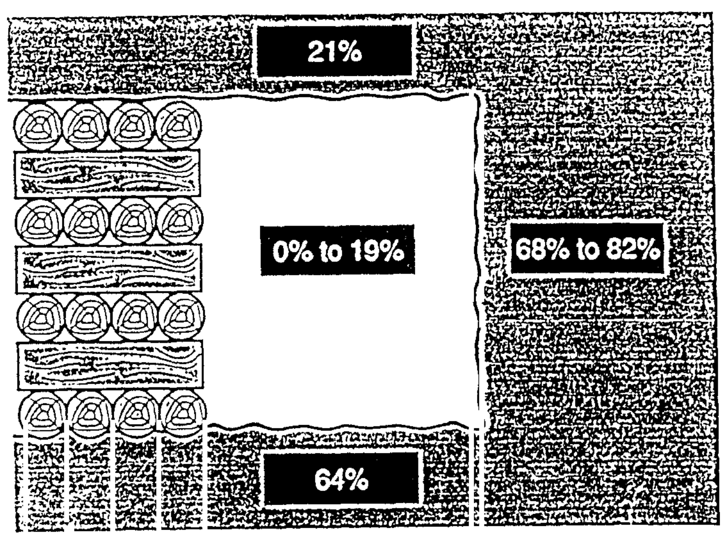

Figure 112 QUARTZ CONTENT : ROCK AND AIRBORNE DUST

9.5 Comparison of Sampling Pumps

Several investigations were carried out with different types of sampling pumps, i.e. Gilian type and rotating sponge type in parallel.

The results of a comparison made between Gilian pumps is shown in Figure 113 where a very good correlation is demonstrated. The results of a controlled test where Gilian pumps sampled in parallel with rotating sponge type pumps is presented in Figure 114. In this field test the rotating sponge pumps consistently undersampled the Gilian pumps. At test site 2 Gilian pumps were routinely operated in parallel with rotating sponge pumps. As is the case with the controlled test the rotating sponge pumps consistently undersampled the Gilian pumps. This is seen in Figure 115.

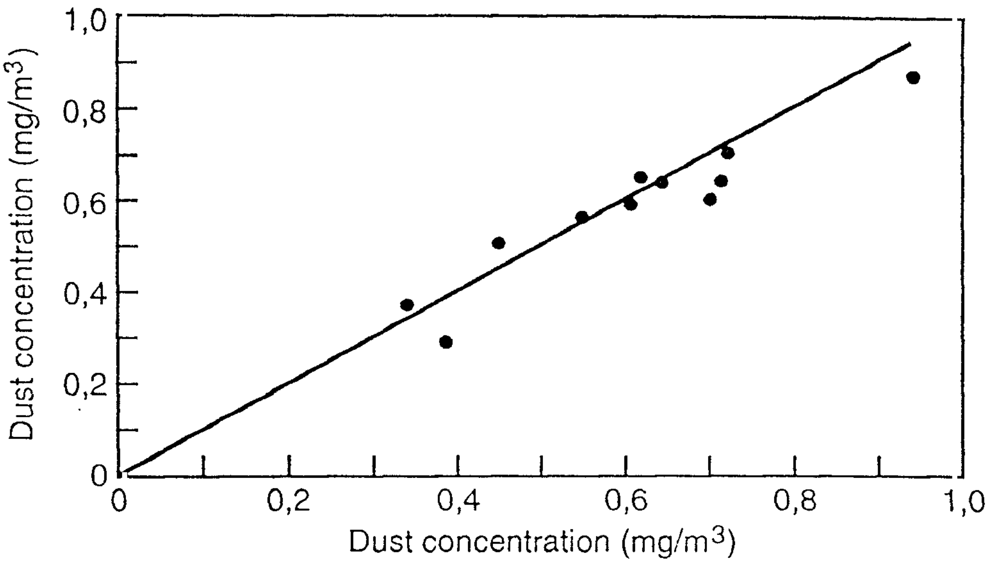

Figure 113 GILIAN VS GILIAN : DUST (mg/m³)

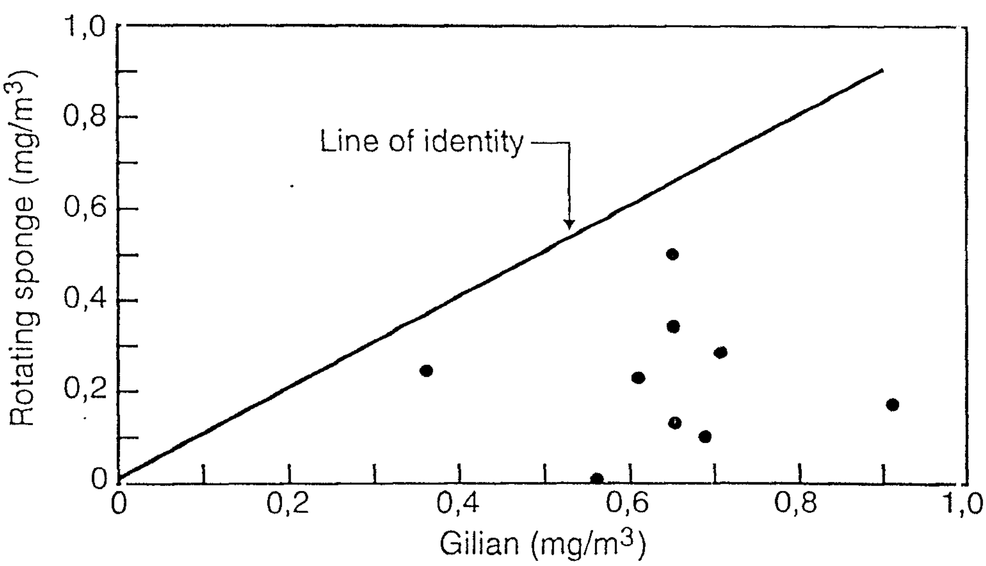

Figure 114 GILIAN VS ROTATING SPONGE : DUST (mg/m³)

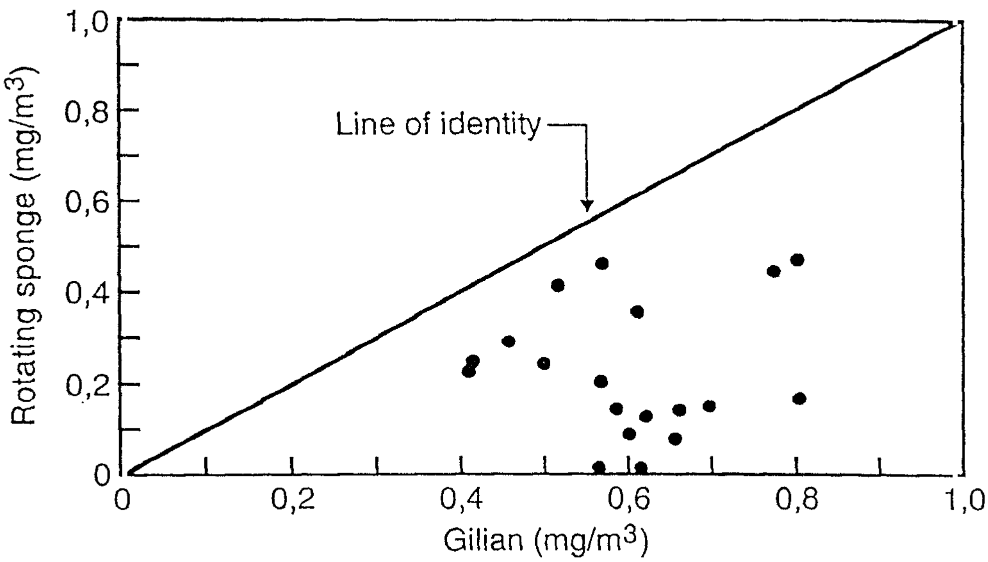

Figure 115 COMPARISON OF GILIAN AND ROTATING SPONGE SAMPLES (ROUTINE MEASUREMENTS)

At the same test site a comparison was made with rotating sponge pumps sampling in parallel and the poor correlation obtained is presented in Figure 116.

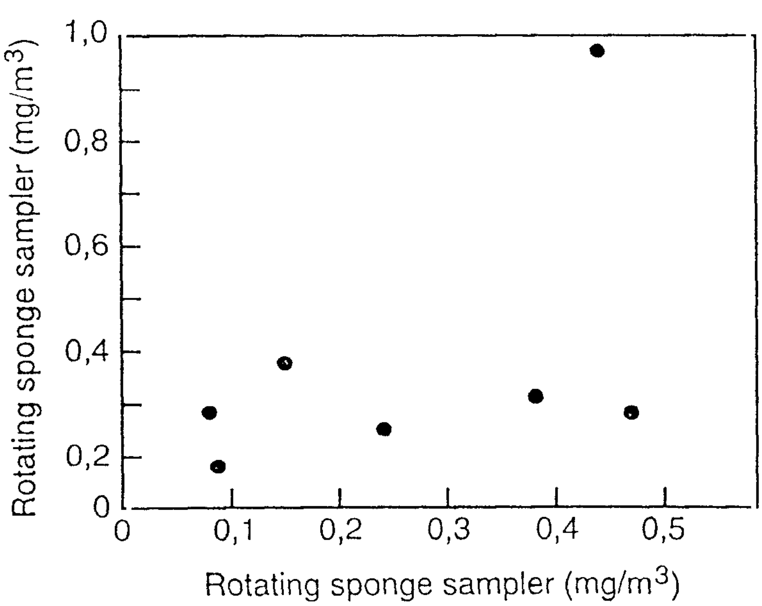

Figure 116 COMPARISON OF ROTATING SPONGE SAMPLERS

9.6 Quartz Concentrations Obtained in Parallel Sampling

Although a good correlation was obtained between dust concentrations for Gilian pumps sampling in parallel, the quartz content of the parallel samples displayed very poor correlation as shown in Figure 117. This result was surprising but has been noted in the literature[8, 9]. In one study[8] 185 samples including 25 paired samples were evaluated. The 25 paired samples had differences of percentage of silica values ranging from less than 0,1 to 19,2. The magnitude of percentage of silica content of samples collected from the same section ranged from differences of 7,5 to 88. The findings in this SIMRAC report are very similar. ***Attention is drawn to the implications of these findings for any tests for adherence to or compliance with pre-set standards.*** No explanations for these anomalies were advanced in the literature nor were any forthcoming as a result of this investigation.

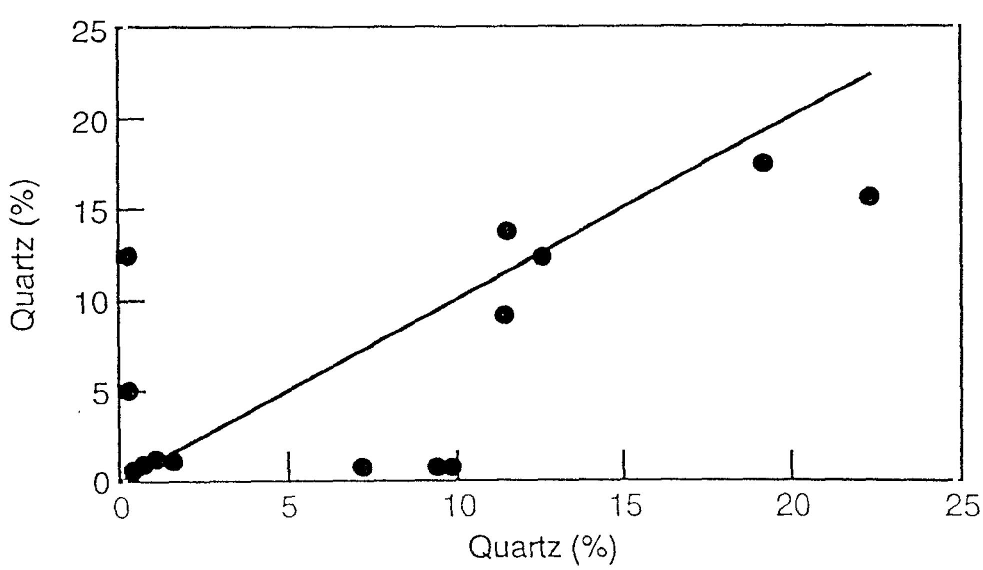

Figure 117 GILIAN VS GILIAN QUARTZ PER CENT

10 CONCLUSIONS AND RECOMMENDATIONS

10.1 The impact of quartz on risk calculation has been shown to be very considerable. The way risk is presently defined and assessed does not adequately reflect any measures taken to reduce airborne concentrations of dust and mines are penalised for something over which they have no control, namely the quartz content of the airborne dust. In risk assessment the non-quartz fraction or Particles Not Otherwise Classified (PNOC) (nuisance dust) is not taken into consideration at all.

Although the risks for both situations would increase the disparity between taking PNOC into account and totally omitting it, as at present, is considerably reduced. This approach could make risk assessment more equitable but it would still largely be being based on "random" quartz concentrations, which would still be unacceptable. The inclusion of diesel soot in a risk formula would introduce another element of uncertainty.

10.2 The present dust sampling programme, sample analysis and reporting system features eight-hour TWA results by "activity" and not by occupation. These results make any study of dose response very difficult, and, furthermore some form of averaging random quartz concentrations is incorporated. Exposure levels are calculated for the time that the sampling pump operates, whether or not the wearer was in dusty conditions, for example, while travelling to and from the working place. This is said to enable a "dose" for the working shift to be calculated. However, it could be argued that the full 24-hour period should be considered to evaluate daily dose. In reality it is the dose at the working place which should be evaluated in order to be able to study a dose-response relationship. The logistics of determining workplace dose has militated against this approach but this matter should be reconsidered for future studies.

10.3 Dust sampling for control purposes is not readily accomplished using gravimetric dust sampling equipment. Presently, the only use to which gravimetric samples are put is to calculate an AQI and then a risk from which a dust levy is then calculated. The flow charts, as set out in Figure 118 show that if this is indeed the main purpose of the present dust sampling effort then this effort can be considerably reduced, as it is not necessary to weigh any filters to determine an AQI. An AQI can be determined from the volume of air sampled and the analytical mass of the quartz in the sample. This technique, which achieves the same objective, completely eliminates all precision weighing of filters before and after field sampling, and could represent considerable savings in terms of labour used to perform these operations. Serious consideration should be given to this approach.

10.4 Results extracted from reports submitted to the GME do not show any significant differences in dust and quartz levels in the six geographical regions investigated. On an industry basis a slight shift is indicated over six sampling cycles that would place a greater working population being exposed to lower concentrations of dust with a lower quartz content. These indicated changes cannot be adequately explained.

It is feasible to abolish all quartz analysis in view of what has been stated in this report, and to use an industry value of 20 per cent. This would be within one standard deviation of the average values reported. Should this be accepted, then a dust concentration of 0,5 mg/m^3 would give an AQI of one (and a risk of four per cent). This approach would also allow an immediate evaluation of dust levels in terms of being satisfactory or not - any dust level in excess of 0,5 mg/m^3 would be unsatisfactory.

A noticeable Industry shift for the stoping and developing category from 0,2-0,4 mg/m^3 to the next range, i.e. 0,4-0,6 mg/m^3, would be moving results towards an Industry AQI of one. When surface dust sampling results are added to the overall analysis of dust exposures for the six sampling cycles the number of persons exposed to dust concentrations in excess of 1,2 mg/m^3 is increased. This means, with an industry quartz concentration of 20 per cent, more persons would be exposed to an AQI in excess of two and on an industry basis this should elicit an investigation.

10.5 If the original data are still available on mines there is the potential to extract information pertaining to occupational dust exposure levels. This could form the basis of a research project that can link with epidemiological studies. The issue of different sampling systems yielding results that could be different would need to be addressed.

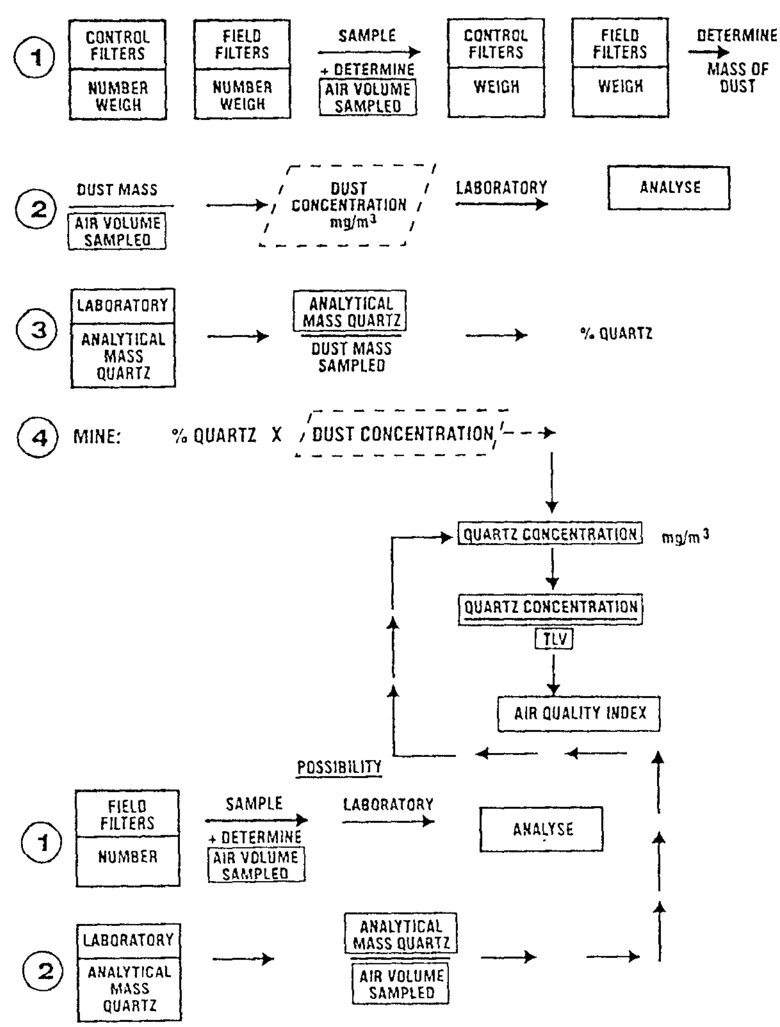

Figure 118 PRESENT AND POSSIBLE TECHNIQUES TO DETERMINE AQI

PART 3

11 TECHNIQUES TO RECOMBINE RESPIRABLE AND NON-RESPIRABLE DUST FOR TOTAL POLLUTANT ASSESSMENT

Analytical techniques for quartz are based on analysing a deposition of particulates in as even a bed as possible. The particulate size should not exceed 10 µm diameter. Analysis of other pollutants is based on "total" sample evaluation, that is the full sample and not only a fraction of the sample.

It was anticipated that the GME would request mines to analyse all airborne pollutants so that future risk could be based on all airborne pollutants. This could have meant that mines could have been faced with double sampling, one set of samples to evaluate quartz and another set of samples, based on total dust sampling techniques as outlined in the guidelines for gravimetric dust sampling, for other airborne pollutants. If a way could be devised to be able to perform quartz and other pollutant analyses from a single sample, mines could save on both effort and cost of collecting the samples. As shown in Part 1 this is already possible for mineral dust and diesel soot (RCD).

Initially, experiments were conducted with small thimbles which fitted inside the catch or grit pots of the Gilian 10 mm diameter cyclones. It was visualised that if these thimbles could be dissolved and redeposited with the respirable dust, by now X-rayed for quartz content, the sample would be made available for further analysis. These thimbles weighed between 125 and 170 mg and the technique for catching the coarse fraction of the dust in a catchpot lining worked well. The major difficulty was that the thimbles were only available in fibreglass, and not cellulose nitrate, and could, therefore, not be cleanly dissolved. In addition, the thimbles had to be cut to the correct size and were difficult to remove from the catchpot. The next development was to flush the contents out of the catchpot into the redepositing distilled water with the respirable fraction of the sample, again after the respirable fraction had been X-rayed for quartz content.

It is necessary to weigh all filters used in the redepositing process to determine how much coarse dust, if any, has been added to the final sample. The total mass of dust is needed to calculate pollutant percentage (if required). Furthermore, it is necessary to weigh three control filters and to pour distilled water through the controls and then, after drying, to reweigh the controls as a check on the cleanliness of the distilled water. Any substantial gain in weight on the controls would invalidate the sample under consideration.

Figure 119 shows the usual, separate sampling techniques for the required analyses but would entail a double sampling requirement, i.e. one sample would have to be collected for respirable dust and a <u>second</u> sample for total dust. Figure 120 shows the proposed technique.

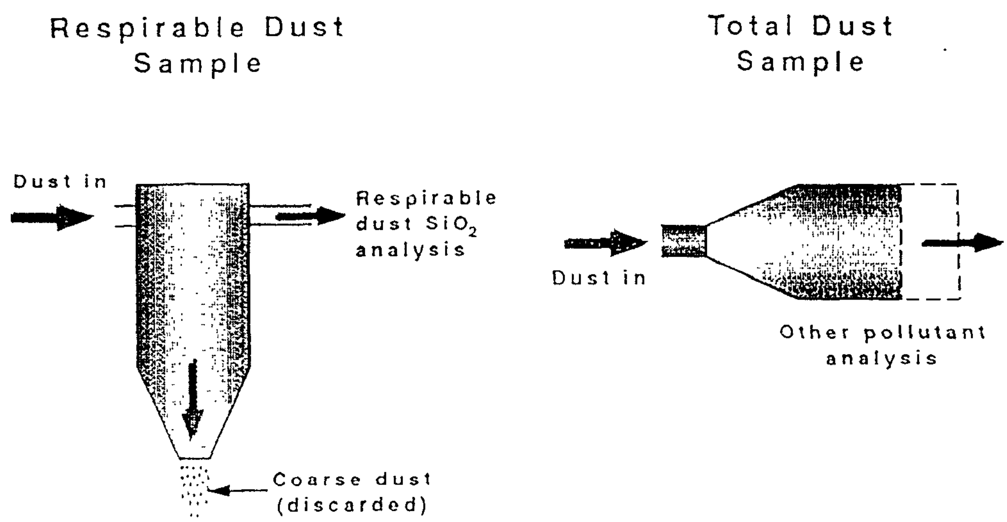

Figure 119 SEPARATE RESPIRABLE AND TOTAL DUST SAMPLING

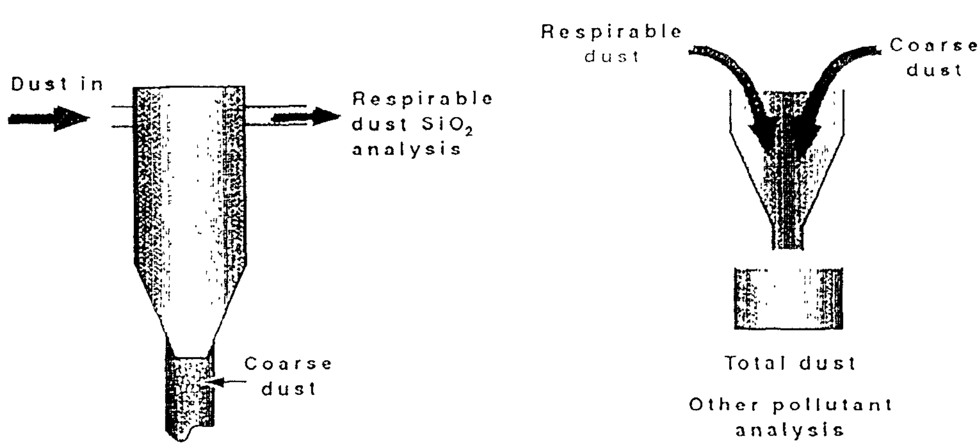

Figure 120 PROPOSED COMBINED RESPIRABLE AND TOTAL DUST SAMPLING TECHNIQUE

Although the proposed technique works for a conventional sampling train, care has to be taken so that the catchpot is not dislodged during the sampling shift and that the sampling train is transported with care to the laboratory. It is also a matter of not only submitting a filter for analysis, but also its relevant catchpot.

This recombination technique is unlikely to work on samples that are analysed with an infra-red technique. Recombination has not been tried with CIP 10 samplers.

During the experimental work carried out in this investigation the possible influence of water soluble salts and carbon particulates on quartz concentrations was examined. Although these contaminants do not affect the quartz scan,* and therefore the analytical mass of the quartz, their presence can result in an incorrect percent quartz being reported.

In the redeposition technique practised by CSIR/Miningtek, the filters, with the samples deposited on them, are dissolved in acetone, the residue ashed, and then washed in triple distilled water. The ashing and washing processes would get rid of carbon particles and water borne salts. This treatment is similar to that to which konimeter slides were subjected in order to ensure that only the mineral dust of the samples was evaluated.

It is clear that if percent quartz is reported in terms of all particulates captured in the filter medium, considerable errors could arise. This could have affected the results reported in Part 2, and, in fact, true quartz levels could be significantly higher. However, since the present quartz is only used for re-determining the analytical mass of this quartz to enable calculations of AQI and Risk to be done the determination of AQI and Risk would not have been affected.

* The presence of large amounts of diesel soot do, however, affect the results and must be taken into account.

PART 4

12 EXPOSURE AND ENGINEERING CONTROL MONITORING

12.1 Description

An eight-hour sample or a sample collected over several hours, although it collects dust when high levels are generated, cannot indicate adverse conditions once the total dust load is divided by the air volume sampled because the high level, which may be of relative short duration, is being averaged with the rest of the sample.

Konimeter sampling was of very short duration, approximately 0,2 seconds, and very useful in indicating high concentrations of dust, but could hardly be regarded as providing reliable data on full shift exposures and could not, of course, be analysed for quartz content. It was also a criticism of the Leon Report[1] that high dust levels were not being identified and subsequently being investigated. This part of the project was aimed at testing the feasibility of worker exposure monitoring and engineering control monitoring, using equipment already in use on the mines.

It was realised that for reporting on workplace conditions and control purposes a short duration sample was needed. Because it was anticipated that the dust mass collected over a period of about 10-15 minutes would be low, giving a very unfavourable dust mass/filter mass ratio, a 13 mm cellulose nitrate filter size was selected for a trial series.

A typical trace of dust concentration with time from a tyndallometer (aerosol monitor) would look like the trace presented in Figure 121. The eight hour average dust concentration, including the high level of 20 mg/m^3 which lasted for 10 minutes, was 0,7 mg/m^3 and did not give any hint of any unsatisfactory condition during the shift.

Shown in Figure 122 are the possibilities when making use of short duration samples.

For example:

- Mode 1 shows the conventional eight hour average dust concentration,
- Mode 2 shows the result if the 10 minute sample was collected only during the peak dust level,
- Mode 3 indicates the result that would be obtained if only half of the peak dust level had been sampled; the 10-minute average would exceed the eight-hour average considerably and alert those in charge to a need for action,

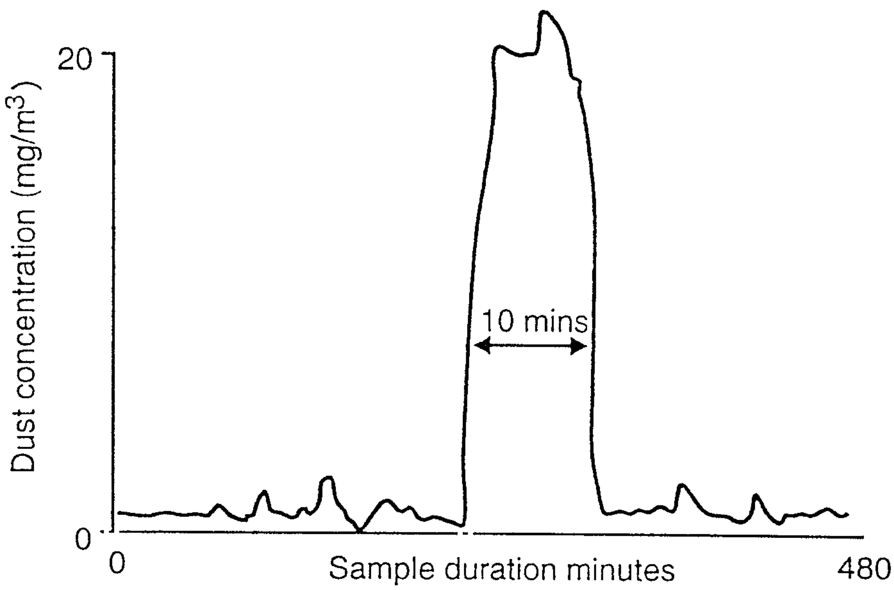

Figure 121 CONTINUOUS DUST LEVEL TRACE

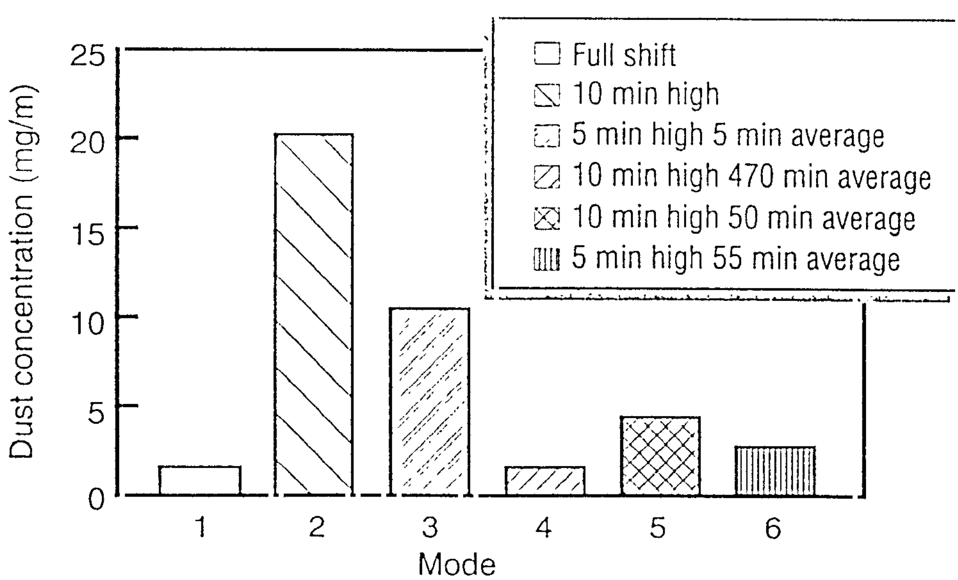

Figure 122 COMPARISON OF SAMPLING TECHNIQUES AND REGISTERING OF HIGH DUST LEVELS

- Mode 4 is again, effectively, the result of the eight-hour sampling; instead of a 10 minute sampling period a 60 minute sampling period could be considered.

- Mode 5 shows the effect of sampling the peak dust and 50 minutes of the average dust, the result would again indicate a need for action when compared with the eight hour result, and

- Mode 6 shows the result of sampling only five minutes of the peak dust, yet again the result would indicate the need for action. It is, of course possible, that even with short duration sampling the peak dust levels could be missed entirely.

The desirability of evaluating transient peak dust levels has also been discussed in section 3.9.

12.2 Preliminary Results

Two underground trials were held using the short duration technique. The first short duration samples were collected over 10-12-minute intervals. After each sample was collected an unused cassette was fitted to the pump. Samples were collected over the period that the environmental officer made all his other observations, e.g. temperature, air velocity, etc. In addition, a standard sampling train was started as the stope was entered and stopped when the stope was exited. The duration of the sample was 69 minutes. An eight-hour personal sample was also collected for comparison of results. The results of this exercise are depicted in Figure 123.

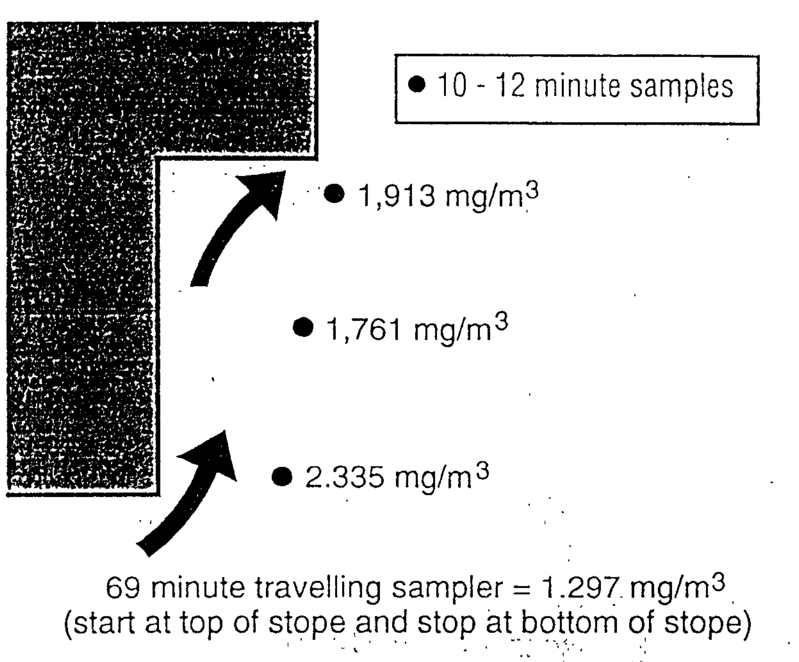

Figure 123 DUST LEVELS FOUND FOR SHORT DURATION SAMPLING (1)

It is obvious that the short duration samples are able to indicate places of concern with respect to dust levels. The 69-minute travelling sampler yielded a result almost twice as large as the eight-hour personal sampler, i.e. 1,3 mg/m³ compared to 0,7 mg/m³.

A second trial was held at another mine and additional measurements were made. In addition to the travelling sampler (this time 121 minutes), a conventional sampling pump was used by starting and stopping it with the short duration pump but not changing cassettes. Thus, the dust collected at the environmental monitoring stations was deposited on a single filter and gave an integrated sample. This gave a much higher result than the continuously operated pump, and although it compares well with the short duration samples, it does not give detail. A Hund tyndallometer was also used and two full shift samples were collected, one with a Gilian pump and the other with a CIP 10 pump worn by the same person. All the results are shown in Figure 124.

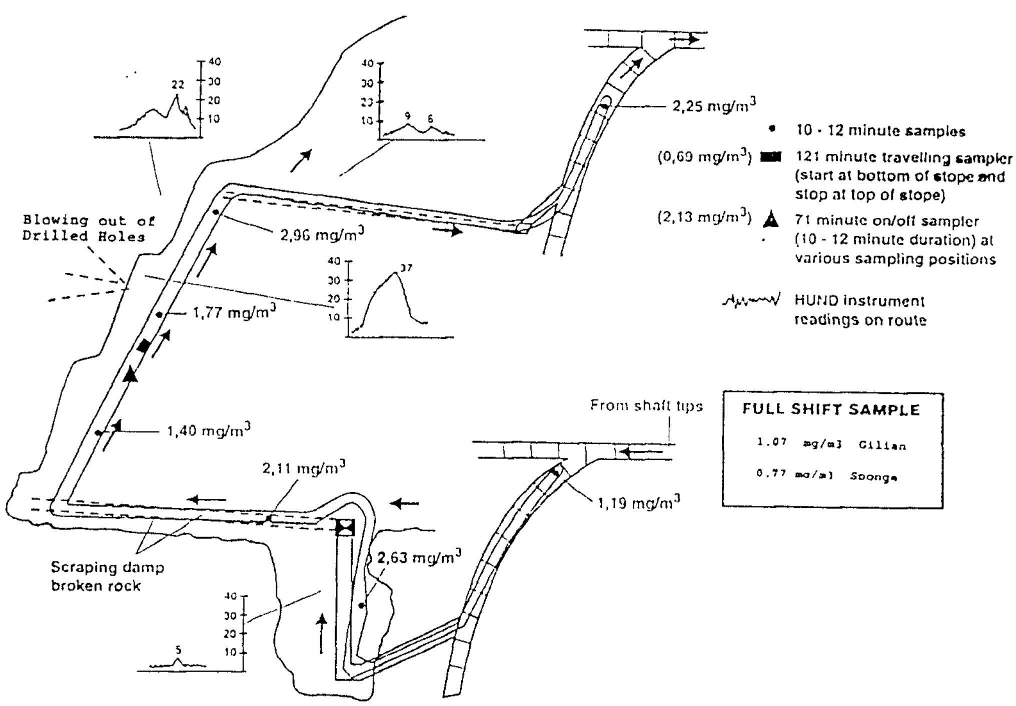

Figure 124 DUST LEVELS FOUND FOR SHORT DURATION SAMPLING (2)

12.3 Discussion

At both test sites the short duration samples returned results higher than the eight-hour or full shift sampling results. This illustrates the potential to assist in identifying localities and operations where unsatisfactory dust conditions may exist.

Whilst useful in providing a dust level "index" for a working place, the continuous workplace sample (± 121 minutes) is unlikely to be of assistance in pinpointing either unsatisfactory working conditions or "dusty" operations. The stop/start sample gave a value which more closely approximated dust levels found with the short duration samples but would also not be useful for isolating either unsatisfactory work environments or practices.

The tyndallometer (Hund), which gives real-time readings of aerosol levels, could be used with effect to locate high aerosol levels without being able to indicate actual dust concentrations. Elevated dust levels, as found with the short-duration samples, correlated with elevated aerosol concentrations. However, this may not always be the case.

As can be seen from Figure 124 the full shift samples gave no indication of high dust levels caused by specific mining operations.

12.4 Conclusions

Of the methods checked, the greatest detail was provided by the short term samplers and the tyndallometer.

The full shift samplers give no indication of any abnormalities and would not be of any use for engineering control purposes.

The method is very promising and can address the problem of locating and identifying areas with unsatisfactory dust levels.

The method is being further investigated in a 1996 SIMRAC project.

13 OVERALL CONCLUSIONS AND RECOMMENDATIONS

13.1 Recombination of Respirable and Coarse Fractions of Dust for Complete Analysis

After X-ray analysis of a conventional sample, i.e. dust collected on a filter, it was found that the coarse fractions can be recombined with the respirable fraction by redepositing both fractions on a second filter. The combined sample is then available for further analysis of additional airborne pollutants.

This technique cannot be used with samples collected on a rotating sponge filter, nor is it possible with infrared analysis because the original filter paper is destroyed in the preparation of the necessary wafer. Where pollutants other than quartz have to be assayed in addition to quartz, this technique offers cost savings in that only one sample needs to be collected for complete analysis, as opposed to a respirable sample for quartz analysis and a total dust sample for other airborne pollutants.

As, and when, the Government Mining Engineer (GME) requires analyses of other pollutants in addition to quartz, this technique can be used. It is already feasible to analyse for diesel soot and mineral dust, and thereafter the quartz fraction of the mineral dust, on a single conventional filter. Hence, multiple analyses from a single filter is already possible and the technique discussed in this report can be adopted.

13.2 Investigation of the Possibility of Replacing 'Personal Sampling' with Stationary, Area or Representative Place Sampling

Field investigations were conducted at three underground test sites and one assay/sample preparation laboratory, which was repeated after several months. Dust samples were collected over full shifts at stationary samplers at main returns and/or representative places simultaneously with samples collected on roving (personal) samplers. It was found that no correlation could be seen between stationary samplers placed at different positions, i.e. main returns or representative places, between stationary samplers and roving samplers, or between roving samplers. This latter result was expected because dust samples collected for different occupations have been shown to differ.

This lack of correlation, as outlined above, has been demonstrated for dust levels, quartz concentrations, Air Quality Indexes and "risk", and was common to all the test sites. Only two exceptions were found at two different test sites and for different parameters.

Dust levels, quartz concentrations, AQIs and risk have been found to vary from day to day and even from shift to shift for samples collected at the same site or at the same person. Furthermore, dust levels, quartz concentrations, AQI and risk were found to vary from Statistical Population to Statistical Population and from one dust sampling cycle to the next. Moreover, very large ranges in quartz concentrations (4-72 per cent) were found for individual dust samples of a Statistical Population, and a range of 17 to 98 per cent was found for dust samples in a single working section.

No correlation could be found at any position at any test site between dust concentration and quartz concentration.

It is also clear from the investigation that any results obtained could depend largely on the day and the shift when the samples were collected[9]. Because of the very considerable impact that quartz concentrations bring to bear on the calculation of risk additional investigations were conducted to try to establish any possible reasons for the large variations in quartz concentrations found for airborne dust. The matter was not resolved and has not been resolved in overseas countries undertaking similar investigations.

It can be clearly concluded that on the evidence acquired at the four test sites, personal sampling cannot be replaced by area sampling. In essence, it would not be possible to reduce the sampling effort required by mines and still achieve the same personal sampling results.

13.3 Assessment of Data from the GME's Sampling Programme on Gold Mines

Mines were divided into six geographical regions, namely East (Eastern Transvaal), Elsburg, Klerksdorp, North Free State, South Free State and West Wits. Reports of half-yearly results for the period January 1992 to June 1994 were analysed. Results were further classified into underground stopes and development, underground roving, and surface.

No significant differences were found in either dust levels or quartz concentrations between the three activity classifications or between the regions.

As pointed out in Part 3, unless carbon particles and water borne contaminants are taken into account, then quartz concentrations could be in error. On an industry basis airborne quartz levels reported could thus inadvertently have been too low.

The industry eight-hour TWA dust concentration was found to lie in the range 0,2 to 0,4 mg/m^3 and the quartz concentration in the range 10 to 20 per cent. It is recommended that an Industry figure of 20 per cent for quartz should be used when evaluating exposures. In this case a dust concentration of 0,5 mg/m^3 would have an AQI of one. The adoption of this procedure would simplify the evaluation of working place conditions for engineering control purposes, as well as provide management with information with regard to likely worker exposure levels with a minimum of delay, since the dust samples would not need to be analysed for quartz content. Also, Air Quality Indexes, based on eight-hour TWA exposures and "fixed" quartz concentrations, can be used to gauge worker exposure with minimal delays. Routine analyses for quartz concentration no longer needs to be carried out. Nevertheless, there may still be occasions when the analysis of a sample may be required, for whatever reason, and this can then be done.

If the original records are still available on mines there is the potential to extract information with respect to occupational dust exposures. This could be the basis of a research project that could be linked to epidemiological studies. The considerable volume of data, used only to calculate levies, could, in this way, be put to more meaningful use.

13.4 Recommendations for a more Equitable Risk Formula

From research work conducted and reports to the GME it is obvious that the present risk formula is not equitable and does not reflect steps taken to reduce dust levels.

The formula would become more equitable if all dusts are incorporated into its evaluation. However, because of the highly variable dust and quartz levels, risk assessment is being based on very random variables. The position would be exacerbated by the inclusion of more and more pollutants, such as diesel soot, etc.

It is recommended that risk assessment for levy purposes through the GME's dust sampling programme should be discontinued and that levies, which are to pay compensation for past events, should be based on other criteria formulated by the Commissioner of Compensation.

13.5 The GME's Dust Sampling Programme

Dust sampling is undertaken by mines to determine a risk for levy purposes. Dust sampling for control purposes using gravimetric dust sampling equipment is rarely undertaken. Mines prefer to use konimeters for control sampling, if at all.

The results of the dust samples collected for the GME reports are not used by mines nor can they be used to tie in with medical surveillance. In general, from results submitted to the GME it would be difficult to trace an individual sample or locate an individual working place where an unsatisfactory dust sample was recorded. With a time lapse of several months possible before submission of results to the GME any meaningful official action for an unsatisfactory dust sample is also not possible. Furthermore, persons may have left their employment or working places closed down. This type of sampling strategy has thus been found to provide little use in locating or controlling unsatisfactory dust conditions in work places. Therefore, there seems to be little purpose in continuing with the sampling programme. If levies can be determined, as recommended in Section 13.4, then mines should be permitted to sample dust for control purposes by whatever means is found to be acceptable and useful until research can point the way to an enhanced technique. Mines should, however, assist with occupational dust sampling, which would be for research purposes, and not for the determination of a levy. In such a sampling programme all pollutants sampled would be used to gauge relative and total toxicity. This is in keeping with a recommendation in the literature.

13.6 Exposure Monitoring and Monitoring for Dust Control Purposes

Initial trials have indicated the feasibility of gravimetric dust sampling with small diameter filters for short time periods to evaluate working conditions and to determine if control measures are necessary. These samples can be used to check on effectiveness of controls. It can be assumed that if techniques are made available to monitor the control of dust emissions so that dust can be brought under control then exposure levels will also be controlled. However, there is still a delay in obtaining the mass of dust on the filters for evaluation of the samples and the need for a direct reading instrument that can exclude all unwanted aerosols such as water vapour and oil mist is indicated.

There is, nevertheless, a need for occupational sampling on an industry basis in which dust levels (all dusts) and the toxicity of the dusts is evaluated for risk of a particular occupation group. These data can then gainfully be integrated with medical surveillance to investigate dose response relationships.

Occupational dust sampling and short duration sampling for engineering control purposes are the subject of another research project (SIMRAC 1996).

14 REFERENCES

1. Commission of Enquiry into Safety and Health in the Mining Industry. Report - Volume 1 (1995).

2. Guidelines for gravimetric dust sampling. Department of Mineral and Energy Affairs. November 1992.

3. Method Development for the Gravimetric Determination of Respirable Combustible Dust (RCD) in Air. Rex, D A and Gardiner, L R. Chamber of Mines Research Organization, Project No. GE2P, March 1989. Internal Report No. 580.

4. Exposure Variability in the Workplace : Its implications for the Assessment of Compliance. Eltjo Buringh, Roel Lanting. Am Ind. Hyg. Assoc. J. (52), January 1991, pp 6-13.

5. Elementary Statistics. Elizabeth Harris in Environmental Engineering in South African Mines. The Mine Ventilation Society of South Africa. Cape and Transvaal Printers 1982, pp 819-846.

6. The Changing Face of Respiratory Illness. Stephen G Minter. Occupational Hazards, February 1995, pp 43-44.

7. SIMRAC Final Project Report : Control of Diesel Exhaust Emissions in Underground Workings. Test Results from Exposure Measurements in South African Mines. Haase, H. And Unsted, A D. Project GEN 010, March 1995.

8. Regulatory Implications of Airborne Respirable Free Silica Variability in Underground Coal Mines. Jacqueline M Villnave, Morton Corn, Marcie Francis, Thomas A Hall. AM Ind. Hyg. Assoc. J. (52)/March 1991, pp 107-112.

9. Respirable Dust and Free Silica Variability in Mine Environments. Thomas A Hall, Morton Corn, S Zeger, CC Law. Strategies for Mine Dust Measurement, pp 1151-1159.

10. Untersuchungen zur Ausspülbarkeit von Makrophagen. Rehn, B, Zou, Tong-Tong, Hobusch, G and Bruch, J. Ergebnisse von Untersuchungen auf dem Gebiet der Staub-Silikosebekämpfung im Steinkohlenbergau. BAND 17. Arbeitsgemeinschaft Staub-und Silikosebekämpfung. 1989.

APPENDIX A

TWA AND QUARTZ CONCENTRATION DATA EXTRACTED FROM REPORTS SUBMITTED BY MINES TO THE GOVERNMENT MINING ENGINEER FOR THE EAST, ELSBURG, KLERKSDORP, NORTH FREE STATE, SOUTH FREE STATE AND WEST WITS REGIONS.

TABLE 1 EAST STOPING AND DEVELOPMENT POPULATION TWA DISTRIBUTIONS

Dust Conc.	Persons	Persons	Persons	Persons	Persons	Persons
Grouping (mg/m^3)	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6
0-0,2	1233	738	1126	662	1799	1273
0,2-0,4	1373	2066	3191	2448	2665	2945
0,4-0,6	2451	3402	3317	3085	2280	1281
0,6-0.8	1309	810	1126	601	600	36
0,8-1,0		610	60	281	258	52
1,0-1,2			50	271		140
>1,2						

EAST UNDERGROUND ROVING POPULATION TWA DISTRIBUTIONS

Dust Conc.	Persons	Persons	Persons	Persons	Persons	Persons
Grouping (mg/m^3)	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6
0-0,2	807	911	470	284	436	479
0,2-0,4	3236	2754	3126	2707	4074	2375
0,4-0,6	2159	1312	2089	2918	1138	941
0,6-0,8	300	2296	963	1272	394	1541
0,8-1,0	420	222		534	152	519
1,0-1,2	173	332	55	304	223	272
>1,2	160	247			55	124

EAST SURFACE POPULATION TWA DISTRIBUTIONS

Dust Conc.	Persons	Persons	Persons	Persons	Persons	Persons
Grouping (mg/m^3)	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6
0-0,2	189	256	114	241	470	8
0,2-0,4	250	216	385	515	296	546
0,4-0,6	270	47	265	151	317	1315
0,6-0,8	182	334	280	268	307	568
0,8-1,0	293	618			239	
1,0-1,2	40	48	228			
>1,2	218		57	57		303

TABLE 2 EAST STOPING AND DEVELOPMENT POPULATION QUARTZ DISTRIBUTION						
Quartz	Persons	Persons	Persons	Persons	Persons	Persons
Grouping (%)	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6
0-5	0	0	384	608	1321	1405
5-10	711	646	4396	3613	2163	2318
10-15	1954	2599	2381	1424	2114	1078
15-20	2464	3130	437	685	1229	1117
20-25	1183	1215	769	621	382	52
25-30	0	0	503	272	268	0
30-35	54	36	0	0	0	0
35-40	0	0	0	125	125	0
>40	0	0	0	0	0	0

EAST UNDERGROUND ROVING POPULATION QUARTZ DISTRIBUTION						
Quartz	Persons	Persons	Persons	Persons	Persons	Persons
Grouping (%)	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6
0-5	311	314	1413	2575	2280	1671
5-10	1713	2080	2373	2331	1869	3046
10-15	1586	1781	1336	1816	1277	1386
15-20	183	2327	234	783	619	108
20-25	538	562		132	132	
25-30	464	581	259	130	130	
30-35	153	28				
35-40				165	165	
>40	242	296				

EAST SURFACE POPULATION QUARTZ DISTRIBUTION						
Quartz	Persons	Persons	Persons	Persons	Persons	Persons
Grouping (%)	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6
0-5	438	566	462	428	626	543
5-10	65	64	501	537	90	1961
10-15	423	358	339	150	317	236
15-20	358	381	17	17	216	
20-25		150			103	
25-30	158			100	237	
30-35						
35-40						
>40						

TABLE 3 ELSBURG STOPING AND DEVELOPMENT POPULATION TWA DISTRIBUTION

Dust Conc.	Persons	Persons	Persons	Persons	Persons	Persons
Grouping (mg/m^3)	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6
0-0,2	87	167	196	127	603	
0,2-0,4	1692	148	195	1642	1586	
0,4-0,6	4273	2131	2675	2655	2676	
0,6-0.8	2284	3641	2294	4696	1909	
0,8-1,0	1227	1033	706	101	216	
1,0-1,2	206			130		
>1,2	373					

ELSBURG UNDERGROUND ROVING POPULATION TWA DISTRIBUTION

Dust Conc.	Persons	Persons	Persons	Persons	Persons	Persons
Grouping (mg/m^3)	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6
0-0,2	183	245	346	648	1025	65
0,2-0,4	860	536	665	1105	169	824
0,4-0,6	791	389	119	142	199	241
0,6-0,8	157		129		66	286
0,8-1,0		8	8			66
1,0-1,2				127	130	
>1,2				7	7	133

ELSBURG SURFACE POPULATION TWA DISTRIBUTION

Dust Conc.	Persons	Persons	Persons	Persons	Persons	Persons
Grouping (mg/m^3)	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6
0-0,2	183	245	346	648	1025	65
0,2-0,4	860	536	665	1105	169	824
0,4-0,6	791	389	119	142	199	241
0,6-0,8	157		129		66	286
0,8-1,0		8	8			66
1,0-1,2				127	130	
>1,2				7	7	133

TABLE 4 ELSBURG STOPING AND DEVELOPMENT POPULATION QUARTZ DISTRIBUTION

Quartz Grouping (%)	Persons Cycle 1	Persons Cycle 2	Persons Cycle 3	Persons Cycle 4	Persons Cycle 5	Persons Cycle 6
0-5	1008	659	92	127	131	
5-10	1072	230	689	734	232	219
10-15	2331	1907	700	1006	509	1349
15-20	3082	2241	3465	4523	2255	2065
20-25	1577	1275	1055	1712	2568	1692
25-30				1033		
30-35	1072	184	67	216	1148	932
35-40						
>40					147	

ELSBURG UNDERGROUND ROVING POPULATION QUARTZ DISTRIBUTION

Quartz Grouping (%)	Persons Cycle 1	Persons Cycle 2	Persons Cycle 3	Persons Cycle 4	Persons Cycle 5	Persons Cycle 6
0-5	98	499	94	553	479	516
5-10	1046	1489	150	1013	1326	2087
10-15	1388	1957	1005	2580	736	1437
15-20	725	1915	235	1271	4456	4850
20-25	363	653	631		925	593
25-30	431	367		610		135
30-35		916				
35-40	233	240				
>40						

ELSBURG SURFACE POPULATION QUARTZ DISTRIBUTION

Quartz Grouping (%)	Persons Cycle 1	Persons Cycle 2	Persons Cycle 3	Persons Cycle 4	Persons Cycle 5	Persons Cycle 6
0-5	254	182	492	734	381	426
5-10	599	324	110	215	290	291
10-15	87	94			650	357
15-20	312	66	178	514		275
20-25	462	390	87	78	130	
25-30	100		160	234	145	
30-35			240	242		126
35-40	9			10		140
>40	168	181				

TABLE 5 KLERKSDORP STOPING AND DEVELOPMENT POPULATION TWA DISTRIBUTION

Dust Conc.	Persons	Persons	Persons	Persons	Persons	Persons
Grouping (mg/m³)	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6
0-0,2		114			224	1184
0,2-0,4	1065	713	3929	4052	2754	7483
0,4-0,6	5578	8656	10919	7182	16125	15224
0,6-0.8	8789	9681	6428	2614	4084	1342
0,8-1,0	5465	3762	1680	922	959	122
1,0-1,2	351	1336	1460	508	249	813
>1,2	1500		435		806	

KLERKSDORP UNDERGROUND ROVING POPULATION TWA DISTRIBUTION

Dust Conc.	Persons	Persons	Persons	Persons	Persons	Persons
Grouping (mg/m³)	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6
0-0,2	509	13	715	197	1369	1946
0,2-0,4	6768	6867	7666	6817	8135	13299
0,4-0,6	7911	9740	11390	5314	8891	7784
0,6-0,8	5070	4281	1189	1517	1617	843
0,8-1,0	1532	887	854	325	3085	
1,0-1,2	1469	688			631	8
>1,2	547	69			178	

KLERKSDORP SURFACE POPULATION TWA DISTRIBUTION

Dust Conc.	Persons	Persons	Persons	Persons	Persons	Persons
Grouping (mg/m³)	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6
0-0,2	485	524	58	212	494	232
0,2-0,4	952	1280	1827	746	2702	2131
0,4-0,6	1728	611	1602	890	1989	2509
0,6-0,8	327	1246	623	356	705	25
0,8-1,0	144	221	247	493	232	7
1,0-1,2	55	218	140	58		
>1,2	505	262			456	248

TABLE 6 KLERKSDORP STOPING AND DEVELOPMENT POPULATION QUARTZ DISTRIBUTION

Quartz Grouping (%)	Persons Cycle 1	Persons Cycle 2	Persons Cycle 3	Persons Cycle 4	Persons Cycle 5	Persons Cycle 6
0-5					766	2143
5-10	223	234	1876	493	1128	5863
10-15	2409	3304	5089	2751	5287	4883
15-20	9787	9734	6109	4536	8535	8920
20-25	6629	6933	7006	521	6536	2858
25-30	1763	1869	2315	2148	1998	1364
30-35	1975	1158	1399	662	479	
35-40	351	523	639		652	
>40	446	507	418			136

KLERKSDORP UNDERGROUND ROVING POPULATION QUARTZ DISTRIBUTION

Quartz Grouping (%)	Persons Cycle 1	Persons Cycle 2	Persons Cycle 3	Persons Cycle 4	Persons Cycle 5	Persons Cycle 6
0-5	672	532	965	342	1323	2322
5-10	2111	2026	1506	1601	3837	6467
10-15	7688	6632	5980	5109	8407	5810
15-20	7387	6967	6545	3197	6288	7066
20-25	2704	2997	2938	2620	2196	1356
25-30	1950	1756	2217	631	1758	746
30-35	325	324	432	470	86	
35-40	905	1266	1086			
>40	45	45	145		11	113

KLERKSDORP SURFACE POPULATION QUARTZ DISTRIBUTION

Quartz Grouping (%)	Persons Cycle 1	Persons Cycle 2	Persons Cycle 3	Persons Cycle 4	Persons Cycle 5	Persons Cycle 6
0-5	289	289	328	189	797	886
5-10	455	365	836	365	571	975
10-15	1333	1422	1240	1294	1703	1308
15-20	609	820	571	320	1379	150
20-25	243	203	579	258	504	1100
25-30	571	459	414	193	821	544
30-35	171	196	201		505	132
35-40	38		85	136	77	
>40	497	569	243		130	57

TABLE 7 NOFS STOPING AND DEVELOPMENT POPULATION TWA DISTRIBUTION

Dust Conc. Grouping (mg/m³)	Persons Cycle 1	Persons Cycle 2	Persons Cycle 3	Persons Cycle 4	Persons Cycle 5	Persons Cycle 6
0-0,2	900	1357	1117	1315	590	2059
0,2-0,4	12411	10980	16747	23229	23367	18464
0,4-0,6	15572	13180	12872	10929	9958	14261
0,6-0.8	3061	3502	5023	7083	4710	6786
0,8-1,0	346	1670	1079	16	16	65
1,0-1,2		2092		435		
>1,2				15		75

NOFS UNDERGROUND ROVING POPULATION TWA DISTRIBUTION

Dust Conc. Grouping (mg/m³)	Persons Cycle 1	Persons Cycle 2	Persons Cycle 3	Persons Cycle 4	Persons Cycle 5	Persons Cycle 6
0-0,2	3339	3479	5462	6546	7516	6236
0,2-0,4	15731	11982	14973	16130	14724	14958
0,4-0,6	3455	5286	4278	3113	2871	4691
0,6-0,8	898	1880	887	1328	1874	2149
0,8-1,0	120	556	247	293	77	146
1,0-1,2	164	49	94			
>1,2	23707	23232	25941	27410	27062	28180

NOFS SURFACE POPULATION TWA DISTRIBUTION

Dust Conc. Grouping (mg/m³)	Persons Cycle 1	Persons Cycle 2	Persons Cycle 3	Persons Cycle 4	Persons Cycle 5	Persons Cycle 6
0-0,2	716	690	878	1264	1756	1334
0,2-0,4	1432	899	1382	1987	2209	1339
0,4-0,6	623	692	1118	588	554	902
0,6-0,8	138	330	934	625	193	722
0,8-1,0	659	16	215	10	222	180
1,0-1,2	87	135	376	329	66	94
>1,2	253	412	145	551	147	180

TABLE 8 NOFS STOPING AND DEVELOPMENT POPULATION QUARTZ DISTRIBUTION

Quartz Grouping (%)	Persons Cycle 1	Persons Cycle 2	Persons Cycle 3	Persons Cycle 4	Persons Cycle 5	Persons Cycle 6
0-5	1744	1757	1246	1910	316	1506
5-10	2072	2081	6510	7507	5168	9592
10-15	9910	10309	12208	12758	15881	15454
15-20	11230	11299	8342	10547	12506	12610
20-25	4560	4577	1717	2431	2417	1178
25-30	2378	2359	4031	4401	1020	443
30-35	399	399	581	846	1234	806
35-40			1305	1020	99	121
>40			898	1602		

NOFS UNDERGROUND ROVING POPULATION QUARTZ DISTRIBUTION

Quartz Grouping (%)	Persons Cycle 1	Persons Cycle 2	Persons Cycle 3	Persons Cycle 4	Persons Cycle 5	Persons Cycle 6
0-5	3393	3332	2193	2220	2148	2426
5-10	5774	5784	7795	8602	9413	10614
10-15	5969	5361	6838	7788	8211	10552
15-20	4514	4564	5083	4390	5801	3457
20-25	1877	1911	2408	2827	659	926
25-30	269	269	1290	1049	628	
30-35	314	414	215	215	202	205
35-40	289	289		122		
>40	1308	1308	79	79		

NOFS SURFACE POPULATION QUARTZ DISTRIBUTION

Quartz Grouping (%)	Persons Cycle 1	Persons Cycle 2	Persons Cycle 3	Persons Cycle 4	Persons Cycle 5	Persons Cycle 6
0-5	1402	1043	966	836	967	632
5-10	1069	783	1381	1528	1526	1389
10-15	573	589	1245	1390	1164	1080
15-20	273	278	744	798	1032	1056
20-25	470	477	390	266	703	594
25-30			225	193		
30-35			89	89		
35-40	40					
>40	61	75	8			

TABLE 9	SOFS STOPING AND DEVELOPMENT POPULATION TWA DISTRIBUTION					
Dust Conc.	Persons	Persons	Persons	Persons	Persons	Persons
Grouping (mg/m^3)	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6
0-0,2			36		151	
0,2-0,4	1246	349	1886	2045	2115	932
0,4-0,6	1839	2761	3876	4051	3229	2610
0,6-0.8	2152	1213	1699	1887	812	2573
0,8-1,0	841	1351	690	84	495	1217
1,0-1,2	1439	331				226
>1,2	345	996				

SOFS UNDERGROUND ROVING POPULATION TWA DISTRIBUTION						
Dust Conc.	Persons	Persons	Persons	Persons	Persons	Persons
Grouping (mg/m^3)	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6
0-0,2	325	423	63	196	537	16
0,2-0,4	1957	1601	1096	1616	1878	622
0,4-0,6	1067	639	1412	1111	900	948
0,6-0,8	259	556	144	567	77	1259
0,8-1,0	187					198
1,0-1,2						334
>1,2			594	107		

SOFS SURFACE POPULATION TWA DISTRIBUTION						
Dust Conc.	Persons	Persons	Persons	Persons	Persons	Persons
Grouping (mg/m^3)	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6
0-0,2	68	148	331	41	190	159
0,2-0,4	681	1042	581	1247	981	637
0,4-0,6	654	605	1840	558	344	403
0,6-0,8	467		214	133	104	84
0,8-1,0	397	545	6	72		184
1,0-1,2				4	5	26
>1,2	89	191				

TABLE 10 SOFS STOPING AND DEVELOPMENT POPULATION QUARTZ DISTRIBUTION

Quartz Grouping (%)	Persons Cycle 1	Persons Cycle 2	Persons Cycle 3	Persons Cycle 4	Persons Cycle 5	Persons Cycle 6
0-5	1064	632	830	2749	2312	875
5-10	3973	3572	3811	1804	876	4710
10-15	2346	2413	4305	2009	2393	1594
15-20	335	343	241	1240	1221	379
20-25	144	41		199		
25-30						
30-35						
35-40				66		
>40						

SOFS UNDERGROUND ROVING POPULATION QUARTZ DISTRIBUTION

Quartz Grouping (%)	Persons Cycle 1	Persons Cycle 2	Persons Cycle 3	Persons Cycle 4	Persons Cycle 5	Persons Cycle 6
0-5	633	853	288	334	489	1766
5-10	2696	1660	1588	3062	998	777
10-15	367	607	596	201	1522	633
15-20	99	99	243		383	
20-25						
25-30						
30-35						
35-40						
>40						201

SOFS SURFACE POPULATION QUARTZ DISTRIBUTION

Quartz Grouping (%)	Persons Cycle 1	Persons Cycle 2	Persons Cycle 3	Persons Cycle 4	Persons Cycle 5	Persons Cycle 6
0-5	1040	1048	766	1357	665	812
5-10	421	867	1271	444	110	599
10-15	780	515	678	139	282	13
15-20	85	101	257	103	554	65
20-25	30			12	13	
25-30						4
30-35						
35-40						
>40						

TABLE 11 WEST WITS. STOPING AND DEVELOPMENT POPULATION TWA DISTRIBUTION

Dust Conc. Grouping (mg/m³)	Persons Cycle 1	Persons Cycle 2	Persons Cycle 3	Persons Cycle 4	Persons Cycle 5	Persons Cycle 6
0-0,2	2277	1878	3527	4258	5427	4086
0,2-0,4	11326	15966	22347	22159	29249	18188
0,4-0,6	14151	15085	8793	13265	7584	15172
0,6-0.8	6696	3389	2570	2685	1062	1668
0,8-1,0	2722	1066	1328	0	799	765
1,0-1,2	573	763	0	0	0	339
>1,2	1526	646	171	0	0	293

WEST WITS. UNDERGROUND ROVING POPULATION TWA DISTRIBUTION

Dust Conc. Grouping (mg/m³)	Persons Cycle 1	Persons Cycle 2	Persons Cycle 3	Persons Cycle 4	Persons Cycle 5	Persons Cycle 6
0-0,2	2229	800	2530	2077	6672	5983
0,2-0,4	10274	12350	16661	16114	13974	17588
0,4-0,6	9761	11155	7830	7200	6873	6992
0,6-0,8	3369	3219	1951	4829	4778	2536
0,8-1,0	2593	190	1388	995	954	540
1,0-1,2	461	0	0	211	217	377
>1,2	561	370	0	0	78	1242

WEST WITS. SURFACE POPULATION TWA DISTRIBUTION

Dust Conc. Grouping (mg/m³)	Persons Cycle 1	Persons Cycle 2	Persons Cycle 3	Persons Cycle 4	Persons Cycle 5	Persons Cycle 6
0-0,2	2202	1972	2987	2970	3659	2000
0,2-0,4	2785	4137	4194	5112	2885	3032
0,4-0,6	3695	2426	2100	2338	2866	906
0,6-0,8	896	769	635	549	1024	592
0,8-1,0	553	74	268	67	210	366
1,0-1,2	149	0	80	205	180	0
>1,2	312	0	125	0	181	56

TABLE 12 WEST WITS. STOPING AND DEVELOPMENT POPULATION QUARTZ DISTRIBUTION

Quartz Grouping (%)	Persons Cycle 1	Persons Cycle 2	Persons Cycle 3	Persons Cycle 4	Persons Cycle 5	Persons Cycle 6
0-5	1443	1502	2735	2800	2863	2259
5-10	7174	7876	10583	9775	14392	15910
10-15	13758	13742	19727	17270	15422	14031
15-20	4968	5604	3966	9678	4748	6988
20-25	5066	3402	1247	1582	2502	1089
25-30	335	2382	382	647	3808	356
30-35	204	303	779	960	533	0
35-40	3105	3224		49	49	128
>40	1378	1390			206	339

WEST WITS. UNDERGROUND ROVING POPULATION QUARTZ DISTRIBUTION

Quartz Grouping (%)	Persons Cycle 1	Persons Cycle 2	Persons Cycle 3	Persons Cycle 4	Persons Cycle 5	Persons Cycle 6
0-5	4005	4488	6521	5787	7279	8631
5-10	6210	5516	14897	12185	11769	9374
10-15	7747	8392	6283	6588	9340	11308
15-20	4257	3844	592	3517	2148	3280
20-25	2392	2775	1247	1846	1553	520
25-30	695	420	345	592	146	1085
30-35	3025	2599				25
35-40	416					181
>40	1085	1153	661	661	1140	653

WEST WITS. SURFACE POPULATION QUARTZ DISTRIBUTION

Quartz Grouping (%)	Persons Cycle 1	Persons Cycle 2	Persons Cycle 3	Persons Cycle 4	Persons Cycle 5	Persons Cycle 6
0-5	1196	1015	2408	2164	2797	2821
5-10	2433	2316	3758	4116	3511	1849
10-15	3324	2509	2443	3305	2518	1664
15-20	1616	1713	803	928	1623	40
20-25	1191	1093	657	69	186	835
25-30	577	577	538	289	194	362
30-35	7	7	95	95	264	139
35-40		39				52
>40	501	297		233		78

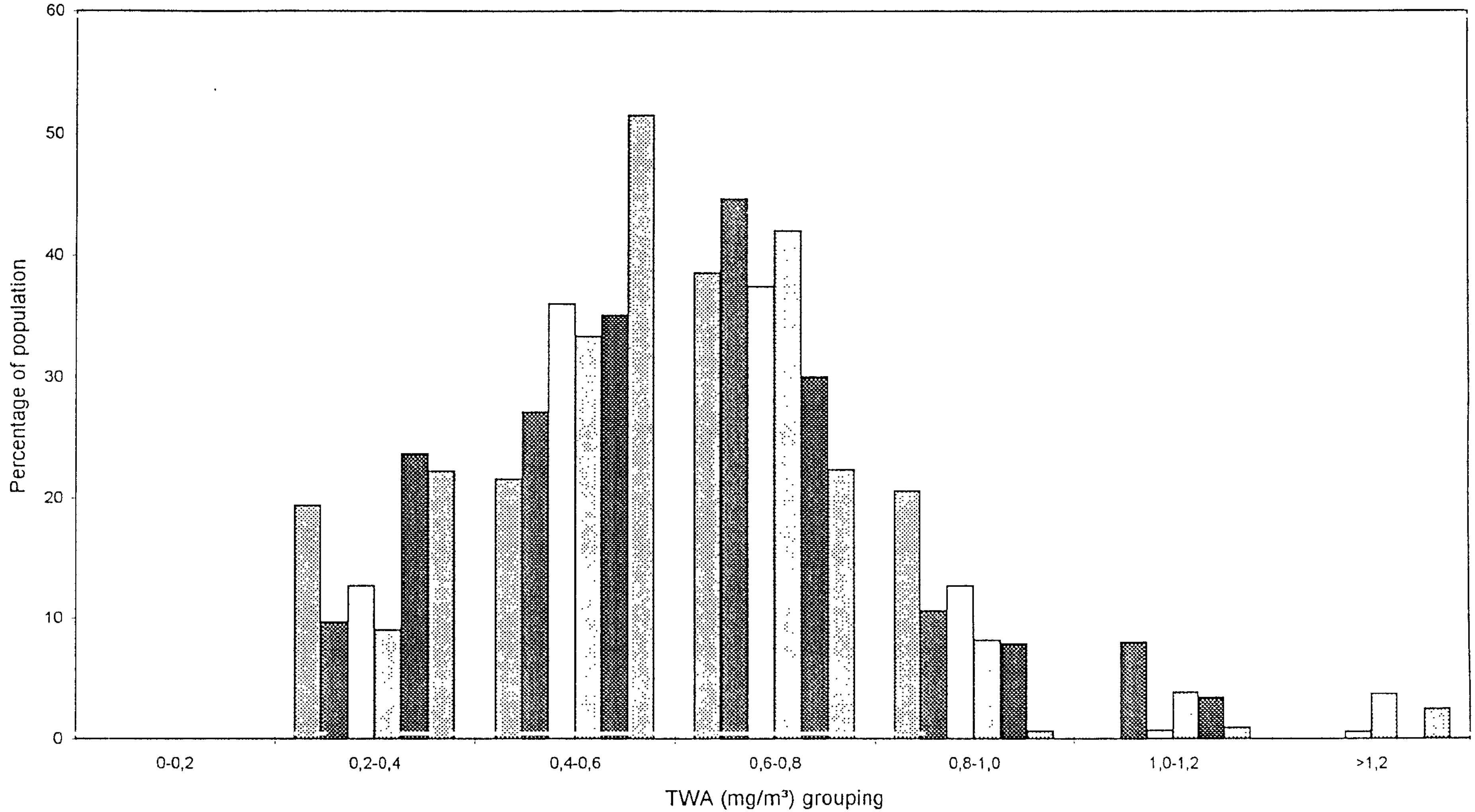

Figure 1 Eastern region stoping and development population TWA distribution (half yearly cycles Jan. 1992 to Jun. 1994)

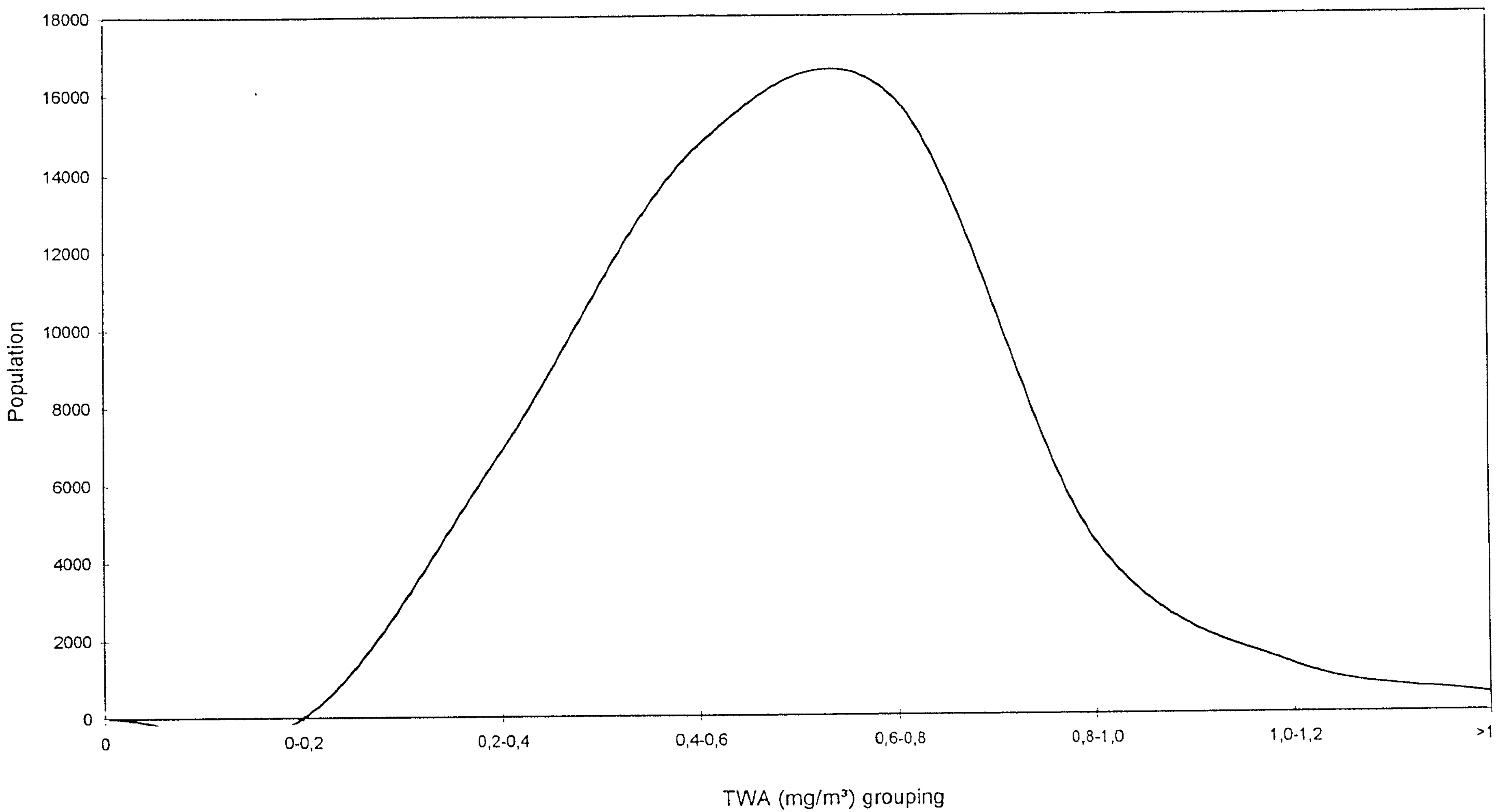

Figure 2 Eastern region stoping and development population TWA distribution

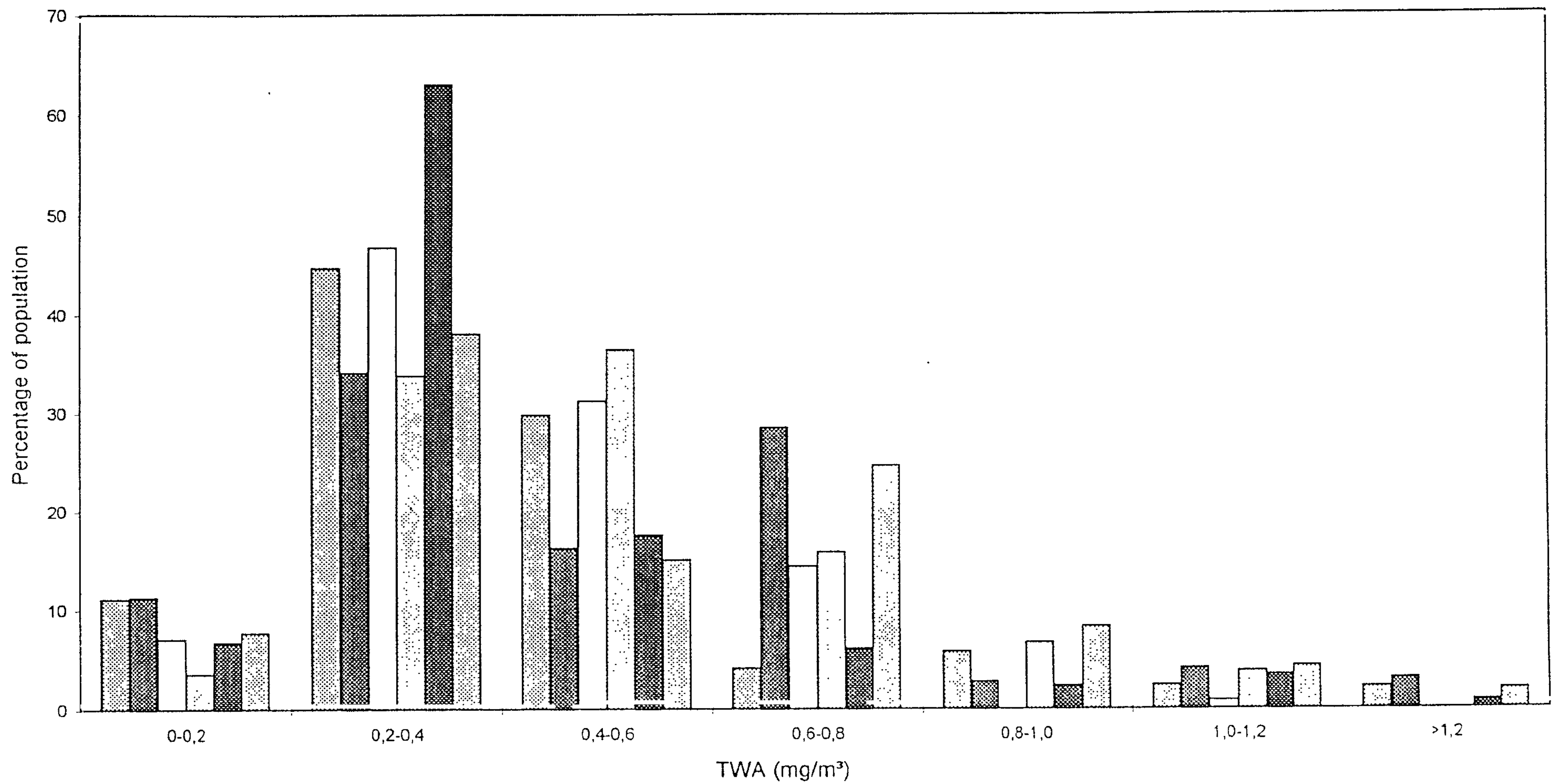

Figure 3 Eastern region underground roving population (half yearly cycles Jan. 1992 to Jun. 1994)

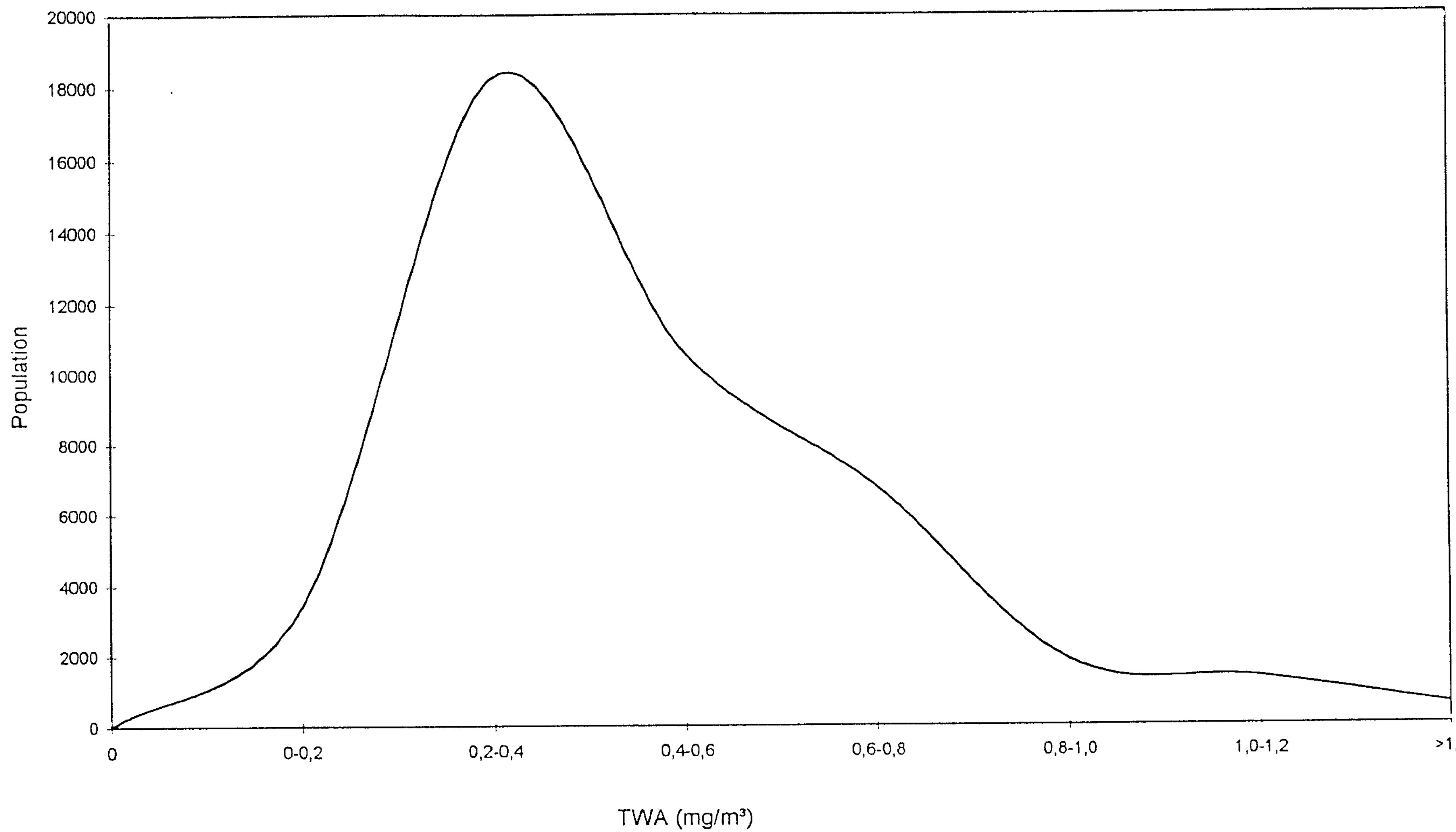

Figure 4 Eastern region total underground roving population TWA distribution

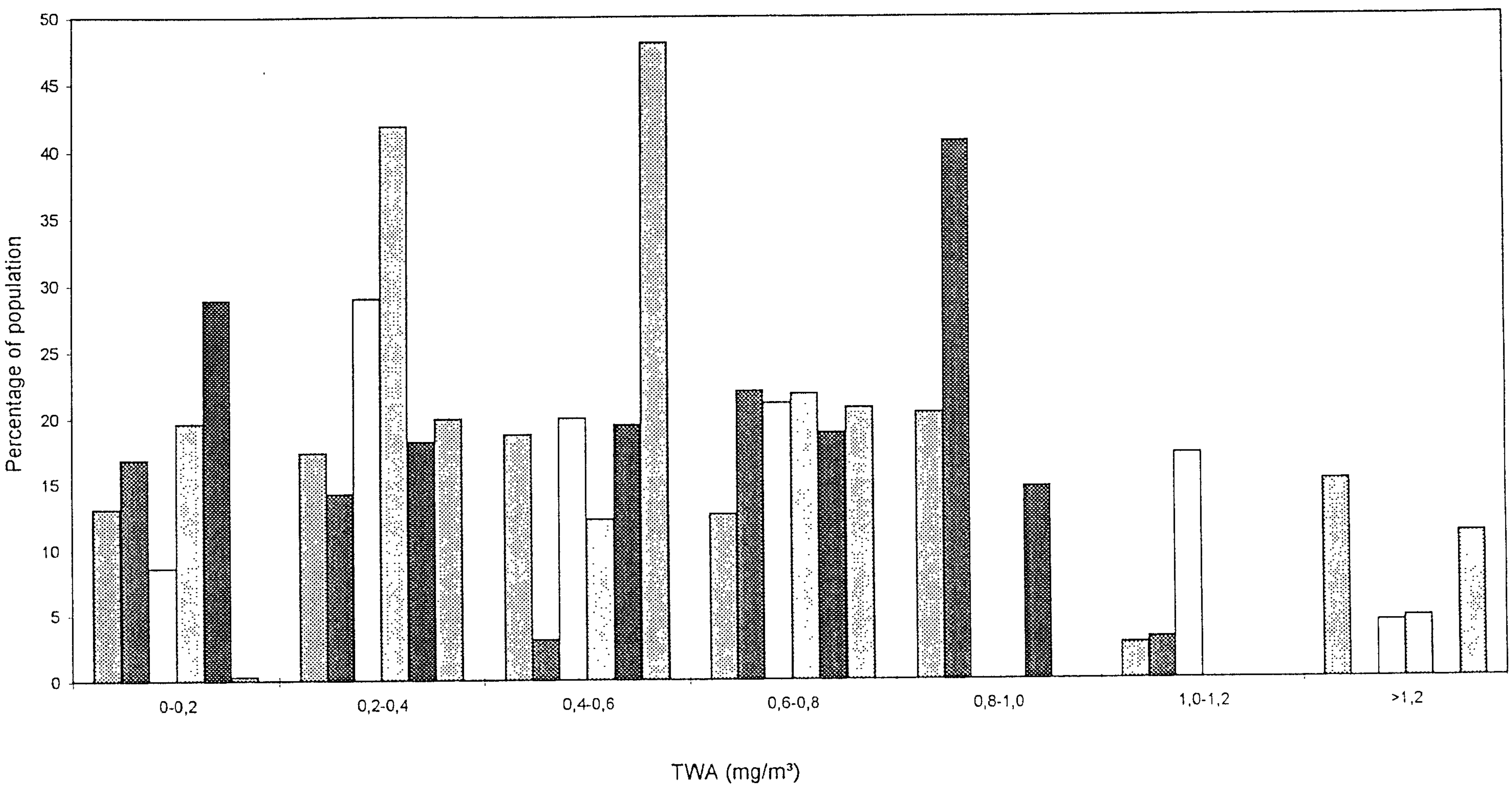

Figure 5 Eastern region surface population TWA distribution (half yearly cycles Jan. 1992 to Jun. 1994)

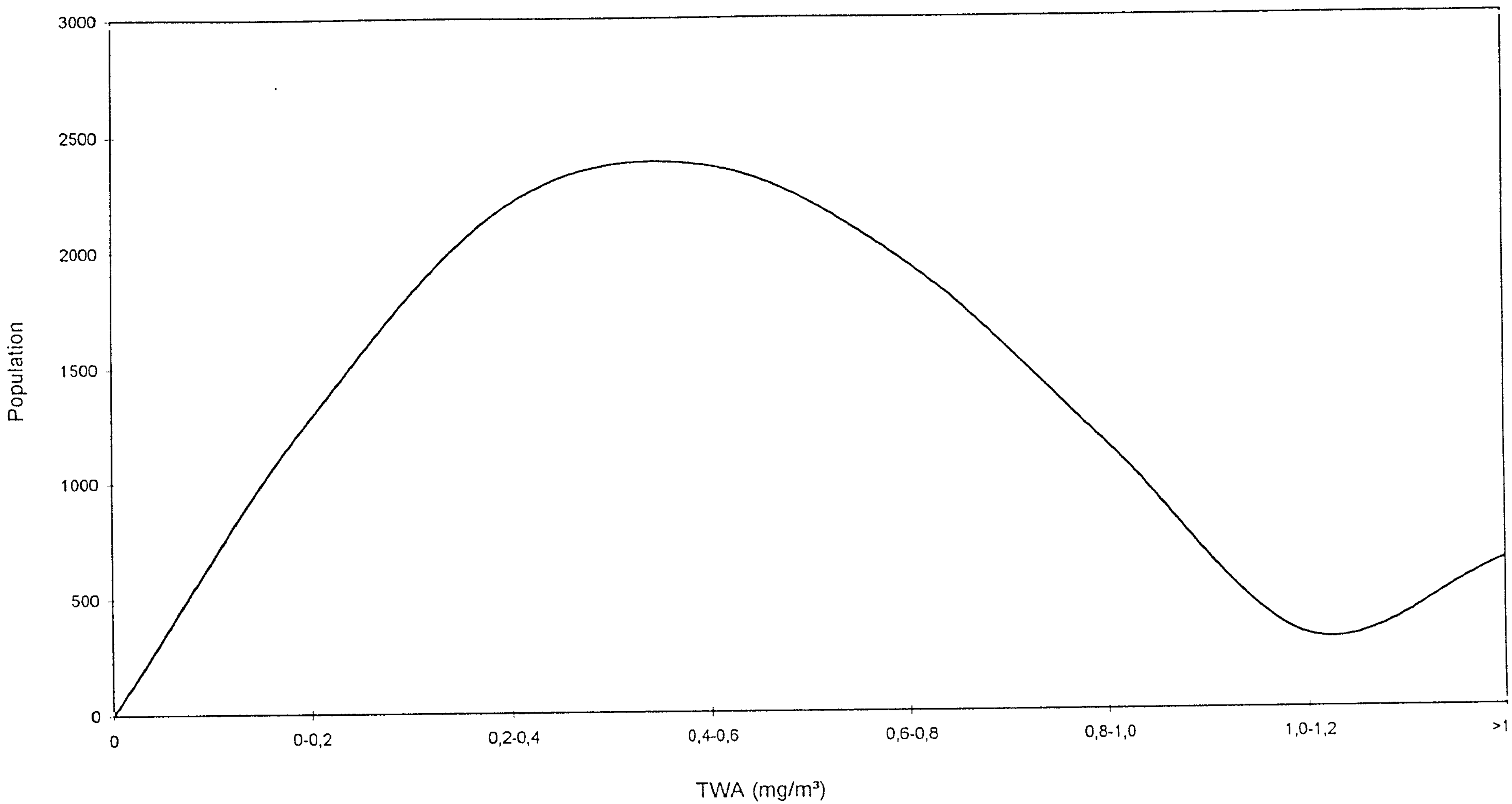

Figure 6 Eastern region total surface population TWA distribution

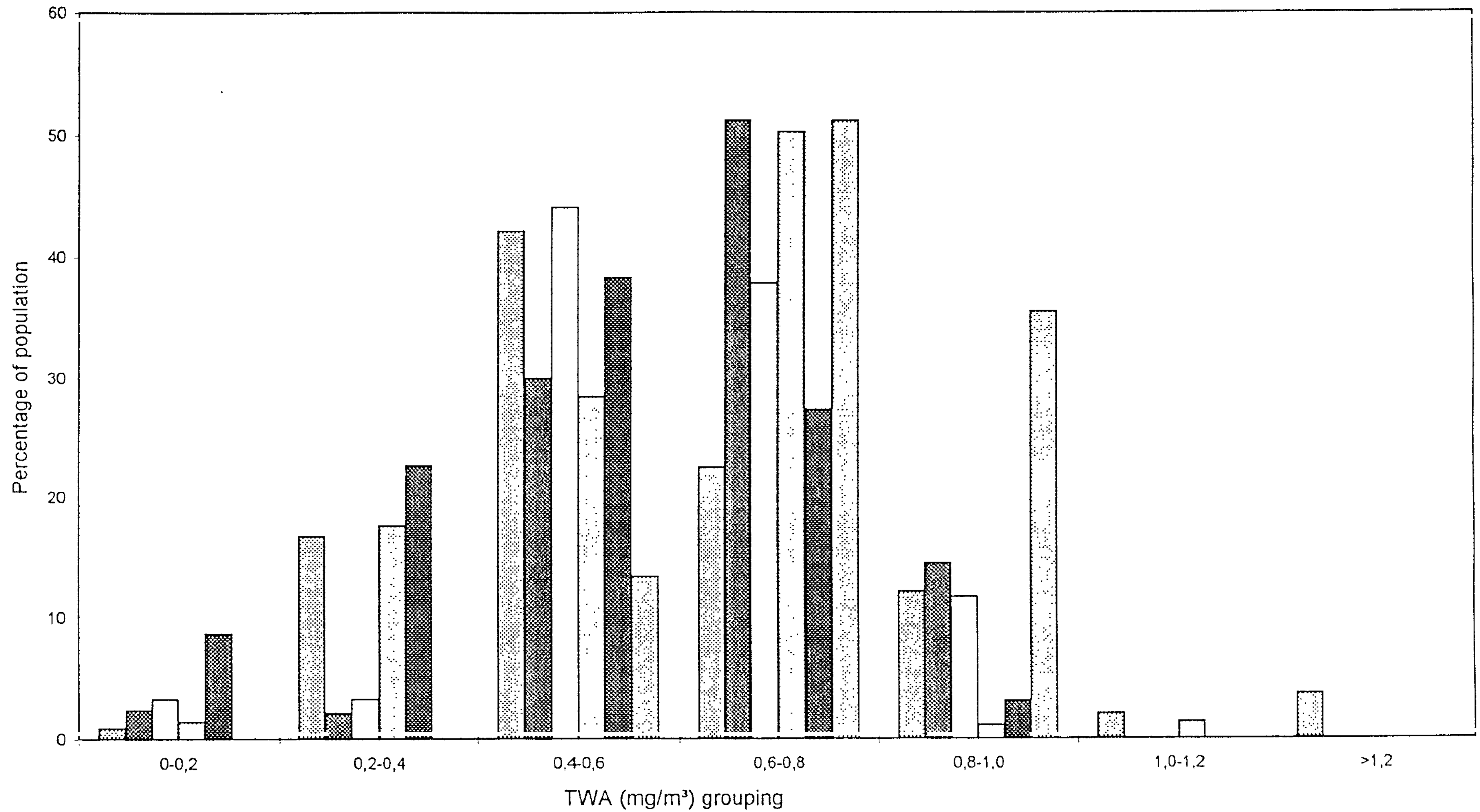

Figure 7 Elsburg region stoping and development population TWA distribution (half yearly cycles Jan. 1992 to Jun. 1994)

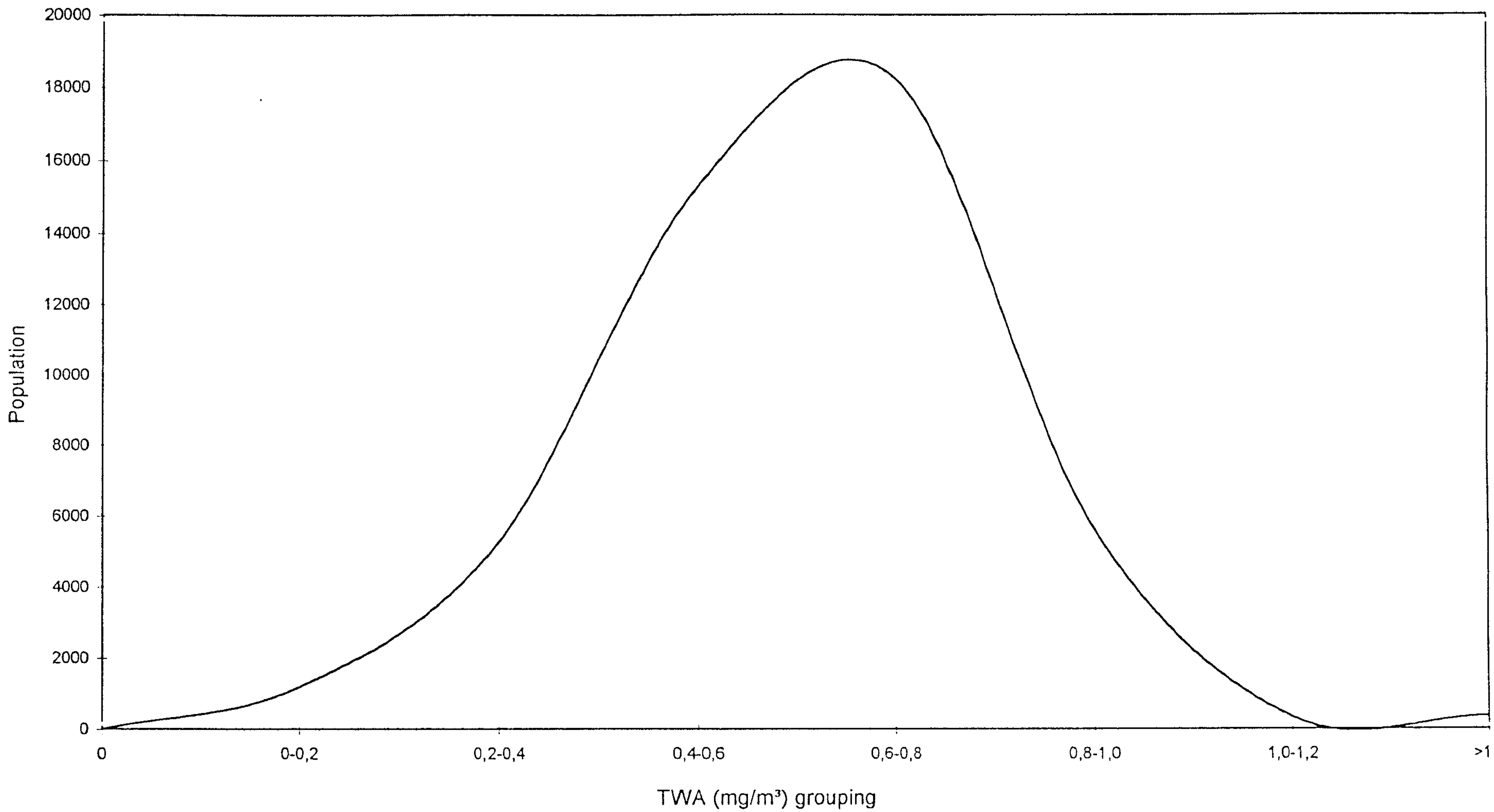

Figure 8 Elsburg region total stoping and development population TWA distribution

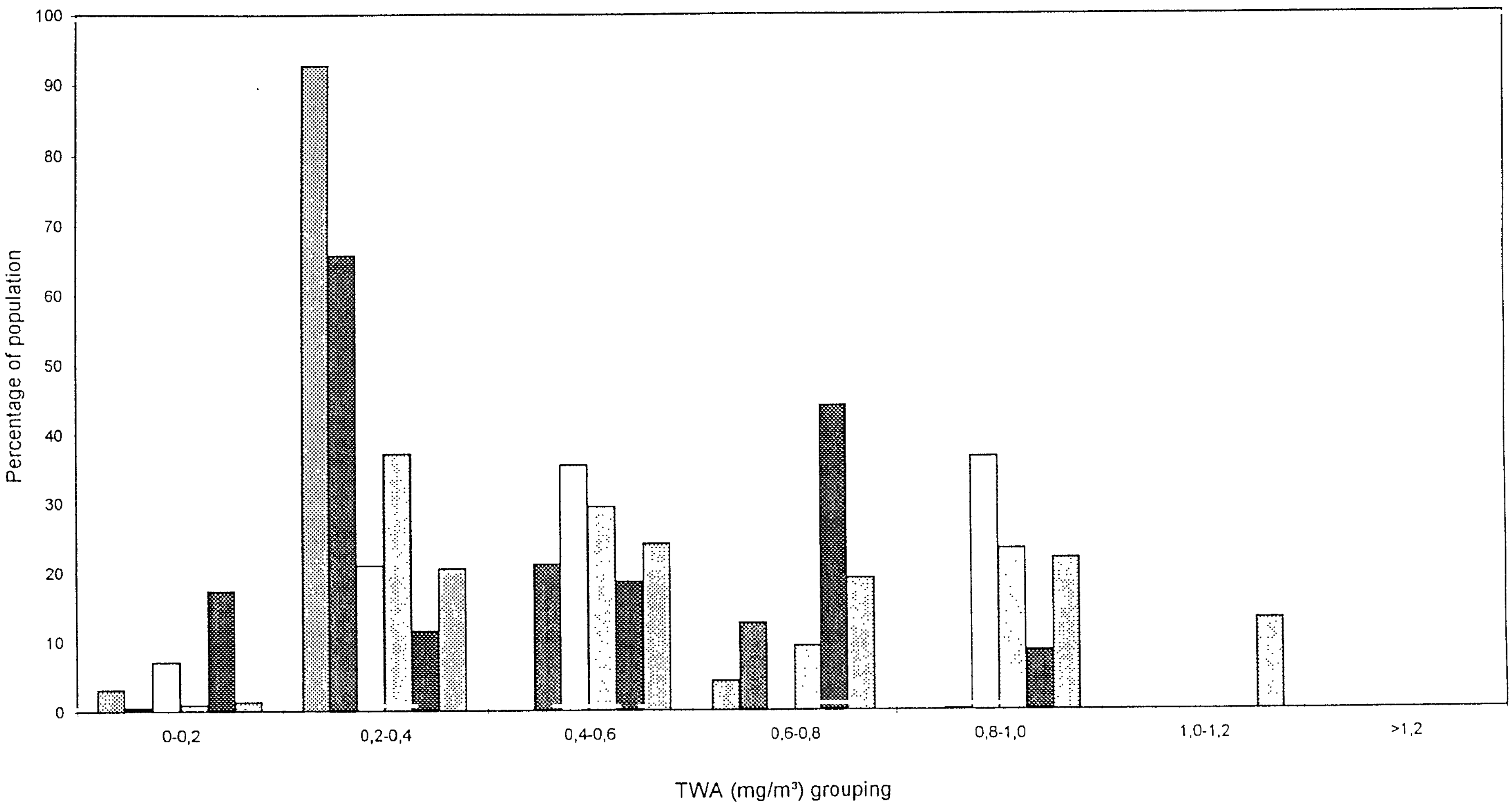

Figure 9 Elsburg region underground roving population TWA distribution (half yearly cycles Jan. 1992 to Jun. 1994)

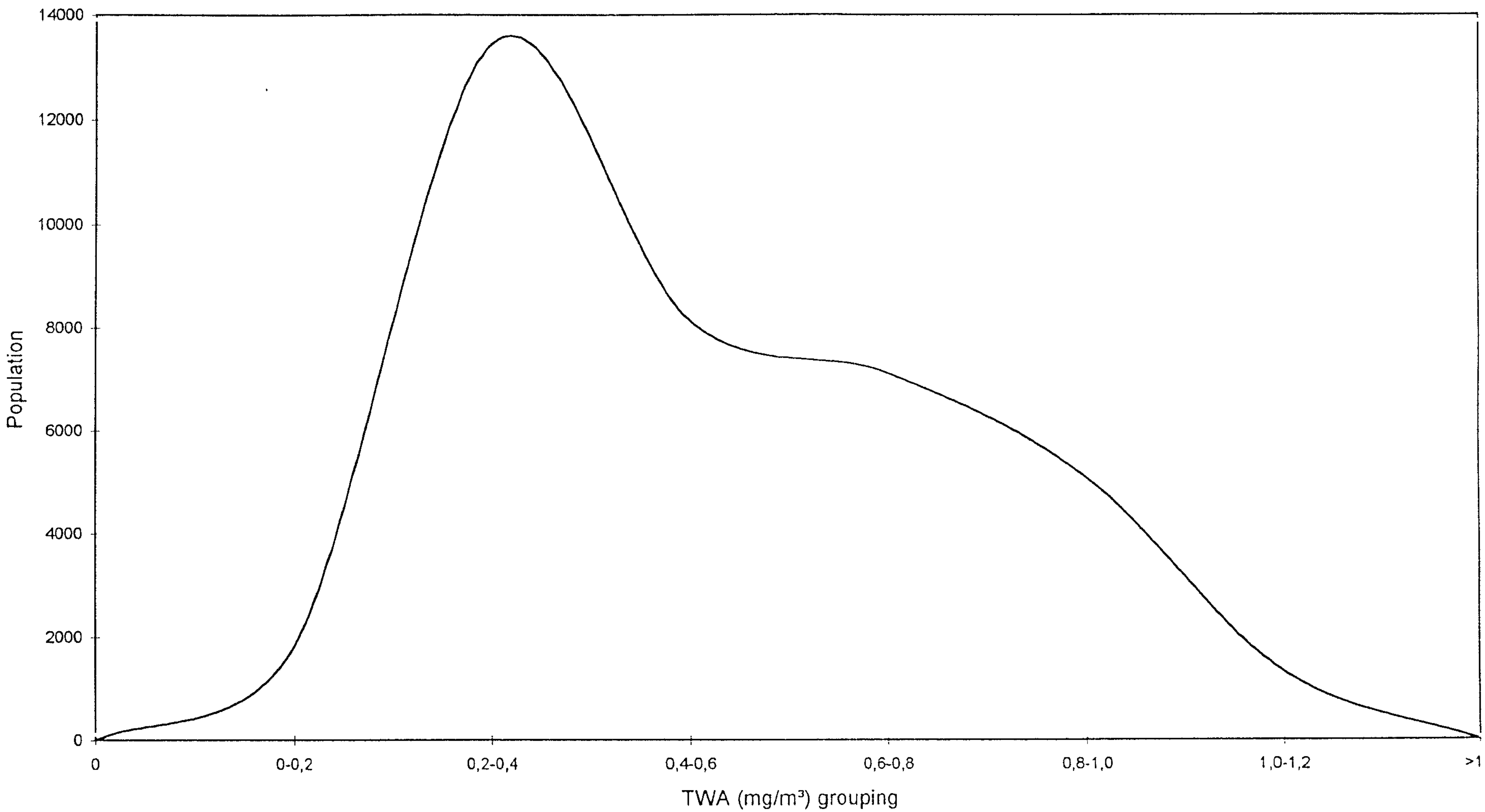

Figure 10 Elsburg region total underground roving population TWA distribution

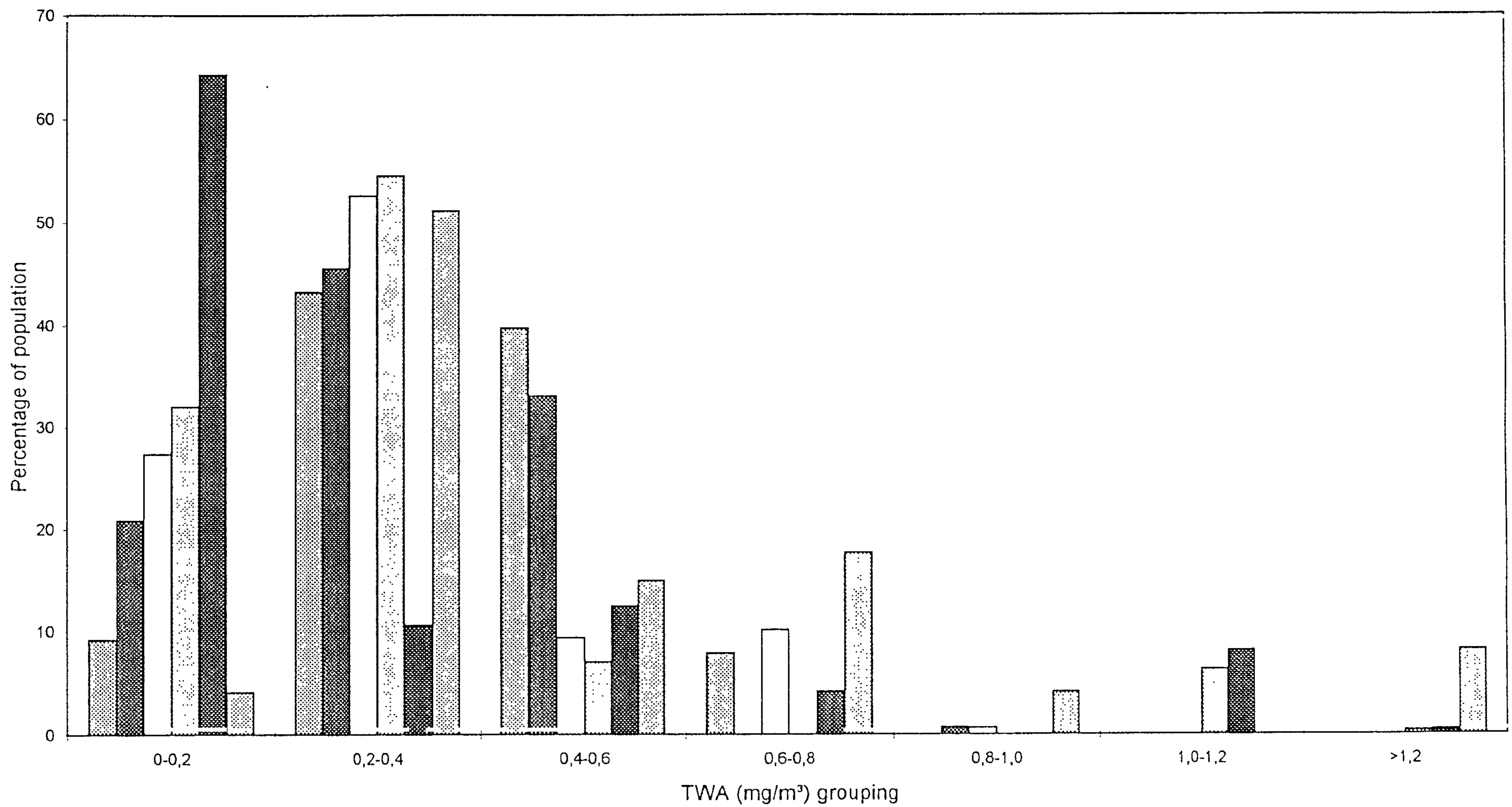

Figure 11 Elsburg region surface population TWA distribution (half yearly cycles Jan. 1992 to Jun. 1994)

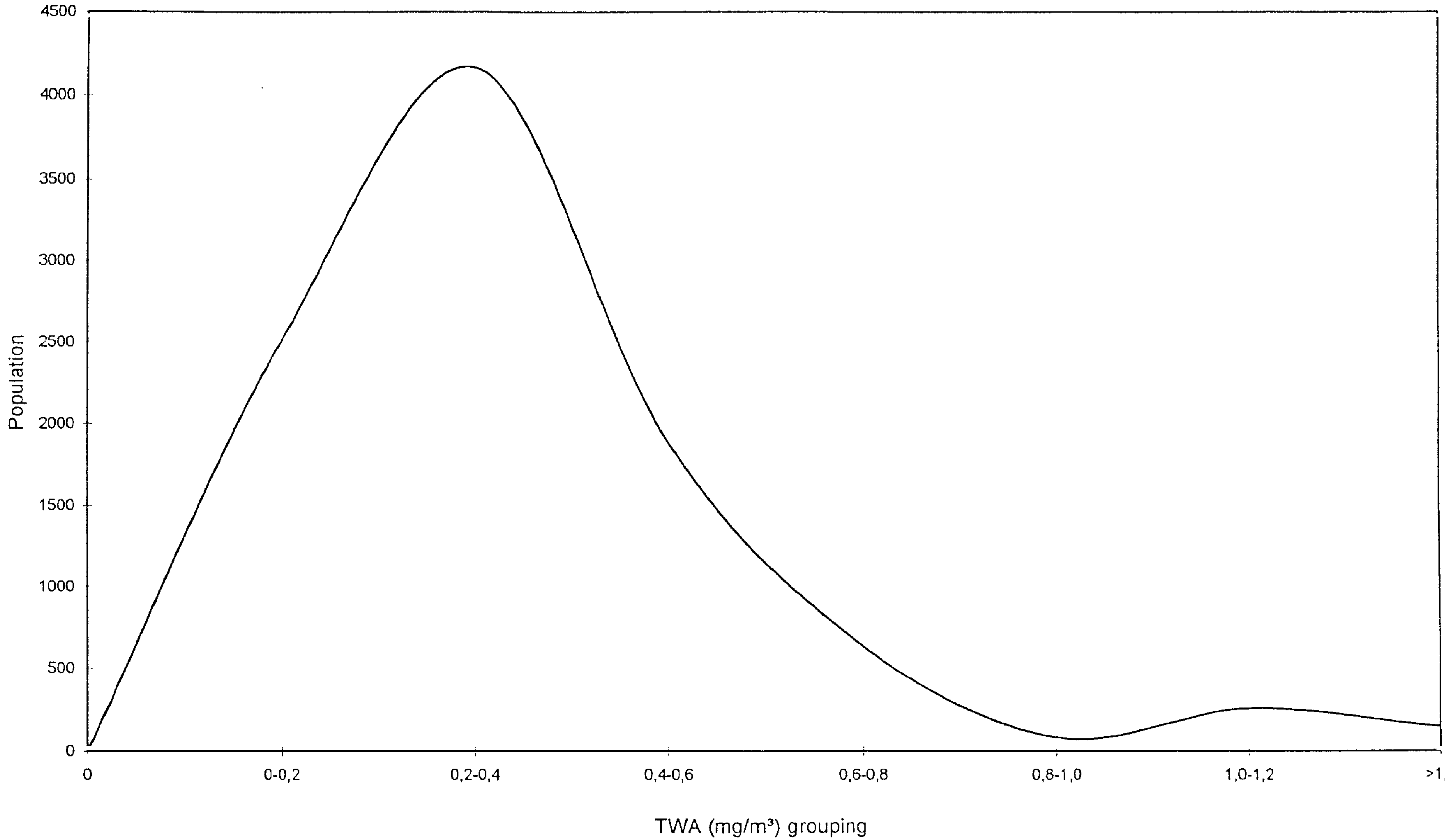

Figure 12 Elsburg region total surface population TWA distribution

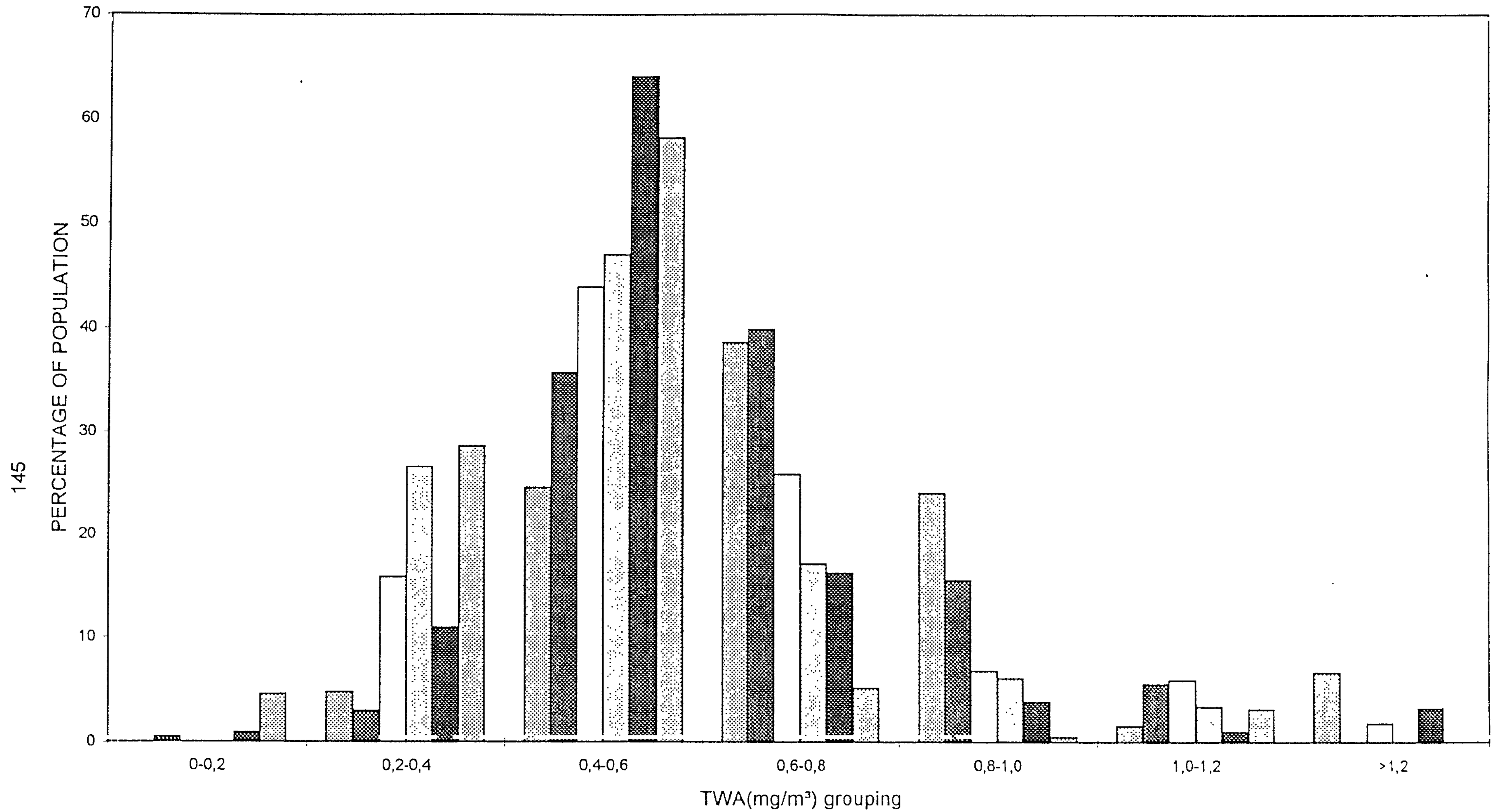

Figure 13 Klerksdorp region stoping and development population TWA distribution (half yearly cycles Jan. 1992 to Jun. 1994)

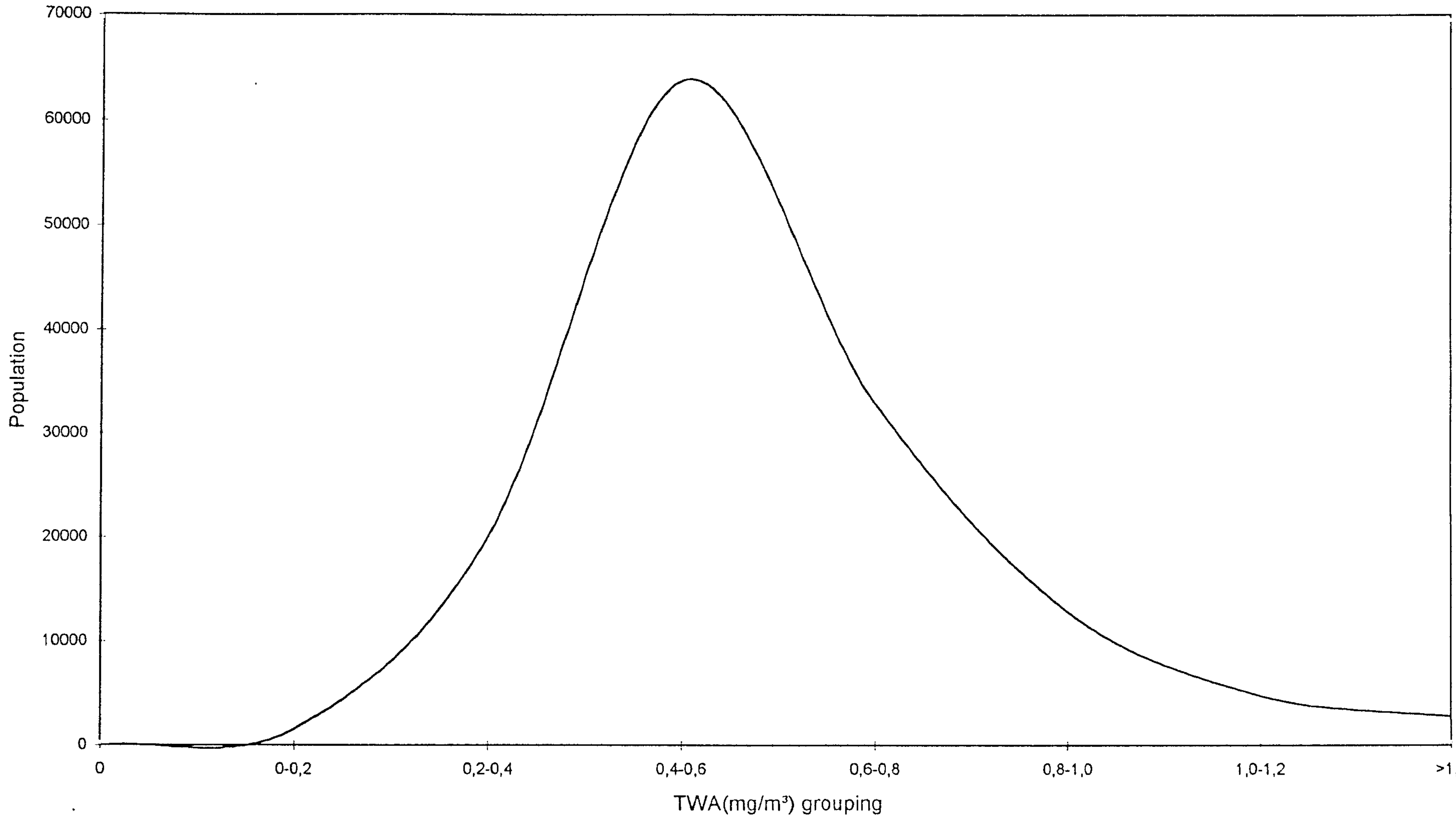

Figure 14 Klerksdorp region total stoping and development population TWA distribution

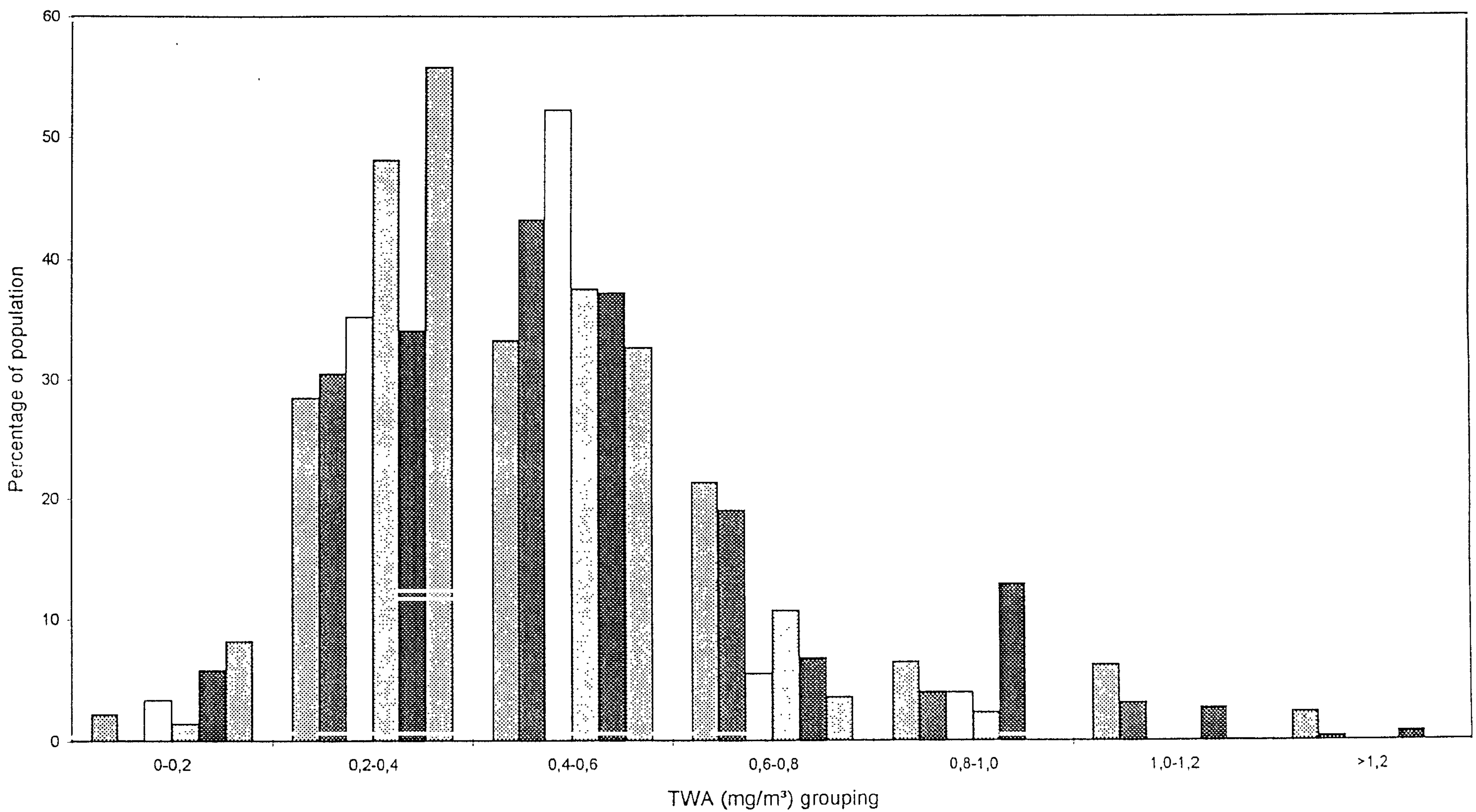

Figure 15 Klerksdorp region underground roving population distribution (half yearly cycles Jan. 1992 to Jun. 1994)

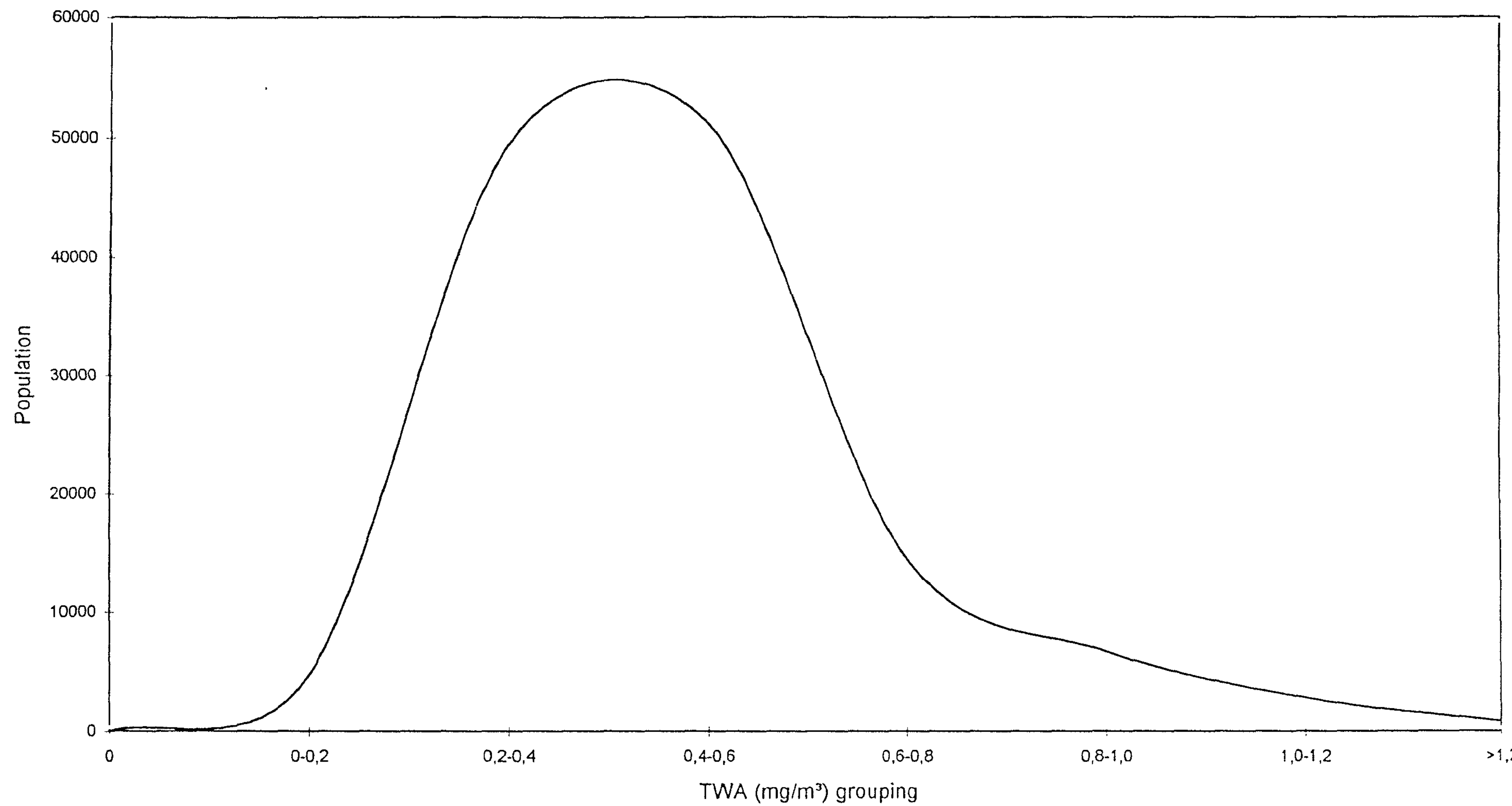

Figure 16 Klerksdorp region total underground roving population TWA distribution

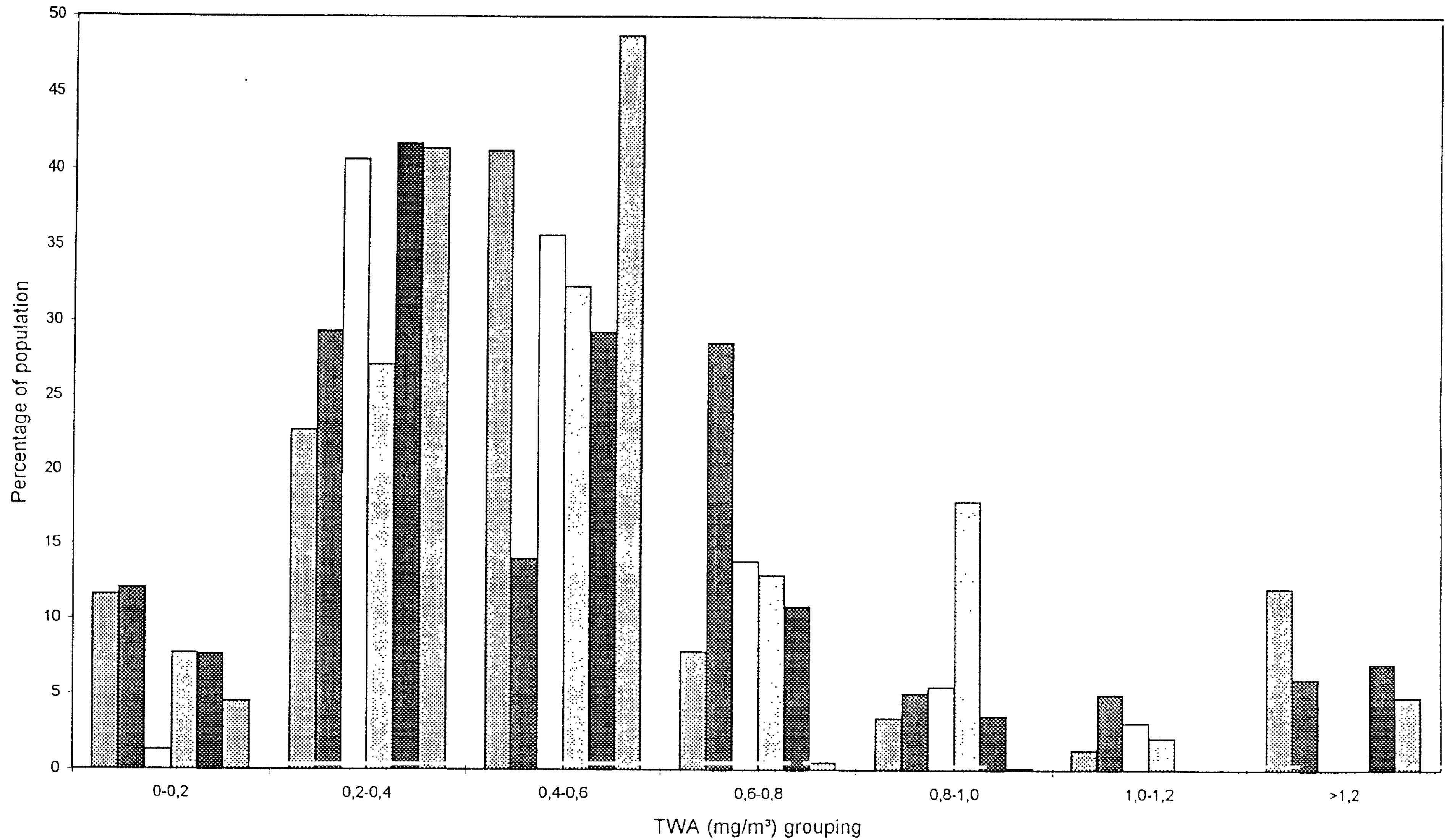

Figure 17 Klerksdorp region surface population TWA distribution (half yearly cycles Jan. 1992 to Jun. 1994)

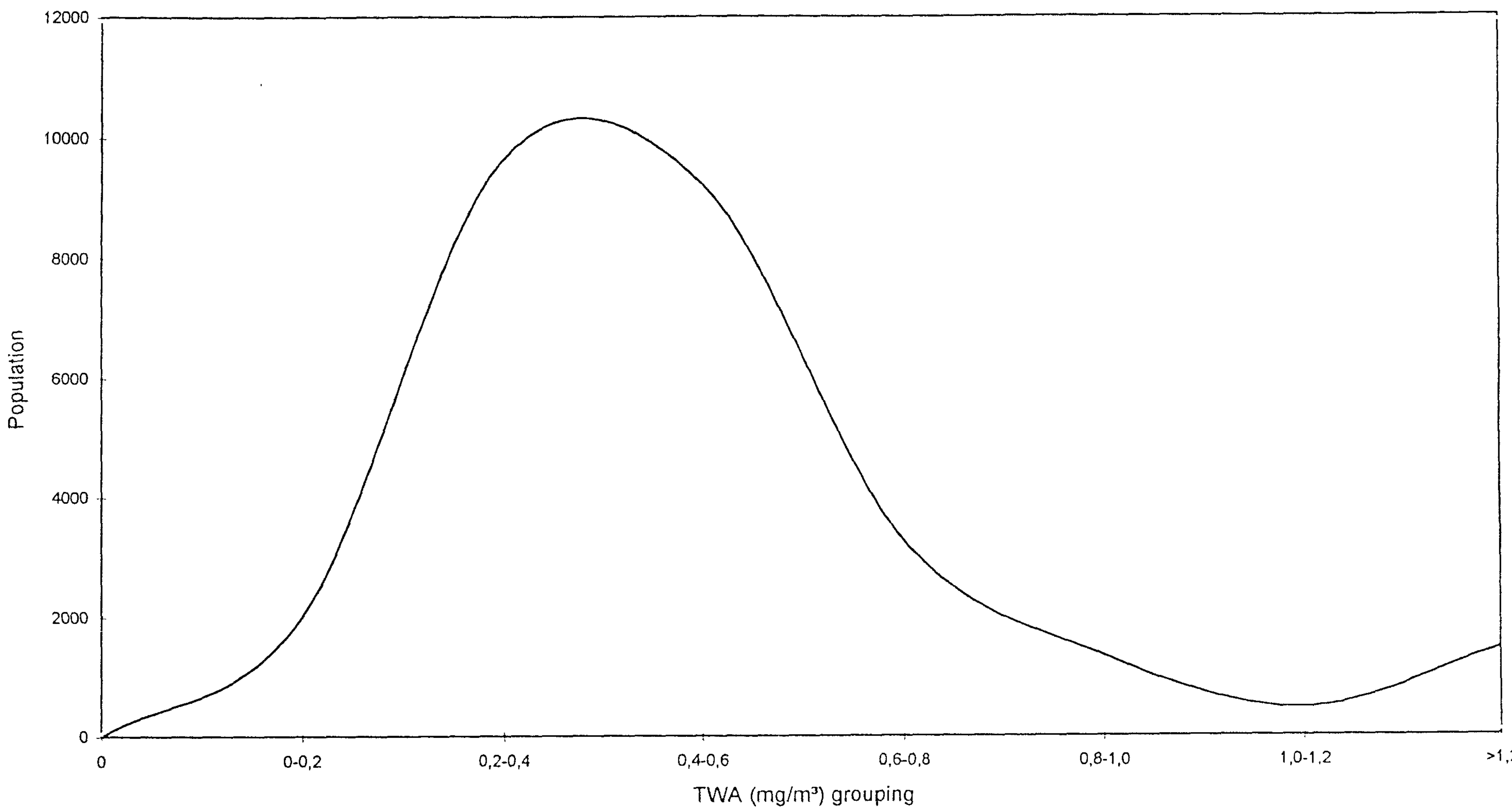

Figure 18 Klerksdorp region total surface population TWA distribution

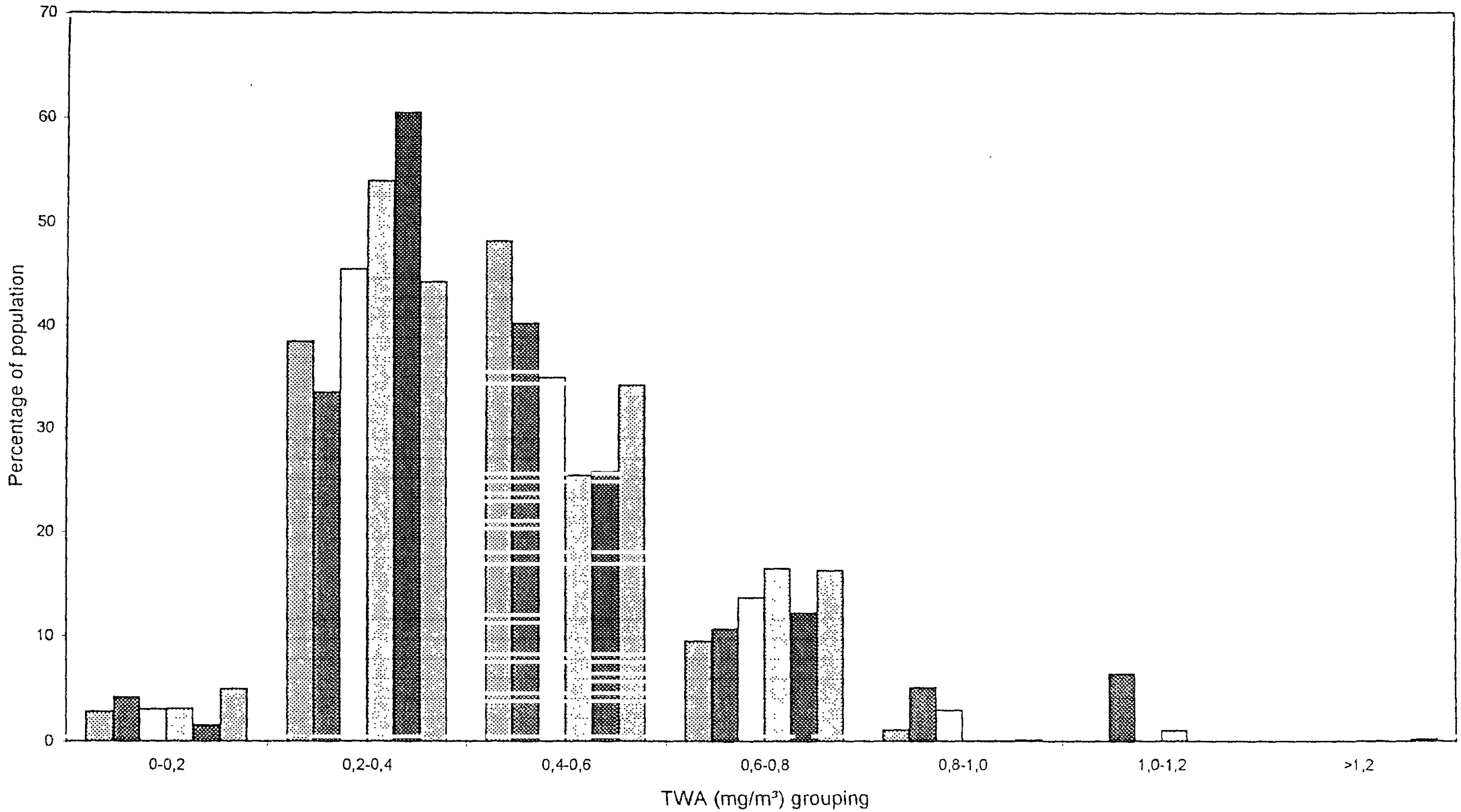

Figure 19 NOFS region stoping and development population TWA distribution (half yearly cycles Jan. 1992to Jun. 1994)

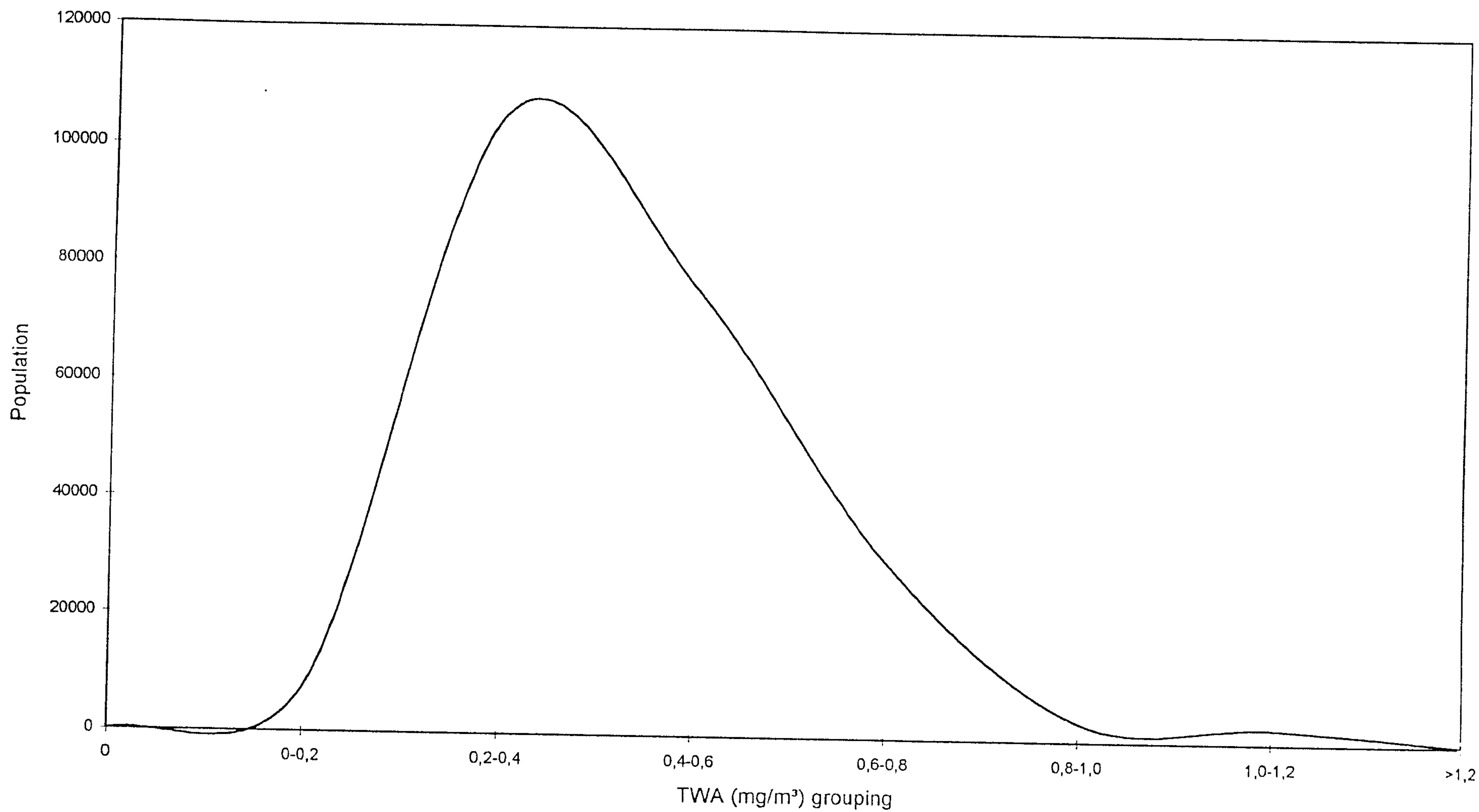

Figure 20 NOFS region stoping and development population TWA distribution

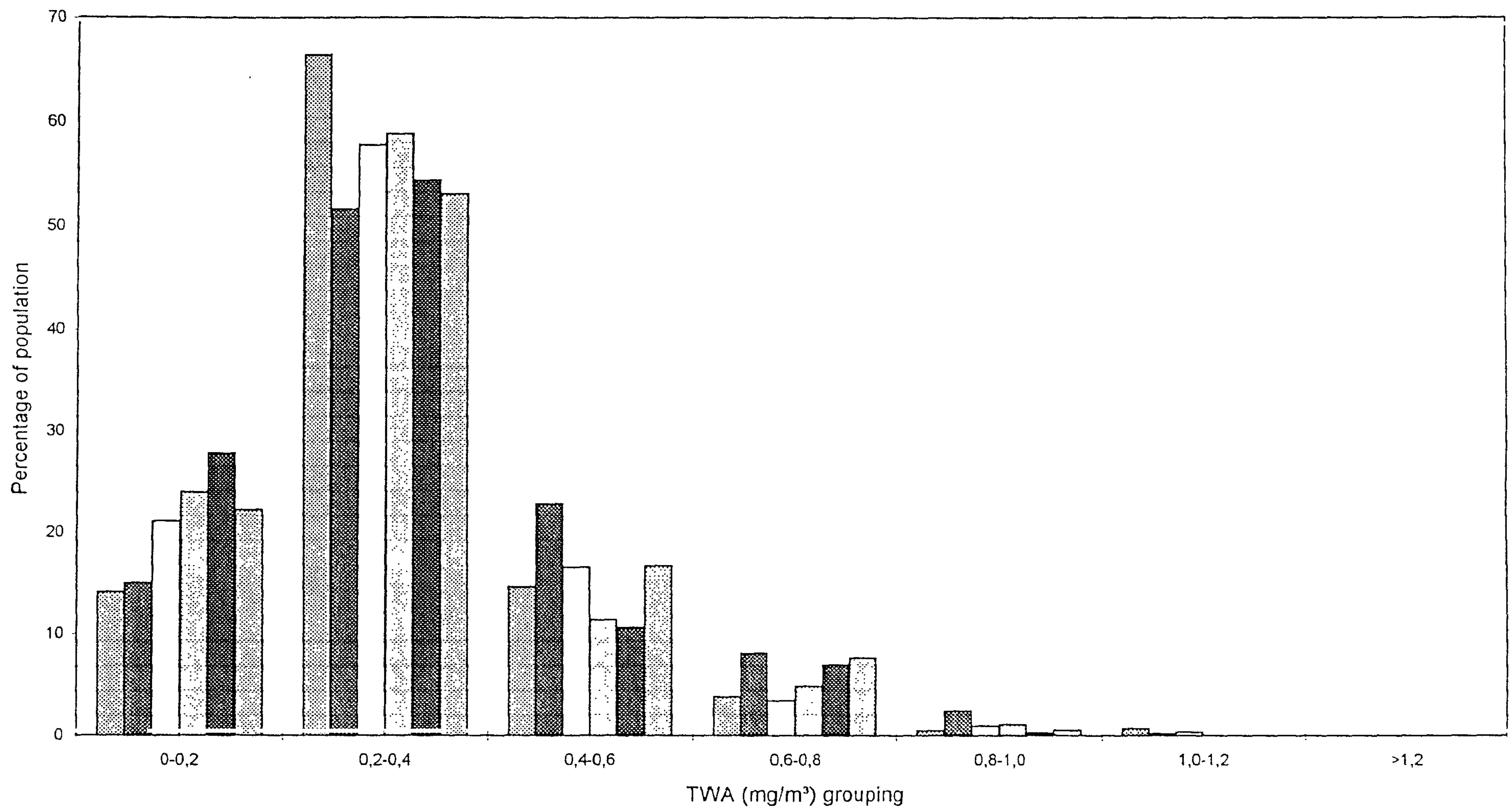

Figure 21 NOFS region total underground roving population TWA distribution (half yearly cycles Jan. 1992 to Jun. 1994)

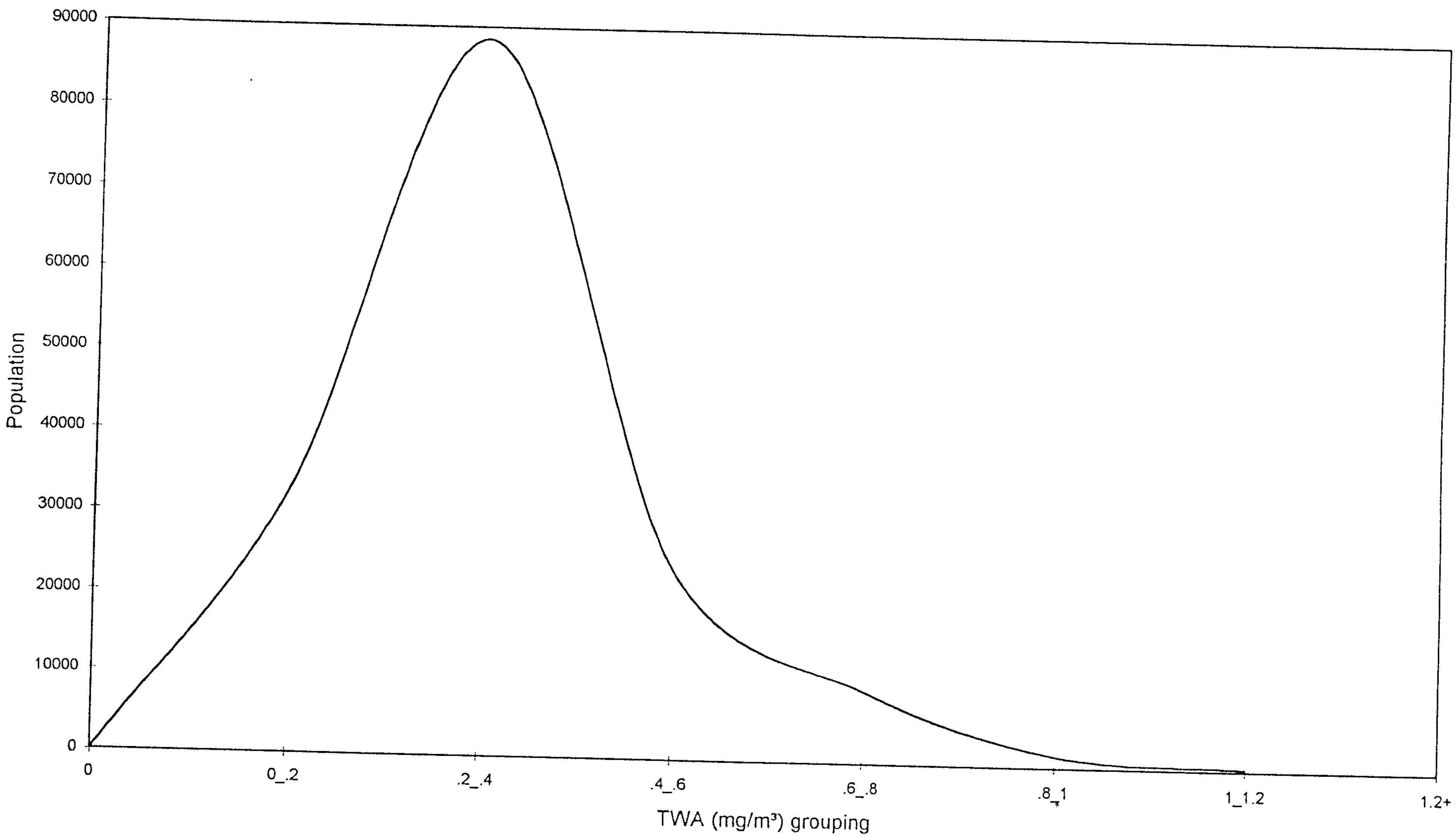

Figure 22 NOFS region total underground roving population TWA distribution

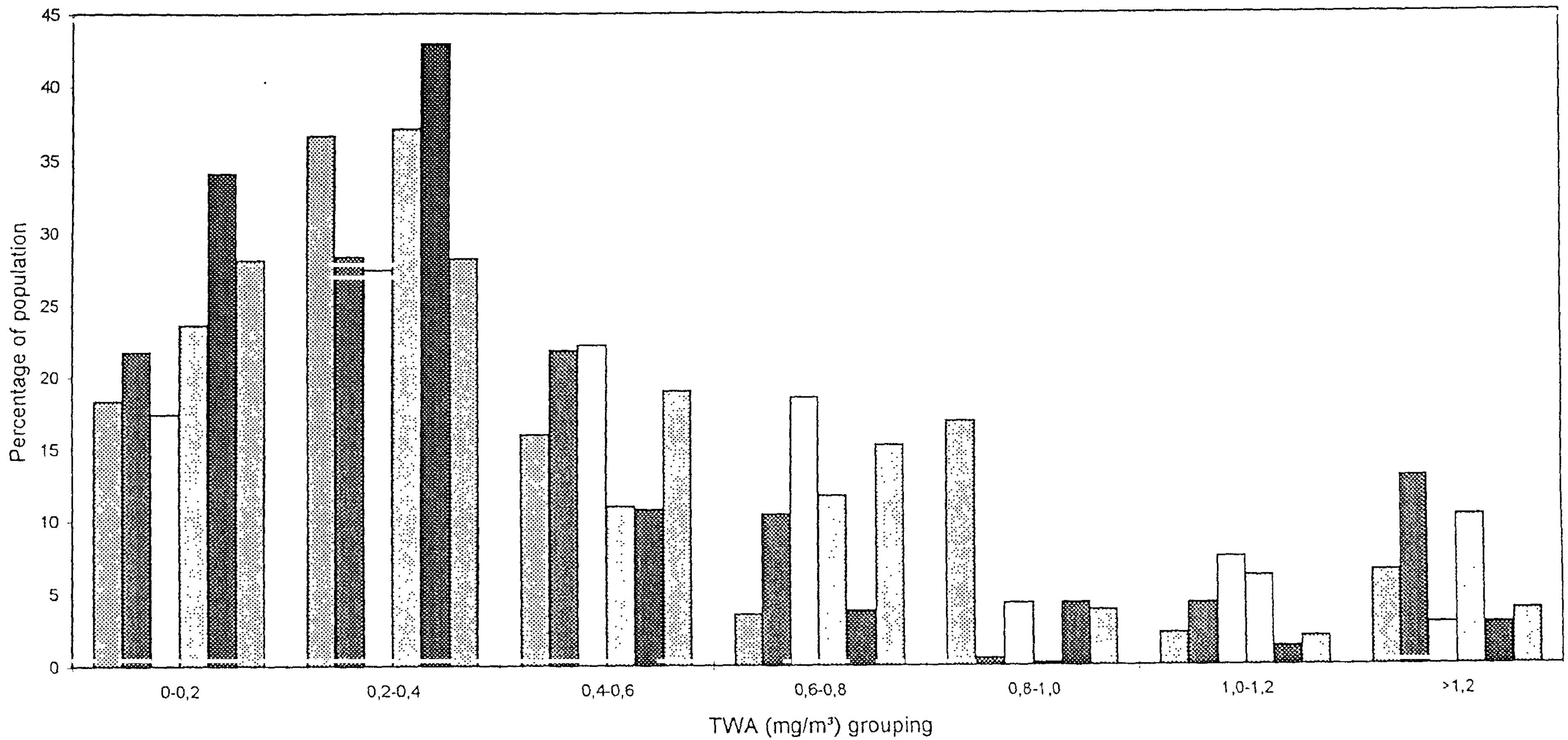

Figure 23 NOFS region surface population TWA distribution (half yearly cycles Jan. 1992 to Jun. 1994)

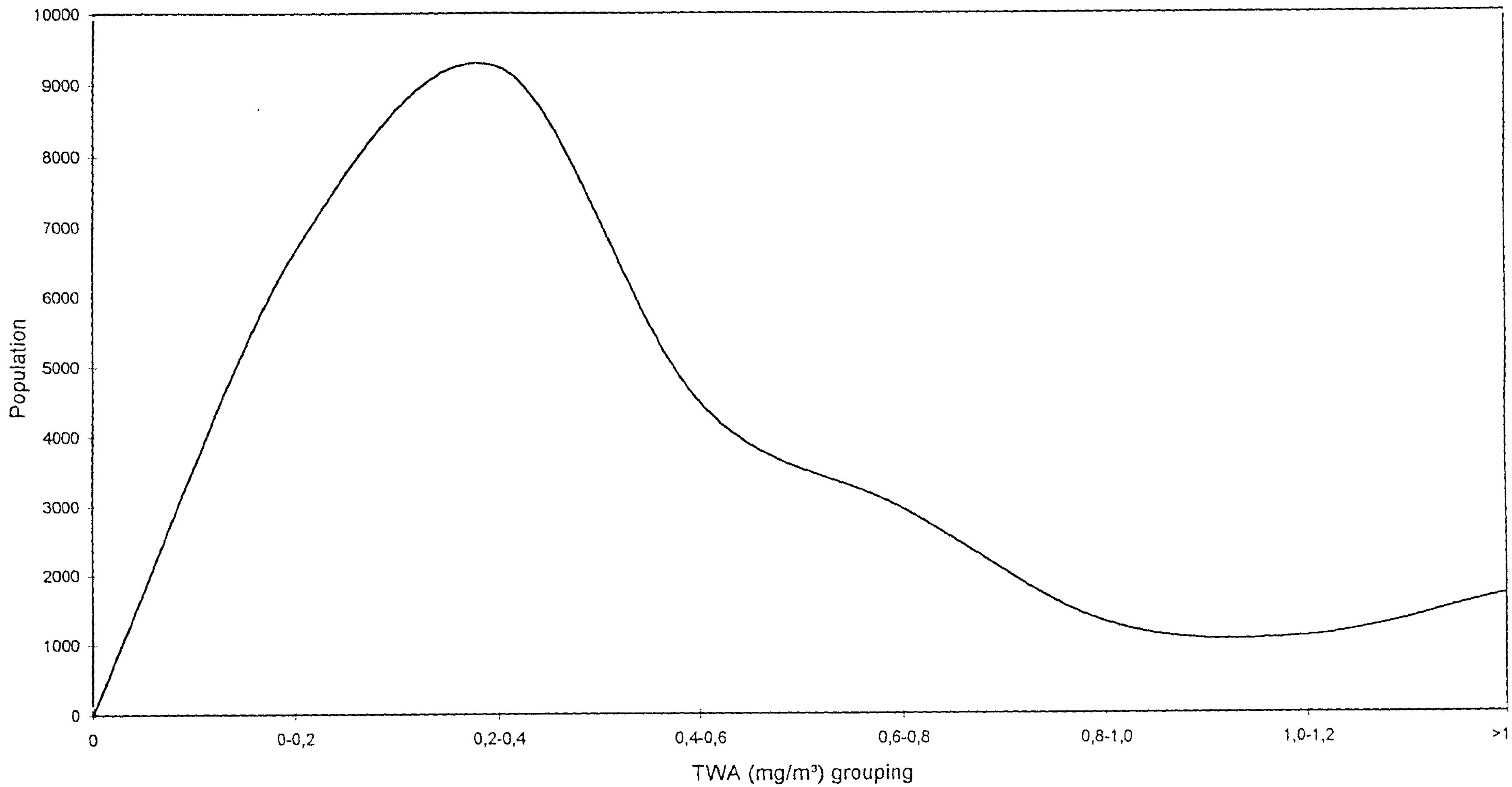

Figure 24 NOFS region total surface population TWA distribution

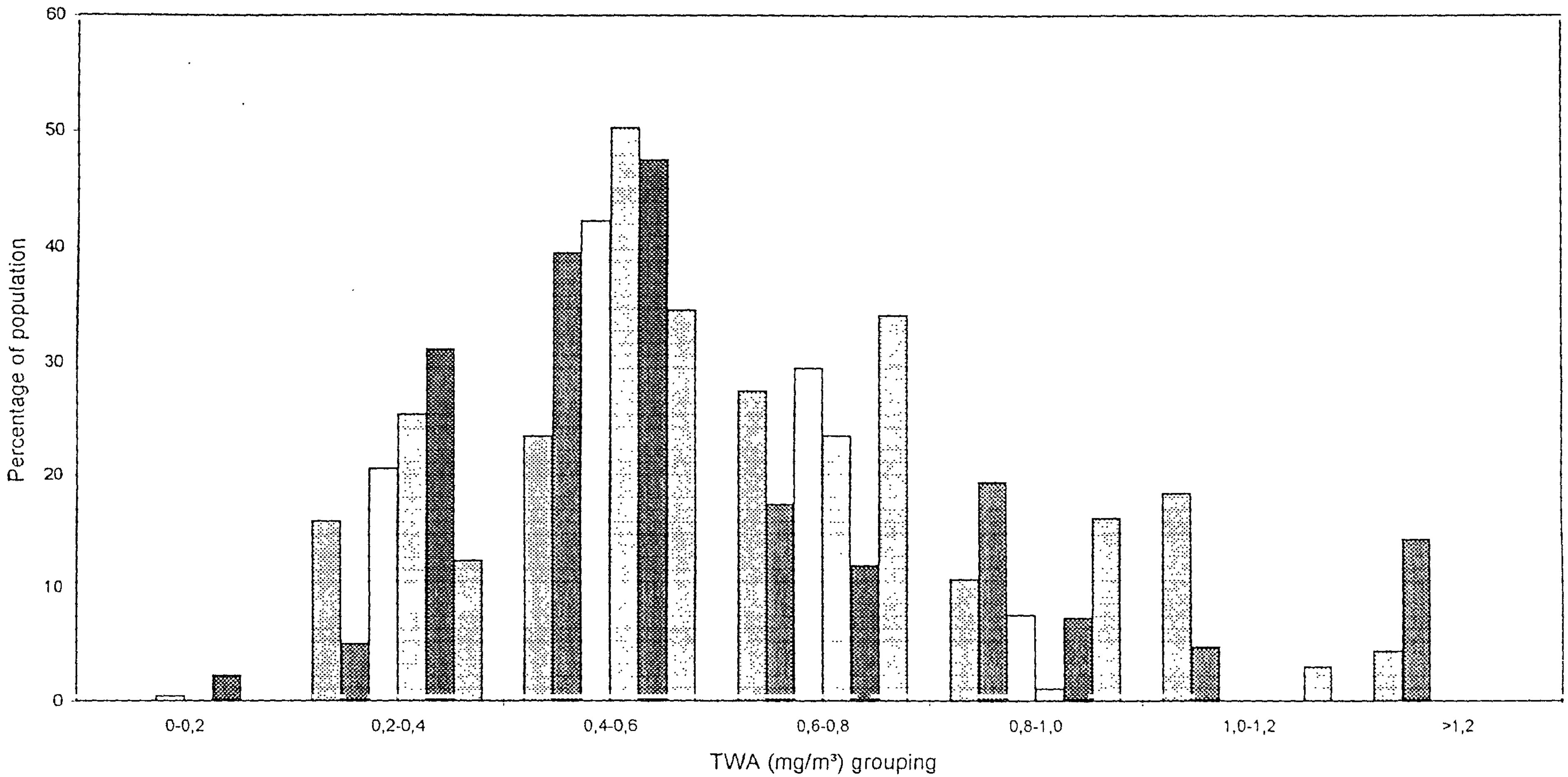

Figure 25 Southern OFS region stoping and development population TWA distribution (half yearly cycles Jan. 1992 to Jun. 1994)

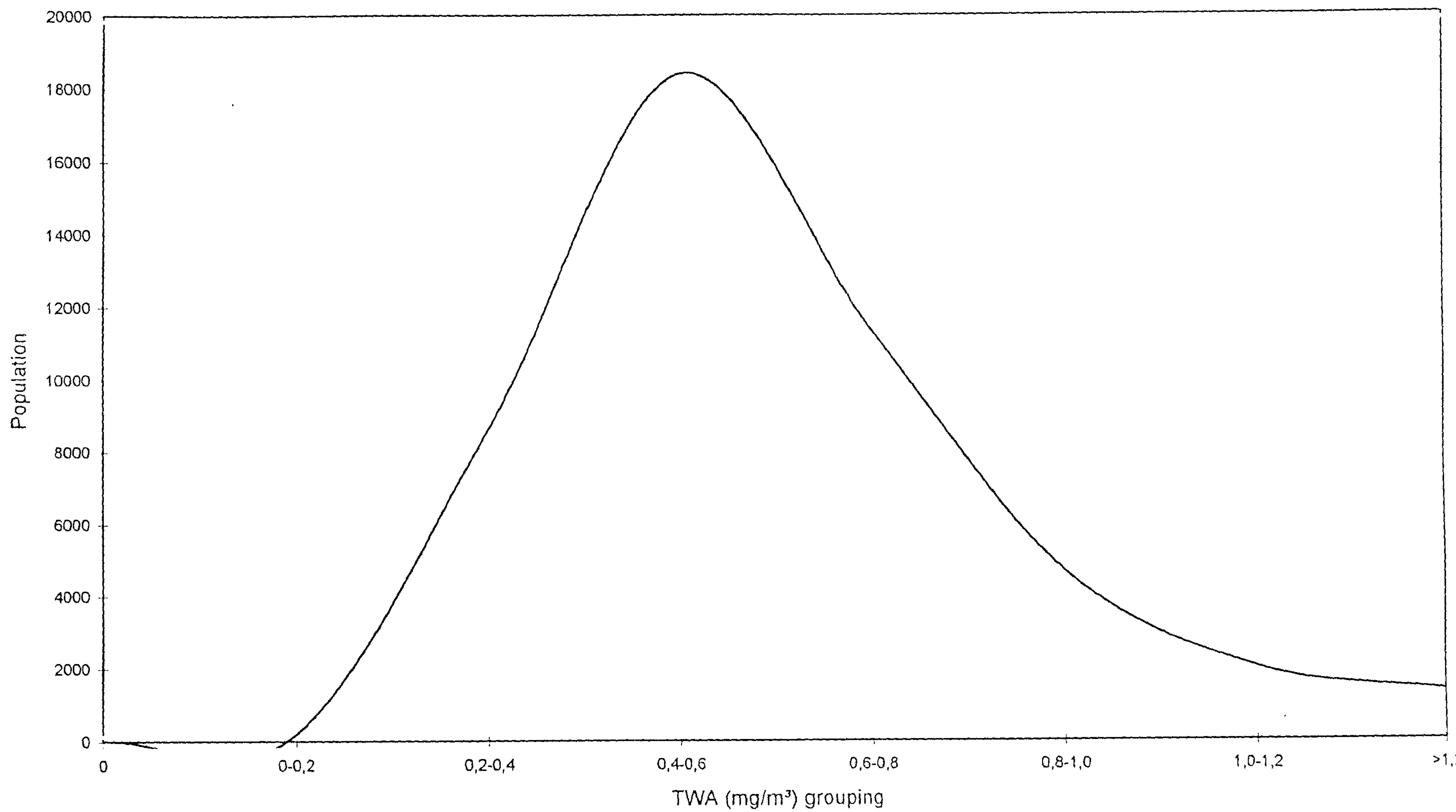

Figure 26 Southern OFS region stoping and development population TWA distribution

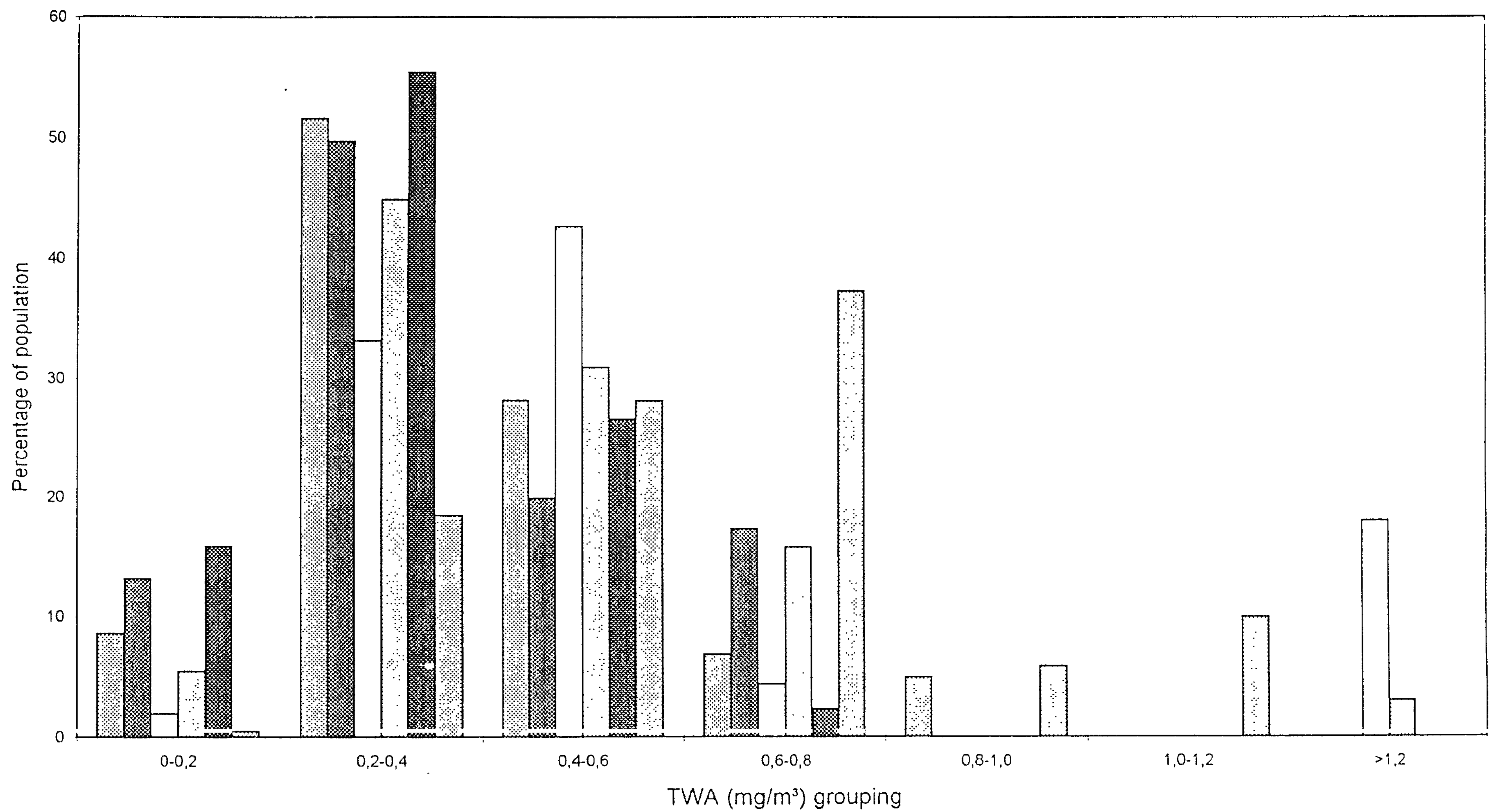

Figure 27 Southern OFS underground roving population TWA distribution (half yearly cycles Jan. 1992 to Jun. 1994)

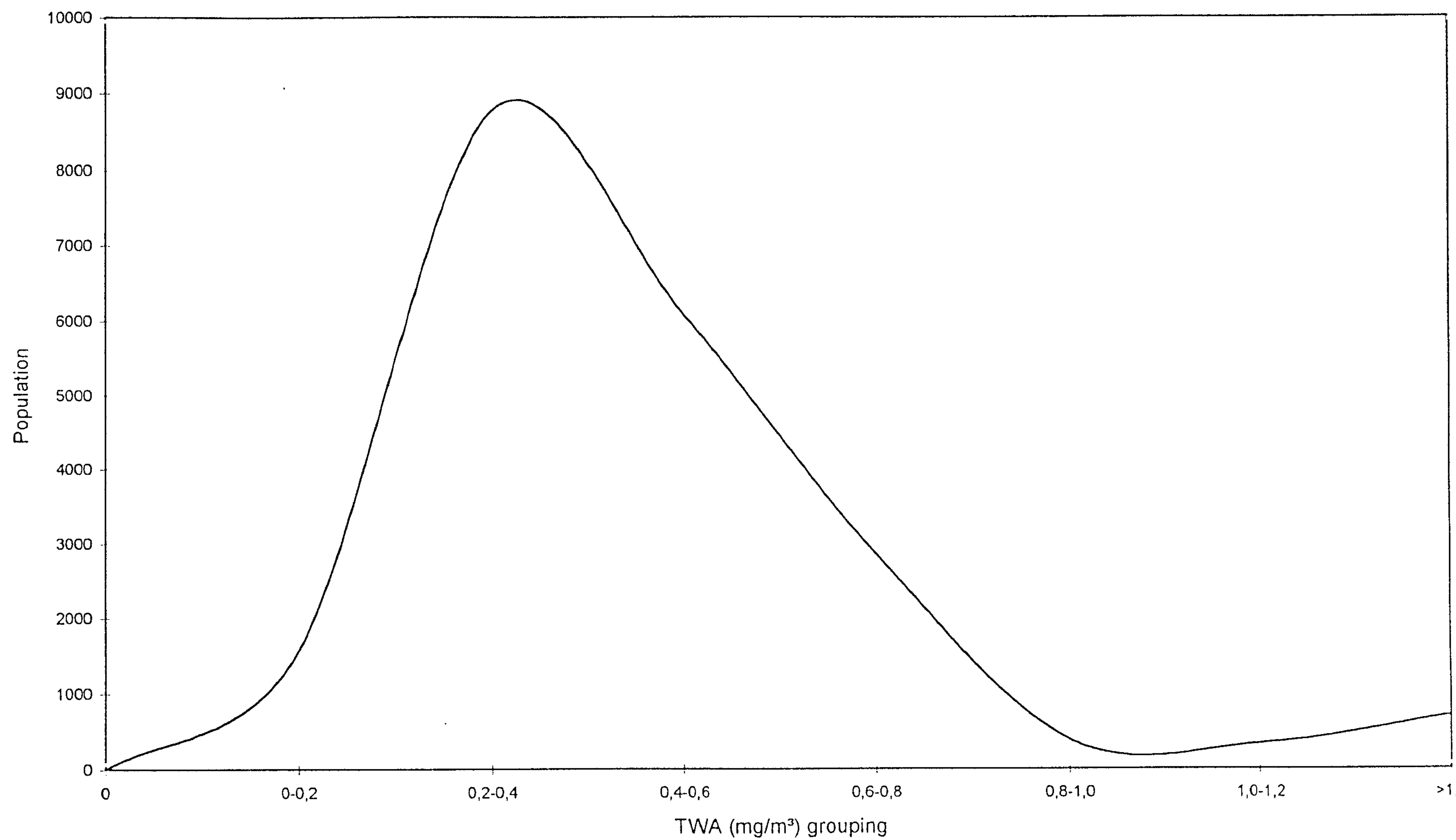

Figure 28 Southern OFS region total underground roving population TWA distribution

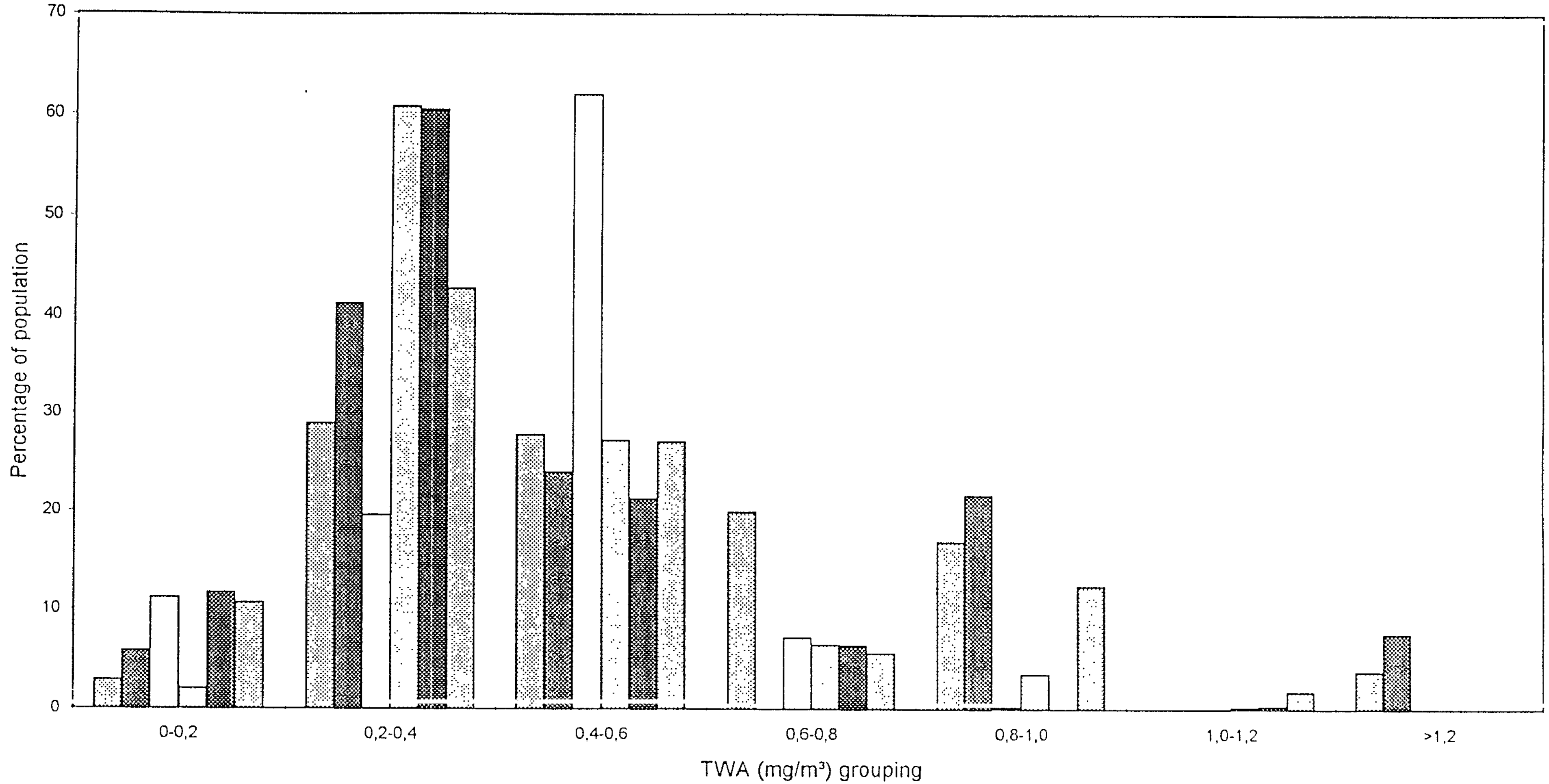

Figure 29 SOFS surface population TWA distribution (half yearly cycles Jan. 1992 to Jun. 1994)

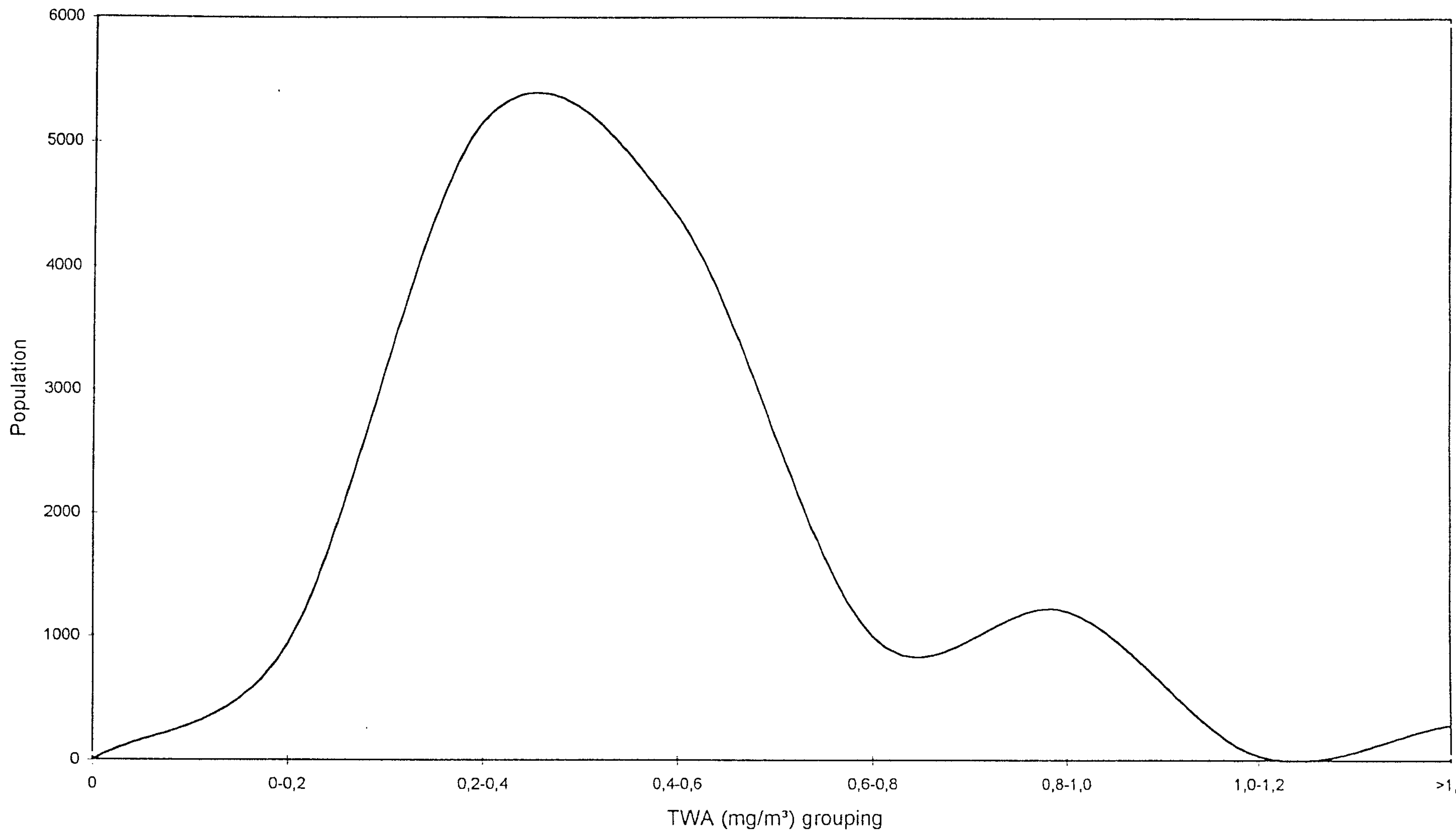

Figure 30 Southern OFS region total surface population TWA distribution

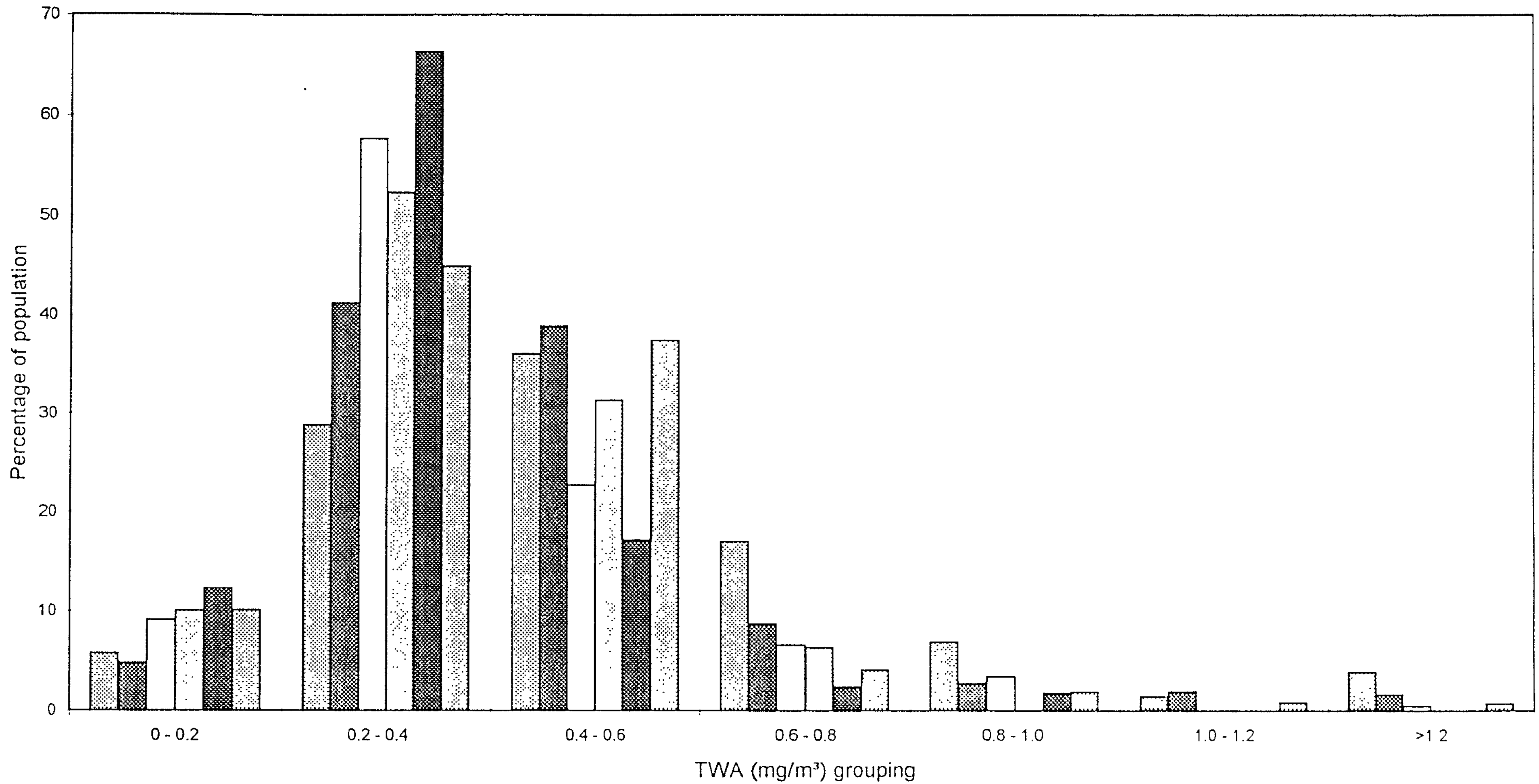

Figure 31 West Wits. stoping and development population TWA distribution (half yearly cycles Jan. 1992 to Jun. 1994)

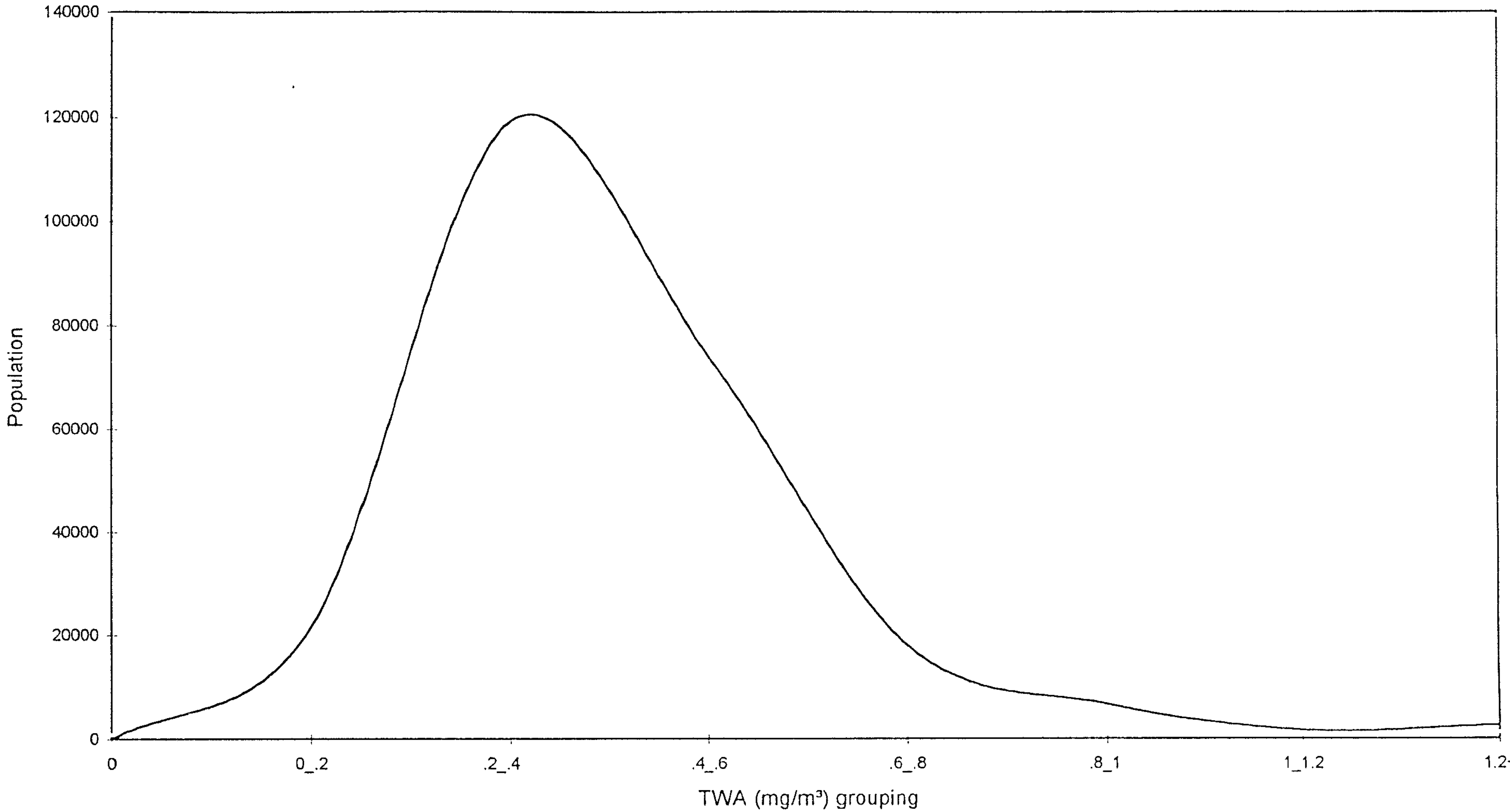

Figure 32 West Wits. region total stoping and development population TWA distribution

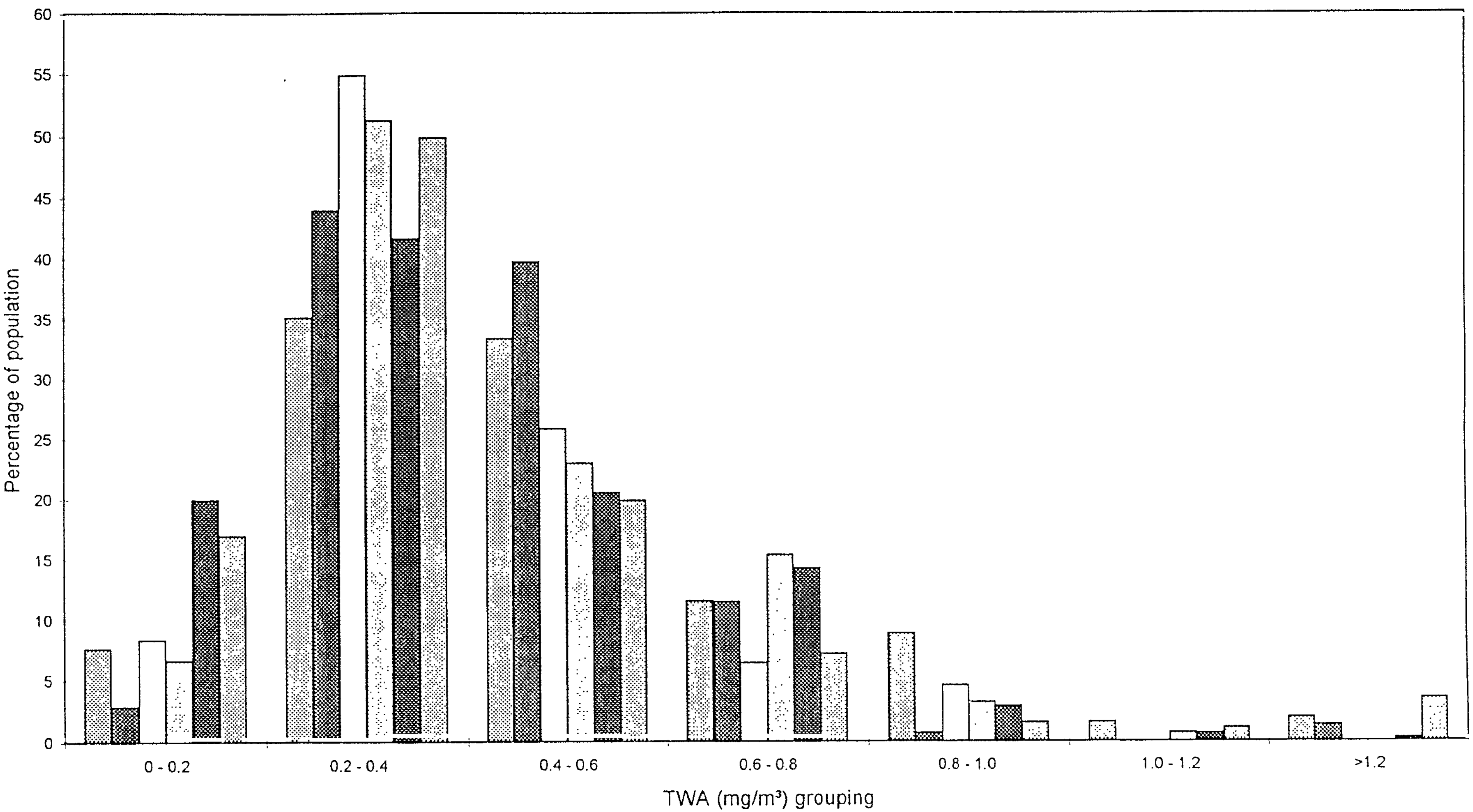

Figure 33 West Wits. region underground roving population TWA distribution (half yearly cycles Jan. 1992 to Jun. 1994)

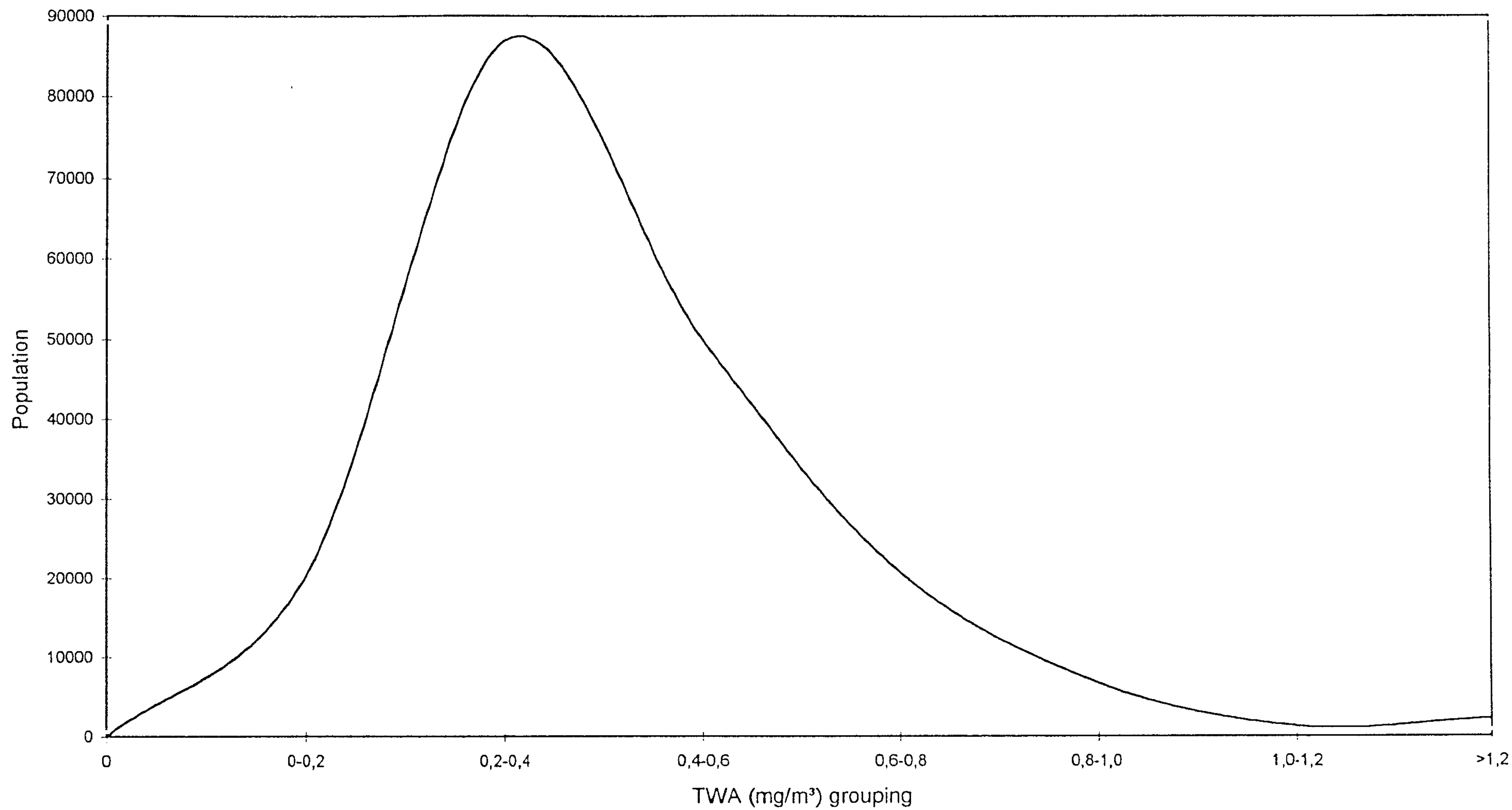

Figure 34 West Wits. region underground roving population TWA distribution

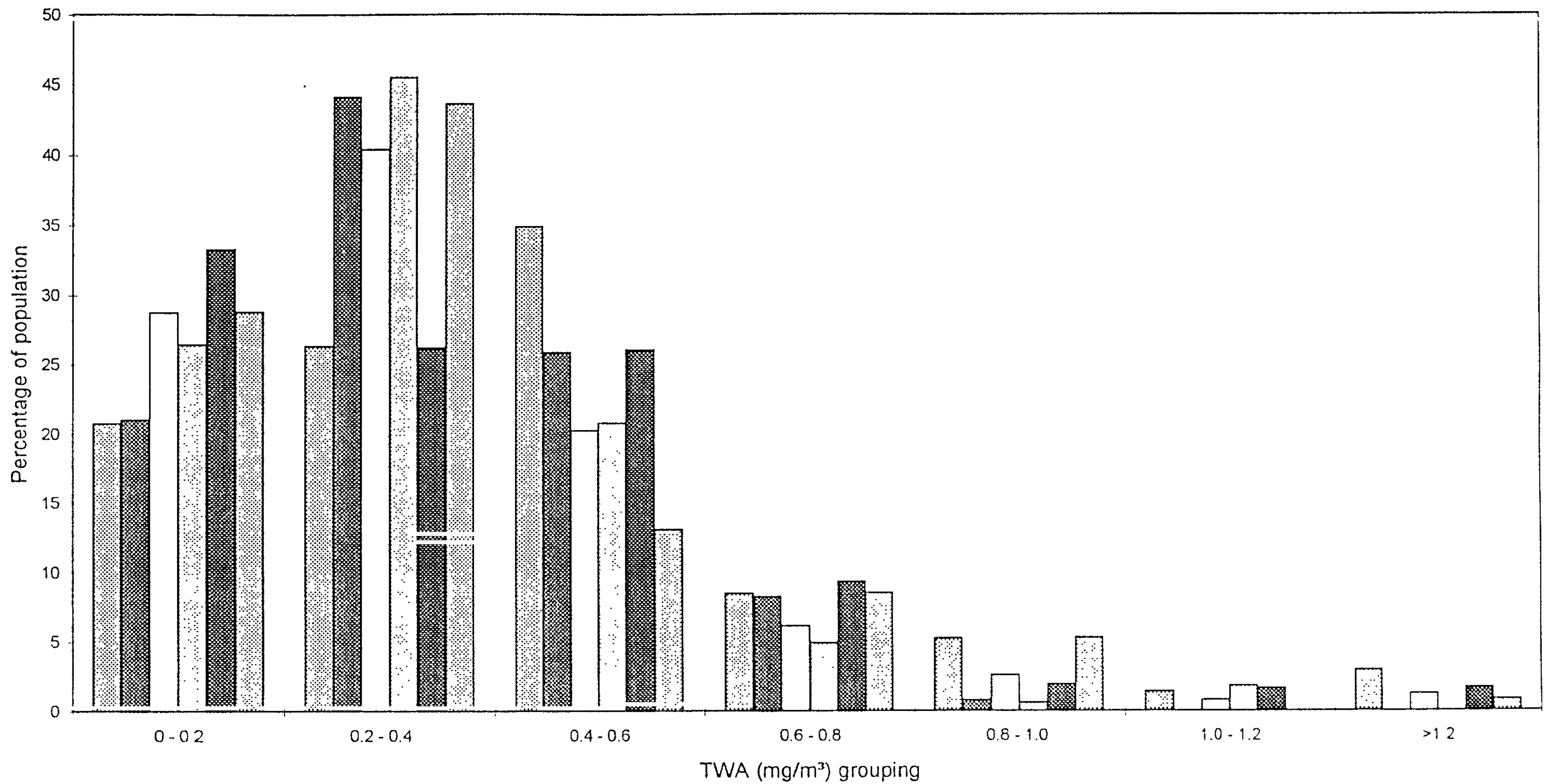

Figure 35 West Wits. surface population TWA distribution (half yearly cycles Jan. 1992 to Jun. 1994)

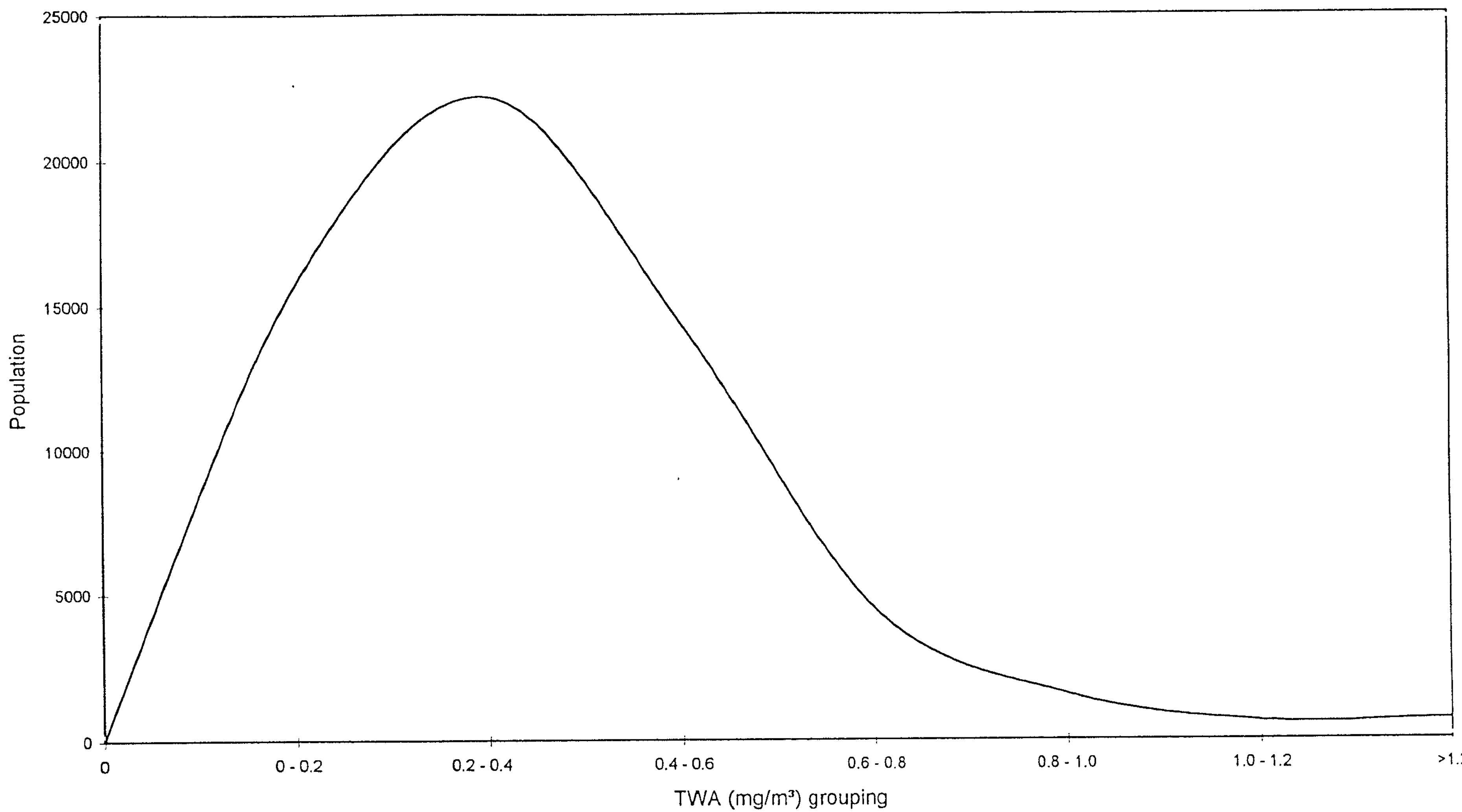

Figure 36 West Wits. region total surface population TWA distribution

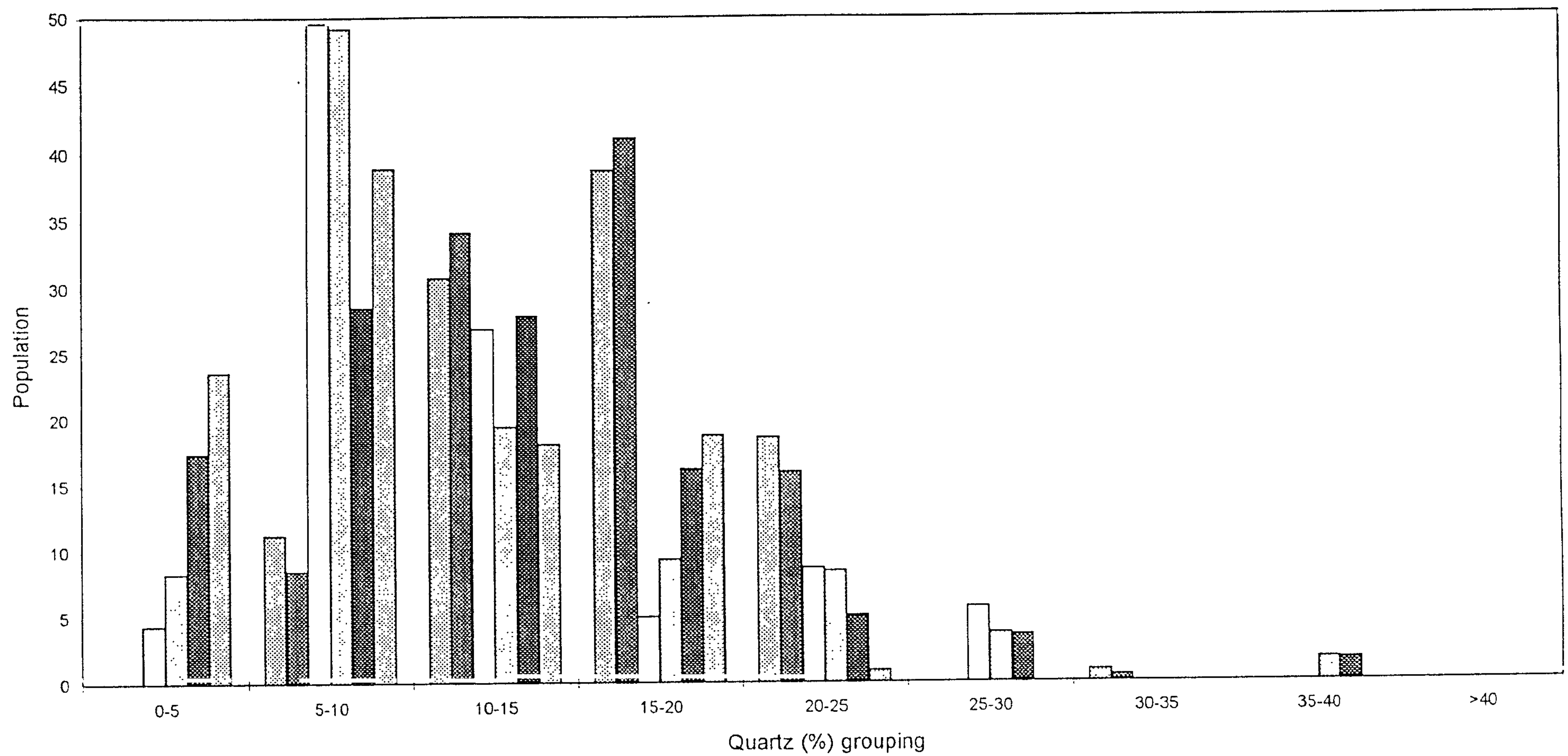

Figure 37 Eastern region total stoping and development population quartz distribution (half yearly cycles Jan. 1992 to Jun. 1994)

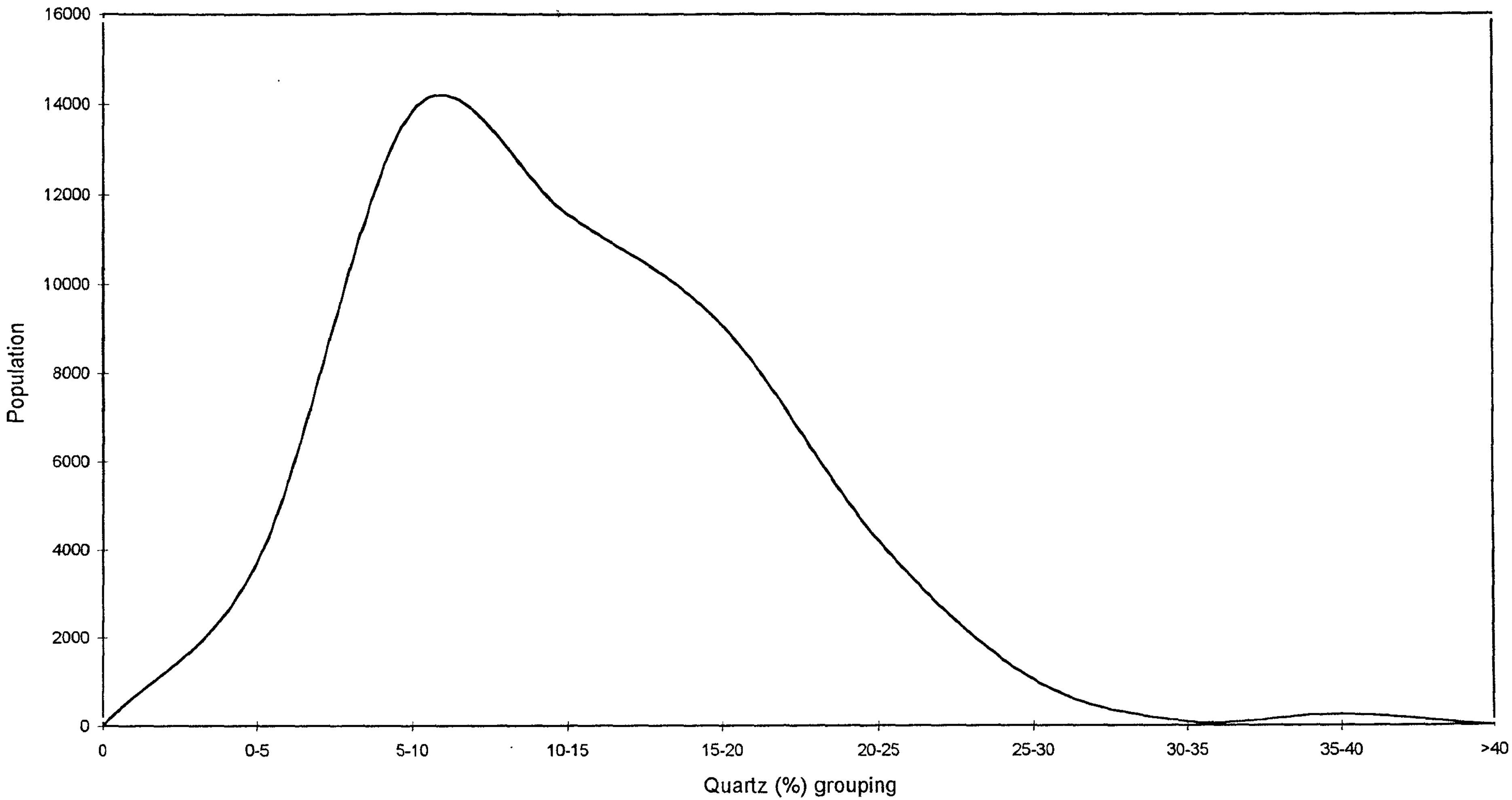

Figure 38 Eastern region total stoping and development population quartz distribution

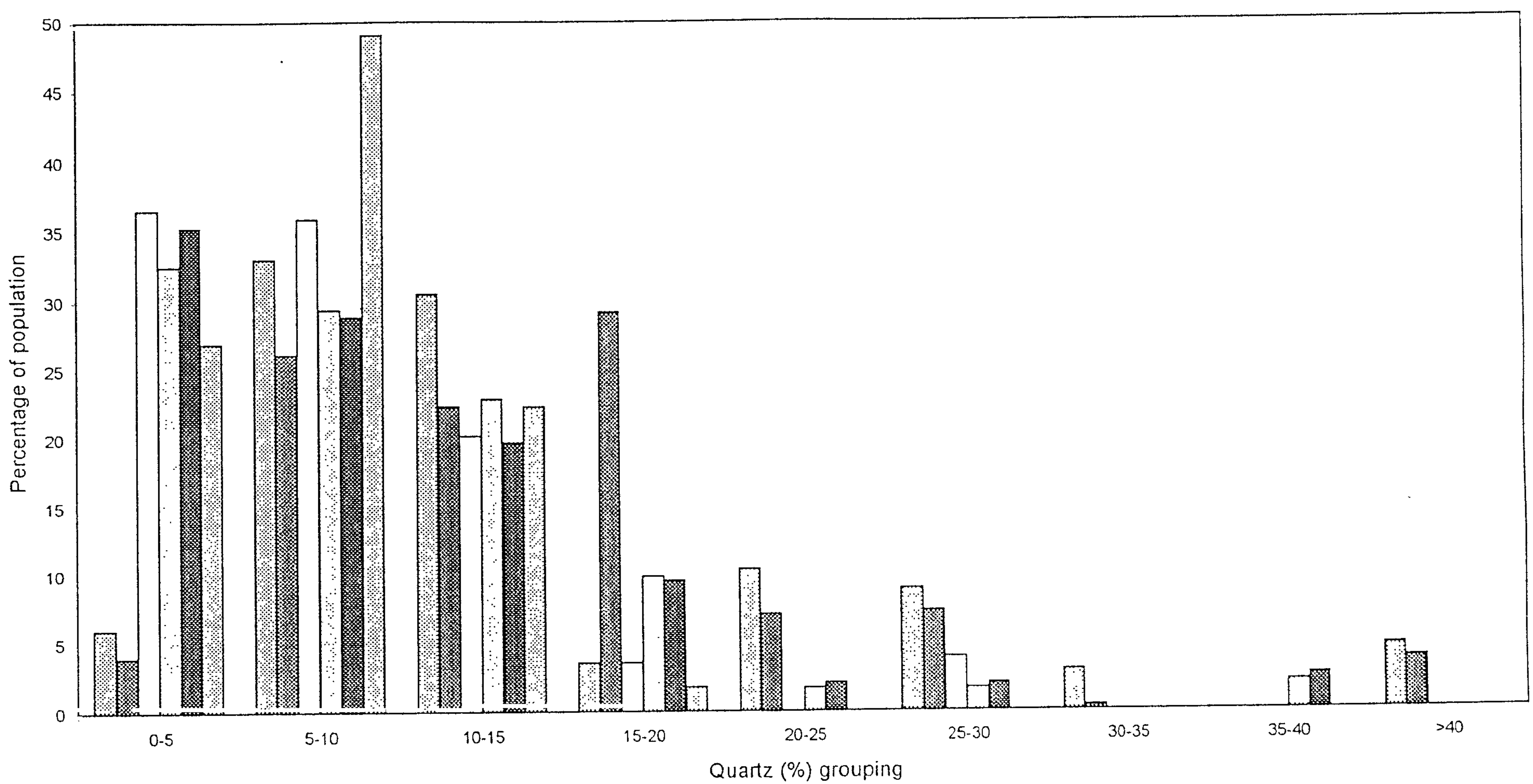

Figure 39 Eastern region underground roving population quartz distribution (half yearly cycles Jan. 1992 to Jun. 1994)

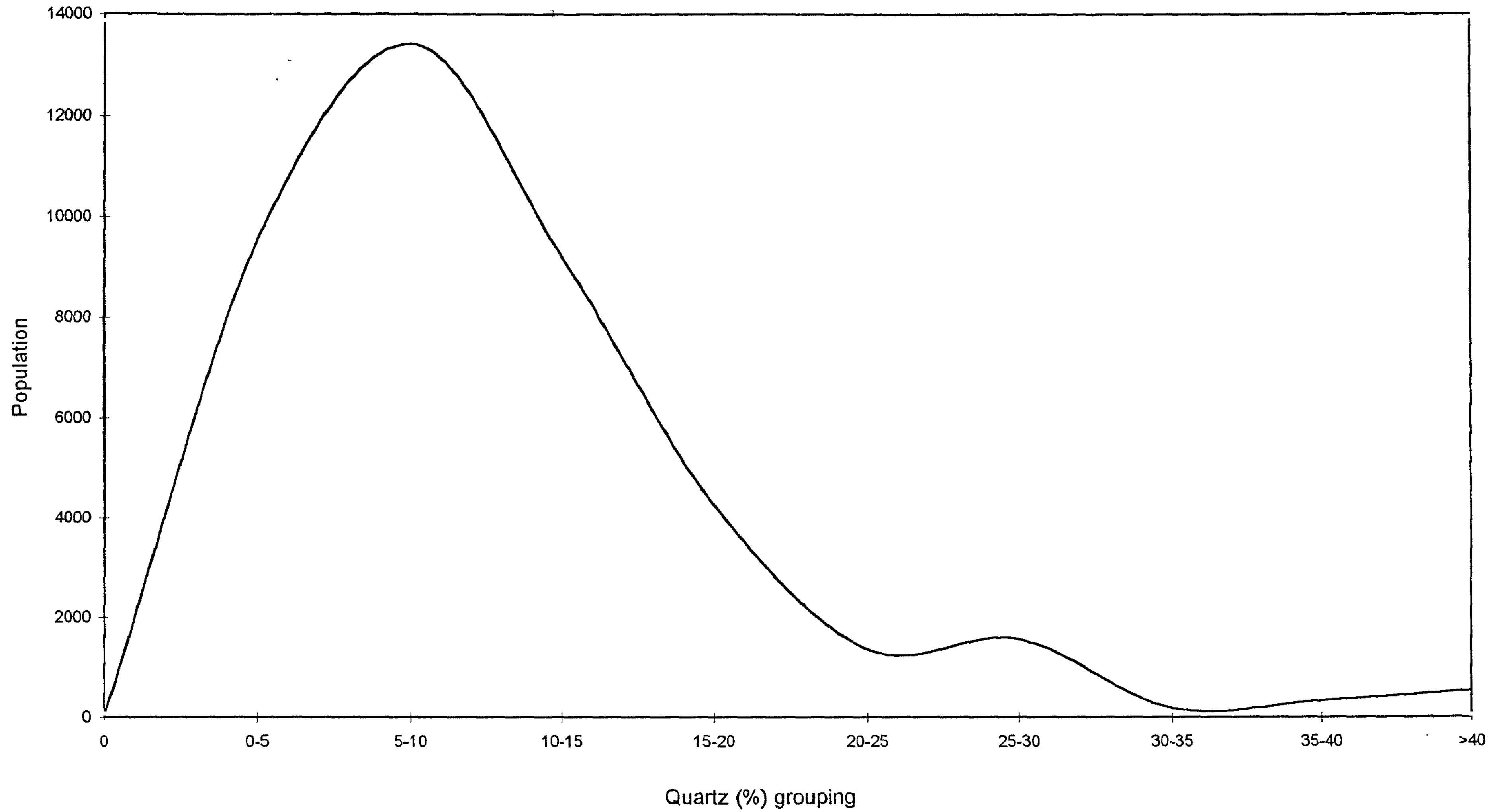

Figure 40 Eastern region total underground roving population quartz distribution

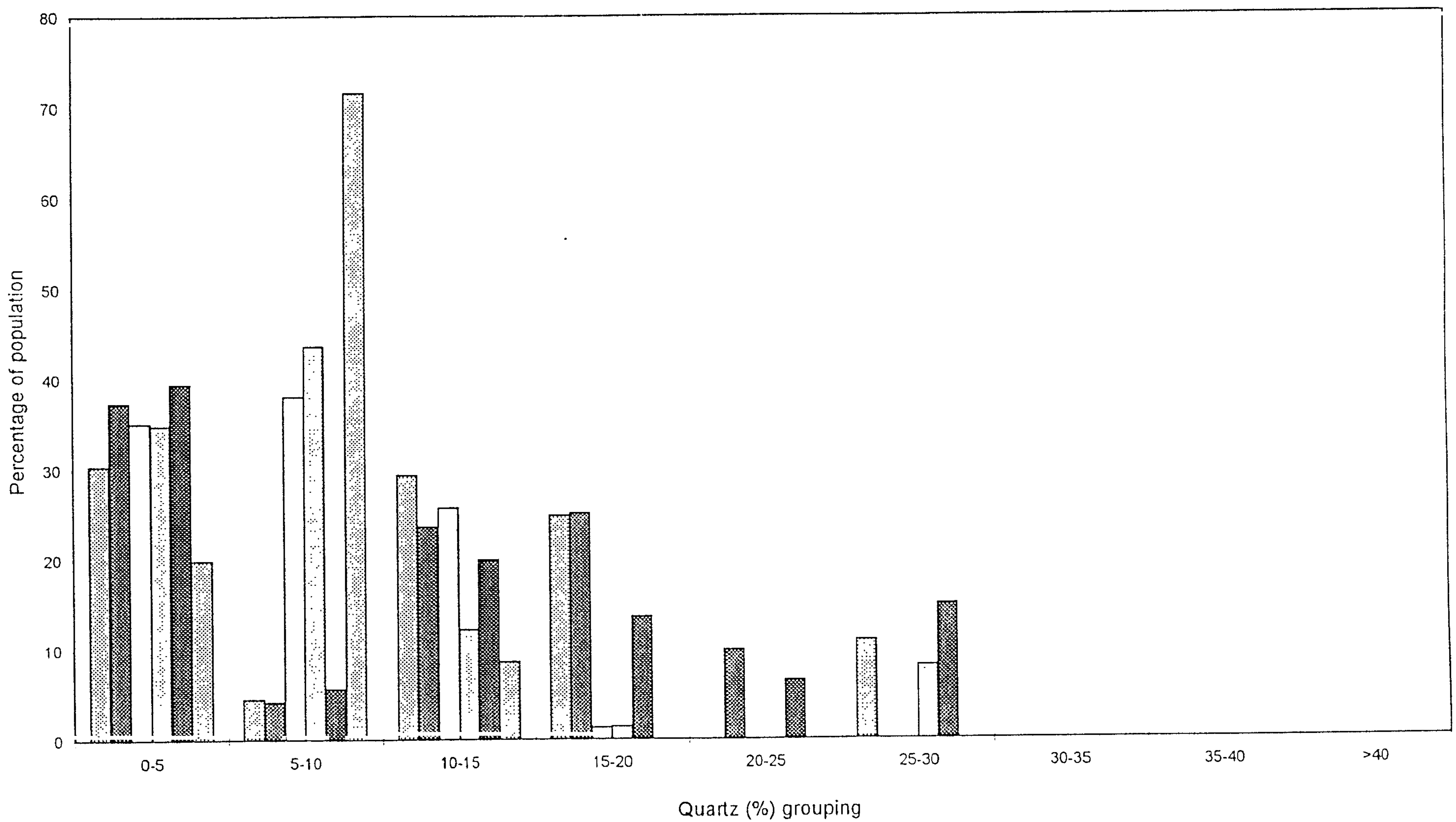

Figure 41 Eastern region surface population quartz distribution (half yearly cycles Jan. 1992to Jun. 1994)

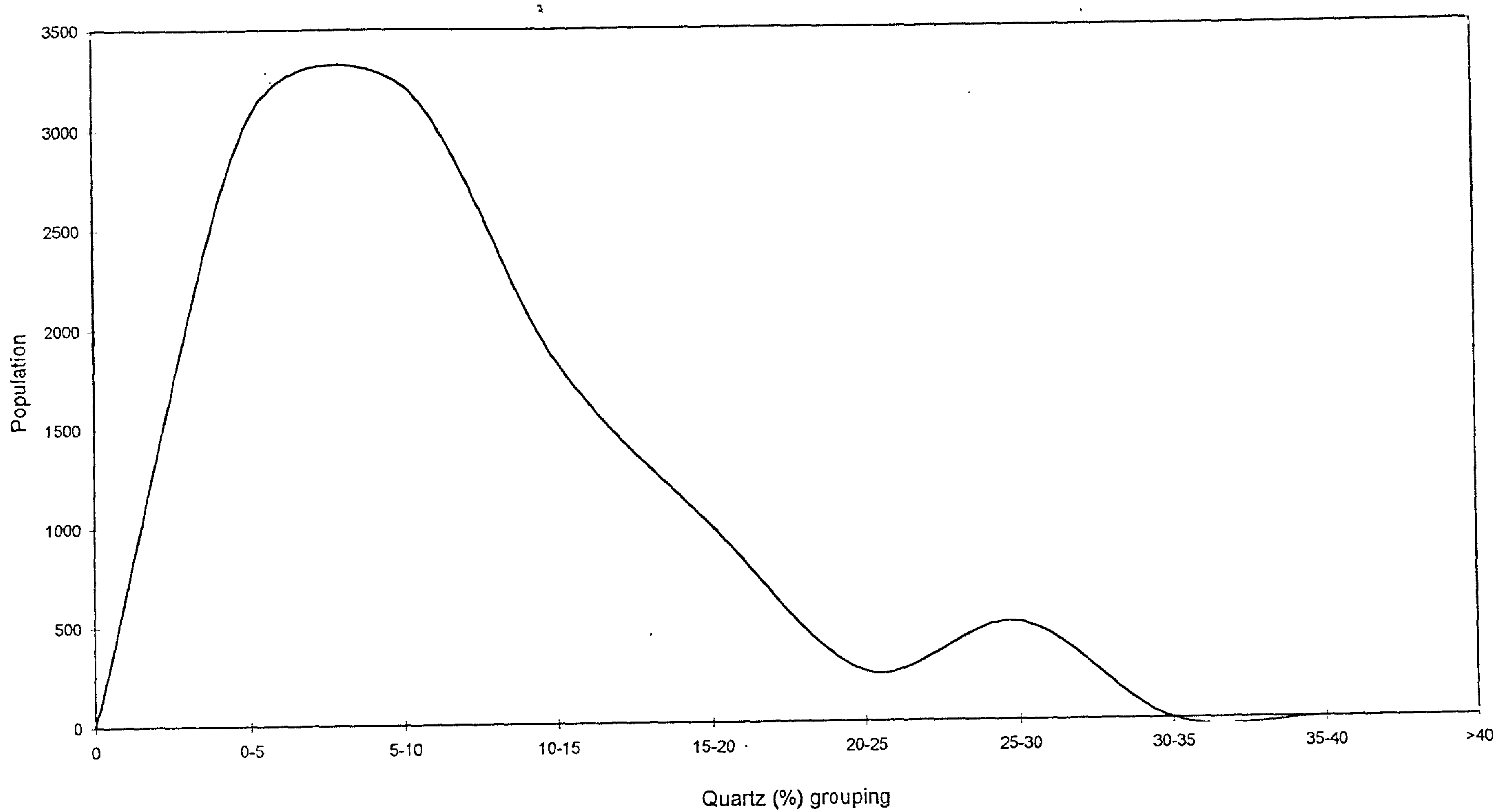

Figure 42 Eastern region total surface population quartz distribution

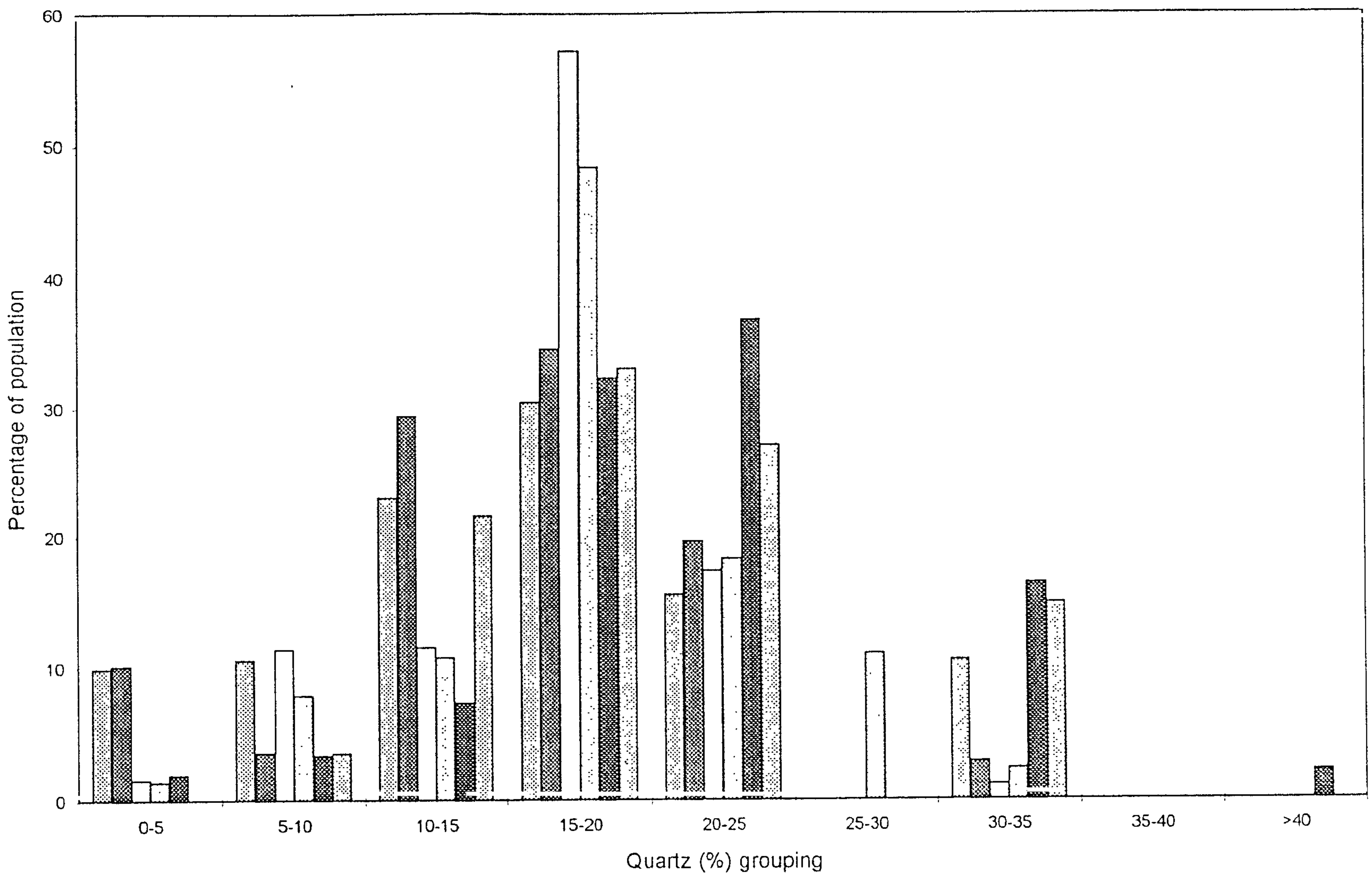

Figure 43 Elsburg region stoping and development population quartz distribution (half yearly cycles Jan. 1992 to Jun. 1994)

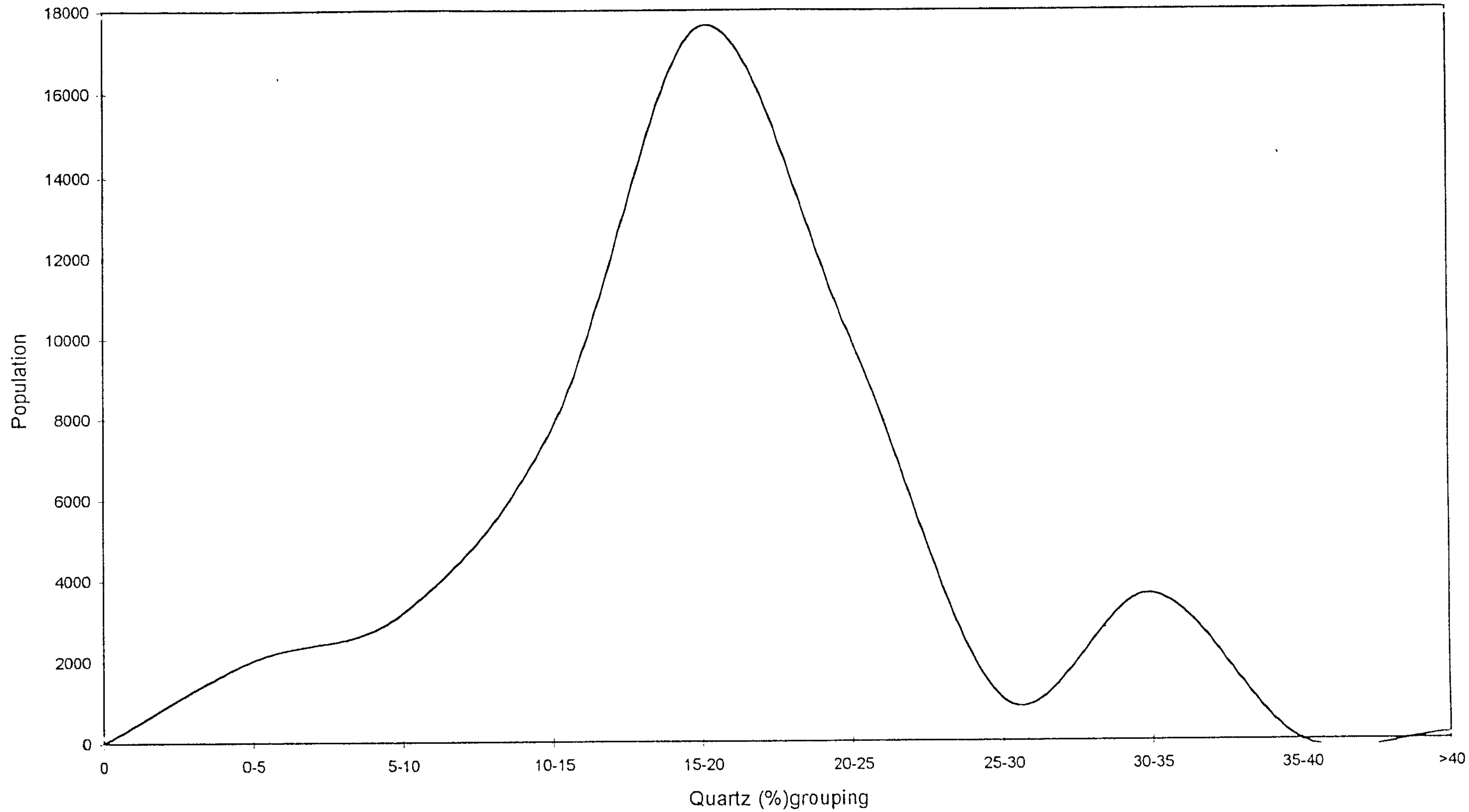

Figure 44 Elsburg region total stoping and development population quartz distribution

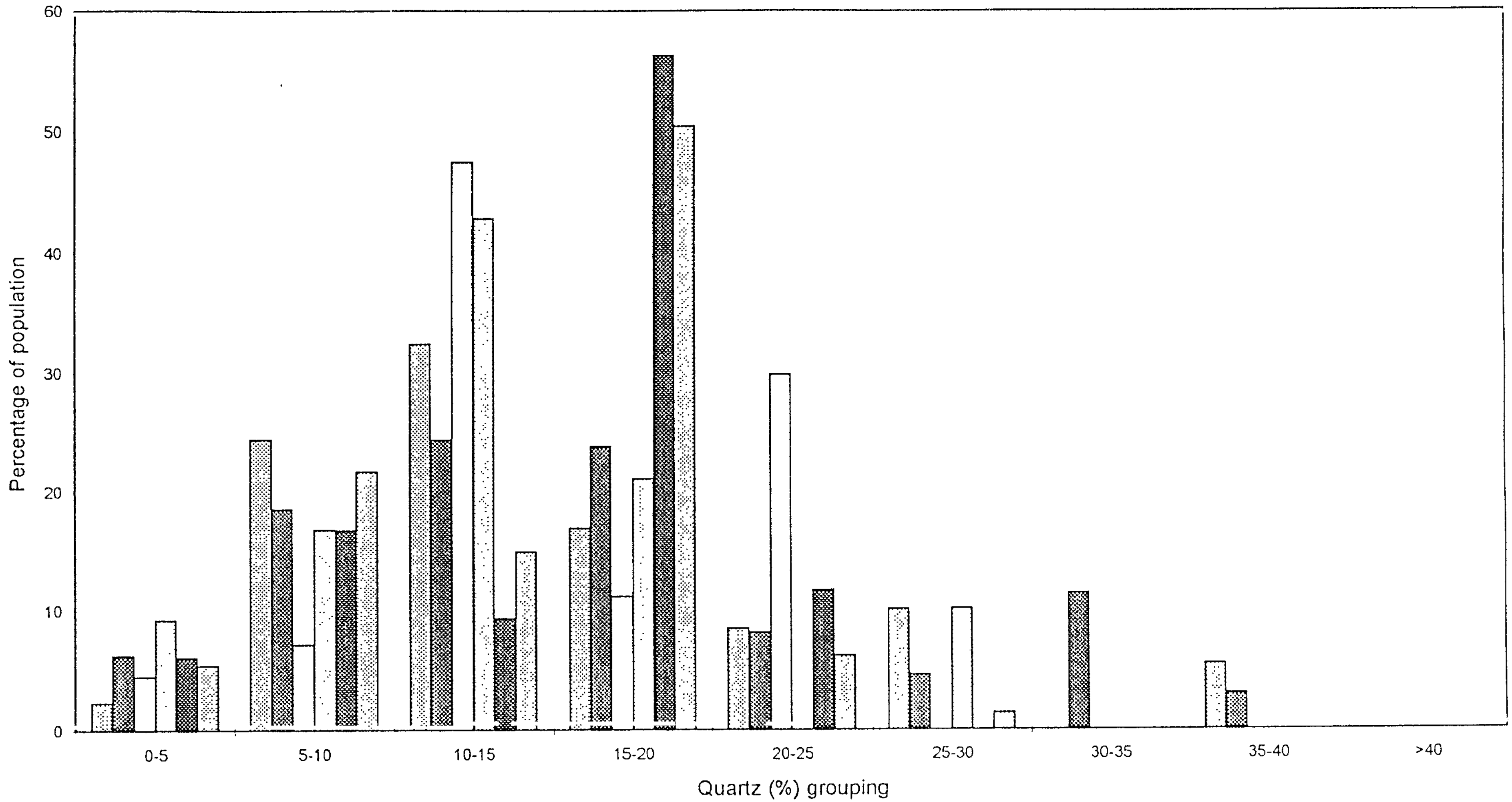

Figure 45 Elsburg region underground roving population quartz distribution (half yearly cycles Jan. 1992 to Jun. 1994)

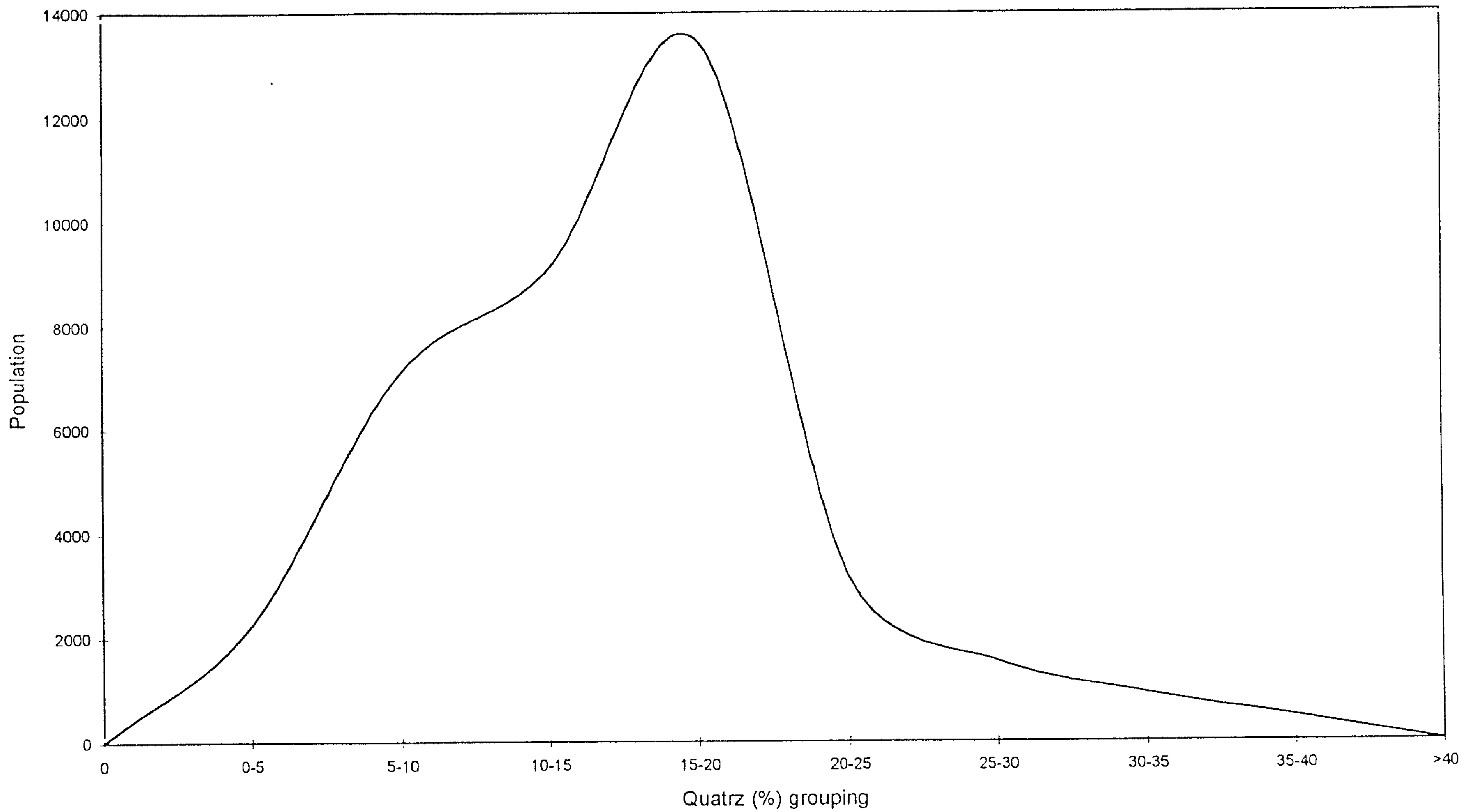

Figure 46 Elsburg region total underground roving population quartz distribution

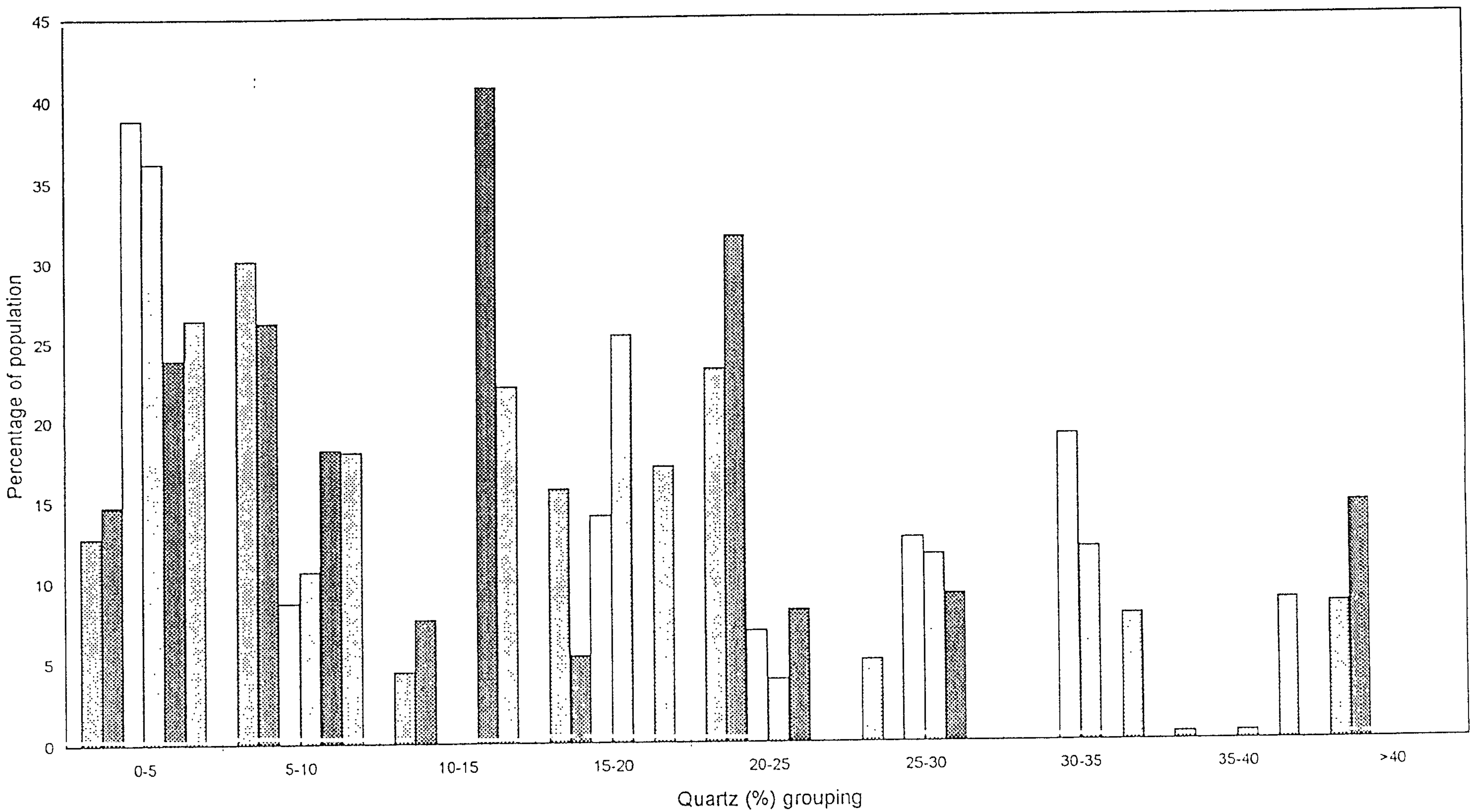

Figure 47 Elsburg region surface population quartz distribution (half yearly cycles Jan. 1992 to Jun. 1994)

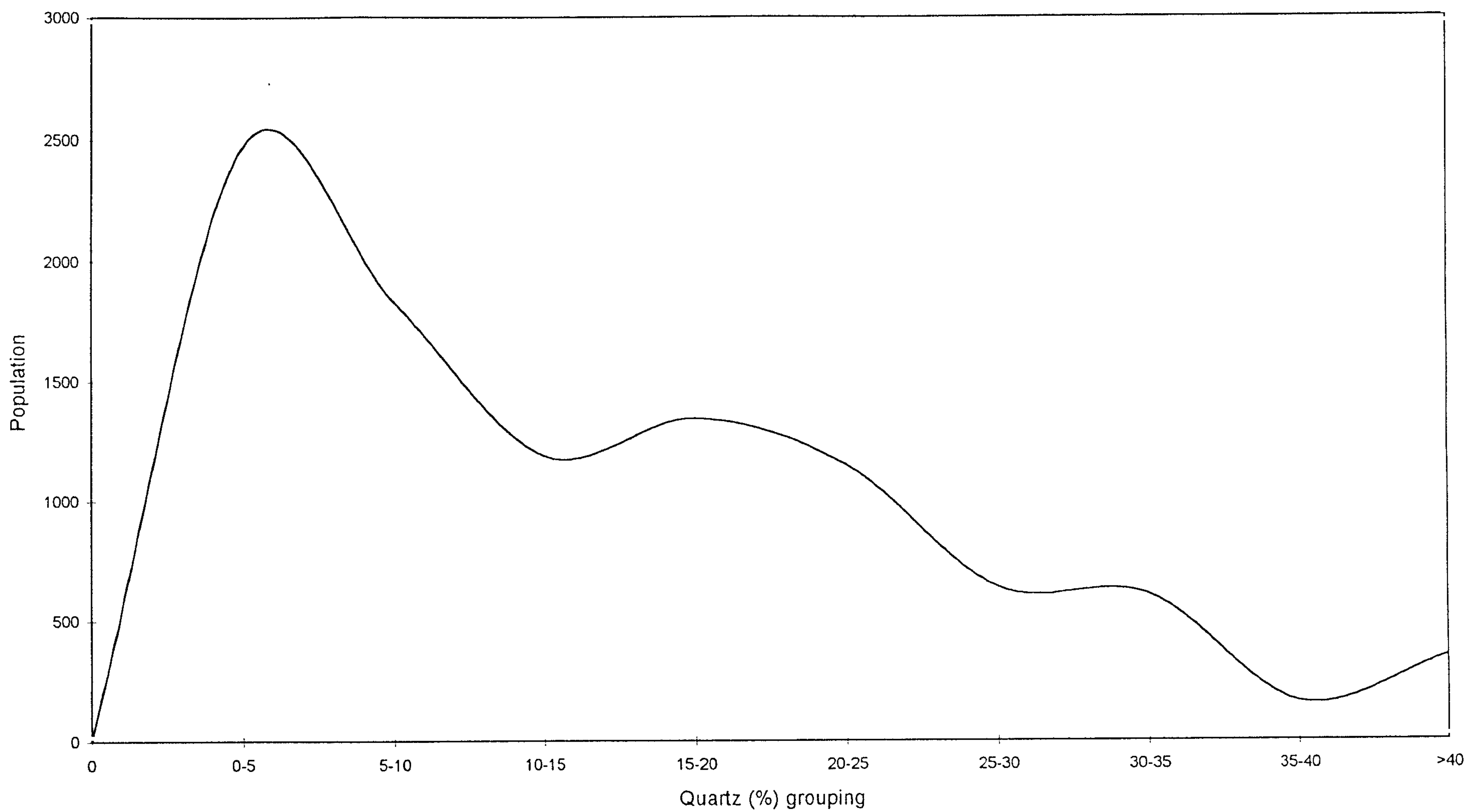

Figure 48 Elsburg region total surface population quartz distribution

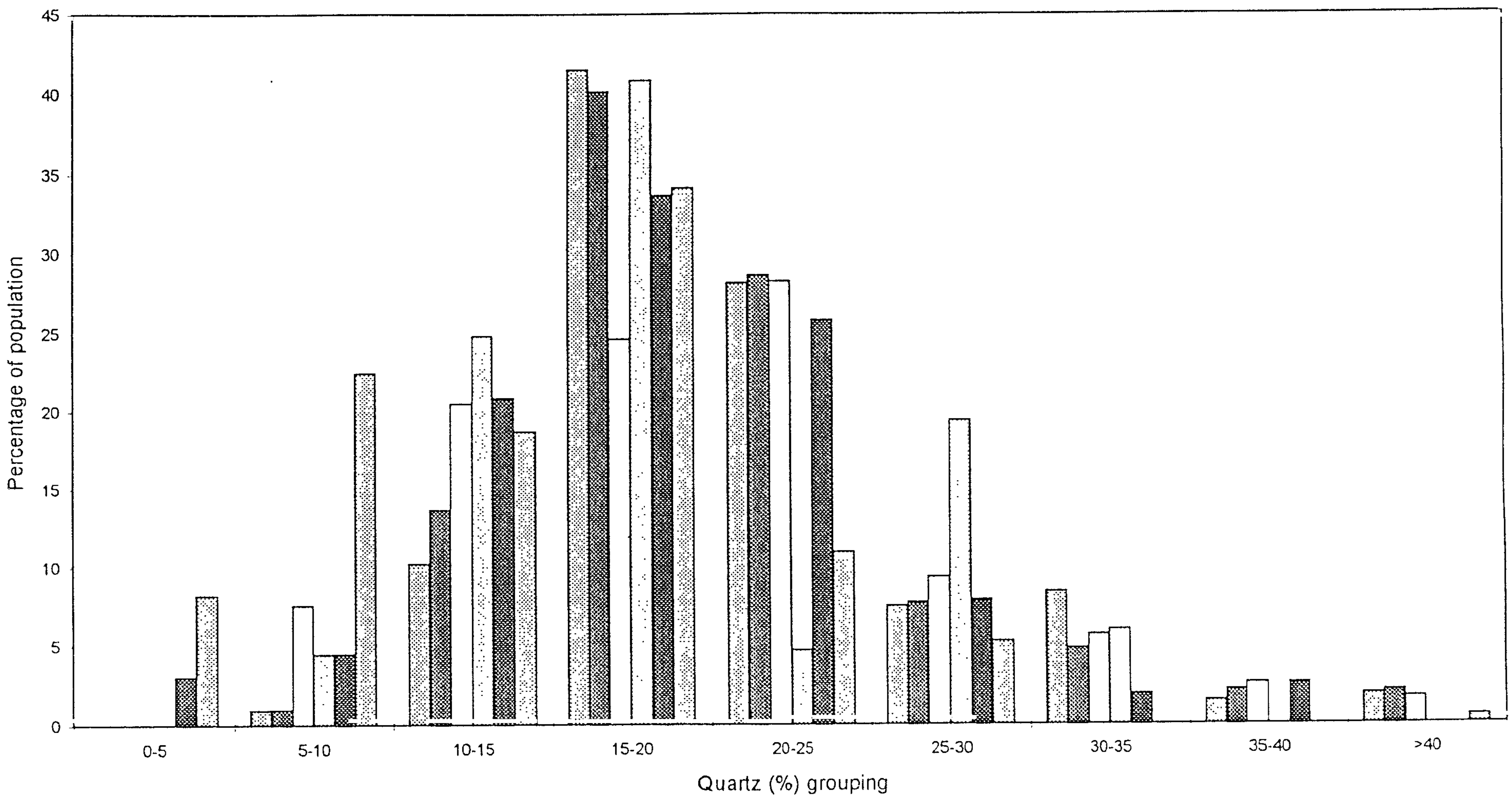

Figure 49 Klerksdorp region stoping and development quartz distribution (half yearly cycles Jan. 1992 to Jun. 1994)

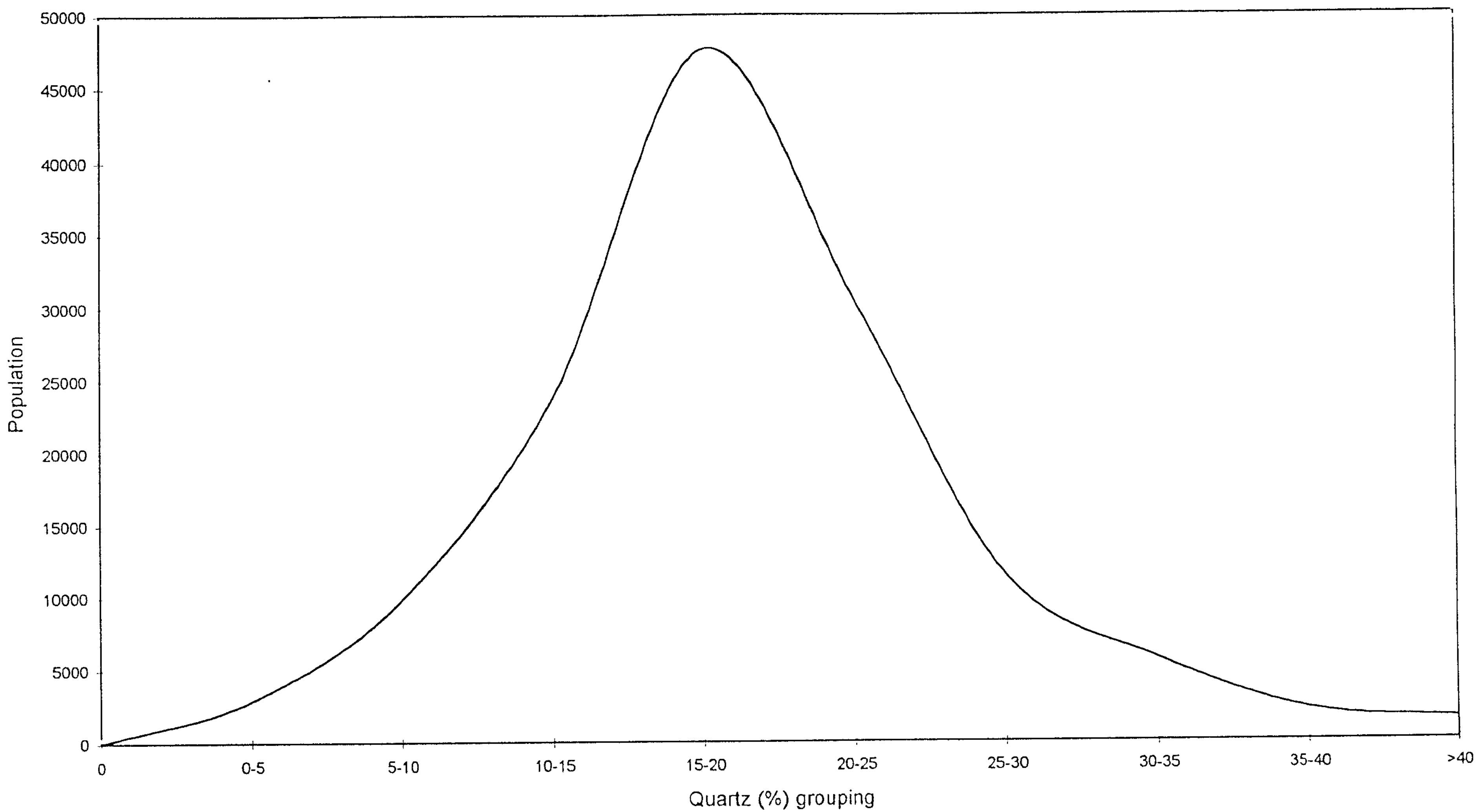

Figure 50 Klerksdorp region total stoping and development population quartz distribution

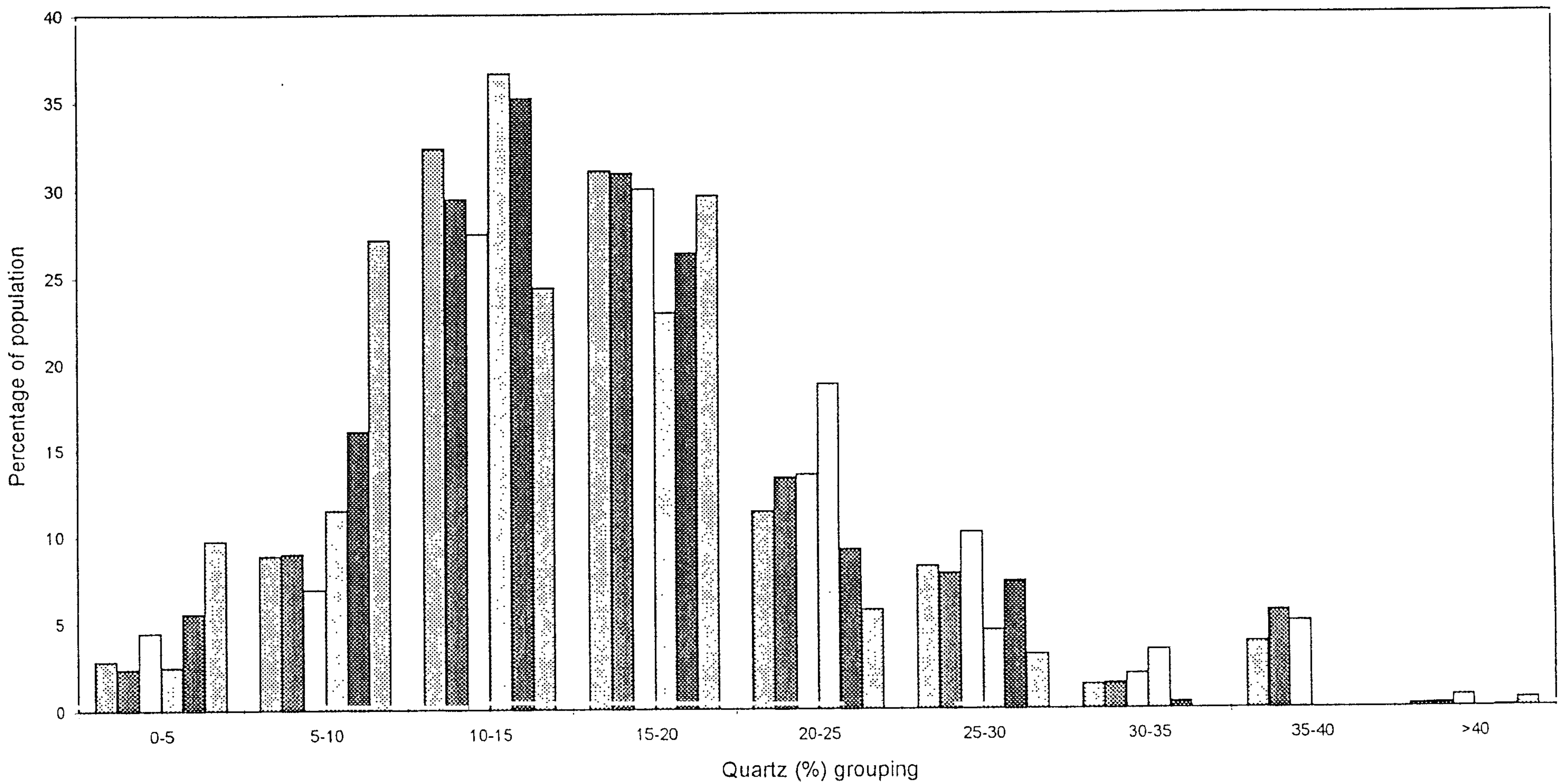

Figure 51 Klerksdorp region underground roving population quartz distribution (half yearly cycles Jan. 1992 to Jun. 1994)

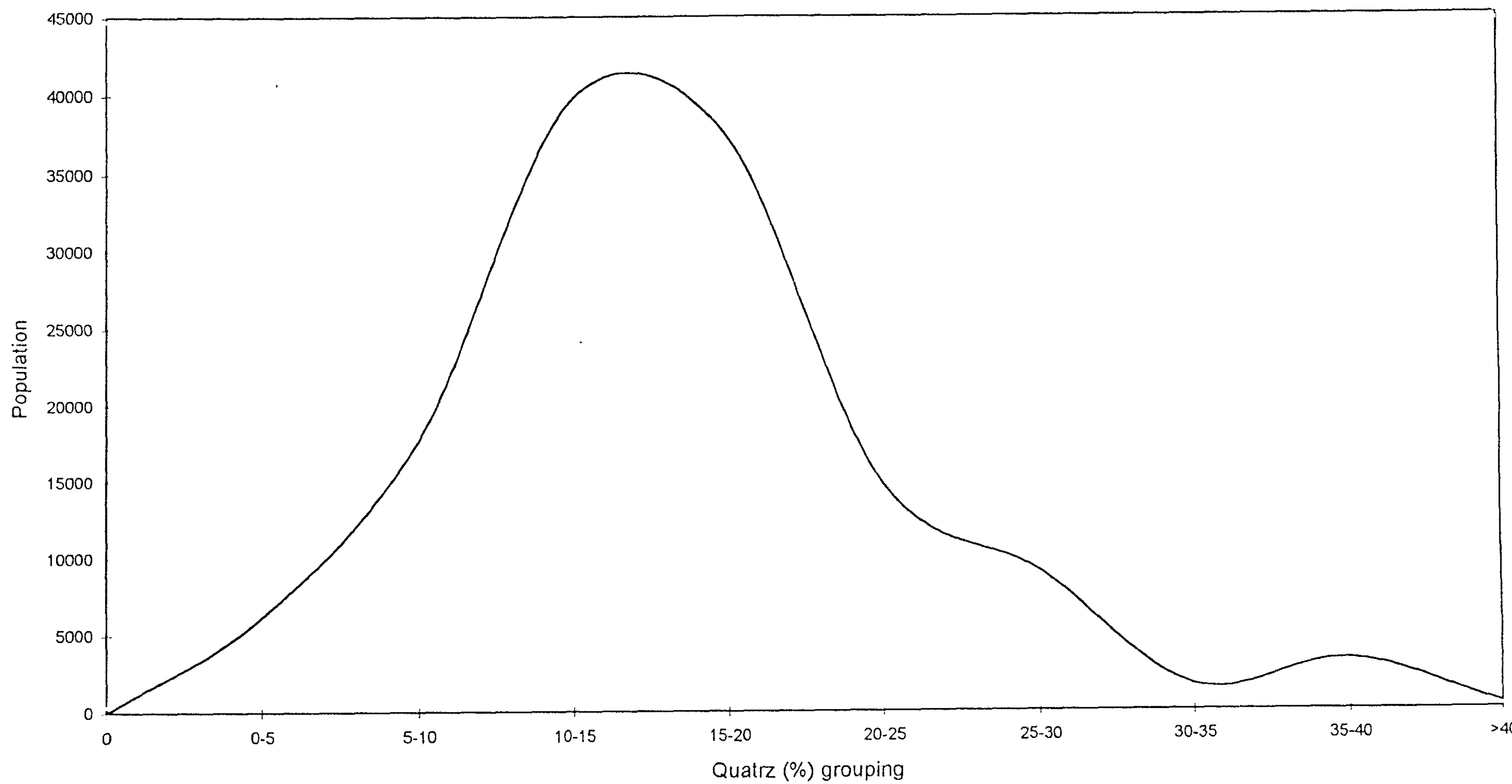

Figure 52 Klerksdorp region total underground roving population quartz distribution

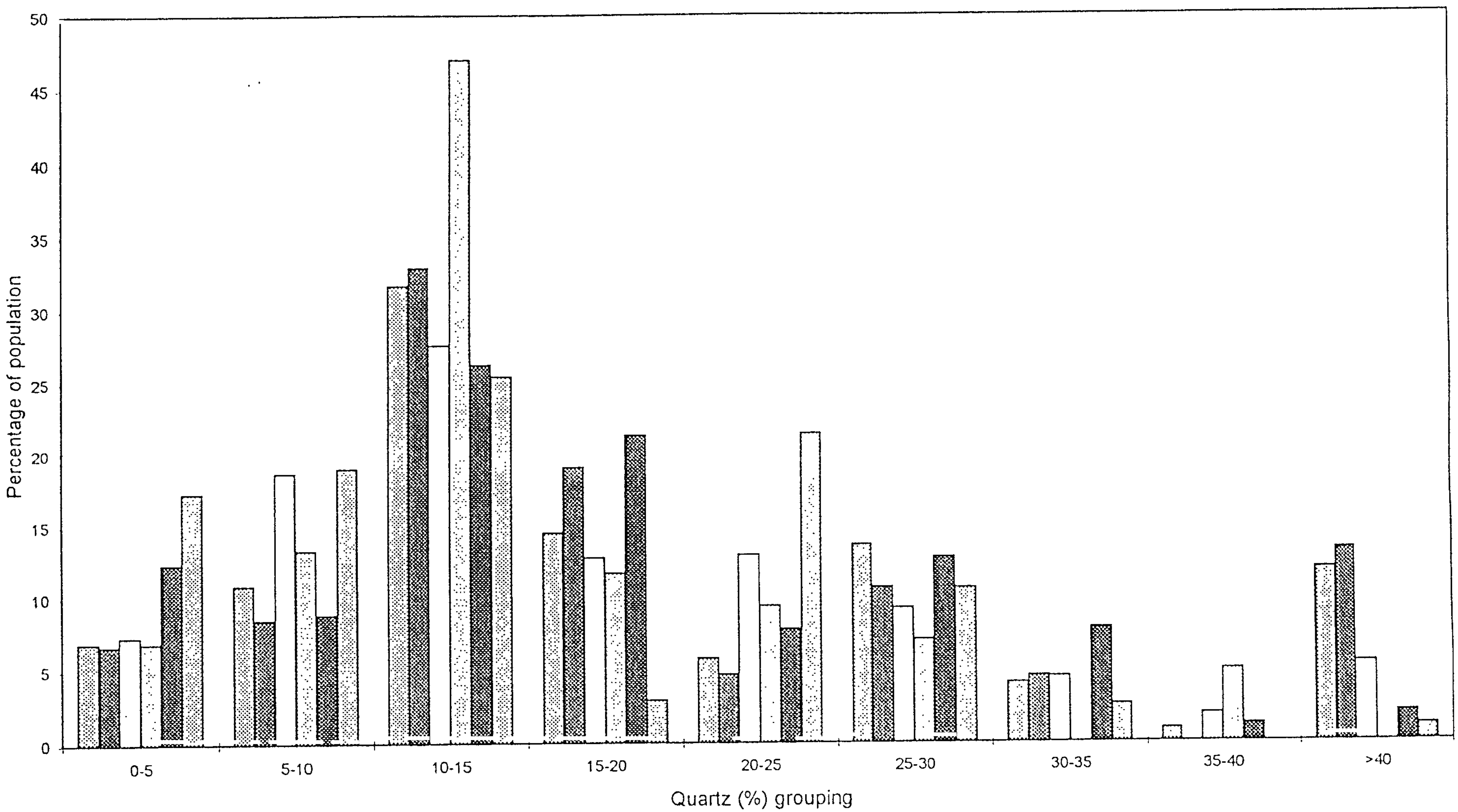

Figure 53 Klerksdorp region surface population quartz distribution (half yearly cycles Jan. 1992 to Jun. 1994)

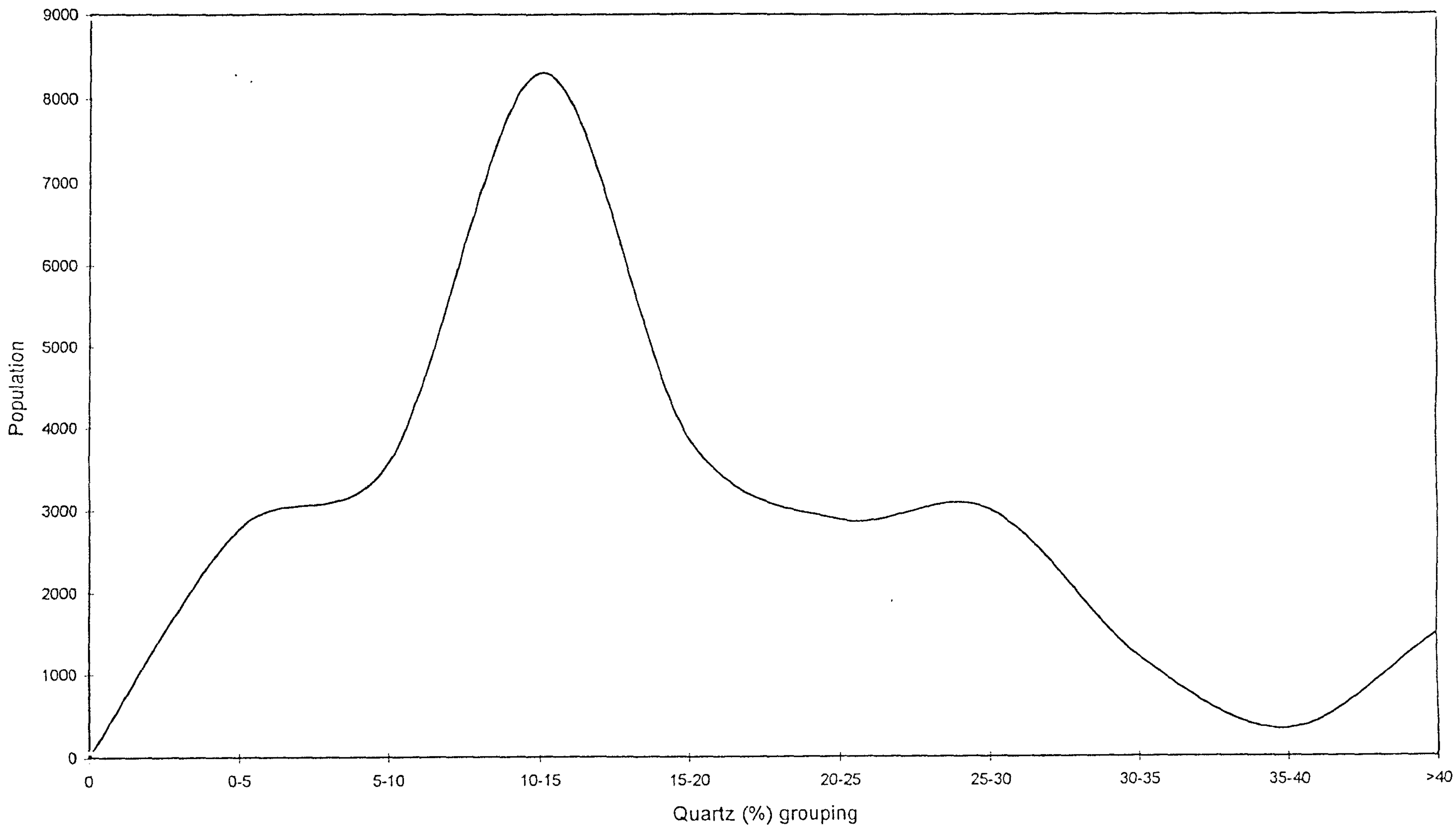

Figure 54 Klerksdorp region total surface population quartz distribution

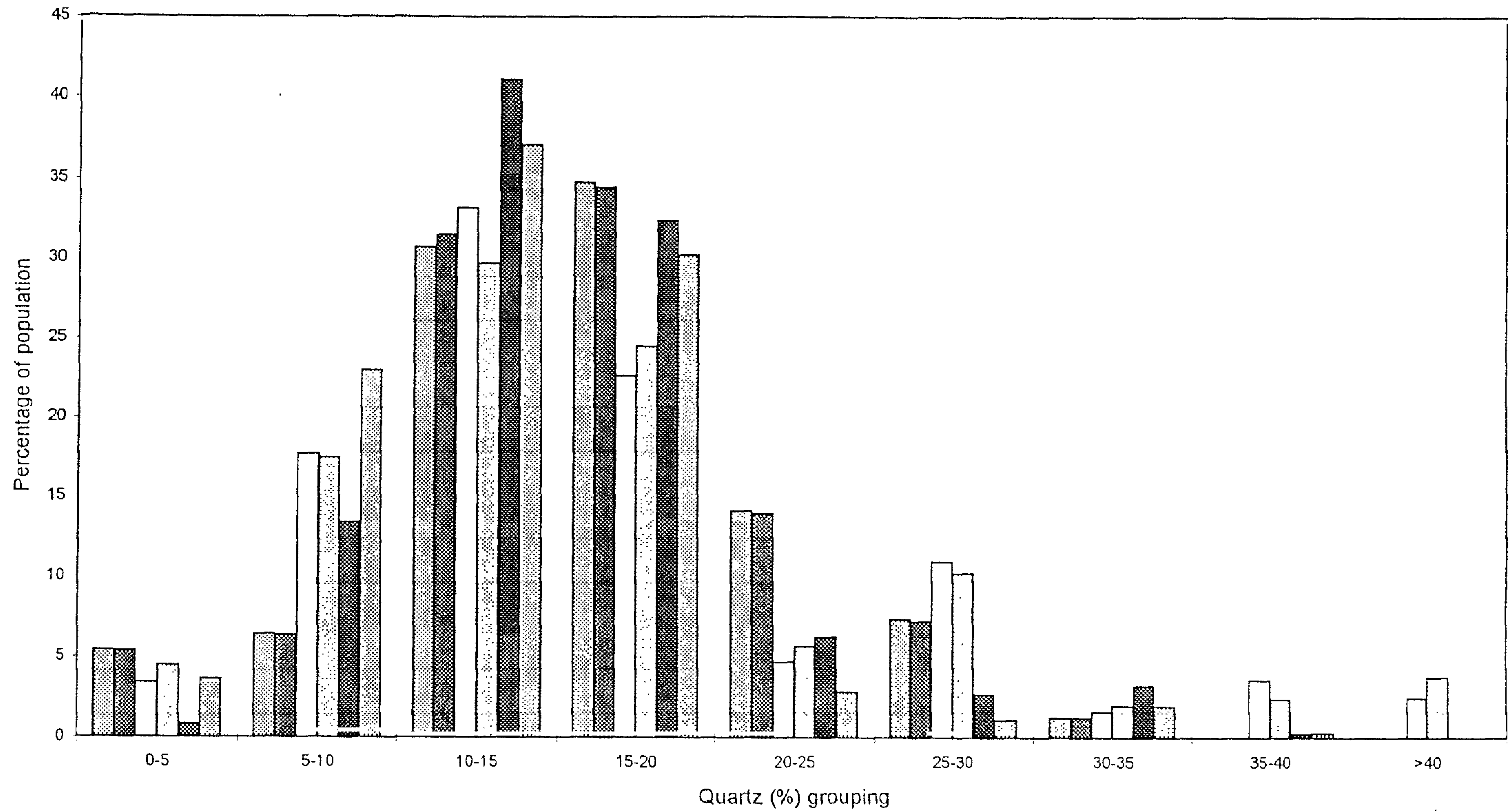

Figure 55 NOFS region stoping and development population quartz distribution (half yearly cycles Jan. 1992 to Jun. 1994)

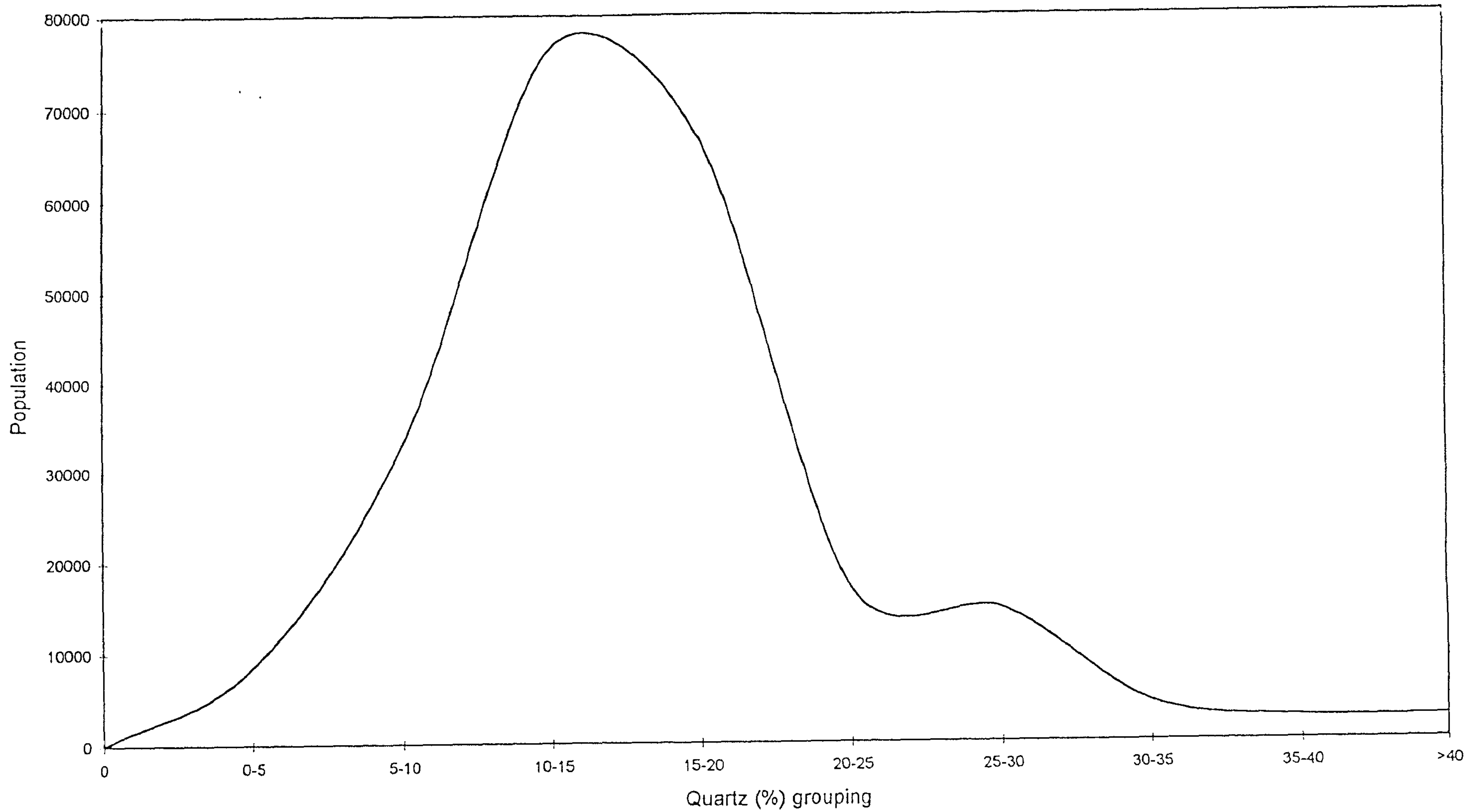

Figure 56 NOFS region total stoping and development population quartz distribution

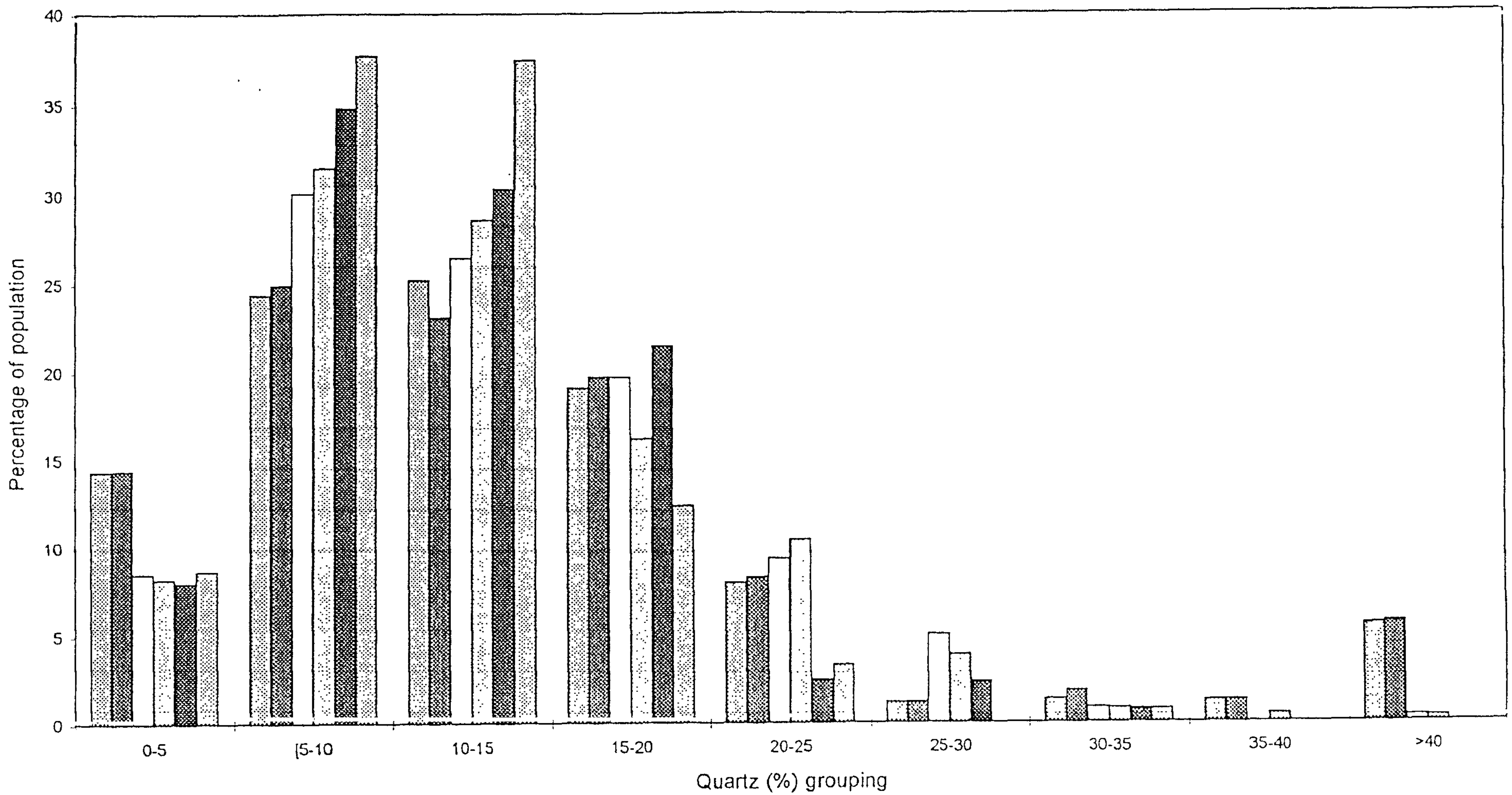

Figure 57 NOFS region underground roving population quartz distribution (half yearly cycles Jan. 1992 to Jun. 1994)

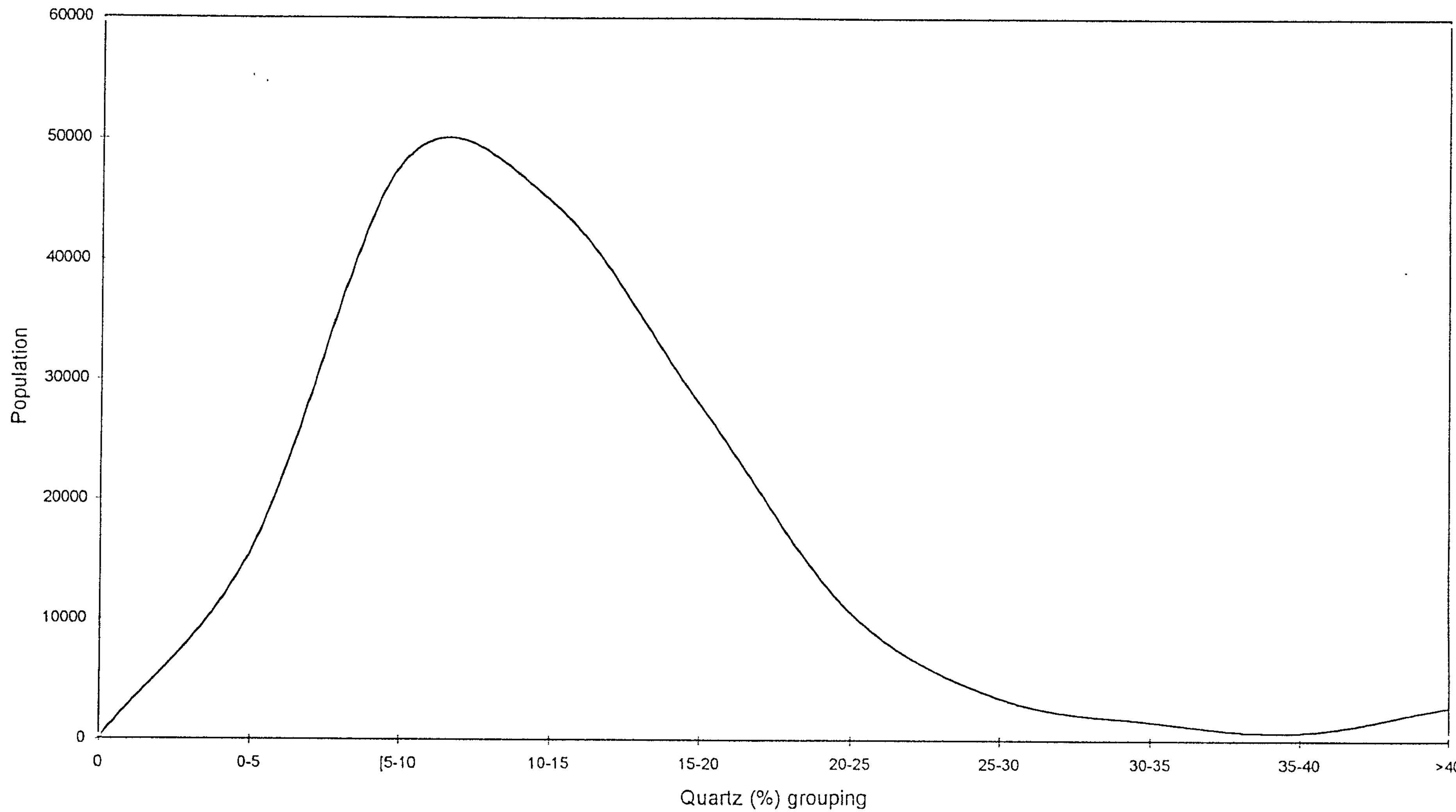

Figure 58 NOFS region total underground roving population quartz distribution

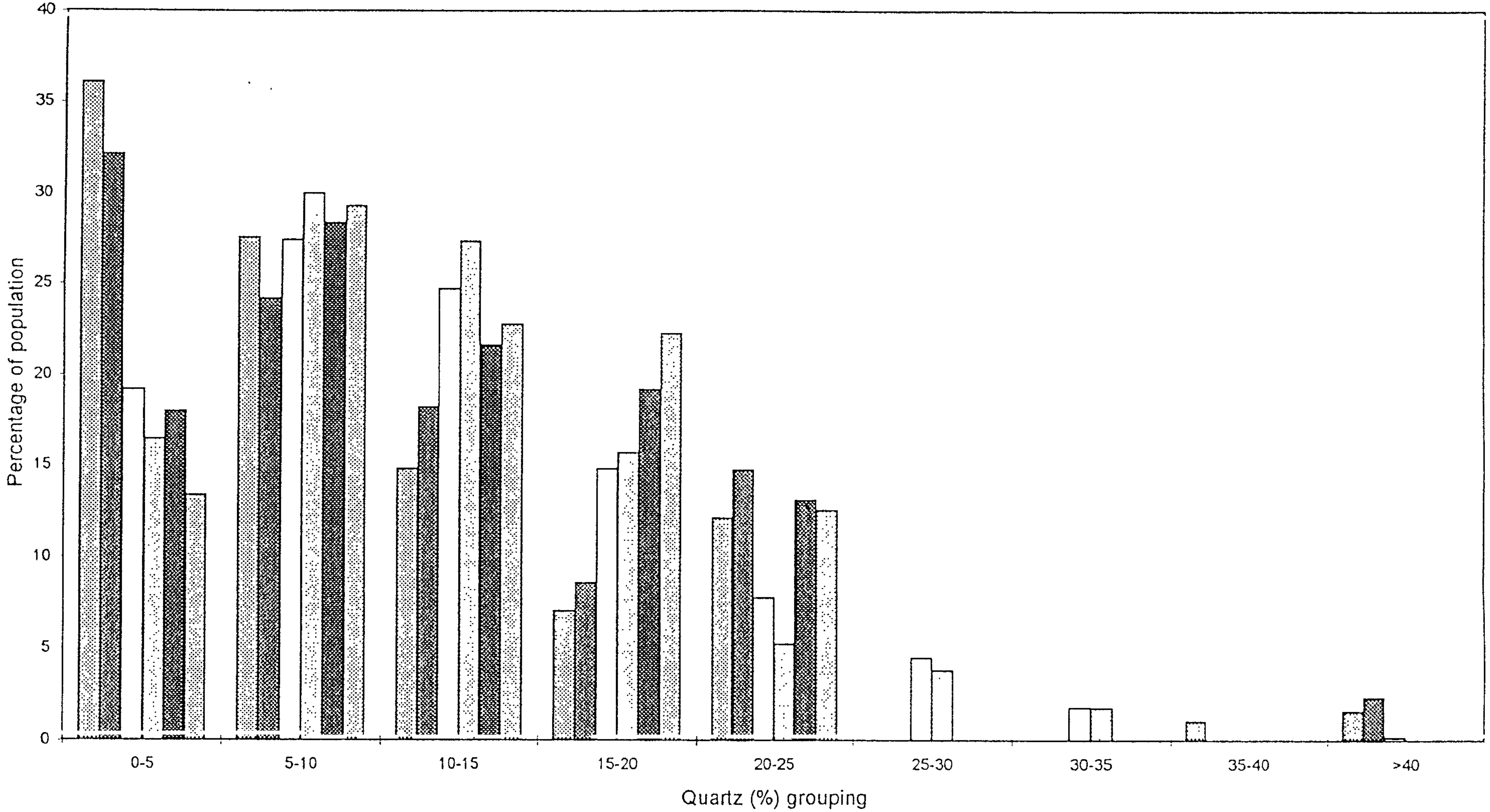

Figure 59 NOFS region surface population quartz distribution (half yearly cycles Jan. 1992 to Jun. 1994)

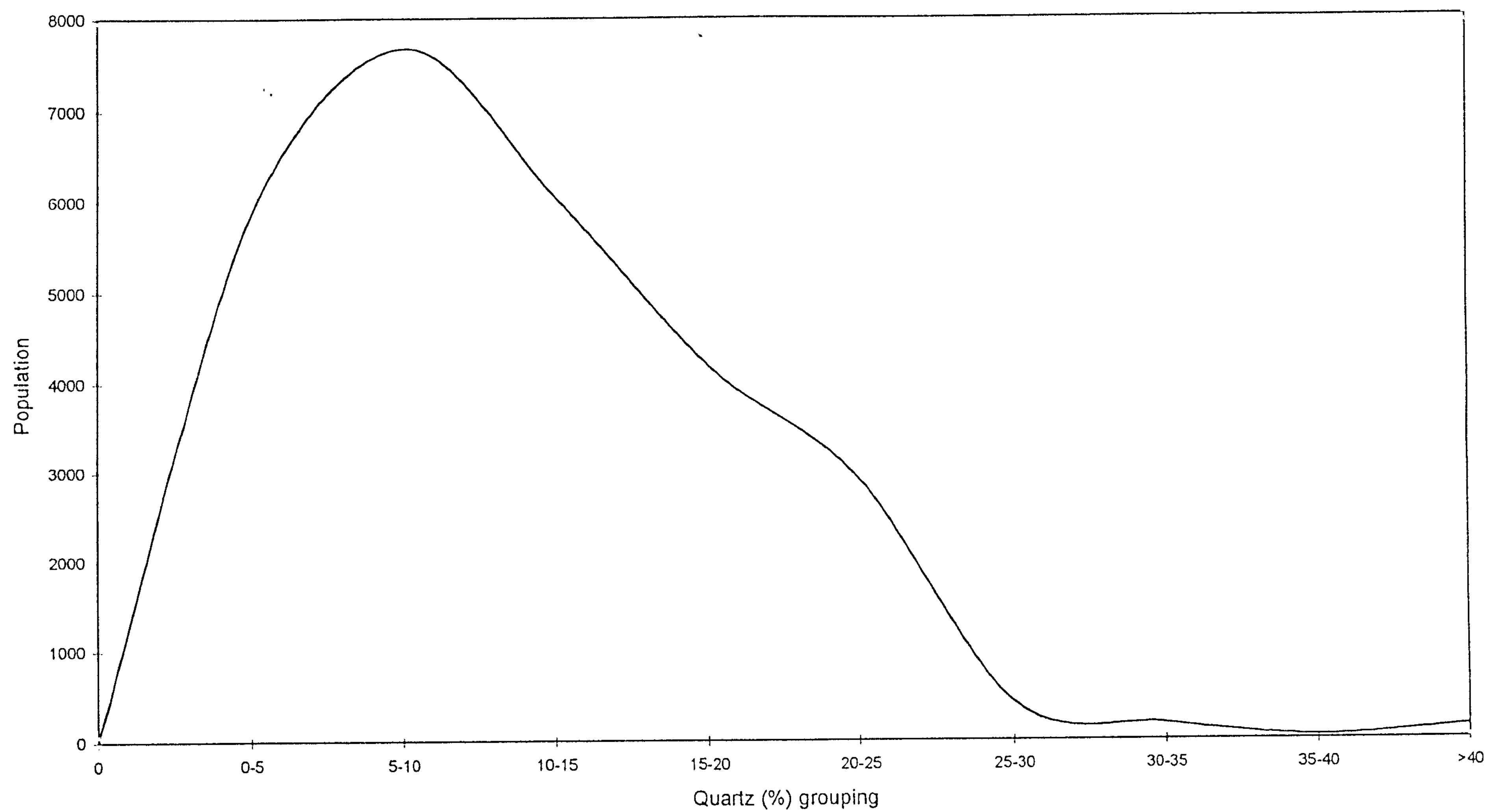

Figure 60 NOFS region total surface population quartz distribution

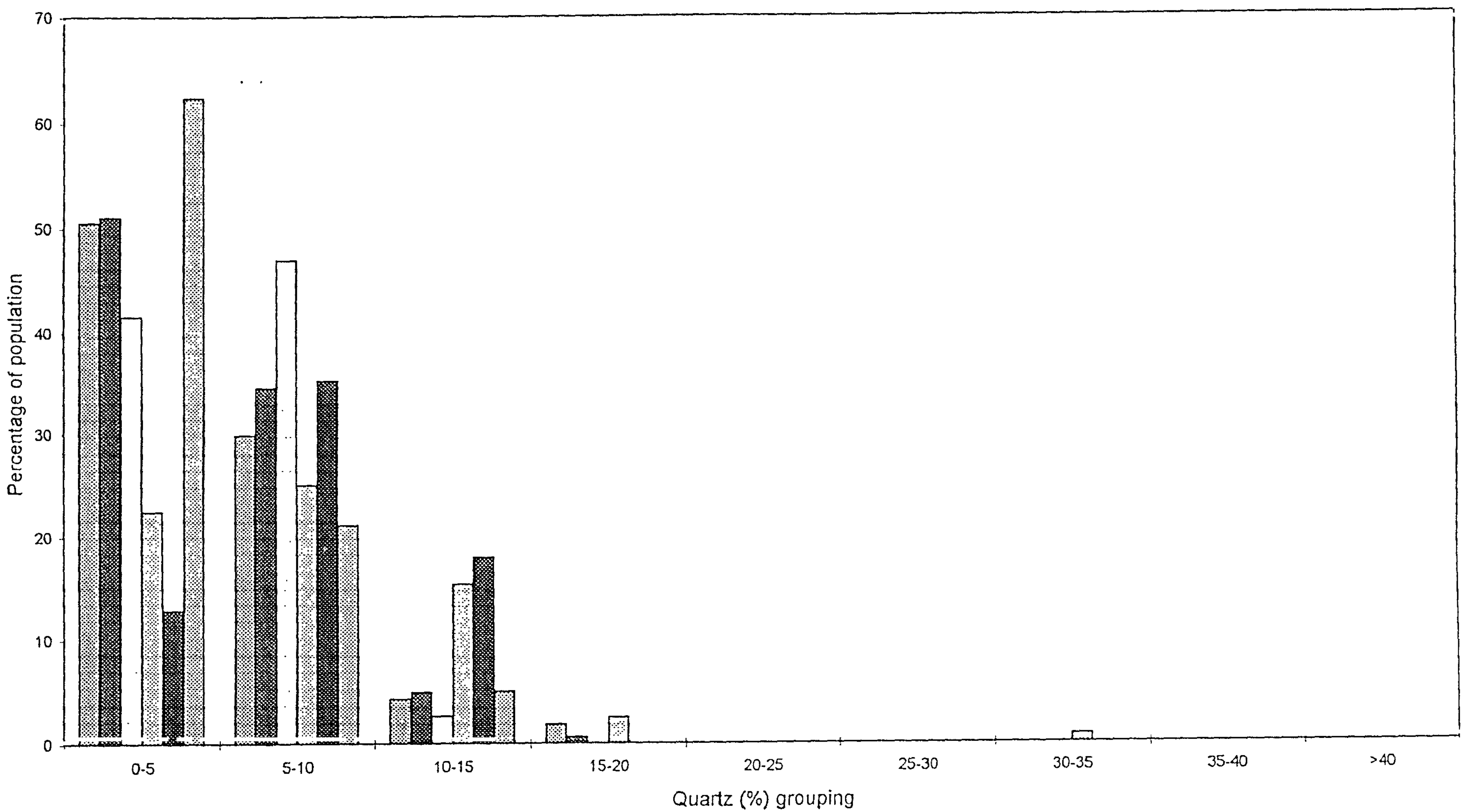

Figure 61 SOFS region stoping and development population quartz distribution (half yearly cycles Jan. 1992 to Jun. 1994)

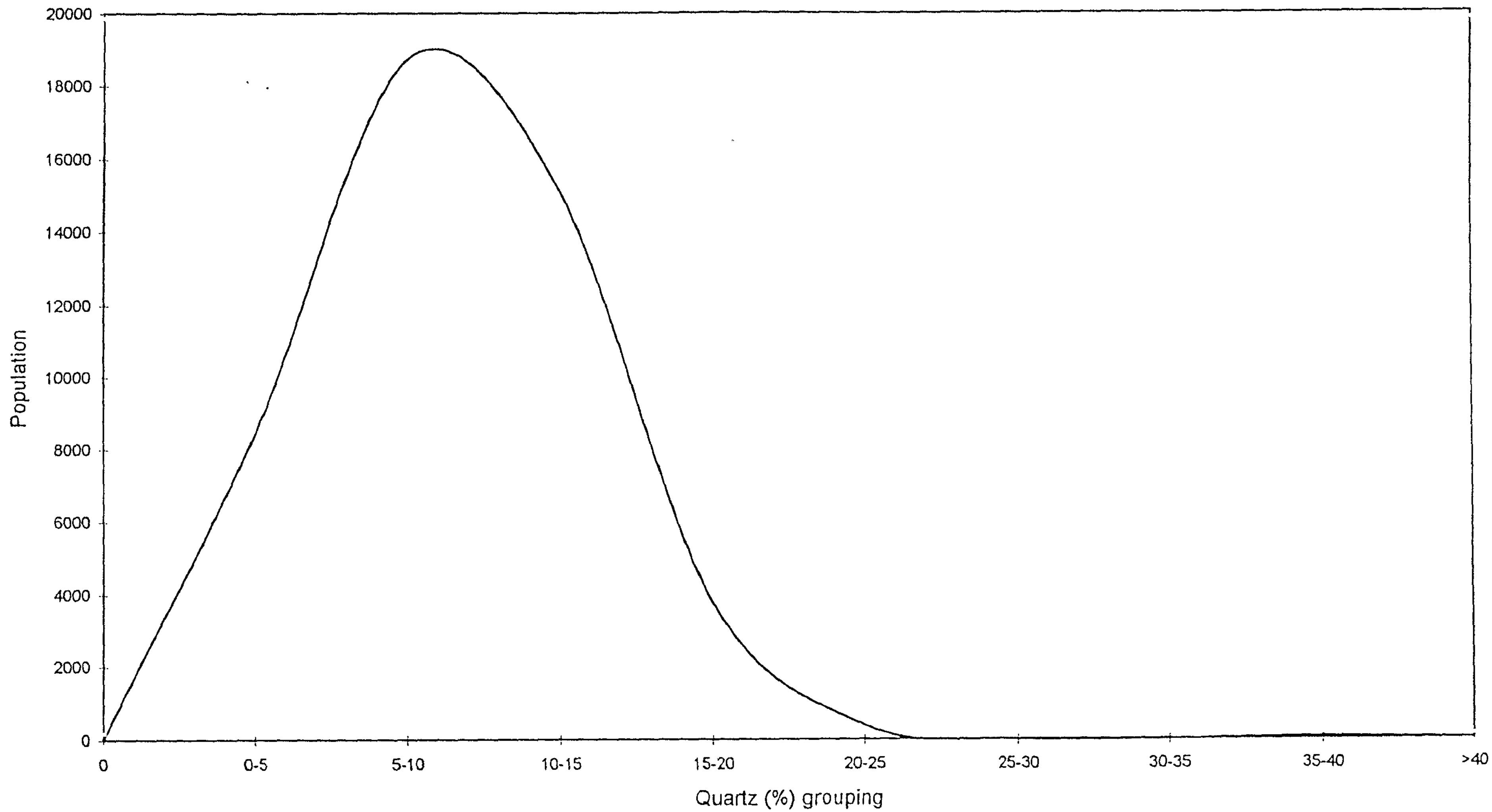

Figure 62 SOFS region total stoping and development population quartz distribution

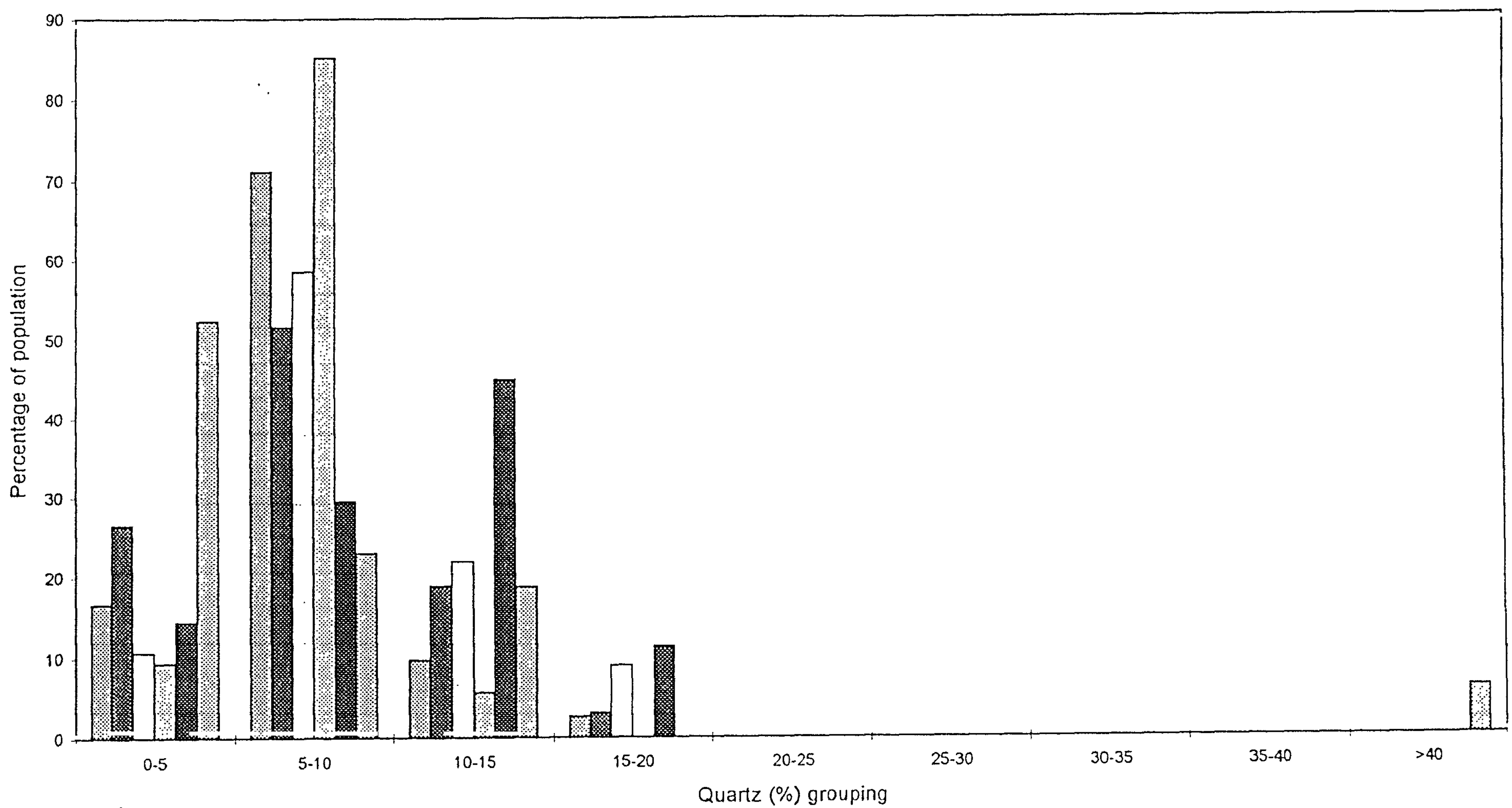

Figure 63 SOFS underground roving population quartz distribution (half yearly cycles Jan. 1992 to Jun. 1994)

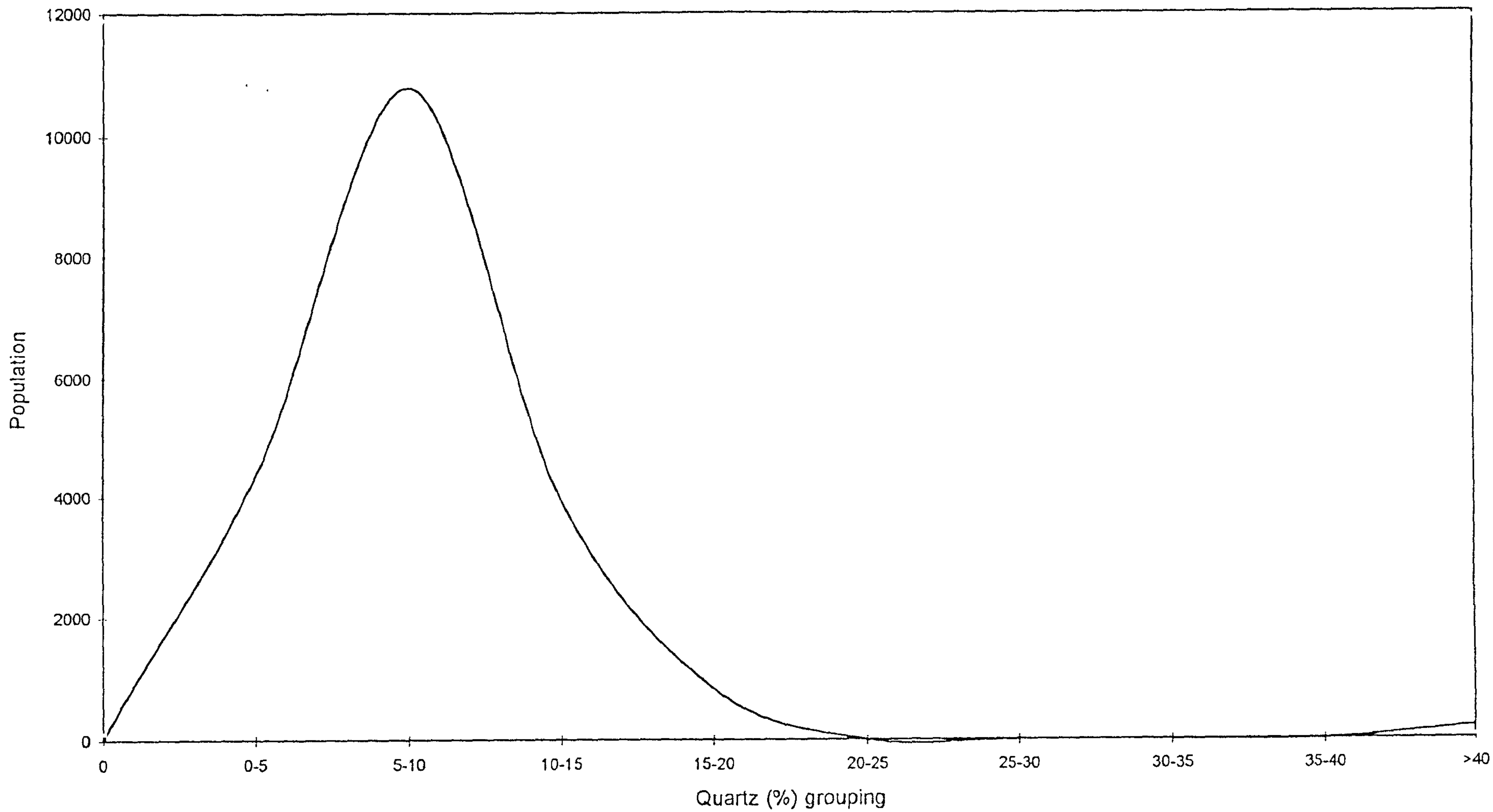

Figure 64 SOFS region total underground roving population quartz distribution

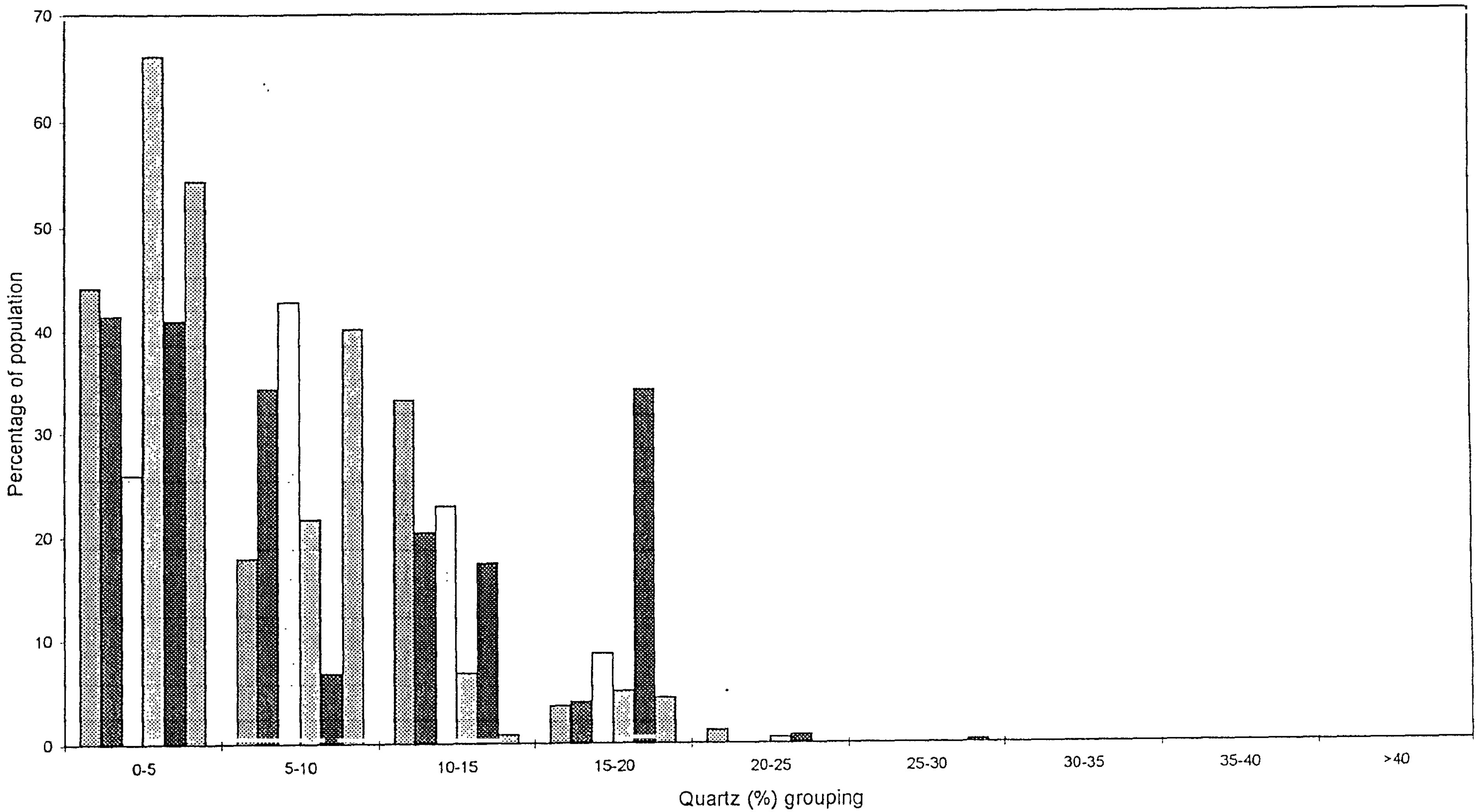

Figure 65 SOFS region surface population quartz distribution (half yearly cycles Jan. 1992 to Jun. 1994)

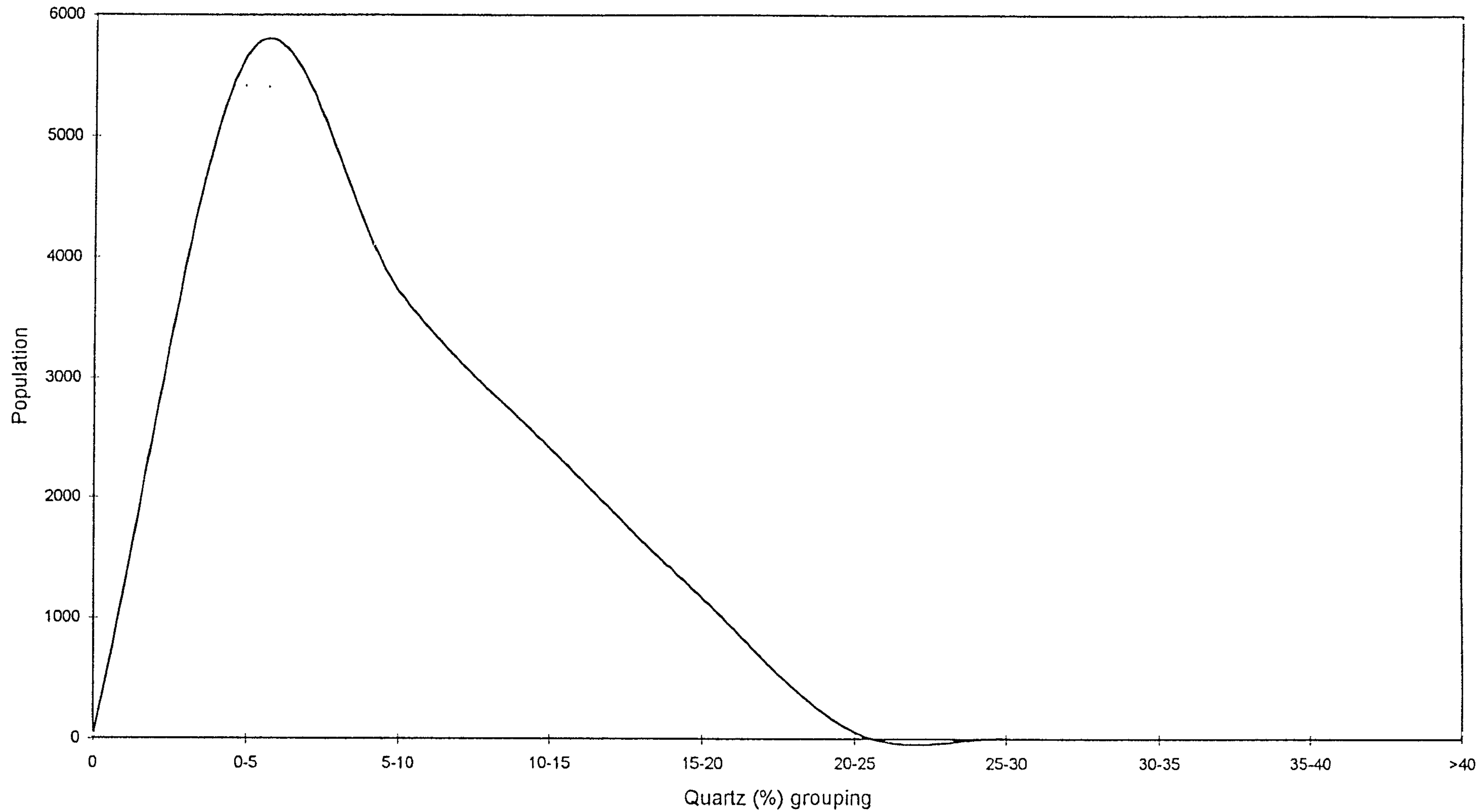

Figure 66 SOFS region toyal surface population quartz distribution

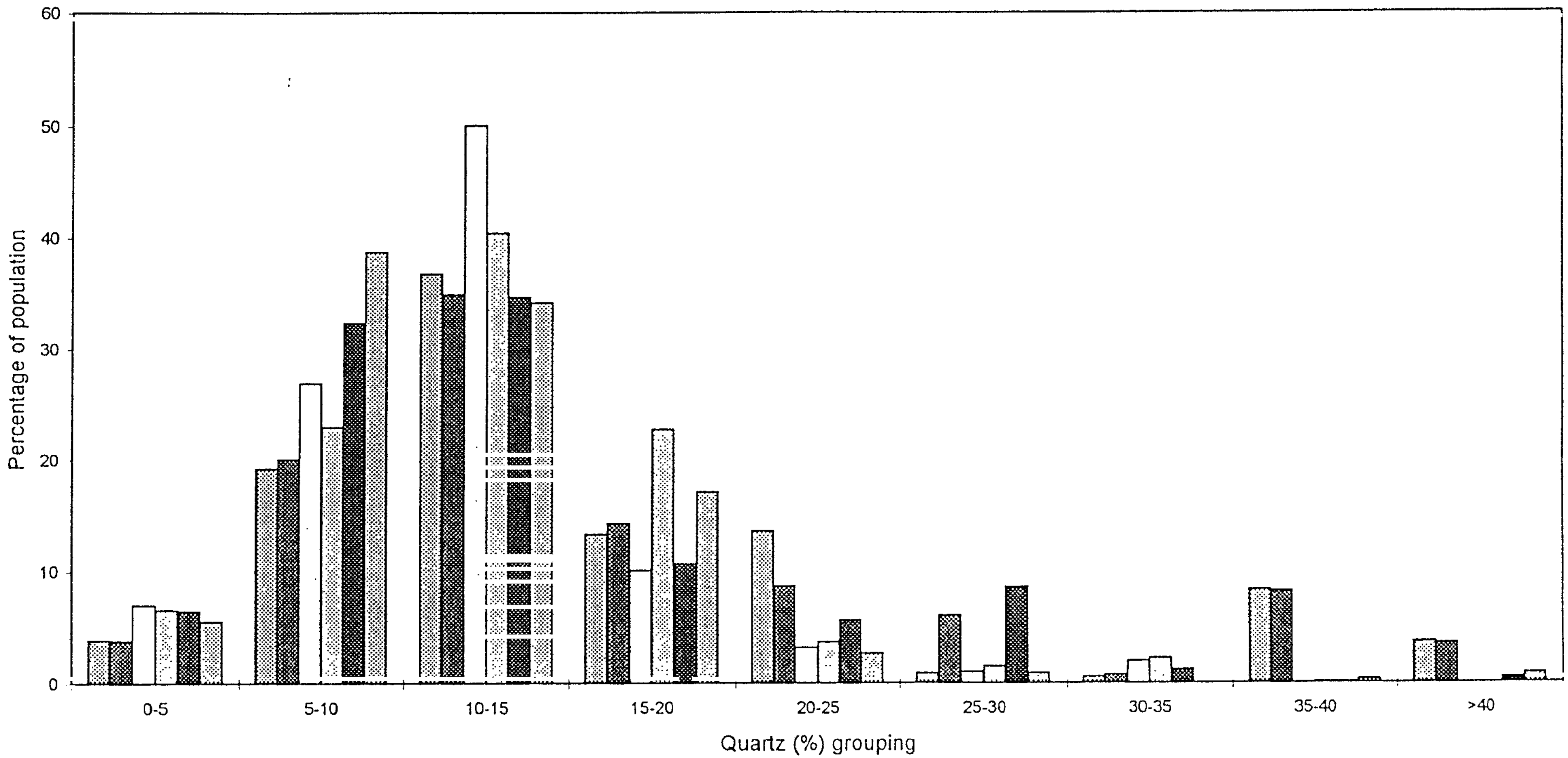

Figure 67 West Wits. region stoping and development population quartz distribution (half yearly cycles Jan. 1992 to Jun. 1994)

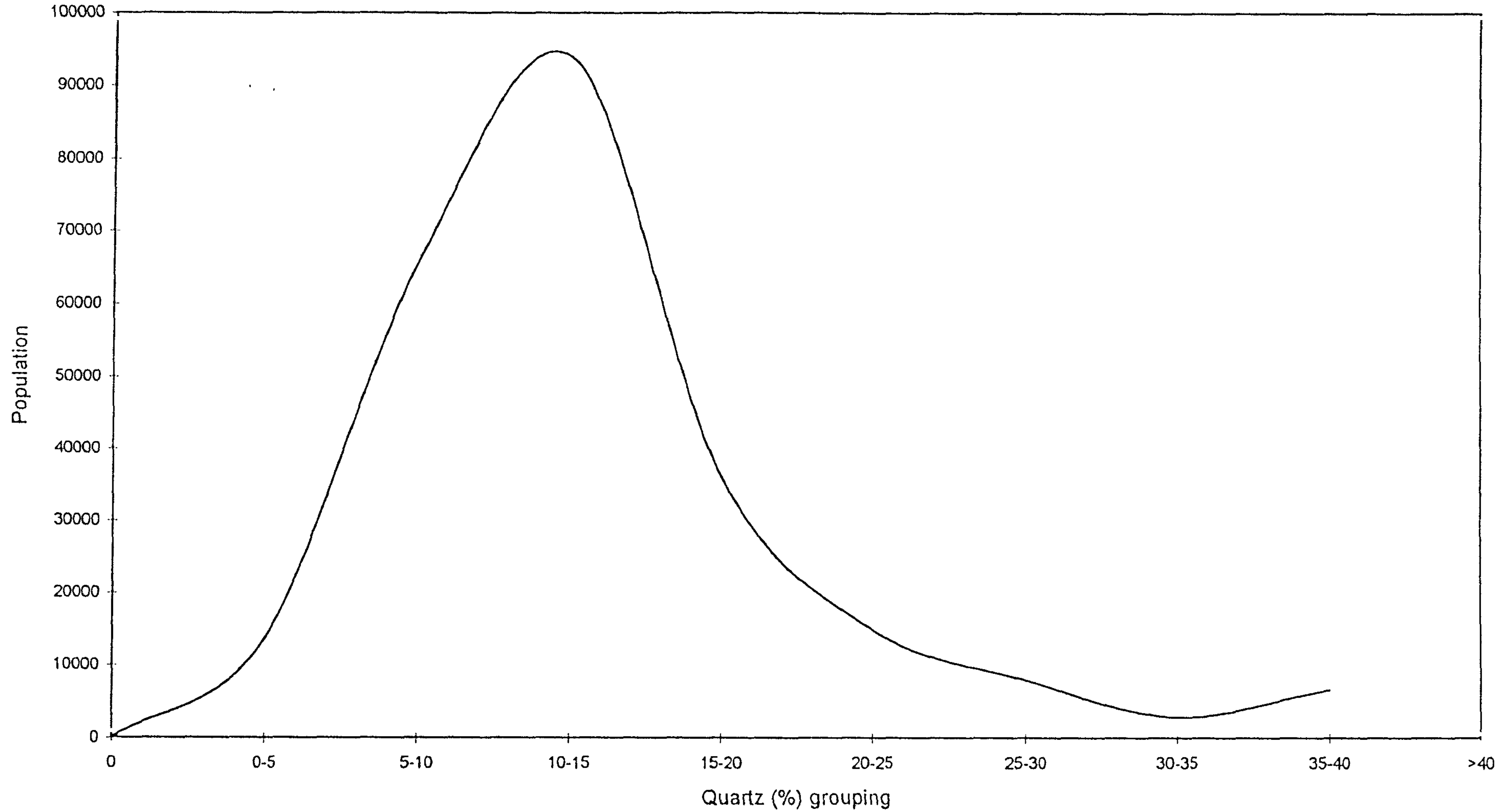

Figure 68 West Wits. region total stoping and development population quartz distribution

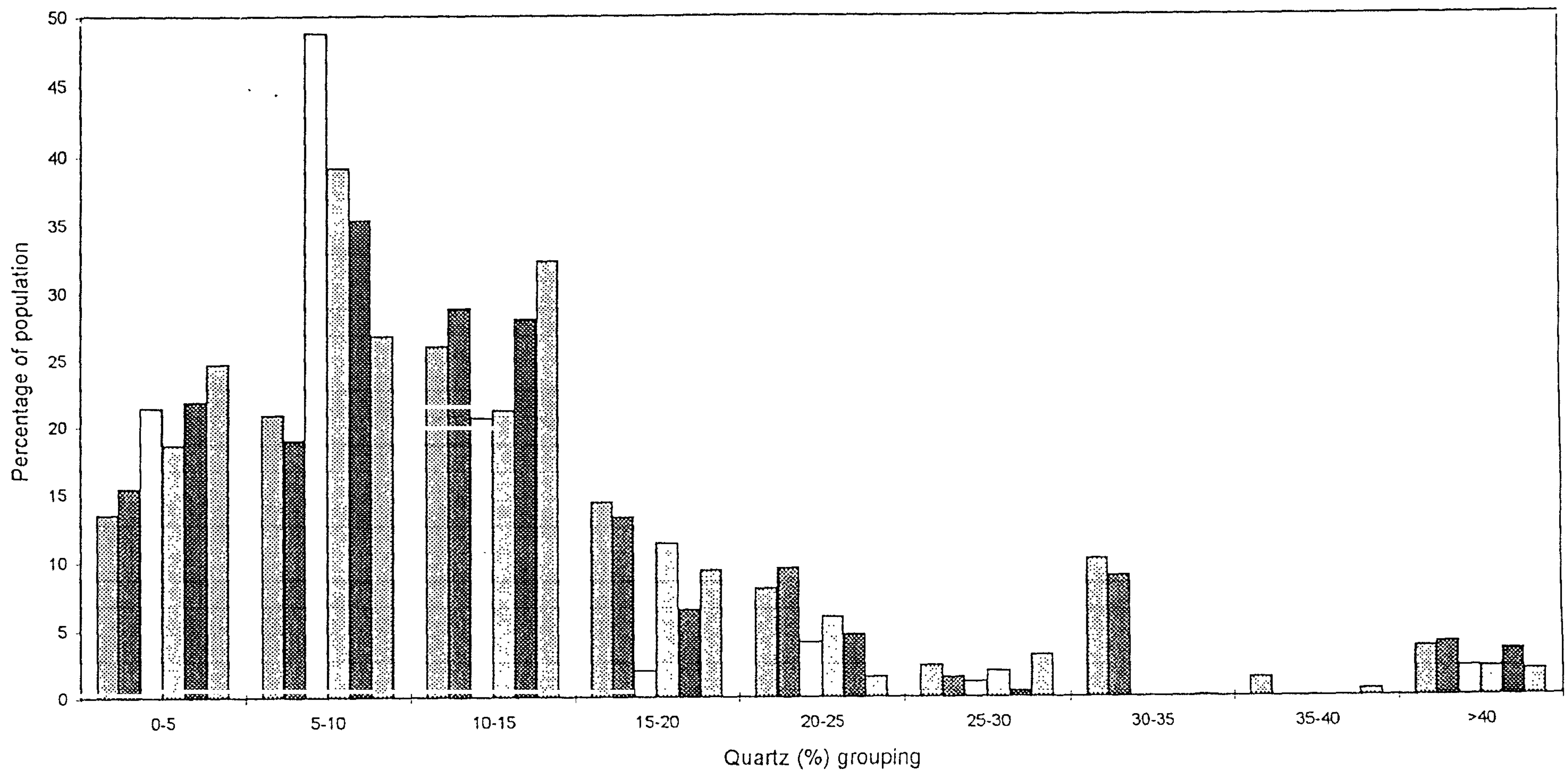

Figure 69 West Wits. region underground roving population quartz distribution (half yearly cycles Jan. 1992 to Jun. 1994)

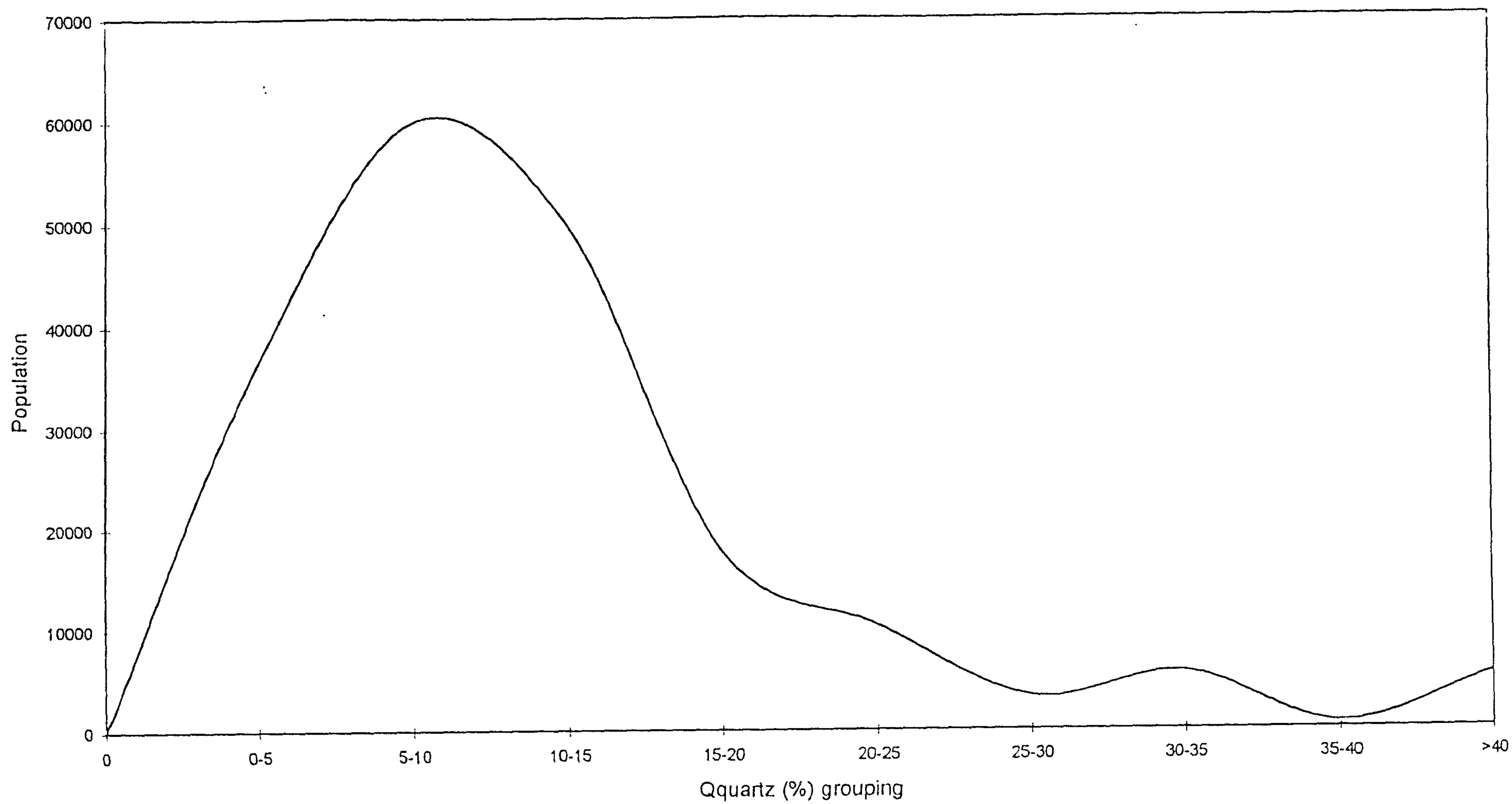

Figure 70 West WITS. region total underground roving population quartz distribution

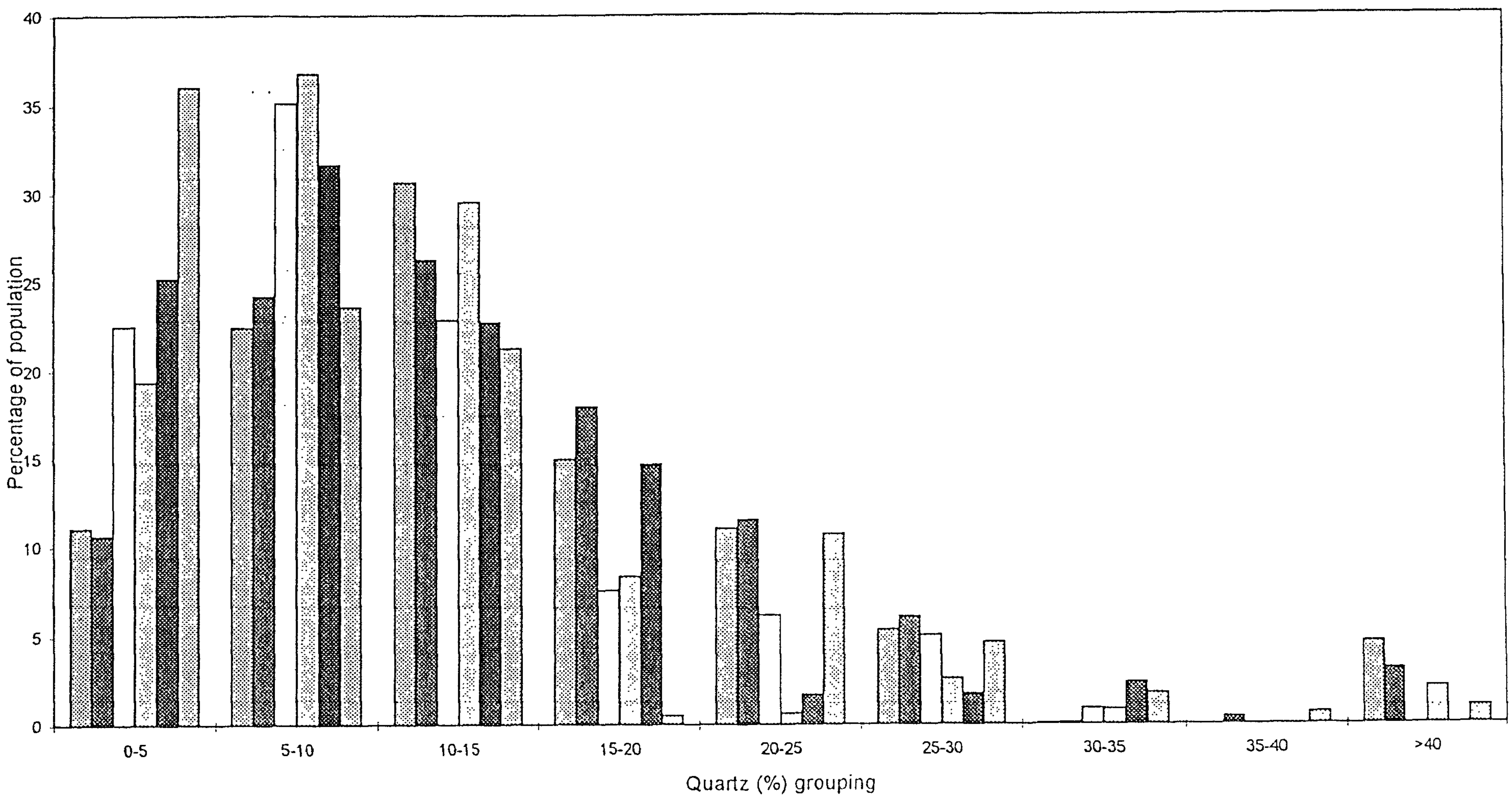

Figure 71 West Wits. region surface population quartz distribution (half yearly cycles Jan. 1992 to Jun. 1994)

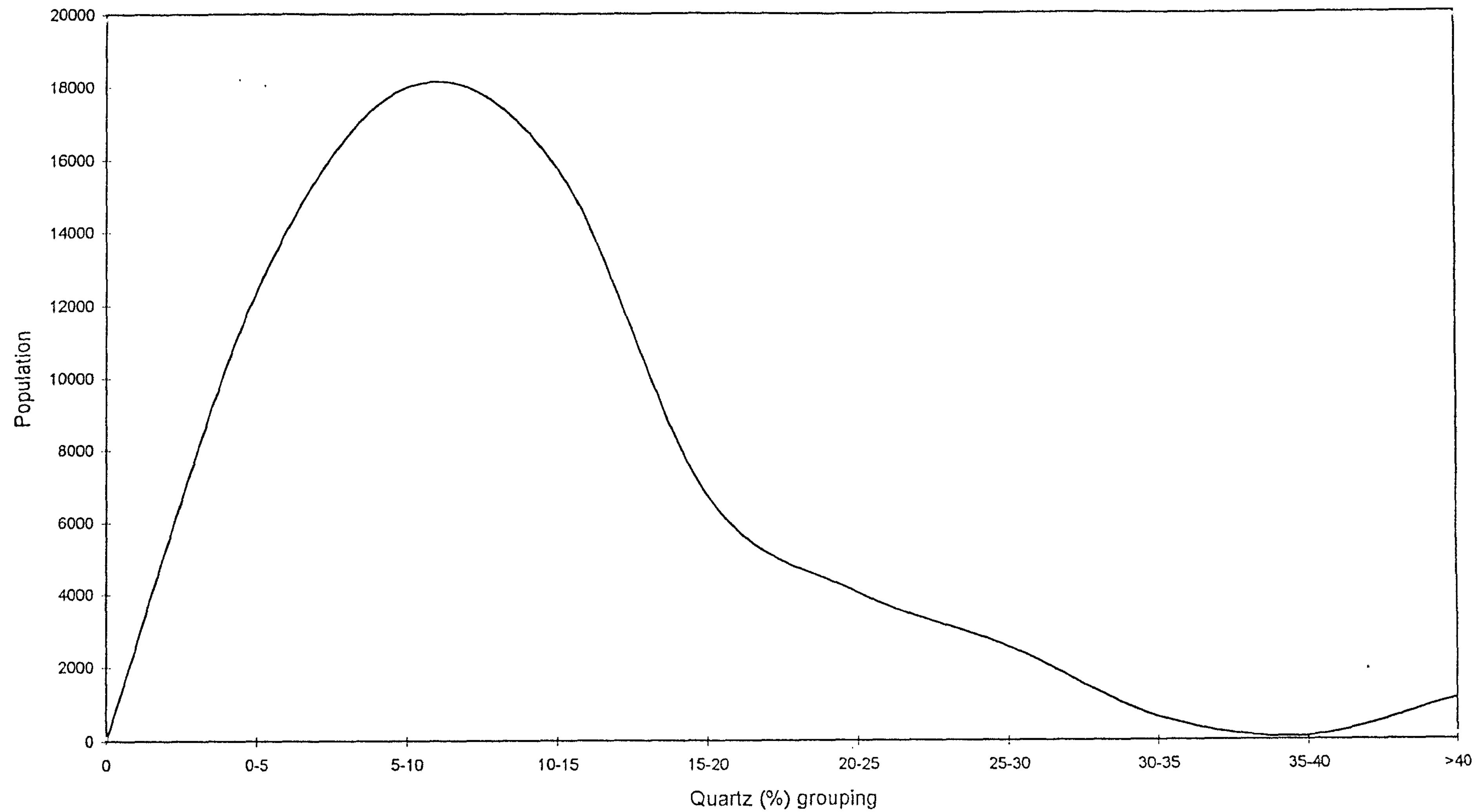

Figure 72 West Wits. region total surface population quartz distribution