

AN INVESTIGATION CONCERNING RECORDED
DUST COUNTS AND SILICOSIS IN SOUTH AFRICAN
CONTROLLED GOLD MINES OF THE WITWATERSRAND
AND EXTENSIONS AND THE ORANGE FREE STATE

P. S. J. DU TOIT

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AFRICAN CONTROLLED GOLD MINES OF THE
WITWATERSRAND AND EXTENSIONS AND THE
ORANGE FREE STATE BY R.S.J. DU TOIT
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The work is my own.

R.S.J. Du Toit
(R.S.J. DU TOIT).



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S U M M A R Y.

The investigation concerns the routine measurement of air-borne dust in the South African gold mines by means of the konimeter and the degree of silicosis in European mine workers. The important aspects of the problem are considered briefly and the history of the konimeter is reviewed.

The konimeter counts recorded by Government Inspectors of mines at a few strategic points in air since 1931, are analysed. Allowances are made for the few changes made since then which affected the results recorded. The changes in dustiness with calendar years at each of the strategic points are estimated.

The European mine workers are classified into a number of main groups. By way of estimates of the proportions of the underground shift which each group spends between the strategic underground points, the dustiness per shift of each group was estimated. The estimates were made at intervals from 1931 to 1955 in order to obtain the variation in the dustiness for each of the main groups over this period. Shift dustiness curves were extrapolated back to 1926. Estimates for the main classes of non-officials are compared with actual observations made during full shift time dust studies in 1926 and in 1949 - 1950. Reasonable agreement is established between the estimates and the actual observations.

57 Recently deceased European mine workers were selected in each of whom the degree of silicosis was determined from full histological post mortem examination of the lungs.

The degree of silicosis is compared with the number of underground years of service and with the number of underground shifts.

By /

By way of estimates of the duration of the underground shift of each of the main underground occupational groups, estimates are made of the total number of hours spent underground by each of the deceased mine workers selected. The degree of silicosis is compared with the number of hours spent underground.

From the dustiness per shift of each of the main occupational groups, estimates are finally made of the dust exposure, expressed in the number of konimeter particle-hours, of each of the deceased mine workers selected. The degree of silicosis is compared with the number of konimeter particle-hours.

The results are analysed statistically and indicate that there is:

- (1) No association between degree of silicosis and years of service,
- (2) very little, if any, association between degree of silicosis and number of underground shifts,
- (3) probably a real association between degree of silicosis and number of underground hours,
- (4) a strong association between degree of silicosis and konimeter particle-hours.

The results are discussed and the conclusion arrived at is that the konimeter need not be replaced by another dust sampling instrument until a significantly stronger association than that in "4" above can be established between the degree of silicosis and dust exposure as based on the results recorded during routine dust sampling with the other instrument.

The /

The recommendation is made that dust exposure records are compiled as the normal routine from now onwards for European mine workers, by adding the hours worked per shift and the dustiness per shift, as based on the routine dust sampling results of the places in which the mine workers spend their underground shifts, to the present records of service.

SYNOPSIS

A. MAIN HEADINGS.

1. Introduction.
2. Associated Aspects.
3. The Main Investigation.
4. Discussions of Results.
5. Conclusions.
6. Application.
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1. INTRODUCTION.

First thoughts about the present investigation occurred to the author a number of years ago as a result of arguments for and against the konimeter as a dust sampling instrument, by members of the Chemical, Metallurgical and Mining Society in South Africa. (1)

In view of the facts :

- (a) that the dustiness of mine atmospheres were for many years controlled by means of the konimeter,
- (b) that there existed strict medical control of underground workers,
- (c) that accurate records were kept of the type of work that miners were employed on,
- (d) that proof of a functional relationship between "konimeter dust exposure" and silicosis was lacking,

an investigation of this nature appeared very desirable.

1.1 The Problem:

The problem is to know whether konimeter dust counts are related to the silicosis hazard due to dust in mine air, and if so, whether the relation is sufficiently close to warrant the continued use of the konimeter as the dust sampling instrument on South African Mines. .

It is argued that the problem will be solved if the "konimeter count exposure" of a person was a measure of the degree of silicosis in the person.

Unfortunately, the actual "konimeter count exposures" of persons are not available. Estimates thereof have, therefore, to be resorted to.

As a result of inaccuracies introduced by these estimates, in addition to the varying susceptibility of

individuals /

individuals to contract silicosis, as well as the broad classifications of the degree of silicosis, there will be a tendency to obscure any functional relationship between these two measures.

1.2 The value of the investigation:

The main value of the investigation will lie in the answer provided to the question in "1.1". Additional value will also lie in the record provided of a method followed to correlate dust determinations with medical findings, and in the directives resulting therefrom which could lead to a diminution of the dust hazard.

2. ASSOCIATED ASPECTS.

Before dealing with the actual investigation it is appropriate to touch on the more important aspects associated with the dust problem.

2.1 Medical Aspects:

2.1.1 The Respiratory System (after Sabotta⁽²⁾):

Two of the outstanding features of the respiratory system are the many changes in direction of the air passages and their irregular cross sectional area. These two properties, in addition to the hair in the nose and the fact that the walls of the air passages are lined with mucus favour the elimination of particulate matter contained in the inspired air.

Entry to the nose takes place across approximately $\frac{1}{2}$ square centimetre per nostril⁽³⁾ into the 'nasal vestibulum' (Sabotta fig. 113) where the cross-sectional area suddenly increases by some 50 - 100%. The whole nasal cavity is lined with hair and mucus. Its cross sectional shape changes to a narrow slit caused by a

'fold /

CUMULATIVE NUMBER OF ARTICLES OVER 20

'fold of mucous membrane called the plica ductus nasolacrimalis' and the total cross sectional area available to inspired air reduces from about $1\frac{1}{2}$ - 2 square centimetres in the nasi vestibulum (the largest portion of the nasal cavity) to about one square centimetre. This reduction in cross section takes place suddenly, and furthermore, from the roomy nasi vestibulum the air flows along a narrow slit called the meatus nasi communis (Sabotta figs. 115 and 116), which in cross section measure about 2 millimetre by a few centimetre, for each nostril. From here the air flows down into the throat which measures a few centimetres in diameter when extended (Sabotta figs. 132 and 133) and past the vocal chords to the trachea i.e. the main windpipe.

Apart from the changes in cross sectional area there are also the changes in direction that breathed air is subjected to. These changes may be summarised as follows:

from all sides into the nose,
then upward in the nose,
then more or less horizontal along the nasal slits,
then vertically down the throat and into the trachea.

The trachea proper is about 20 centimetre long with a diameter of about $2\frac{1}{2}$ centimetre at the top and about 1 to $1\frac{1}{2}$ centimetre lower down, in the normal person. (Sabotta P. 118 and fig. 145).

The trachea divides at an angle of about 70° into the two bronchi'. The two bronchi divide at large angles into the rami bronchiales. (('The branches of the bronchi no longer have rings of cartilage like the trachea and the main bronchi')). The bronchial rami enters the lung /

lung proper where it further sub-divides until 'the finest branches of the bronchial tree have a diameter of 0.5 millimetre and less (Sabotta P. 129), have no cartilage in their walls and are termed bronchioles (bronchuli) and lie within the lobules of the lung.

'Sections of the lung reveal, in the first place, the boundaries of the individual lobules (lobuli pulmonis) formed by the delicate strands of connective tissue and, secondly, sections of the bronchial rami, and the larger vascular branches'. (Sabotta P. 129).

The Bronchial Epithelium (after Policard⁽⁴⁾)

The bronchial epithelium may be described as follows: From the periphery of the bronchi extend inwards 'a layer of connective tissue containing elastic muscle-fibres, many glands, and blood and lymph-vessels', from which extend the cilia (fine hair-like processes) from the tips of which in turn extends the layer of 'viscid mucous, which is driven towards the mouth by ciliary action, carrying with it the dust particles which have adhered to it.' ("4" P.P. 11 and 12.)

The Alveoli

The finest branches of the bronchial tree terminate in the alveoli or air sacs which measure about 200 - 250 micron in dia. (5)

The alveoli have no epithelium or cilia. The oxygen-carbon dioxide exchange takes place along the alveolar walls.

Scavenging cells wander along the inner or "air" - side of the walls and any particulate matter which attaches itself onto the walls gets removed by these cells.

The /

The number of alveoli in the normal person is estimated at 150×10^6 to $1,000 \times 10^6$.⁽⁶⁾

The total alveolar wall area is put at 30 to 200 square metres. ("5" page 40).

Size of Cells.

The size of a red blood cell is about 8 micron⁽⁷⁾, whilst that of a white blood cell is about 10 micron and that of a dust scavenging cell (in medical literature referred to as phagocytic cells or macrophages) are 25 to 30 micron in diameter.

2.1.2 At what velocity does air flow along the air passages?

The rate of breathing varies from a minimum of the order of 5 litres per minute for a normal person at rest through 20 to 30 litres per minute during medium exercise, to a maximum of about 60 litres per minute at severe exercise. Actual tests on the Author^x gave 36 litre per minute during medium exercise. At this value the maximum instantaneous breath-rate was 1.5 litres per second with an average breath-rate of 1.2 litres per second over 30 inhalations per minute.

As indicated above, the cross-section of the upper respiratory channels vary greatly and the table below lists some of the positions with the corresponding orders of cross-sectional areas and orders of inhalation velocities at one litre per second

* Conducted by Dr. Margaret Becklake on
1.6.55., at the then Pulmonary Disability
Section of the Silicosis Medical Bureau.

Position /

<u>Position</u>	<u>Approximate Area</u>	<u>Velocity</u>
Nasal Entry	1 sq. cm.	1.0 metre/second
Nasal Vestibulum	2 sq. cm.	0.5 metre/second
Nasal slit	1 sq. cm.	1 metre/second
Throat (during inhalation)	5 sq. cm.	0.2 metre/second
Upper Trachea	5 sq. cm.	0.2 metre/second
Trachea	2 sq. cm.	0.5 metre/second.

Summarising the velocities, one can say that for normal breathing during medium exercise, inhaled air flows through the upper respiratory channels at velocities which, due to the varying cross-sectional area, vary from a fraction to one and more metres per second.

2.1.3 Dust retention and elimination

The medical terms dealt with below are usually used in descriptions of dust retention and elimination and it is essential to be familiar with them in order to follow medical descriptions on what happens to dust in the lung.

The terms are:

- Amoeboid = having no fixed form, but creeping and putting out pseudopodia.
- Leucocyte = a white blood corpuscle; one of the colourless amoeboid cells occurring in suspension in the blood-plasma.
- Lymph = a colourless fluid flowing from the alveoli and the air passages back into the lung.
- Makrophage = a large cell which ingests dust particles.
- Phagocitose = the process whereby amoeboid cells remove particulate matter from the alveolar walls.

Medical /

Medical literature on the above subject may be summarised as follows:

Particles enter the lung with each inspiration. Some are caught by the hair in the nose, some settle on the mucus covered walls of the air passages but some reach the terminals of the air passages, viz. the alveoli.

A portion of the suspended particles reaching the alveoli settles on the alveolar walls, a further portion settles on the air passages as the air is exhaled and a portion of the suspended particles is exhaled again.

Generally speaking, the coarse particles settle out first so that particles larger than 20 micron do not easily pass beyond the nose whilst practically all particles larger than five micron settle before the air reaches the alveoli. (Ultra fine particles are also deposited on the air passage walls - due to them being in brownian motion).

The particles that become fixed on the alveolar walls are removed by cells that wander over the alveolar walls.

These dust-laden cells, called phagocytes, can then move in one of two directions, viz.

- (a) they may move along the alveolar wall towards the alveolar duct where 'the dust-cells reach the liquid layer covering the epithelium and are swept along by the moving superficial layer, and also driven by the expiratory air stream' (Policard "1947" P.14)⁽⁸⁾ to the windpipe, 'being subsequently expectorated' or swallowed, (Strachan P.4)⁽⁸⁾ some dust-cells may also

lymphatic /

lymphatic system (Policard P. 14);

- (b) alternatively, the dust-cells 'may move into the substance of the lung where they tend to become aggregated in certain specific sites' (Strachan P. 4). This means that the dust laden cells pass through the alveolar walls into the lymphatic system.

Lymphatic capillaries drain from the alveolar walls and the air passage walls. The lymph fluids flow in thin vessels via the lymph nodes. The dust laden cells are transported in this lymph fluid and the dust particles are arrested in the nodes and are deposited in the 'lymph node reticulum' (Policard "1947" P. 15).

Two German pathologists, viz., Drs. Gersing and Schumacher⁽⁹⁾, during laboratory experiments, could actually observe under the microscope, how certain cells, viz., Leucocytes and Makrophages, phagocitosed dust particles.

The leucocytes were observed to move at a rate of about 25 - 30 microns per minute whilst the makrophages, which are much larger than the leucocytes moved at about one quarter the rate of the leucocytes, (G. & S. P.P. 43 and 44).

Gersing and Schumacher states: ((Author's translation from the German publication)) 'Small particles (less than 1 micron) were ingested by cells with ease' 'Leucocytes could on the average envelope completely only particles which were not larger than 3 micron. Leucocytes crawled underneath large particles which were then carried on their backs for a distance without the particle actually being phagocitosed (i.e. enveloped and removed). Particles taken up by leucocytes /

CUMULATIVE NUMBER OF PARTICLES OVER SIZE

leucocytes were often lost again'. (P.46)
'Makrophages can envelope completely, considerably larger particles viz. particles up to 10 micron in diameter. Particles which were taken up by makrophages were not seen to be lost again and there was also no differentiation between large and small particles (P. 47)'.
CUMULATIVE NUMBER OF PARTICLES OVER SIZE

2.1.4 The size range of harmful particles.

In 1913, McCrae⁽¹⁰⁾ reports as follows on the proportions and sizes of particles observed in the lungs of six cases of miners who suffered from silicosis: 'the amount of material with diameter less than 1 micron was, very approximately, 70 per cent of the whole.!!' No attempt was made to measure diameters less than one micron. Many measurements were made of the particles constituting the remaining 30 per cent of the material..... In an extensive survey of several microscope preparations only a negligibly small number of particles was seen whose longest diameter exceeded 8.5 micron, and the very longest observed was 10.5 micron'.

In 1916 Watkins-Fitchford and Moir⁽¹¹⁾ reports as follows on the particles seen in silicotic lungs: 'There appeared to be some selection of particles about 1 micron in average diameter. The mean of the average diameters of 120 particles was 1.2 micron. The great preponderance of relatively small particles in the specimen examined was indicated by the fact that for every particle of an average diameter of 8 micron or upwards there were 2,000 which were smaller. (P. 17) The great majority of the quartz particles in such specimens of (silicotic) lung-tissue are less than 2 micron in diameter; none of them have been found to exceed 14 micron, and

particles /

particles of such a size as this are relatively, very rare - say 1 in 100,000.' (P. 16).

Referring to the above disclosures, the Miners Phthisis Prevention Committee⁽¹²⁾ states:

'The whole outlook on miners phthisis (and incidentally on the analytical problems connected with it) was changed by the recent ((pre 1916)) discovery of the almost infinitesimal minuteness of the silica particles retained by miners' lungs. It became obvious that the ordinary gravimetric determinations of the total dust floating in the air must (whenever large particles are present) lead to quite false ideas as to the state of the air, since, for example, a single particle of 100 microns diameter weighs the same as 125,000 particles of 2 microns diameter'. Continuing, the Miners Phthisis Prevention Committee states: 'An important point that emerges from recent (pre 1916) investigations is that, as a measure of the injurious character of any air breathed, the number of particles per cubic centimetre is a better criterion than its weight, because, 'in the great majority of instances' (in South African Gold Mines) 'number of particles of "very fine" (i.e. of below 12 microns) injurious dust exceeds 98 per cent of the total number of particles.'

The Miners Phthisis Prevention Committee⁽¹⁴⁾ further pointed out that 'the count of particles only referred to those which could be identified with the best microscope constructed' (1916), and that 'there was in mine air almost certainly particles of a diameter so small that they could not be identified by such aid. The question whether such particles were also of an injurious character could not be answered' (1916), 'since the problem

was beyond the limits of any histological examination'.

Mavrogordato (1922)⁽¹⁵⁾ considered this question further and said: 'particles which are not susceptible of microscopic analysis (viz. those below 0.1 micron) are within the limits of size of the particles of the physiological colloids which form the milieu interne of the body. Chemically inert foreign particles of this order of size can hardly do any harm.'

((For purposes of comparison it is interesting to remember that the size of a red blood cell is about 8 microns in diameter)).

Then referring to the work of McCrae and Watkins-Pitchford, Mavrogordato⁽¹⁶⁾ stated that he 'repeated their experiments, both on lungs of subjects of Silicosis and on the lungs of guinea-pigs that had been experimentally exposed' and studied the dust 'by the dark-ground method as used with the konimeter, as well as by direct illumination' and that 'there was no appreciable increase with darkground illumination'. Hence, he concluded that 'the particles were well above 0.25 micron'. He pointed out that 'similar studies had been made in the States by Smyth and Iszard who particularly mentioned that they used darkground illumination as well as direct lighting' and that 'they reported that their findings as to size distribution of dust particles in guinea-pig lungs agreed closely with those of McCrae and of Watkins-Pitchford and Moir in human lungs'.

Mavrogordato⁽¹⁷⁾ was of opinion that 'all the evidence, direct and indirect, was against ultra microscopic particles of silica conveyed by inspired air, being responsible for silicosis' and he concluded: 'Phthisis

producing / ...

producing dust is the dust of free silica of from one quarter to five micron in diameter'.

After considering the lower limit of particles to be included in the measurement of dust concentrations Wynn⁽¹⁸⁾ (1952) concluded that there was inadequate knowledge of the biological importance of particles smaller than 0.5 micron in diameter.

Dawes and Nagelschmidt⁽¹⁹⁾ (1956), in summarising the pneumoconiosis problem concluded that animal experiments have shown so far that fibrosis was roughly proportional to the surface of fibrogenic dust, but that there was an optimum particle size of about 1 micron.

The animal experiments referred to are those by King and others⁽²⁰⁾ (21) which were based on equal weights and equal surface areas of different sized particles. Hence, if on the bases of equal weights and equal surface area, small particles become relatively unimportant, they are even less important on a number basis.

2.1.5 The difference between soluble and insoluble substances when inhaled:

In 1923, Mavrogordato⁽²²⁾ said: 'When we are dealing with readily soluble toxic particles, these ultra-microscopic counts become very important; industrial metallic poisoning, for instance, is closely related to them, but the dust of free silica, if it is soluble in the tissues, as I believe it to be, is too slowly soluble to affect the lungs unless it stays there for some time'.

The following explanation by Roach⁽²³⁾ is of interest in this connection: 'particles which have been deposited /

CUMULATIVE NUMBER OF PARTICLES OVER SIZE

deposited in the alveoli may remain in the lungs indefinitely if they are insoluble, so that the amount of dust in a man's lungs is roughly proportional to the product of his age and the average concentration of dust to which he has been exposed since birth.

'On the other hand, a relatively soluble dust such as lead, is absorbed in the lungs so that it fairly rapidly accumulates in the blood, tissues and skeleton, and is eventually excreted. The rate of solution increases with the amount of material deposited in the lungs and the rate of excretion of the material increases with the amount in the body, so that under exposure to a constant concentration a level of equilibrium will eventually be reached when the amount in the body is such that the rate of excretion just equals the rate of deposition in the lung.

'In contrast to coal and silica, the lead in the body is slowly excreted when exposure ceases and the lead content usually reaches normal values within about 18 months (Kehoe, Thamann and Cholak, 1933). Thus the amount of lead in the body is determined by the level of exposure over the previous 18 months and, to a great extent, by that within the previous few weeks.

'The period of accumulation is even shorter in the case of harmful gases. 'For example, with a vapour such as benzine, saturation of the blood is reached within a few minutes; and saturation of the tissues is reached in two or three days'.

'Once this state of equilibrium is attained the amount accumulated in the body is independent of the duration of exposure and if the effects on the men are

non /

CUMULATIVE NUMBER OF PARTICLES OVER SIZE

non progressive the risk to health is a function of the atmosphere concentration and the duration of exposure may safely be ignored.

'With materials which are for all practical purposes insoluble, the amount accumulated in the body increases steadily at a constant rate proportional to the atmospheric concentration. The material remains in the lungs more or less permanently, even after exposure ceases.'

2.2 Dust Measurement.

2.2.1 What parameter should be measured, mass, surface area or number of particles?

Wynn and Dawes⁽²⁴⁾ (1952), when considering the size distribution of dust in British coal mines and the lung retention of different sized particles obtained curves, ((figs. 14(a) and (c) of Research Report No. 28)) which 'suggest that the count in the range 0.5 - 5 microns as determined from the thermal precipitator is valid as an index of the surface of particles less than 5 microns in the air and also of the area retained in the lung (Fig. 14d), and hence of the hazard of the dust. In like fashion the count in the range 1.0 - 5.0 microns is an index of the hazard of the dust, if the hazard is proportional to the surface area of the dust in the lung'.

The question was further considered by Wynn⁽²⁵⁾ (1952) who stated: 'Before methods of assessing airborne dust concentration can be discussed, it is necessary to decide upon ways of describing the concentration of airborne dust that are relevant to its capacity to

cause /

cause disease. Methods of measuring airborne dust concentration which give an approximate estimate of the hazard of health of the environment are to be preferred to methods of dust measurement which measure purely arbitrary parameters. Measurements of dust may be regarded as satisfactory from this point of view only if they measure a parameter which is approximately proportional to the quantity of dust retained by the lung. This may be achieved within the limits of accuracy of existing experimental knowledge in a number of different ways. It has often been postulated that the surface area of the dust particles retained by the lung is the most relevant parameter, however, for airborne dust clouds in mines the number, surface area and weight of dust per millilitre of air in the size range 0.5 to 10 microns are roughly proportional so that it is not altogether necessary to assume that the total surface area of the dust particles should be assessed'.

2.2.2 The "Average" versus the "Peak"
hypothesis:

In order to decide between these two theories, B.M. Wright⁽²⁶⁾ (1953) considered the mechanism of dust inhalation and retention and summarised the position as follows: "it appears that there is no definite physical or physiological basis for the concept of a threshold below which lungs free themselves completely of dust on the contrary, the lungs would be expected to start collecting dust from the first breath, and continue to do so throughout their owner's life. We are left then with the conclusion that there is nothing in our knowledge of the relationship between dust exposure and disease

incidence /

incidence, or the mechanism of inhalation and retention of dust, to substantiate the 'peak' hypothesis or to conflict with the 'average' hypothesis."

2.3 The Konimeter.

A vast amount of work has been published on the konimeter and it is proposed to record very briefly the main conclusions arrived at by others in publications with which the author is familiar. Of special interest are the disclosures and arguments which led to the introduction of the konimeter with the microscope system and the slide treatment technique of today.

2.3.1 The Kotze konimeter and microscope system:

The well known Kotze konimeter was introduced by the Miners Phthisis Prevention Committee⁽²⁷⁾ and has been in use since 1916. The microscope system⁽²⁸⁾ 'is that of a 2/3 inch objective with an ocular magnifying ten or twelve times' giving 'a magnification of about 150'. The light field system of lighting was used, initially, making the lower limit of detectibility about $\frac{1}{2}$ micron.

The present day konimeter dust counting microscope has the following specifications:

Eye piece X15 Compensating.
Objective 16 m.m. N.A. 0.30.
Tube length 160 m.m.
Condensor Abbe N.A. 1.2.
Condensor Stop 9 m.m.⁽²⁹⁾

Over the years, the Department of Miners has gradually gone over from the old to the new type.

2.3.2 Dark field system of lighting:

In order to decrease the lower limit to which particles could be detected, the dark field system of lighting /

TABLE 2.3.1(a)
THERMAL PRECIPITATOR WORK

Observation No.	COUNT @ 1000 L.F.		X 150 d.f. X 1000 L.F.
	Particles in 6X.3087 m.m.strips	p.p.c.c.	
1	752	2770	.75
2	574	2820	.74
3	480	2720	.86
4	382	2370	.89
5	329	2220	.83
6	570	4200	.78
7	205	1260	1.04
8	329	1630	.99
9	486	2100	.51
10	482	1890	.46
11	150	490	.85
12	122	320	.87
13	160	540	.98
14	213	750	.61
15	285	490	.53
16	194	290	1.12*
17	240	510	.83
18	263	740	.86
19	236	510	.92
20	136	300	.83
21	278	640	.95
22	131	440	1.06
23	323	680	.80
24	234	490	.60
25	103	330	.89
26	192	320	.71
27	176	770	.71
28	325	1000	.56
		Total Average	22.53 0.80 (sd = 0.03)

* Slide surface uneven and difficulty experienced to keep focus on slide surface.

... 17
... introducing my introduction (1963)
... L. Bergstrom (30) pointed out
... applying the dark field method
... spots could not be found in the
... as that in fact, all the spots
... are unfortunately ignored, so
... microscopic effect as far as
... without attached by the dark
... as that it was probably caused
... microscopic effect altogether,
... almost stated that the method
... known.
... as stated before, the
... without particles was better
... microscopic particles were
... (1963) also pointed out
... improved technique for use
... on day carried out the study
... warranted by the dark ground
... technique on the microscope
... now, the position of the spot
... for center by sector, the
... dark ground were then
... camera lens, and the spot
... dark lighting. The two parts
... as found that the dark ground
... particles that the immersion
... result. The conclusion, there
... of the ground illumination, as
... in connection with his knowledge
... microscopic particles, but did

lighting was introduced (1923) and in this connection A. Mavrogordato⁽³⁰⁾ pointed out that the manner of applying the dark field method of counting konimeter spots would not be found in any text book on microscopy and that in fact, all the rules of darkground illumination were deliberately ignored, so as to evade the ultra-microscopic effect as far as possible whilst retaining the contrast afforded by the dark background. He pointed out that it was probably impossible to cut out the ultra-microscopic effect altogether, but that the counts obtained showed that the method followed, went far in that direction.

As stated before, the reason for eliminating the finest particles was because it was believed that ultra-microscopic particles were not injurious. Mavrogordato⁽³¹⁾ also pointed out that when working out a dark ground technique for use with the konimeter, C.J. Gray carried out the following experiment: 'A spot was examined by the dark ground method which had since been adopted on the Witwatersrand', using a sector micrometer, 'the portion of the spot within the segment was drawn sector by sector, the 2/3 inch objective and the dark ground outfit were then replaced by a 1/12th inch immersion lens, and the spot was redrawn, using ordinary direct lighting. The two pictures corresponded, for it was found that the dark ground method had not disclosed any particles that the immersion 1/12th inch failed to reveal'. The conclusion, therefore, was that the method of dark ground illumination, as used by Sir Robert Kotze in connection with his konimeter, did not reveal ultra-microscopic particles, but did reveal all particles down

to /

d.f.
L.F.

(sd = 0.03)

CUMULATIVE NUMBER OF PARTICLES OVER SIZE

TABLE 2.3.I.(b)

SIZE DISTRIBUTION - AVERAGE OF 28 COUNTS		
Size in Microns	Per Cent.	Cumu- lative.
Less than		
0.2	51.5	100.16
0.23	24.8	48.66
0.46	14.3	23.86
0.84	6.2	9.56
1.37	1.9	3.36
1.82	.66	1.46
2.40	.27	.80
2.85	.12	.53
3.42	.12	.41
4.56	.11	.29
5.7	.11	.18
Larger than		
5.7	.07	.07
TOTAL	100.16	

to the limit of visibility
2.3.1. Lower 1/2

dark
bottom

The lower limit

may appear to be 1/2

the size may be determined

the same under high

enlarged by their

number of magnifying

microscopes

microscopes

The results

comparisons are given in

the following table

2.3.2. Observations

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to the limit of visibility by ordinary direct lighting.

2.3.3 Lower limit of detectability of the
dark field system as used in
konimeter practice:

The lower limit of detectability of the microscope system used is 1/5 to 1/6 micron.

This size may be determined by conducting size distribution counts under high power on thermal precipitator samples and by then counting the same samples under the konimeter microscope system, viz. at X150 under dark field illumination.

The results recorded by the author during such a comparison are given in table 2.3.1. The mean ratio of the low power count to the high power count came to 0.80 (for 28 observations). The results all refer to rock drill tests.

The size distribution of the dust is depicted graphically in fig. 2.1.

The size above which 80% of the number of particles fall, is the lower limit of detectability. As seen on the graph, this occurs in the neighbourhood of 0.17 micron. (The exact size is of course not known due to the uncertainty of the lower limit of detectability of the high power microscope system.)

2.3.4 Performance of the konimeter:

2.3.4.1 The Miners Phthisis Prevention

Committee⁽²⁷⁾ in paragraph 37 of

their Final Report (1919), submits the results of tests with a konimeter with two nozzles in series, which seemed to indicate that 'the dust contained in 5 c.c. of air sampled was all caught, if the number of particles

per /

COUNTS

mi-
ve.

16

66

86

56

36

46

80

53

41

29

18

07

CUMULATIVE NUMBER OF PARTICLES OVER SIZE

per cubic centimetre was not too high', and that the loss probably amounted to 5 per cent or less in samples going under 500 p.p.c.c. and to 7 or 8 per cent for double that number.

2.3.4.2 Mavrogordato⁽³²⁾ after considering five investigations on the efficiency of the konimeter, with the method of treatment of the slides and the counting technique then in vogue (1923) felt that they were 'left rather in the air as to the efficiency of the konimeter' but he was of opinion that it was not so much the absolute efficiency of the konimeter that concerned them but that so long as a konimeter count varied with the concentration of 'phthisis'-producing dust, and so long as it afforded a means of defining the danger zone, it did not matter in the least whether konimeter returns accurately represented dust concentrations in the air or not.

The conclusion of importance brought out by a consideration of the whole subject ((by 1923)) was: 'in practice, the konimeter yields what one may call a "figure of merit" rather than an absolute measure, and that this figure would vary within wide limits, according to the method of illumination adopted and, to a minor extent, with the observer'. (P. 39).

2.3.4.3 H.S. Patterson⁽³³⁾ (1937) compared the efficiency of the konimeter with that of the thermal precipitator and concluded: "for sizes between 5 and 2 microns there is general agreement between the two curves ((instruments)), but below 2 microns the divergence increases, until at a size of 0.5 micron the konimeter only gives a small fraction".

((In /

TABLE 2.3.II.

(Two thermal precipitators were used and konimeter samples were taken at one-minute intervals over a period of 30 minutes)

TEST NO.	Ignition - Immersion - Ignition at x 150 darkfield.		K/TP RATIO.
	Average Count in p.p.c.c.		
	Konimeter	Thermal Precipitator	
1	2290	3100	.74
2	1055	1555	.68
3	840	1170	.72
4	340	420	.81
5	500	580	.86
6	320	430	.74
7	425	480	.89
8	1300	2160	.60
9	270	400	.67
10	470	590	.80
11	390	460	.85
12	400	495	.83
13	1220	2190	.56
14	320	630	.51
15	170	280	.61
16	300	340	.88
17	265	265	1.00
18	270	290	.93
Mean			= 0.76
s.d.			= 0.03

X

(In this connection the konimeter slides were ignited, whilst the thermal precipitator, and this slide, for the smaller number of slides.)

Reliability of the konimeter due to the known microscope aperture given in section 2.3.1, section 2.3.2, and the sampling between the microscope and by the konimeter after the microscope. A sample of each recorded in table 2.3.II. In the table, there.

In order to obtain the results of the main series.

Relatively high konimeter data on thermal precipitator for a given konimeter accuracy.

These results, which are the konimeter data, are the basis of detection.

2.3.3.4 Each as follows from his series of data likely to be used the konimeter has a type to that of the thermal

((In this connection, it should be pointed out that the konimeter slides were first immersed in acid and then ignited, whilst the thermal precipitator slides were only ignited, and this difference was mainly responsible for the smaller number of fine particles left on konimeter slides.))

Inability of the konimeter to deposit all particles down to the limit of detectability of the konimeter microscope system (which is 1/5 to 1/6 micron as shown in section 2.3.3 above) may be demonstrated by parallel sampling between konimeter and thermal precipitator and by counting the slides of both instruments under the microscope system used for the konimeter. An example of such results obtained by the author, is given in table 2.3.II. The results were recorded during rock drill tests.

As can be seen, the mean konimeter count came to about 75% of the mean thermal precipitator count.

Relatively higher concentrations of particles on konimeter than on thermal precipitator slides may have been responsible for a portion, but not the whole reduction in konimeter counts.

These tests, therefore, supports the conclusion that the konimeter does not deposit all particles down to the limit of detectability of the microscope system used.

2.3.4.4 Lambrechts⁽³⁴⁾ in 1940, concluded as follows from his series of investigations: 'For most types of dust likely to be encountered in Witwatersrand mines the konimeter has a collecting efficiency almost equal to that of the Thermal Precipitator. For certain

dusts /

CUMULATIVE NUMBER OF PARTICLES OVER SIZE

dusts, such as ore-bin dust in which aggregates of particles are likely to occur, the konimeter may have an apparent efficiency exceeding that of the Thermal Precipitator, due to the breaking up of aggregates by the former', 'Generally speaking, the konimeter with the new (ignition-immersion-ignition instead of the Acid-Vapour) method of treatment, should give an entirely reliable indication of the dust risk at the time and place of sampling'.

In reply to discussions of his paper, Lambrechts⁽³⁵⁾ points out that when submitting dust slides to the ignition-immersion-ignition method of treatment and counting them under a magnification of X150 with dark field illumination for both konimeter and thermal precipitator, 'the general agreement between counts obtained during a representative number of investigations covering such processes as scraping, drilling and lashing, has been reasonably close'. In 1945, Lambrechts⁽³⁶⁾ submitted a graph which indicates that for counts up to 1,000 p.p.c.c. by thermal precipitator @ X1,000 light field, the konimeter count @ X150 dark field is approximately 60% of that obtained by thermal precipitator. Above 1,000 p.p.c.c. (by t.p.) the konimeter count gradually becomes a smaller proportion of the thermal precipitator count (according to Lambrechts' curve) until it is about 40% at 5,000 p.p.c.c.

2.3.4.5 Rabson⁽³⁷⁾ (1946) compared the circular konimeter with the thermal precipitator and concluded: 'The Konimeter, in correct adjustment and with the recommended film of adhesive on the slide, is capable of catching up to 90% of the dust (viz. the

incombustible /

incombustible acid-in-soluble rock particles) in the air; the collecting efficiency of the konimeter begins to fall only at the finest particles, 0.2 microns in size and less, ... it compares very favourably with the Thermal Precipitator at particles over 0.2 microns. If the slides are first ignited before acid treatment, the jelly is burnt away and the particles appear to become "fixed" to the slide, so that in the subsequent acid treatment only a small loss of rock particles occurs, and it can be taken that over 90% of the particles remain on the slide; The visibility of particles with dark field illumination vary with the density of the spot and the resulting scattering of light, ... the heavier the spot the lower the visibility, but even in samples of 1,000 p.p.c.c. counting efficiencies of over 60% may be obtained, provided the spot is well formed; For spots up to 500 p.p.c.c. the counting efficiency may be taken as 70% without serious error; the overall efficiency of the circular konimeter (i.e. the one having a $\frac{1}{8}$ " straight cylindrical jet) with the ignition first technique, is:

$$0.9 \times 0.9 \times 0.7 = 60\%.$$

((It is generally accepted on the Witwatersrand, that for routine purposes, there is not a significant difference between the results recorded by the circular konimeter and the Kotze konimeter.

The main difference between the two konimeters being the $\frac{1}{8}$ " cylindrical jet of the circular konimeter as against the $1\frac{1}{4}$ " tapered jet of the Kotze konimeter.))

2.3.4.6 Davies, Aylward and Leacy ⁽³⁷⁾

(1951), when comparing a Kotze konimeter with a thermal

precipitator /

precipitator and when using coal dust that had been allowed to settle for one hour, found that when glycerin jelly was used, the Kotze konimeter agreed well with the thermal precipitator for particles between 9 and 2 micron in diameter but over estimated the number of smaller particles.

This over estimation of smaller particles was, under the conditions of their tests, not attributed to shattering of large particles but to disaggregation of particles, especially that of small particles being pulled off large particles during the acceleration of the particles at the intake end of the konimeter nozzle.

Their experiments also indicated (P. 382) that a velocity which was below 200 m/sec. did not cause fine quartz particles to fracture on impact.

2.3.4.7 Beadle⁽¹⁾ (1951) when comparing the circular konimeter with "immersion first" treatment of slides against the thermal precipitator with "ignition first" treatment of slides concluded: 'The collecting efficiency of the konimeter is found to depend to a large extent on the size distribution of the dust sampled, and also on the concentration. With a low concentration of coarse dust the konimeter appears to have a high efficiency and sometimes gives counts significantly higher than the thermal precipitator, due possibly to the breaking up of aggregates or large particles. With fine dust the efficiency is low, and becomes still lower with higher concentration.'

2.3.4.8 Hasenclever⁽³⁹⁾ (Born, Germany, 1955) compared the Sertorius Konimeter with the thermal precipitator for particles

above /

above 0.7 micron. Tests were conducted in freshly generated quartz dust clouds where the coarse particles were given a chance to settle out, so that particles above 10 micron did not form more than 0.1% of all particles.

With similar microscopic magnifications, the konimeter + thermal precipitator count for less than five micron particles varied between 0.84 and 1.32, with a mean of 1.07. Six tests were conducted. (P. 427). Hasenclever also submits graphs showing konimeter and thermal precipitator counts that were taken in various types of dust viz., in ceramic industries, asbestos industries, a "workshop" and a lead factory. In spite of the variety of dusts and the great differences in the dust concentrations the assessments of the two instruments agreed well with each other.

Hasenclever concluded that provided a sufficient number of konimeter samples were taken within the sampling period of the thermal precipitator, one might put the konimeter value for particles over 0.7 micron equal to that of the thermal precipitator, $\pm 15\%$. He also concluded that with a coarse dust, on account of the difference in the principles of operation of the two instruments, it could be expected that the konimeter would give a higher count than the thermal precipitator; and that for dusts with 87% to 100% of the particles less than 5 micron and where larger than 20 micron particles were absent, the figures of the two instruments were comparable.

2.3.4.9 Roesher⁽⁴⁰⁾ (1957, Germany), discusses in detail the theory underlying dust measurement

by /

by konimetry. He points out that ideally, a konimeter should really sample continuously but that nevertheless, a well designed hand konimeter was very suitable as a routine dust measuring instrument, that it was an excellent instrument for measuring fine dust and that it incorporated a maximum number of advantages. ((He was satisfied that dust in the size range 0.5 to 5 micron was the dust to be measured for hygienic purposes.)) He was also of opinion that the unfavourable judgements often made of the konimeter from comparison tests, was related to the fact that the types of konimeters used were not of the most suitable design and also that the individual konimeter samples were not taken at sufficiently short time intervals. ((He specifically refers to Beadles⁽¹⁾ and Ferry, Farr and Hartman's⁽⁴¹⁾ work in this respect.))

2.3.4.10 Summary and comments: In view of what has been said about the performance of the konimeter, it is evident that the suitability of the konimeter depends on the characteristics of the dust clouds in which it is used.

There are three main factors which influences the performance of the konimeter. They are: (1) the ease with which particles are fractured, (2) their concentration and (3) their size distribution.

The konimeter is suitable to measure hard, tough particles of low concentration and of medium size distribution.

The particles to be measured in Witwatersrand mine dust are mostly free silica and silicates, which, when below 20 micron, do not appear to fracture under the conditions of konimeter sampling.

In /

TABLE 2.4.1.

YEARS OF SERVICE VERSUS NUMBER OF NEW CASES. (43)

Years of Service.	Number of New Cases Detected	
	During 1924-25 to 1928-29	During 1946-47 to 1950-51
Upto 5	3	1
" 10	98	5
" 15	160	23
" 20	30	53
" 25	2	62
" 30	-	39
More than 30	-	26
TOTAL	293	209

The results of the above table are represented diagrammatically in figure 2.5.

TABLE 2.4.II.

YEARS OF SERVICE VERSUS SILICOSIS RESPONSE. (43)

Years of Service.	Silicosis in the first stage per 1000	
	During 1924-25 to 1928-29	During 1946-47 to 1950-51
Upto 5	0.67	0.07
" 10	22.1	0.67
" 15	57.1	4.29
" 20	74.9	21.6
" 25	41.3*	57.7
" 30	- *	86.2
More than 30	- *	133

* Cohorts too small for figures to be representative.

The results of the above table are represented diagrammatically in figure 2.6.

In Witwatersrand mine
No. Most samples taken are
500 p.p.m. are exceptional.

High concentrations are, there
effect on the lung count record

The same size thorax
with insoluble particles being
that of drilling and that of

The number of, surf.
distribution with respect to
figures 2.2, 2.3

which cumulative curves for
size of particles against
of individuals (34) showed the
percentage of a certain di-

stribution for a fine dust.
Figures 2.2, 2.3, 2.4
show concentration of particles

which a larger surface area
particles is likely to be re-
sults that the South African

mined that other fine dust
the proportions retained in
greater retention curve was

sufficient for a coarse dust
Therefore, error in the right
2.4 General conclusion

and silicosis.
As pointed out by
bismeter has been very effi-

cient in Witwatersrand in
of using it has undergone

NEW CASES. (43)

ses Detected

During
1946-47
to
1950-51

1
5
23
53
62
39
26

203

presented

CNSE. (43)

st stage per

uring
1946-47
to
1950-51

0.07
0.67
4.29
1.6
7.7
5 2

be repre-

e repre-
2.6.

In Witwatersrand mines, dust concentrations are low. Most samples taken are below 200 p.p.c.c. whilst 500 p.p.c.c. are exceptional. Underestimation due to high concentrations can, therefore, not have a large effect on the mean count recorded.

The mean size distribution of the incombustible, acid insoluble particles sampled, lies somewhere between that of drilling and that of ore bin dust.

The number -, surface area -, and volume distribution with respect to size of these two dusts are depicted in figures 2.2, 2.3 and 2.4. The figures contain cumulative curves for number, surface area and volume of particles against particle size. Beadle⁽¹⁾ and Lambrechts⁽³⁴⁾ showed that the konimeter tends to over estimate for a coarse dust as compared with its efficiency for a fine dust.

Figures 2.2, 2.3 and 2.4 reveal that for equal number concentration of particles breathed, a larger volume, a larger surface area and even a larger number of particles is likely to be retained in the alveoli when coarse dust (by South African gold mining standards) is inhaled than when fine dust is inhaled. ((In computing the proportions retained in the alveoli, Brown's⁽⁴²⁾ alveolar retention curve was used.)) In being more efficient for a coarse than for a fine dust, the konimeter, therefore, errs in the right direction.

2.4 General correlations between konimeter counts and silicosis.

As pointed out by Lambrechts⁽³⁴⁾ in 1940: 'the konimeter has been very closely associated with dust control in Witwatersrand mines since 1916 and the method of using it has undergone various changes. Yet it has always /

CUMULATIVE NUMBER OF PARTICLES OVER SIZE

TABLE 2.4.III

SILICOSIS RESPONSE AGAINST CALENDAR YEARS. (43)

Period	Period Mid Point.	Cases per Thousand		
		5 to 10 years	10 to 15 years	15 to 20 years
1923-24 to 1927-28	1925	24	64	87
1928-29 to 1932-33	1930	7.4	31	44
1933-34 to 1937-38	1935	1.3	13	41
1938-39 to 1942-43	1940	1.1	7.2	38
1943-44 to 1947-48	1945	0.7	6.0	23
1946-47 to 1950-51	1948	0.67	4.3	22

See Figure 2.7.

always been accepted that on these incidents, even if only a person is at risk to which person it can be claimed that is reflected by silicosis incidence.

In the following section, incident in greater detail.

2.4.2 Reduced Risk

The reduction in the frequency of silicosis is depicted in the reduced silicosis. Amongst silicosis:

- (a) Increase in the risk of contracting silicosis
- (b) Decreased silicosis service activities with earlier years
- (c) Increasing silicosis years.

2.4.1(a) Increase before

The change that was evident from the results depicted graphically in frequency histograms of the against years of service for figures show that whereas the about 12 years service by the one cases had about 22 years

RS. (43)

Thousand	
5	15 to 20 years
87	
44	
41	
38	
23	
22	

always been accepted that on an average the konimeter does indicate, even if only very approximately, the silicosis risk to which persons are exposed underground, and it can be claimed that in general, actual results as reflected by silicosis incidence rates, have borne out this assumption.'

In the following sections this "agreement" is considered in greater detail.

2.4.1 Reduced dust concentrations versus reduced silicosis hazard.

The reduction in dust concentration at six strategic points is depicted graphically in figure 3.7 whilst the reduced silicosis hazard is illustrated by the following indices:

- (a) Increase in the underground service before contracting silicosis.
- (b) Decreased silicosis response, of similar service cohorts (of later years as compared with earlier years).
- (c) Decreasing silicosis response with calendar years.

2.4.1(a) Increase in underground service before silicosis is contracted.

The change that took place over about 20 years is evident from the results in table 2.4.I which is depicted graphically in figure 2.5 which contains two frequency histograms of the "new" cases of silicosis against years of service for two calendar periods. The figures show that whereas the majority of "new" cases had about 12 years service by the late '20s, the majority of new cases had about 22 years service by the late '40s.

((During /

CUMULATIVE NUMBER OF PARTICLES OVER SITE

((During the earlier period the "new" cases were termed the "ante-primary stage" whereas by 1940, the "new" cases were termed "first stage" but the two stages are comparable in degree of silicosis.))

2.4.1(b) Decreased silicosis response:

Silicosis responses, for two periods which are 22 years apart, are submitted in table 2.4.II, and depicted in figure 2.6. The two curves give the silicosis response (as measured by the number of cases with silicosis per thousand) against years of underground service. The two curves are for the two periods 1924 - 1929 and 1946 - 1951. The two curves demonstrate the lower silicosis response for equal years of service, during the later than during the earlier period. Eg., whereas by the late nineteen twenties about 55 men had silicosis out of every 1,000 with 12 years service, only 5 had silicosis by the late nineteen forties.

2.4.1(c) Falling response with calendar years:

The decreasing silicosis response is revealed by the results in table 2.4.III, which is graphically illustrated in figure 2.7. Three main service co-horts are considered viz. the 5 - 10 years, the 10 - 15 years and the 15 - 20 years service groups.

((For purposes of comparison, the mean dust curve obtained for: the bottoms of intake shafts, main intake airways, stopes, and development ends combined, is also shown in figure 2.7.))

As can be seen, the silicosis response came down more or less in sympathy with the dust concentration.

2.4.2 Exposure-Responses.

In a paper on "permissible dustiness" Hatch⁽⁴⁴⁾ (1955) said: "systematic studies of health hazards in the /

CUMULATIVE NUMBER OF PARTICLES OVER SIZE

the dusty trades have demonstrated a direct relationship between

- (a) the magnitude and duration of dust exposure and
- (b) the incidence and rate of production of dust disease.

For separate industries, the findings have indicated that tolerable dust concentrations exist, below which disabling dust disease does not develop (in the absence of tuberculosis) over a normal span of working life. At such levels of dustiness the probability of silicosis developing, even in its earliest and non-disabling stage, is low."

Hatch followed Roachs' ⁽⁴⁵⁾ method of obtaining an exposure-response curve and plotted such a curve, on log-probability paper, for the South African gold miners (the data coming from the Report of the Silicosis Medical Bureau for the year March, 1951 ⁽⁴³⁾). This plot, based upon yearly examinations of 25 - 30,000 individuals, shows the progressive development of silicosis in several "generations" of underground workers whose periods of employment began at various times prior to 1950 back to 1920, ... He submits graphs on probability paper which reveal a linear relationship between accumulated exposure and the proportion with silicosis.

The dust exposure is expressed as a mass concentration viz., in milligrams per cubic metre, as determined by means of the sugar tube. He points out that: 'the different experiences of the several generations in respect to the development of silicosis fall on the same line when the "dose" is expressed as the product of concentration and years of exposure'.

The sugar tube results which Hatch used are depicted graphically in figure 2.8, and for purposes of comparison /

CUMULATIVE NUMBER OF PARTICLES OVER SIZE

TABLE 3.1.1.
(1952)

DESCRIPTION OF SAMPLE	INTAKE		WORKING POINT		RETURN		TOTAL AND AVERAGE	
	S.	O.	S.	O.	S.	O.	S.	O.
1. Air entering downcast shafts at surface.	192	45	-	-	-	-	192	45
2. At shaft loading box platform in downcast shafts -								
(1) Vertical	-	-	260	150	-	-	260	150
(2) Incline	-	-	124	112	-	-	124	112
3. Air leaving downcast shafts before passing tipping stations	528	69	-	-	-	-	528	69
4. Tipping stations in main intake airstream	356	67	904	135	392	102	1,652	112
5. Other tipping stations	184	101	584	165	176	126	944	145
6. Air in main intake airways away from downcast shafts.	616	88	-	-	-	-	616	88
7. Stopes (including backstopes).	3,262	85	9,914	148	3,270	116	16,446	129
8. Development ends-								
(1) Drives and crosscuts.	3,138	81	3,518	135	2,318	118	7,674	116
(2) Winzes	304	90	528	164	288	129	1,120	135
(3) Raises	708	93	1,104	156	676	135	2,488	132
9. Shaft sinking -								
(1) Vertical	4	97	176	364	4	97	184	352
(2) Incline	60	63	160	128	56	106	276	109
10. At shaft loading box platforms in upcast shafts -								
(1) Vertical	-	-	24	51	-	-	24	51
(2) Incline	-	-	44	99	-	-	44	99
11. Upcast shaft stations during hoisting of shifts after blasting.	-	-	-	-	56	73	56	73
12. Main return airways.	-	-	-	-	288	86	288	86
13. Air leaving upcast shafts at surface.	-	-	-	-	106	61	106	61
14. Other samples	76	96	632	119	96	117	804	117
TOTAL :	8,428	82	17,972	147	7,628	116	34,028	124

S. = Number of Spots.
O. = Average count in p.p.o.c.

response, the kilometer r
ground points of "Waterer"
Figure 2.6. As can be see
is a number similar to that
by Bush, and hence, it nee
statistically will be obtain
and located at sugar cube

1. THE NEW INVESTIGATION
2. The purpose of

statistic provide
The results of a

more widespread survey
Plans are published in
Government Mining Department

Table 3.1.1. 38
Results are published. A

sample and the main trend
7. 4 points are given.

The Department
The Government

These also published were
these as recorded by official

the author decided to have
results recorded by the

The main reason
4. The author is not

recorded by the
2. all the mines of

to the chambers
submitted by one

RETURN		TOTAL AND AVERAGE	
C.	S.	C.	S.
-	-	132	48
-	-	260	180
-	-	124	112
-	-	528	68
22	128	1,552	112
75	128	944	148
-	-	616	88
70	116	15,448	128
8	118	7,874	112
8	128	1,120	132
8	128	3,488	132
4	37	124	352
6	108	276	128
-	-	24	56
-	-	44	48
6	72	56	72
86	282	66	
61	108	61	
117	804	117	
118	34,028	128	

comparison, the konimeter results for six strategic underground points of Witwatersrand mines are also depicted in figure 2.8. As can be seen, the konimeter results varied in a manner similar to that of the sugar tube results used by Hatch, and hence, it seems logical that a similar relationship will be obtained if konimeter results are used instead of sugar tube results.

3. THE MAIN INVESTIGATION.

3.1 The dustiness of mine air at a number of strategic points.

The results of konimeter samples taken during routine underground inspections by Government Inspectors of Mines are published in the Annual Reports of the Government Mining Engineer.

Table 3.1.I. is a copy of the form in which the results are published. As can be seen the number of samples and the mean counts at specific classes of underground points are given. ((Table 3.1.I are the results recorded by the Department of Mines in 1952)).

The Transvaal and Orange Free State Chamber of Mines also published results of konimeter dust determinations as recorded by officials of the mining industry but the author decided to base this investigation on the results recorded by the Mines Department only.

The main reasons for this decision are as follows:

- .1 the author is more familiar with the data recorded by the Mines Department than those recorded by the Chamber,
- .2 all the mines did not always submit returns to the Chamber; eg., in 1936, returns were submitted by only 24 out of the 35 working

mines /

CUMULATIVE NUMBER OF PARTICLES OVER SIZE

mines⁽⁴⁶⁾,

- .3 the Chamber of Mines stopped publishing results of dust determinations by 1950,
- .4 the different mines did not always use the same treatment technique, eg. in 1936 'some mines used acid treatment whilst others used other treatments', ⁽⁴⁶⁾
- .5 only by 1950, did the Chamber change over from immersion-ignition to ignition-immersion-ignition treatment whereas the Mines Department changed to the latter method as early as 1942,
- .6 the konimeter samples taken by the Chamber were not cast in the same classifications as those of the Department of Mines which would make a combination of the two sets of data very difficult. Although the Chamber's figures were based on a much larger number of samples, its classifications were not suitable as the Department's for an investigation such as the present one.
- .7 In view of the above, it was doubtful whether the time and labour necessary to combine the Chamber's results with those of the Department would warrant the probable improved accuracy of the estimates.

For the purpose of this investigation it was decided to use the results recorded at the six strategic points mentioned below as indicators of the underground dust conditions.

The six points are:

.1 /

- .1 Air entering downcast shafts at surface,
((referred to as point "1" in table 3.1.I.))
- .2 Air leaving downcast shafts before passing
tipping stations ((referred to as point "3")).
- .3 Air in main intake airways away from downcast
shafts ((referred to as point "6")).
- .4 Air in stopes ((referred to as "7 working
point".))
- .5 Air at development end faces ((referred to
as "8 working point")).
- .6 Air in sinking shafts ((referred to as "9
working point")).

The other points given in the table were not used
on account of one or more of the following reasons:

- (a) They only show where dust is produced, eg.,
 - (i) At shaft loading box platforms
(classifications 2 and 10);
 - (ii) At tipping stations (classifications
4 and 5);
- (b) The points cannot be associated with specific
occupations, eg.,
 - (i) Main return airways (12),
 - (ii) Air leaving upcast shafts at surface (13);
- (c) The classifications were introduced compara-
tively recently such as "intake air" and "return
air" in stopes, development ends and sinking
shafts.
- (d) The classifications represented exceptional
conditions, eg., at upcast shaft stations
during hoisting of shifts after blasting.

Note: The present form of the table was introduced in

1940 /

1940 and was an expansion of the first form which was introduced in 1931. The main alteration consisted in classifying separately, samples that were taken in intake, working point and return air of stopes, development ends and sinking shafts.

Note on development ends (classification "8"):

As can be seen in table 3.1.I the results that were recorded in the three main classes of development ends viz. (1) drives and crosscuts, (2) winzes and (3) raises, were recorded separately in the annual reports.

For the purpose of this investigation, however, the results of these three classes of working places were combined into a single figure. The reason for this being that on the records of service of mine workers, no distinction is made between the various types of development work done by them. The relative weighting of the three counts was considered and it was decided that the proportions in which the number of spots were taken in the three classes of development ends will roughly be the same as the proportions of the time that developers spend at the faces of the three classes of ends.

A criticism of this estimate may be that an Inspector of Mines will not climb up a raise if he can help it but, the counter argument is that a developer will also not do so unnecessarily.

The mean proportions in which spots were taken in the three classes of development ends over the period 1931 to 1950 were approximately 66% in drives and cross cuts, 11% in winzes and 23% in raises.

Sinking Shafts:

The counts recorded in vertical and inclined
shafts /

TABLE 3.1.II.

UNDERGROUND POINT	Ref No.	Mean Count.
At Top of Downcast Shaft	.1	40 p.p.c.c.
At Bottom of Downcast Shaft	.3	60 p.p.c.c.
In Main Intake Airways	.6	85 p.p.c.c.
In Stopes	.7	150 p.p.c.c.
In Dev. Ends	.8	150 p.p.c.c.
At Sinking shaft bottoms	.9	180 p.p.c.c.

...were also combined into
this being that no distinction
series of mine workers between
employed on inclined shaft

The census ratio of
related to that taken in 1930
1931-1936 was approximately
arriving at a mean count, the
related to this proportion.
[A very small prop
the census which qualified for
that arising, so that large
various would affect the final
count.]

The annual mean
1931 and 1935 at each
these were analysed.

"Test estimates" of
was made by about 1935, and
the variation in the

with calendar year
to be able to estimate
with calendar year, and
as far as possible, the
technique introduced over the

This was done by a
for each period during which
technique remained unaltered
in the count between the end
beginning of another was assessed
by the change in the technique

shafts were also combined into one figure. The reason for this being that no distinction is made on the records of service of mine workers between employment on vertical and employment on inclined shaft sinking.

The mean ratio of the number of spots taken in vertical to that taken in inclined shafts for the period 1931 - 1950 was approximately 55 to 45 and for the purpose of arriving at a mean count, the two working places were weighted in this proportion.

((A very small proportion of underground time of the cases which qualified for investigation was spent on shaft sinking, so that large errors with respect to shaft sinking would affect the final result to a relatively small extent.))

The annual mean counts recorded between the years 1931 and 1955 at each of the above six classes of points were analysed.

"Best estimates" of the dust concentrations at these points by about 1950, are summarised in table 3.1.II.

3.2 The variation in the dust count of mine air with calendar years.

To be able to estimate the variation of the dust count with calendar years, it was necessary to estimate as accurately as possible, the effects of the various techniques introduced over the years.

This was done by analysing the results recorded for each period during which the dust determination technique remained unaltered. A significant difference in the count between the end of one period and the beginning of another was assumed to have been brought about by the change in the technique.

The /

Mean Count.
40 p.p.c.c.
50 p.p.c.c.
35 p.p.c.c.
50 p.p.c.c.
50 p.p.c.c.
30 p.p.c.c.

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TABLE 3.2.I.
AIR ENTERING DOWNCAST SHAFTS ON SURFACE :

Year.	Number of spots	Mean Count.
1931	375	54 p.p.c.o.
2	205	59 "
3	422	37 "
4	776	32 "
5	722	21 "
6	1,236	13 "
7	662	28 "
8	730	28 "
9	510	30 "
1940	241	24 "
1	240	26 "
2	318	33 "
3	282	24 "
4	180	24 "
5	260	30 "
6	260	29 "
7	240	32 "
8	160	32 "
9	376	38 "
1950	506	41 "
1	166	37 "
2	192	45 "
3	160	38 "
4	236	38 "
5	308	40 "
6	316	30 "
7	272	50 "
TOTAL	10,093	

* Statistical analyses were done of the results upto 1955 only.

The results recorded
spots selected, are given in
to one to ten, records are
The technique of tre
counting was changed three times
classifying the results recorded
spots was changed once.
Furthermore, during
a gradual change over in the
the temperatures still are
drops have been complete and
and probably have been a no
has been but having been g
impossible to test the effe
are therefore ignored.

The following table

technique in vogue since 1931

Initial.

1931 - 1940 Initial

1941 onwards Initial

1942 onwards Initial

1943 onwards Initial

1944 onwards Initial

1945 onwards Initial

1946 onwards Initial

1947 onwards Initial

1948 onwards Initial

1949 onwards Initial

1950 onwards Initial

1951 onwards Initial

1952 onwards Initial

1953 onwards Initial

1954 onwards Initial

1955 onwards Initial

TABLE 3.2.II.

AIR LEAVING DOWNCAST SHAFTS BEFORE PASSING
TIPPING STATIONS.

Year	Number of Spots.	Mean Count.
1931	355	74 p.p.c.c.
2	461	152 "
3	1,361	64 "
4	609	87 "
5	337	84 "
6	741	64 "
7	936	64 "
8	2,705	43 "
9	1,323	55 "
1940	922	51 "
1	542	46 "
2	532	68 "
3	698	59 "
4	440	56 "
5	512	60 "
6	710	55 "
7	612	55 "
8	596	58 "
9	1,230	57 "
1950	946	73 "
1	676	59 "
2	528	59 "
3	384	52 "
4	548	50 "
5	544	60 "

6	444	60 "
7	622	70 "

TOTAL	20,314	

* Statistical analyses were done of the re-
sults upto 1955 only.

36

1.2.1.1. Results
of the results record
as listed, a paragraph in
annual reports around the 15
will therefore be quoted, but
that the statement was ap-
proposed and almost cer-
tainly during later years
of samples taken in the place
The statement read
"Through the sample
was obtained in the course
of expected or indicated
later as a planned, well-
known represent the area
was sufficiently many
was in fact as to the
one of the main
in the "small" and places
and, and having found the
these small conditions are
there are two places, the
is limited to go to and
we suggested or known to
On the other hand
can always get such a clear
to take a certain number
being kept very busy on
these there to go to, and
samples in places where

3.2.1 Some features of the recorded dust counts.

3.2.1.1 Degree of bias: On the question

of whether the results recorded by Inspectors of Mines are biased, a paragraph in the Government Mining Engineer Annual Reports around the 1936 period is of interest and will therefore be quoted, but it should be pointed out that this statement was specifically applicable to the 1936 period and almost certainly not applicable to the same extent during later periods as far as the proportion of samples taken in bad places are concerned.

The statement reads as follows:

"Though the samples, a large number of which are obtained in the course of inspections where conditions are suspected or definitely known to be bad, are not taken on a planned, well-balanced system, and consequently do not represent the average conditions in the mines, they are sufficiently numerous and well-distributed to give an indication as to the conditions." (47)

One of the main reasons for taking dust samples is to "smell" out places with unsatisfactory dust conditions, and having found them, to keep on taking samples there until conditions are satisfactory. Hence, if there are two places to choose from, an Inspector will be inclined to go to the place where poorer conditions are suspected or known to exist.

On the other hand, the Inspector of Mines has not always got such a choice, because it is expected of him to take a certain minimum number of spots every month. Being kept very busy on other duties, he can not always choose where to go to, but mostly has to take dust samples in places where his routine inspections lead him.

On /

CUMULATIVE NUMBER OF PARTICLES OVER SIZE

SING

Mean
Count.

P.P.C.C.

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TABLE 3.2.III.

AIR IN MAIN INTAKE AIRWAYS AWAY FROM DOWNCAST
SHAFTS.

<u>Year.</u>	<u>Number of spots.</u>	<u>Mean Count.</u>
1931	186	202 p.p.c.c.
2	308	149 "
3	152	110 "
4	519	181 "
5	129	105 "
6	476	78 "
7	798	102 "
8	1,666	147 "
9	1,078	89 "
1940	525	97 "
1	266	71 "
2	460	96 "
3	456	64 "
4	488	83 "
5	624	108 "
6	358	76 "
7	432	73 "
8	540	69 "
9	1,522	87 "
1950	1,656	81 "
1	624	73 "
2	616	88 "
3	272	67 "
4	488	80 "
5	576	110 "
6	468	90 "
7	708	90 "
TOTAL		16,391

* Statistical analyses were done of the results upto 1955 only.

On the whole, therefore, the author is of the opinion that the vast majority of dust samples taken, are unbiased.

Hence, the results recorded at different classes of underground places over the same period, may be compared. Similarly, the results recorded over different periods at the same class of place, may be compared, provided the dust assessment technique did not alter, and if altered, was allowed for.

3.2.1.2 Lines of best fit: To estimate the variation in the dust count at a particular class of place over a particular period, the mean annual counts recorded at that class of place were plotted against calendar years, and the line of best fit to the plots found according to the method of least squares.

For the purpose of this investigation, the annual counts were treated as if they were drawn at random from a normal population. To allow for the assumed small but unknown amount of bias, a significant difference was not decided at the usually accepted 95% level of the t-distribution, but at a higher level viz. the 97.5% level. (For development work there existed additional uncertainty and to allow for this additional uncertainty, decisions were made at a still higher level namely at the 98% level.

3.2.1.3 The three periods of steady conditions: As stated before, there were three periods during each of which the dust assessment technique remained practically unchanged. They were:

.1 /

CUMULATIVE NUMBER OF PARTICLES OVER SIZE

TABLE 3.2.IV.

S T O P E S .

<u>Year</u>	<u>Number of spots</u>	<u>Mean Count.</u>	
1931	1,278	271	p.p.c.o.
2	1,790	240	"
3	1,094	193	"
4	2,324	163	"
5	2,171	168	"
6	4,119	138	"
7	6,418	124	"
8	8,047	125	"
9	6,828	145	"
1940	1,976	164	"
1	1,674	135	"
2	1,914	164	"
3	2,894	149	"
4	3,744	156	"
5	3,828	153	"
6	3,404	137	"
7	4,546	139	"
8	7,968	144	"
9	9,442	151	"
1950	8,272	136	"
1	6,984	154	"
2	9,914	148	"
3	7,664	142	"
4	7,000	164	"
5	2,688	150	"
6	5,888	140	"
7	5,872	150	"
TOTAL		132,731	

* Statistical analyses were done of the results upto 1955 only.

1931 - 1941

1942 to 1948

1949 and onwards

As stated above, an

mentioned in 1940 when a

has samples taken in

of points "A", "B" and "C"

in 1941 was the significant

noticed, so that in the

and and change, a difference

and period was due to the

change

In the analysis

mentioned in the previous

due to extrapolate the results

results that would have been

perhaps been in 1940.

Significant

but for estimation, due to

similar date at which a

normal to have been

3.2.1.4

Although the annual number

of working point varied

work while to weigh annual

number of spots taken.

3.2.2 The count

points

3.2.2.1

media recorded are days

- .1 1931 - 1941*
- .2 1942 to 1948.
- .3 1949 and onwards.

* As stated above, an altered classification was introduced in 1940 when a distinction was made between dust samples taken in intake, working point and return air of points "7", "8" and "9", and only 2 years later, viz., in 1942 was the ignition-immersion-ignition technique introduced, so that in the case of stopes, development ends and shafts, a difference between the first and the second period was due to the combined effect of these two changes.

In the analyses that follow, the periods will be considered in the reverse order, because it is the intention to extrapolate the results of earlier techniques to results that would have been recorded had the present technique been in vogue.

Significant differences between the lines of best fit estimates, for the same point, and for a calendar date at which a change was introduced, was assumed to have been brought about by the change.

3.2.1.4 The difference in the annual number of spots taken per point:

Although the annual number of spots taken at each class of working point varied considerably, it did not prove worth while to weigh annual averages according to the number of spots taken.

3.2.2 The counts recorded at the six selected points:

3.2.2.1 Air entering downcast shafts: The results recorded are depicted in figure 3.1.

3.2.2.1.1 /

TABLE 3.2.V.
DEVELOPMENT ENDS.

Year	Number of f. sta.	Mean Count.
1931	859	348 p.p.c.c.
2	1,362	295 "
3	1,404	346 "
4	2,526	235 "
5	2,122	159 "
6	5,006	150 "
7	7,098	177 "
8	5,997	159 "
9	7,144	166 "
1940	2,176	193 "
1	1,450	177 "
2	854	183 "
3	1,526	191 "
4	2,044	178 "
5	2,331	158 "
6	2,764	177 "
7	3,026	133 "
8	3,924	165 "
9	4,854	134 "
1950	4,266	131 "
1	3,700	166 "
2	5,150	143 "
3	2,660	153 "
4	3,320	153 "
5	3,200	151 "
6	2,836	145 "
7	1,986	140 "
TOTAL	84,885	

* Statistical analyses were done of the results upto 1955 only.

3.2.2.1.1 Period 1949 to 1955: There

is no statistical evidence of a change in dust count at this place over the period 1949 to 1955. The mean count recorded was 40 p.p.c.c.

3.2.2.1.2 Period 1942 to 1948: There

is again no statistical evidence of a change in dust count over the period 1942 to 1948. The mean count recorded was 29 p.p.c.c. There is, therefore, a difference of 11 p.p.c.c. between the means of the two periods. The difference reached the 99.9% level of the t-distribution which was considered significant and attributable to the improved method of applying the adhesive film.

3.2.2.1.3 The 1931 to 1941 period: As

they stand, the observations suggest a change at about 1937 both in count and in trend, but, as there is no knowledge of a change or a reason for the altered trend, one straight line was fitted to the results. A more refined method than a straight line, was considered but it was not felt worth while.

There is no statistical evidence that the change which was introduced in 1942, affected the results recorded as point "1". There is statistical evidence of a lowering of the dust count over the 1931 - 1941 period. (There is therefore, evidence that downcast air was contaminated during earlier years.)

3.2.2.1.4 Allowing for the 1948 change:

The question of whether the effect of the 1948 change would be proportional to the count or to a constant increase of 11 p.p.c.c., was considered and the latter favoured on account of the fact that the change caused an improved field.

The /

TABLE 3.2.VI.
S H A F T S.

Year	Number of Spots.	Mean Count.	
1931	63	289	p.p.c.c.
2	148	186	"
3	170	250	"
4	144	364	"
5	472	211	"
6	456	163	"
7	390	168	"
8	765	202	"
9	344	135	"
1940	188	156	"
1	60	187	"
2	114	201	"
3	142	146	"
4	108	91	"
5	134	122	"
6	104	138	"
7	168	124	"
8	248	183	"
9	609	183	"
1950	410	159	"
1	224	159	"
2	336	258	"
3	168	429	"
4	254	239	"
5	172	144	"
6	342	140	"
7	124	120	"
TOTAL			6,857

* Statistical analyses were done of the results upto 1955 only.

n
t.
p.c.c.
"
"
"
"
"
"
"
"
"
"
The 1931 - 1941 line of best fit, estimates the count for point "1" by 1931, at 45 p.p.c.c. With 11 p.p.c.c. added, the count for that time is brought up to 56 p.p.c.c. To summarise, the dust count of the air at the top of downcast shafts is estimated to have decreased from roughly 56 p.p.c.c. by 1931 to about 40 p.p.c.c. by 1940 at which level it remained constant up to the present time.

3.2.2.2 Air leaving downcast shafts
before passing tipping stations -
see fig. 3.2.

"
"
"
"
"
"
This position in the mine is referred to as point "3".

"
"
"
"
"
"
3.2.2.2.1 Period 1949 - 1955: There is no statistical evidence of a change in the count at point "3" over the 1949 - 1955 period, and the mean for the seven years is estimated at 59 p.p.c.c. with a standard deviation (s.d.) of 10 p.p.c.c.

"
"
"
"
"
"
".2 Period 1942 - 1948: There is also no statistical evidence of a change in the dust count over the 1942 - 1948 period and the mean count is estimated at 59 p.p.c.c. with a s.d. of 3 p.p.c.c. There is no difference between the two means and, therefore, the two periods were combined.

"
"
"
"
"
".3 Period 1942 - 1955: The mean for the combined periods comes to 59 p.p.c.c. with a s.d. of 3 p.p.c.c.

of the
".4 Period 1931 - 1941: For this set of results the log transformation seemed better and it was, therefore, applied.

There is statistical evidence that the dust
count /

count was reduced during this period, viz. from an estimated value of 100 p.p.c.c. by 1931 (by the pre 1942 technique) to 45 p.p.c.c. by 1941.

.5 Effect of the 1942 change:

There is statistical evidence that the counts recorded at this point was increased by the change introduced in 1942 viz., from 41 p.p.c.c. to 59 p.p.c.c. which represents an increase of 44%.

It is reasonable to assume that this effect would be proportional to the count so that the estimates for all years prior to 1942 should, for this point, be increased by 44%. Hence, at this point the dust count is estimated at 144 p.p.c.c. by 1931.

3.2.2.3 Air in main intake airways away from downcast shafts - see fig.

3.3.

3.2.2.3.1 The 1949 - 1955 Period:

There is no statistical evidence of a change in the dust concentration during the 1949 - 1955 period and the mean for the period is estimated at 84 p.p.c.c., s.d. = 5 p.p.c.c.

.2 The 1942 - 1948 Period:

There is again no statistical evidence of a change in the dust concentration during this period and the mean dust count is estimated at 81 p.p.c.c., s.d. 6 p.p.c.c. The difference between the means is not significant.

.3 The 1942 - 1955 Period: The hypothesis of a change in dust count with time, was rejected on a visual examination of the plots of mean counts against calendar years (see figure 3.3). The mean dust count for the combined period is 83 p.p.c.c. with a

s.d. /

s.d. of 4 p.p.c.c.

.4 The 1931 - 1941 Period:

There is statistical evidence of a reduced dust concentration over this period, from an estimated count of 167 p.p.c.c. by 1931, to one of 76 p.p.c.c. by 1941.

Effect of the 1942 change: The hypothesis of an effect could not be proved statistically and was, therefore, rejected.

The slope of the 1931 - 1941 line was found significant and because of this, the results of the two periods were not combined. A summary of the variation with calendar years of the dust count at point "6" is: a reduction from about 165 p.p.c.c. by 1931 to about 80 p.p.c.c. by 1942, where it remained constant.

3.2.2.4 Air in stopes - see figs. 3.4(i), (ii) and (iii).

3.2.2.4.1 The 1949 - 1955 Period:

There is no statistical evidence of a change in the dust content over the 1949 - 1955 period and the mean for the period is estimated at 149 p.p.c.c. with a s.d. of 3 p.p.c.c.

.2 The 1942 - 1948 Period:

Once more, there is no statistical evidence of a change in dust count over the 1942 - 1948 period and the mean count comes to the same value as the one for the 1949 - 1955 period.

.3 The 1942 - 1955 Period:

The hypothesis that there was no change during this period seemed reasonable and a statistical analysis did not lead to its rejection. The mean dust count is estimated at 149 p.p.c.c. with a s.d. of 2 p.p.c.c.

At /
* Point "6" = air in main intake airways away from downcast shafts.

At this stage it was noticed that the 1940 and 1941 results could reasonably be considered as belonging to the 1942 - 1955 population rather than to the 1931 - 1941 population.

There is justification for this step because there was a change of classification in 1940.

.4 The 1940 - 1955 Period: Including the 1940 and 1941 results in the 1942 - 1955 set of results cause no change in the estimate of the mean count of 149 p.p.c.c. Its s.d. comes to 3 p.p.c.c.

.5 The 1931 - 1939 period: Over this period, the logarithms of the counts approximate more closely to a straight line than the normals of the counts and, therefore, a straight line was fitted to the logarithms of the counts (see fig. 3.4(ii)). There is statistical evidence that the count decreased over this period viz. from about 240 p.p.c.c. by 1931, to about 120 p.p.c.c. by 1939 (pre 1940 technique).

.6 Combined effect of the 1940 and 1942 changes: This is estimated by comparing the 1931 - 1939 results with 1940 - 1955 results.

The effect was to increase the count by about 27%.

The proportion of the number of spots that were taken in intake and return air to the number of spots that were taken at the working points of stopes, naturally had a bearing on the increase recorded. This ratio may not have been constant over the 1931 to 1939 period, but for the purpose of extrapolating the pre 1940 stope counts, to that of the present technique, it was assumed that the ratio was constant.

An /

An increase of 27% was applied to the 1931 - 1939 line of "best" fit results.

Summary: The stope working point count is, therefore, estimated to have decreased from approximately 310 p.p.c.c. by 1931 to about 150 p.p.c.c. by 1940 where it remained steady up to the present time.

3.2.2.5 Development Ends - see fig. 3.5(i)

and (ii): As pointed out in section 3.1, in the Government Mining Engineer's annual reports, the dust counts recorded at drives and crosscuts, raises, and winzes are tabulated separately, so that the annual counts of the three classes of development ends had to be combined into a single count for development ends.

By this combination an additional uncertainty may have been introduced and in an endeavour to allow for this, the "t"-level at which to decide a significant difference was arbitrarily increased from 97.5 to 98.0.

3.2.2.5.1 The 1949 - 1955 period:

There is no statistical evidence of a change in the dust level over this period and the mean is estimated at 147 p.p.c.c. with a s.d. of 5 p.p.c.c.

.2 The 1940 - 1948 period:

There is statistical evidence that the dust level was lowered gradually over this period. Line of best fit estimates are, 190 p.p.c.c. by 1940 and 156 p.p.c.c. by 1948.

The 1949 change did not affect the results recorded significantly.

.3 The 1931 - 1939 period:

There was an abrupt change in the trend of the annual counts recorded after 1935. This change in trend

co-incided /

co-incided with a very large increase in the annual number of spots taken in development ends and in view of this, it was decided to consider the results recorded during the two periods separately. (The 1935 count was included in both sets of results.)

The question of whether or not the results recorded prior to 1935 included a disproportionate number of samples taken in development ends where conditions were worse than average, was considered but rejected, on the strength of statements in the Government Mining Engineer's annual reports over this period which were to the effect that conditions in development ends in general were still unsatisfactory. (48)

.4 The 1935 - 1939 period: The mean annual count versus calendar years over this period do not suggest a change in dust count. This leads to an estimate of 162 p.p.c.c as the annual mean with a s.d. of 20 p.p.c.c. This count is about 19% less than the 1940 - 1948 line of best fit estimate for 1940. The difference reach the 98% level of the t-distribution and was decided significant and attributable to the combined effect of the changes introduced in 1940 and 1942. These changes are: reclassification in 1940, and the change from acid vapour to ignition-immersion-ignition in 1942.

.5 The 1931 - 1935 period: The line of best fit to these five annual counts, estimates the dust level in development ends as having decreased from about 380 p.p.c.c. by 1931 to about 190 p.p.c.c. by 1935 (pre 1940 technique). The slope of the line reached the t99 level and is, therefore, significant.

By allowing for the +19% effect of the 1940 and

1942 /

1942 charges, the "development end" count by 1931 is estimated at approximately 450 p.p.c.c. (i.e. 376×1.19).

Summarising, it is estimated that the dust level in development ends decreased rapidly from about 450 p.p.c.c. by 1931 to about 200 p.p.c.c. by 1938 from where it decreased slowly to about 150 p.p.c.c. by 1955.

3.2.2.6 Sinking shafts:

The results recorded in sinking shafts are depicted graphically in figures 3.6(a) and (b).

To arrive at an estimate for the mean count in sinking shafts, the following factors were allowed for:

- (a) The results recorded up to 1947 represent essentially the dust conditions during operations other than blowing over.
- (b) The results recorded during 1949 and 1950 represent essentially the mean count for the whole shaft sinking shift because most of these samples were taken during full shift dust studies.
- (c) The results recorded during 1952 to 1955 include a disproportionately large number of samples that were taken during blowing over operations because special attention was then given to this aspect of shaft sinking in an effort to improve conditions.

Effect of blowing over operations on the mean count:

It is estimated that on an average, blowing over occurs during about 5% of the time spent on the cycle of shaft sinking operations (vertical and inclined shafts combined).

When /

1942 changes, the "development end" count by 1931 is estimated at approximately 450 p.p.c.c. (i.e. 376×1.19).

Summarising, it is estimated that the dust level in development ends decreased rapidly from about 450 p.p.c.c. by 1931 to about 200 p.p.c.c. by 1938 from where it decreased slowly to about 150 p.p.c.c. by 1955.

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- (c) The results recorded during 1952 to 1955 include a disproportionately large number of samples that were taken during blowing over operations because special attention was then given to this aspect of shaft sinking in an effort to improve conditions.

Effect of blowing over operations on the mean count:

It is estimated that on an average, blowing over occurs during about 5% of the time spent on the cycle of shaft sinking operations (vertical and inclined shafts combined).

When /

When blowing over is done, a dust count of about 5 times the mean count for other shaft sinking operations prevails.

The mean for the whole cycle of operations (vertical and inclined shafts combined) is, therefore, about 20% ($\frac{19 \times 1 + 1 \times 5}{20} = 1.2$) higher than the cycle of operations excluding blowing over. Similarly, the mean for the operations excluding blowing over is about 17% ($\frac{100}{120} = 0.83$) lower than the mean for the whole cycle of operations.

In view of the above, only the results recorded prior to 1949 were considered, and an allowance made for the effect of blowing over operations as explained. As can be seen from the graph, the estimated mean agree well with the actual observations made during full shift dust studies in 1949 and 1950.

3.2.2.6.1 The 1940 - 1948 period: The 1942 change had apparently no effect on the annual counts. A decision had to be made as to whether the 1940 and 1941 counts should be included with the 1931 - 1939 results or with the 1942 - 1948 results.

The estimated variance (s^2) of the 1942 - 1948 results comes to 1880, and this reduces to 1173 if the 1940 and 1941 counts are added thereto. It was, therefore, decided that the two annual counts in question can reasonably be considered together with the 1942 - 1948 results.

There is no statistical proof of any change in the dust count over this period. The mean count for the period is estimated at 150 p.p.c.c. with a standard deviation of 12 p.p.c.c.

.2 The 1931 - 1939 period:

There is statistical evidence of a change in conditions viz. of an improvement from an estimated value of 270 p.p.c.c. by 1931 to one of 160 p.p.c.c. by 1939.

Statistically it could not be proved that the changed classification introduced in 1940 together with the altered technique introduced in 1942, had a significant effect on the mean counts recorded.

.3 Allowance for Blowing over Operations:

When allowing for blowing over operations as indicated above, the mean dust count for shafts is estimated to have decreased from approximately 330 p.p.c.c. by 1931 to approximately 180 by 1940, after which it remained more or less steady at that concentration.

3.2.2.7 The difference in mean counts between the six selected points:

It was arbitrarily decided that where a significant difference in the dust counts between two points could be proved over any period the two points would be considered separately over all the other periods whether or not a significant difference could be proved.

Points "1" and "3": The "best" estimate for "the bottom of downcast shafts" is 19 p.p.c.c. higher than that for "the top of downcast shafts" by 1955. The difference reach the t99.9 level and was, therefore, decided significant.

Points "3" and "6": The "best" estimate for "intake air away from downcast shafts" is 24 p.p.c.c. higher than that for "the bottom of downcast shafts", by 1955. The difference also reaches the t99.9 level.

Points /

TABLE 3.2.VII.
SUMMARY OF ALLOWANCES MADE FOR THE CHANGES
IN TECHNIQUE.

Classification	CHANGES MADE		
	Separation of intake working point and return counts - (1940)	Acid Vapour to ig.-im.-ig. (1943)	1% Vaseline in Xylol (1949)
Intake air at the top of downcast shafts (1).	Not applicable	Nil	* 11 p.p.c.o.
Intake air at the bottom of downcast shafts (3).	Not applicable	44% ϕ	Nil
Air in main intake airways away from downcast shafts (6)	Not applicable	Nil	Nil
Stopes (7)	27% ϕ	Nil	Nil
Development ends (8)	19% ϕ	Nil	Nil
Shafts (9)	Nil	Nil	Nil

* The question of whether the effect of the change would be proportional to the count was considered but rejected in favour of a constant value on account of the fact that the altered technique resulted in an improved field which would be independent of the dust content of the air sampled.

ϕ Effect of 1940 and 1942 changes combined.

Points "6" and "7"
to 66 p.p.c.o. higher
downcast shafts", by 1
the 199.9 level.
Points "7" and "8"
most ends" to 76 p.p.c.o.
1938, and the difference
to attempt
for "shafts" significant
places, but in view of
entirely different from
or further, "shafts"
Note: All tests
done on the
not after
technique
3.2.2.3
Table 3.2.VI
were made in order to
have recorded had the
the change
1. 1940, further
"Intake
air in
shafts
2. 1942, change
Improve
3. 1949, change
slide
solid

Points "6" and "7": The "best" estimate for "stopes" is 66 p.p.c.c. higher than that for "intake air away from downcast shafts", by 1955, and the difference again reaches the t99.9 level.

Points "7" and "8": The "best" estimate for "development ends" is 76 p.p.c.c. higher than that for "stopes" by 1938, and the difference reaches the t99.9 level.

No attempt was made to prove the "best" estimate for "shafts" significantly different from any of the other places, but in view of all the other points being significantly different from the rest of the points at one time or another, "shafts" were also kept separately.

Note: All tests for significant differences were done on the original sets of results and not after any effects for changes in techniques had been allowed for.

3.2.2.8 Summary of allowances made for the altered techniques:

Table 3.2.VII summarises the allowances that were made in order to represent the counts that would have been recorded had the present technique been in vogue.

The changes may be summarised as follows:

1. 1940, differentiate between samples taken in "intake", "working point" or "return" air for stopes, development ends and shafts.
2. 1942, change from "Acid Vapour" to "Ignition-Immersion-Ignition" treatment.
3. 1949, change from applying adhesive to the slides by hand to applying it as a 1% solution in xylol by means of a dropper.

3.2.2.9 /

1%
Vaseline
in
Xylol
(1949)
11
p.p.
c.c.
N11
N11
N11
N11
N11

uld
of
n

CUMULATIVE NUMBER OF PARTICLES OVER SIZE

TABLE 3.2.VIII

SUMMARY OF THE VARIATION IN THE DUST
LEVELS AT THE VARIOUS POINTS FROM
1931 TO 1955.

YEAR	UNDERGROUND POINTS AND P.P.C.C.					
	.1	.3	.6	.7	.8	.9
1931	56	145	167	309	450	330
33	50	125	148	257	335	295
35	46	105	130	215	250	260
37	43	90	110	178	210	225
39	40	73	95	156	188	200
1941	40	57	85	149	183	187
43	40	60	82	149	177	180
45	40	60	82	149	170	180
47	40	60	82	149	163	180
49	40	60	82	149	155	180
1951	40	60	82	149	150	180
53	40	60	82	149	147	180
55	40	60	82	149	147	180

3.2.2.

Having made
the lines of best fit
curve. Figure 3.7
table 3.2.VIII gives
intervals.

3.3 Classification

All underground
of two main groups,
with the latter group
for the first
official class of
points in the main
to spot and on time
these were called:

(1) Those on
shafts,(2) those on
ways,(3) those on
to and on
is even(4) those on
and on
in work(5) those on
methods
developed

3.3.1

in the first class

3.2.2.9 Smooth curves giving the dust counts from 1931 - 1955:

Having made allowances for the various changes, the lines of best fit were joined together by a smooth curve. Figure 3.7 summarises the results graphically and table 3.2.VIII gives the "best" estimates at two-yearly intervals.

3.3 Classification of Mine Workers into Main Classes.

All underground European mine workers fall in one of two main groups, viz. Officials and non-officials of which the latter group is by far the largest.

For the purpose of this investigation the non-official class of workers were classified according to the position in the mine where the main portion of the shift is spent and on this basis, the following main classifications were made:

- (1) Those employed essentially in and around shafts,
- (2) those employed essentially along travelling-ways,
- (3) those employed essentially along entrances to and exits from working places where rock is excavated,
- (4) those employed largely along entrances to and exits from, but to a certain extent also in working places where rock is excavated,
- (5) those employed essentially on the three main methods of rock excavation viz., stoping, developing and shaft sinking.

3.3.1 The following occupations were included in the first class above:

Hoist /

Hoist Drivers,
Onsetters, Shaft Timbermen,
Ugd. Banksmen,
" Storemen,
" Pump Attendants
" Riggers, etc. and they were referred to as
SHAFT WORKERS.

3.3.2 The following occupations resort under the second class above:

Loco Drivers, Haulage Timbermen, Underground Artisans (e.g. Fitters and Electricians), etc., and they were referred to as TRAVELLING WAY WORKERS.

3.3.3 The following occupations were included in the third class:

Drive Timbermen, Trammers, Pipe fitters, Track layers, Reclaimers, Sand fillers, Waste packers, Haulagemen, etc., and they were referred to as MISCELLANEOUS MINERS.

3.3.4 The following occupations were included in the fourth class above:

Early Examiners, Learner Miners, G.M.T.S. - Apprentices, Assistant Miners, etc., and they were referred to as "S.D.M." standing for stoping, developing and miscellaneous.

3.3.5 The fifth class constitute the virgin - rock breakers and this group was subdivided into:

Stoppers, referred to as "S",
Developers, referred to as "D"
and Shaft sinkers, referred to as "Ss".

Some /

Some occupations were classified as combinations of the above such as development-cleaners, referred to as "D.M.",

stopping and developing, referred to as "S.D.",

stopping and timbering, referred to as "S.M.", etc.

3.3.6 Officials:

The main classes of mine officials were considered separately as follows:

A. Mining Officials:

- (i) Shift Bosses.
- (ii) Mine Overseers.⁶
- (iii) Managers.*

B. Survey and Allied Officials:

- (i) Junior Officials.
- (ii) Senior Officials.⁶

C. Sampling:

- (i) Junior Samplers.
- (ii) Senior Samplers.⁶

D. Engineering:

- (i) Underground Foremen.
- (ii) Underground Engineers.⁶

⁶ Very few of the cases studied were employed in these occupations.

* None fell in this class.

3.4 Duration of the Underground Shift of Mine Workers.

The duration of the underground shift differs for the various classes of underground workers so that an equal number of underground shifts does not mean an equal number of underground hours.

The following table indicates the orders of the duration of the underground shift of the main classes of

workers /

workers:

NON OFFICIALS:

- Artisans - 7 hours.
- All others - 8 hours.

OFFICIALS:

A. Mining:

- (i) Shift Bosses - 6 hours
- (ii) Mine Overseers - $3\frac{1}{2}$ hours
- (iii) Managers^x - 3 hours.

B. Survey and similar officials:

- (i) Juniors - 4 hours.
- (ii) Seniors^d - $3\frac{1}{2}$ hours.

C. Engineering officials:

- (i) Underground Foreman - 6 hours.
- (ii) Underground Engineers^d - 3 hours.

3.5 The Dustiness of the underground Shift of the Various Occupations.

3.5.1 Validity of the dust counts recorded during routine Inspections:

A question that arises is whether the observations made by Inspectors of Mines are representative of conditions over the whole shift? The main reason for such a question is the fact that the vast majority of dust samples taken by Inspectors of Mines are taken between about 9 a.m. and 12 a.m., whereas the underground shift of most occupations extend for several hours on either side of this period and for some occupations over the full 24 hours of the day. The answer to the question lies in the fact that all the mines concerned employ Ventilation Officers who are "responsible" for, and exercise control

over /

CUMULATIVE NUMBER OF PARTICLES OVER SIZE

workers:

NON OFFICIALS:

- Artisans - 7 hours.
- All others - 8 hours.

OFFICIALS:

A. Mining:

- (i) Shift Bosses - 6 hours
- (ii) Mine Overseers - $3\frac{1}{2}$ hours
- (iii) Managers^x - 3 hours.

B. Survey and similar officials:

- (i) Juniors - 4 hours.
- (ii) Seniors^d - $3\frac{1}{2}$ hours.

C. Engineering officials:

- (i) Underground Foreman - 6 hours.
- (ii) Underground Engineers^d - 3 hours.

3.5 The Dustiness of the underground Shift of the Various Occupations.

3.5.1 Validity of the dust counts recorded during routine Inspections:

A question that arises is whether the observations made by Inspectors of Mines are representative of conditions over the whole shift? The main reason for such a question is the fact that the vast majority of dust samples taken by Inspectors of Mines are taken between about 9 a.m. and 12 a.m., whereas the underground shift of most occupations extend for several hours on either side of this period and for some occupations over the full 24 hours of the day. The answer to the question lies in the fact that all the mines concerned employ Ventilation Officers who are "responsible" for, and exercise control

over /

CUMULATIVE NUMBER OF PARTICLES OVER SIZE

over dust conditions in all mine workings where men are employed, and in the fact that inspections by Government Inspectors of Mines may be made and dust samples taken whenever there is reason to believe that satisfactory standards are not maintained. Complaints to this effect may be made by any employee.

In view of the above, it was considered that for the purpose of this investigation, the results recorded by Inspectors of Mines could reasonably be used as a basis for rough estimates of the dustiness of the underground shifts of the main classes of occupations.

3.5.2 Dependence on position in mine:

The dustiness of an underground shift depends essentially on the position or positions in the mine where the shift is spent. For the purpose of estimating the shift dustinesses of the main classes of underground workers, it can be assumed that the various classes spend different proportions of the shift at the main classes of underground working points.

3.5.3 Dependence on proportions of shift spent at the different points of the mine:

If the proportions of the shift which mine workers spend at the various classes of underground places are known, the mean dust level to which they are exposed per shift can be estimated reasonably accurately. The actual proportions are, unfortunately, not known and estimates thereof have, therefore, to be relied on.

3.5.4 Effect of errors in the proportions used:

To estimate the mean dust level per shift of an occupation from the proportions of the shift spent at the various dust levels, is the same as using loading factors to arrive at weighted mean values. In such cases, the accuracy /

accuracy of the factors are not of critical importance because a relatively large error in the loading factor, affects the weighted mean value to a relatively small extent. An example to illustrate this point is given below.

Consider two dust levels of, say, 80 p.p.c.c. and 120 p.p.c.c. Let the true exposure proportions be 50% at each level. The true mean dust level exposed to is, therefore, 100 p.p.c.c.

If the exposure proportions were assumed to be 25% at 80 p.p.c.c. and 75% at 120 p.p.c.c. the weighted mean dust level becomes:

$$20 + 90 = 110 \text{ p.p.c.c.}$$

Therefore, the error = + 10%.

If the exposure proportions were assumed to be 75% at 80 p.p.c.c. and 25% at 120 p.p.c.c. the weighted mean dust level becomes:

$$60 + 30 = 90 \text{ p.p.c.c.}$$

Therefore, the error = - 10%.

In general, therefore, the effect of errors in loading factors may be summarised as follows:

A 50% error in the loading factors of two quantities which differ as 2 is to 3, results in an error of only 10% in the weighted mean value.

3.5.5 Proportions of shift spent at the various Dust Levels:

Estimates of the proportions of the shift spent at the various dust levels for the main classes of underground workers were arrived at as explained below.

The results recorded during the full-shift time-dust studies which were conducted in 1949 and 1950 were examined, and although it was not possible to actually compute /

compute the proportions of the shift spent at or between the six strategic points selected from the observations, some useful indications of the proportions were obtained. Table 3.5.I is an extract of the results recorded. As can be seen from the table, the underground shift was classified into four main portions viz.,

1. At shaft stations and travelling to and from working places,
2. Inspecting hanging, walking and generally supervising at face,
3. At Miners' box,
4. Charging and lighting up.

3.5.5.1 Stoppers: The first classification with respect to the underground shift, mentioned above and in table 3.5.I, corresponds to the stopper being subjected to a dust concentration which rises from that prevailing at the top of downcast shafts (i.e. the dust level represented by curve "1" in figure 3.7), through that prevailing at the bottom of downcast shafts (i.e. the dust level represented by curve "3" in fig. 3.7) to about that prevailing in main intake airways away from downcast shafts (i.e. to the dust level represented by curve "6" in figure 3.7).

The second and fourth classifications correspond to the stoppers' dust level rising to that prevailing in stopes (curve "7" in fig. 3.7) close to which it remains for the main part of these two portions of his shift. The third classification corresponds to the stopper being in air with a dust content well below that prevailing in stopes namely in air with a dust content more or less midway between that of air in stopes (curve "7") and that

of /

TABLE 3.5.I.
RESULTS RECORDED DURING FULL SHIFT
TIME STUDIES.

Shift Classification	SHIFT PROPORTION		
	Class of Workmen		
	Sto- pers	Deve- lopers	Shaft Sinkers
1. At stations and travelling to and from working places:	13%	14%	6%
2. Inspecting hanging, walking and generally supervising at face:	48%	53%	73%
3. At miner's box:	19%	21%	10%
4. Charging and lighting up:	20%	12%	11%
TOTAL	100%	100%	100%

TABLE 3.5.II : STOPERS

Shift Classification.	Proportion of Shift	Mean Dust Level.
(1)	13%	65p.p.c.c.
(2)	48%	139p.p.c.c.
(3)	19%	112 "
(4)	20%	130 "

TABLE 3.5.III : DEVELOPERS

Shift Classification	Proportion of Shift	Dust Level p.p.c.c.
1. At Stations and Travelling to and from Working Places.	14%	65
2. Inspecting Hanging, walking and generally supervising at face.	53%	111
3. At Box.	21%	66
4. Changing and Lighting up.	12%	95

of air in main intake
During the
referred to above,
dust count recorded
for stopers are sub-
The first
interpolates all the
dust levels "1" and
classifications and
is subjected to dust
that he is between 1
In view of
that during the shift
the four dust levels
proportions as given
"1" - 5%
"2" - 10%
"3" - 10%
"4" - 5%
3.5.2
occupies with stop-
proportions of the shift
greater proportions of
smaller proportions of
"1". The reason for
being spent at face
end, the "face" condi-
tion of the working
when the developer is
subjected to the "face"
time he is in less of
the development end.

of air in main intake airways (curve "6").

During the full shift time and dust studies, referred to above, 67 stopers were followed. The mean dust count recorded during the four shift classifications for stopers are submitted in table 3.5.II.

The first classification in table 3.5.II incorporates all the time that the stoper is subjected to dust levels "1" and "3", whilst the second and fourth classifications incorporate all the time that the stoper is subjected to dust level "7" in addition to some time that he is between levels "7" and "6".

In view of the above, it is reasonable to assume that during his underground shift a stoper is subjected to the four dust levels "1", "3", "6" and "7", in the proportions as given below:

- "1" - 5%
- "3" - 10%
- "6" - 30%
- "7" - 55%.

3.5.5.2 Developers: It may be assumed in comparison with stopers, that developers spend the same proportions of the shift at dust levels "1" and "3", but a greater proportion at dust level "6" and a correspondingly smaller proportion at the working face, i.e. at dust level "8". The reason for the smaller proportion of the shift being spent at dust level "8" is that in a development end, the "face" condition prevails over a smaller proportion of the working place than in a stope. It is only when the developer is right at the face that he is subjected to the "face" dust level, and for the rest of the time he is in less dusty air, although he may still be in the development end.

During /

PORTION	
Workmen	
Shift	Sinkers
6%	
73%	
10%	
11%	
100%	

ust
l.
.c.c.
.c.c.
"
"

ERS

Dust Level
p.p.c.c.
65
111
66
95

CUMULATIVE NUMBER OF PARTICLES OVER SIZE

During the 1949 - 1950 full shift dust studies, 43 developers were studied and the results that were recorded, are given in table 3.5.III. With the figures in table 3.5.III as a basis, it is estimated that on an average, developers are subjected to dust levels "1", "3", "6" and "8" for 5%, 10%, 50% and 35% of the shift respectively. Note: If a mine worker is estimated to be subjected to a certain dust level for a certain portion of the shift such as, for 10% of the shift to dust level "3", it should not be taken to mean that he remains on the shaft station for 10% of the shift, which is equivalent to about 50 minutes if he works an eight hour shift, but that for 10% of the shift he is between halfway towards the intake side of that point and halfway towards the return side thereof.

3.5.5.3 Miscellaneous miners: In this group were included occupations such as Pipe Fitters, Drive Timberman, Trammers and the like, i.e. workers who would be in "intake air" for a greater portion of the shift than stopers and developers, and who would spend less time inside stopes and at development faces.

This group was estimated to be subjected to dust levels "1", "3", "6", "7" and "8" for:

5%, 30%, 50%, 10% and 5% of the shift, respectively.

3.5.5.4 S.D.M. Group: This group include Early Examiners, Assistant Miners, Learner Miners, G.M.T.S. Apprentices and the like, and they were considered to be subjected to the mean of the three groups - Stoper, Developers and Miscellaneous Miners.

3.5.5.5 Travellingway workers: Fitters, Electricians, Loco Drivers and the like, were considered together /

TABLE 3.5.IV : NON-OFFICIALS.

DUST LEVEL PROPORTIONS

Type of Mine Worker.	Underground Points.					
	.1	.3	.6	.7	.8	To- tal
Shaft Workers	.50	.50	-	-	-	1.0
Travellingway Workers	.20	.50	.30	-	-	1.0
Miscellaneous Miners	.10	.25	.50	.10	.05	1.0
Developers	.05	.10	.50	-	.35	1.0
Stoppers	.05	.10	.30	.55	-	1.0
Shaft Sinkers	.05	.10	-	-	-	.85 1.0

TABLE : 3.5.V. OFFICIALS.

Type of Official	Combination	Reference Symbols
1. Engineering: Under- ground (Foremen and engineers)	Travellingway and Shaft Workers	Z
2. Mining Officials:		
2.1 Shift Bosses	Stoppers, Developers, Miscellaneous Miners and Travellingway Workers.	S.B.
2.2 Mine Overseers, Managers and Miscellaneous Officials.	As for Shift Bosses plus shaft workers.	M.O.
2.3 Samplers	1.3 x that of "2.2"	SAN.

together, and as their duties seldom take them up to stope and development faces, they were referred to as "Travelling-way workers" and estimated to be subjected to dust levels "1", "3" and "6" for 20%, 50% and 30% of the shift, respectively.

3.5.5.6 Shaft workers: Underground Hoist Drivers, Underground Banksmen, Underground Storemen, Pump Attendants and the like were considered together, and as their duties keep them in the immediate vicinity of the shaft, they were collectively referred to as "Shaft workers", and they were estimated to be subjected to dust levels "1" and "3" only, for equal proportions of the shift.

3.5.5.7 Shaft sinkers: Shaft sinkers were estimated to be subjected to dust levels "1", "3" and "9", for 5%, 10% and 85% of the shift respectively.

3.5.5.8 Skipmen: Skipmen presented a special problem because although they do not leave the shaft area, the mean dust level to which they are subjected is above that for the shaft. The increased level is brought about by the puffs of dust, prevailing around shaft boxes during the filling of skips, to portions of which skipmen are subjected, when rock is hoisted. A large proportion of the Skipman's shift is spent on the filling of skips. To allow for this, it was arbitrarily assumed that skipmen would on an average be subjected to a dust count which would be 50% higher than that of "Shaft Workers."

3.5.5.9 Summary: Table 3.5.IV summarises the proportions of the underground shift which the main non-official type of workers were assumed to spend at the various dust levels.

3.5.6 /

	To- 9 tal
.8	
-	1.0
-	1.0
05	1.0
35	1.0
-	1.0
-	.85 1.0

Reference Symbols
2
S.B.
H.O.
SAH.

CUMULATIVE NUMBER OF PARTICLES OVER SIZE

3.5.6 Mine Officials:

Unfortunately no time dust studies were conducted of mine officials in the same way as for non-officials.

However, it is logical for the dustiness of the underground shift of a mine official to approximate the mean of the main groups of underground workers which he supervises, and estimates of the dustiness of the underground shift of mine officials were based on this assumption. The unweighted mean of the groups concerned was used in each case.

3.5.6.1 Underground Foreman and Engineers:

Underground Foreman and Underground Engineers supervise essentially the work of the classes referred to as "shaft workers" and "Travelling-way Workers", and the dustiness of the underground shift of underground Foremen and Engineers was estimated as equal to the mean of the above two classes.

.2 Shift Bosses: Shift Bosses

supervise essentially the work of stopers, developers, miscellaneous miners and travelling-way workers and the dustiness of the underground shift of Shift Bosses was, therefore, estimated as equal to the mean of these four groups.

.3 Mine Overseers: Mine Overseers supervise a wider field than Shift Bosses and the dustiness of their underground shift was estimated as equal to the mean of stopers, developers, miscellaneous miners, travelling-way workers and shaft workers combined.

.4 Mine Managers^{*}: For Mine Managers, the dustiness of the underground shift was assumed equal to that of Mine Overseers.

(* None of the cases drawn include Mine Managers.)

.5(a) /

TABLE : 3.5.VI(a)
ESTIMATES VERSUS OBSERVED
MEANS - 1950.

Class of Worker	Shift Dustiness		Number Observed
	Estimated	Observed	
1. Travellingway Workers	65 ppsc	66ppsc	6
2. Skipmen	75 "	78 "	13
3. Miscellaneous Miners	83 "	75 "	16
4. Early Examiners	101 " *	103 "	27
5. Developers	103 "	90 "	43
6. Stoppers	116 "	126 "	67
7. Shaft Sinkers	161 "	180 "	8

* As the mean of stoppers, developers and miscellaneous miners.

TABLE . 3.5.VI(b) - 1926

Class of Worker	Mean Counts p.p.c.o.			Expected + "Observed"
	Observed 1926	Obs.x1.3	Extrapolated from 1931	
Miscellaneous Miners	185	241	240	1.00
Early Examiners	206	268	300	1.13
Stoppers	216	281	320	1.44
Developers	316	410	366	0.89
Shaft Sinkers	284	382	378	0.99
Samplers	240	313	325	1.04

this classification was
officials, but not early
underground shift was
overseers.

that some dust is produced
underground shift of
of miscellaneous officials

examines the conditions
officials were based.

3.5.3 Estimation

Estimates for

about 1950 are as follows

main points, refer to

3.5.4

level proportions based

50% at "1" and 50%

The corresponding dust

Fig. 3.7 are: 40 p.p.c.

The shift dustiness,

20 + 30 = 50

3.5.5.4, the shift dust

1.5 x 50 = 75 p.p.c.

level proportions based

and 30% at "5". The

40 p.p.c.

.5(a) Miscellaneous Officials: Under this classification was included survey, study and allied officials, but not samplers. The dustiness of their underground shift was assumed equal to that of Mine Overseers.

.5(b) Samplers: In view of the fact that some dust is produced by sampling the dustiness of the underground shift of samplers was assumed 1.3 times that of miscellaneous officials.

.6 Summary for Officials: Table 3.5.V summarises the combinations on which estimates for mine officials were based.

3.5.7 Estimates for about 1950:

Estimates for a few classes of workers for about 1950 are as follows:- (For the dust levels at the main points, refer to fig. 3.7):

3.5.7.1 Shaft Workers:

(a) Ordinary Shaft Workers: The dust level proportions decided on are:

50% at "1" and 50% at "3",

The corresponding dust levels for about 1950 as given by fig. 3.7 are: 40 p.p.c.c. and 60 p.p.c.c. respectively. The shift dustiness, therefore, becomes

$$20 + 30 = 50 \text{ p.p.c.c.}$$

(b) Skipmen: According to section 3.5.5.8, the shift dustiness for skipmen is estimated at $1.5 \times 50 = 75 \text{ p.p.c.c.}$

.2 Travelling-way Workers: The dust level proportions decided on are: 20% at "1", 50% at "3" and 30% at "6". The corresponding dust levels are:

40 p.p.c.c., 60 p.p.c.c. and 82 p.p.c.c.

The /

Number Observed
6
13
16
27
43
67
8

scell-

ected +
observed"

1.00
1.13
1.14
0.89
0.99
1.04

CUMULATIVE NUMBER OF PARTICLES OVER SIZE

TABLE 3.5.VII DEVELOPERS.

P. P. C. C.

Year	Dust level Proportions.				Shift Dustiness
	"1"x.05	"3"x.10	"6"x.50	"8"x.35	
1931	3	15	84	158	260
3	3	13	74	118	208
5	2	11	65	88	166
7	2	9	55	74	140
9	2	7	48	67	124
1941	2	7	43	64	116
3	2	6	41	62	111
5	2	6	41	60	109
7	2	6	41	57	106
9	2	6	41	55	104
1951	2	6	41	53	102
3	2	6	41	52	101
5	2	6	41	52	101

The shift dustiness, the

level proportions decided

50% at "5", 100% at "7"

and

40, 60, 80, 150 and

The shift dustiness, the

4 + 15 + 41 + 15

these decided on area

and 50% at "5", and the

40, 60, 80 and 150

dustiness becomes: 2

these decided on area

and 50% at "5"

The above

and 150 p.p.c.c. were

became: 2 + 6 + 25 +

proportions decided

80% at "5" and the

and 100 p.p.c.c.

became: 2 + 6 +

This is

the estimation of

The shift dustiness, therefore, becomes: $8 + 30 + 25 = 63$

p.p.c.c.

.3 Miscellaneous Miners: The dust

level proportions decided on are: 10% at "1", 25% at "3", 50% at "6", 10% at "7" and 5% at "8". The dust levels are:

40, 60, 82, 150 and 153 p.p.c.c. respectively.

The shift dustiness, therefore, becomes:

$4 + 15 + 41 + 15 + 8 = 83$ p.p.c.c.

.4 Developers: The dust level propor-

tions decided on are: 5% at "1", 10% at "3", 50% at "6" and 35% at "8", and the corresponding dust levels are:

40, 60, 82 and 153 p.p.c.c., so that the shift dustiness becomes: $2 + 6 + 41 + 54 = 103$ p.p.c.c.

.5 Stoppers: The dust level propor-

tions decided on are: 5% at "1", 10% at "3", 30% at "6" and 55% at "7".

The corresponding dust levels are: 40, 60, 82 and 150 p.p.c.c. respectively, and the shift dustiness becomes:

$2 + 6 + 25 + 83 = 116$ p.p.c.c.

.6 Shaft Sinkers: The dust level

proportions decided on are: 5% at "1", 10% at "3" and 85% at "9" and the corresponding dust levels are: 40, 60 and 180 p.p.c.c. The shift dustiness, therefore, becomes: $2 + 6 + 153 = 161$ p.p.c.c.

.7 Comparison of estimates for 1950 with the results obtained during full shift dust studies done in 1949 and 1950.

This is done in table 3.5.VI(a). As can be seen, the estimates compare well with the results of the full shift /

Shift Dustiness
260
208
166
140
124
116
111
109
106
104
102
101
101

CUMULATIVE NUMBER OF PARTICLES OVER SIZE

TABLE 3.5.VIII.

NON - OFFICIALS.

P.P.C.C.

Year	Shaft Workers	Skipmen (1.5 x Sh. W)	Travel- ling Way Workers.	Miscel- laneous Miners	Devel- opers.	Stopers	Shaft Sinkers
1931	101	151	134	168	260	238	398
3	88	132	117	152	208	203	265
5	76	114	101	131	166	170	233
7	67	100	87	111	140	142	202
9	57	86	74	96	126	123	179
1941	54	81	68	88	116	119	168
3	50	75	63	84	111	115	161
5	50	75	63	84	109	115	161
7	50	75	63	83	106	115	161
9	50	75	63	83	104	115	161
1951	50	75	63	83	102	115	161
3	50	75	63	82	101	115	161
5	50	75	63	82	101	115	161

The results are depicted in fig. 3.8.

shift hour studies.

3.5.8 Full

Full shift

1949 and 1950 were also

interest to compare the

estimates based on the

shift spent at various

periods it is also noted

that counts recorded

1931 back to 1935 and

in technique. Due to

results would have to

technique been followed

those in, size classes

3.5.VIII. The age

3.5.9 The

Calc

The results

occupation would vary

levels at the main

of the shift spent at

purpose of this inve

proportions remained

arrived at in section

occupation of shift

for non-officials,

((The data

points were taken f

A summary

years for the variou

in table 3.5.VIII.

shift dust studies.

3.5.8 Full Shift Results Recorded in 1926:

Full shift dust studies similar to those done in 1949 and 1950 were also done in 1926⁽⁴⁹⁾ and it is of interest to compare the results recorded then with estimates based on assumptions of the proportions of the shift spent at various dust levels. To do such a comparison it is also necessary, firstly, to extrapolate the dust counts recorded at the main points underground from 1931 back to 1926 and, secondly, to allow for the changes in technique. Due to changes in technique the 1926 results would have been say, 30% higher, had the present technique been followed. Estimates for, and observations on, six classes of workers are given in table 3.5.VI(b). The agreement is unexpectedly close.

3.5.9 The Variation of Shift Dustiness with Calendar Years:

The dustiness of the underground shift of any occupation would vary with calendar years as the dust levels at the main points, weighted in the proportions of the shift spent at the various dust levels. For the purpose of this investigation, it was assumed that these proportions remained constant over the years at the values arrived at in section 3.5.5. An example of the computation of shift dustiness against calendar years, for non-officials, is given in table 3.5.VII.

((The dust levels for the various underground points were taken from table 3.2.VIII.))

A summary of shift dustiness against calendar years for the various classes of non-officials is given in table 3.5.VIII. An example of the computation of the shift /

Shift Sinkers	pers
38	898
23	265
70	233
2	202
3	179
9	168
5	161
5	161
5	161
5	161
5	161
5	161

CUMULATIVE NUMBER OF PARTICLES OVER SIZE

shift dust studies.

3.5.8 Full Shift Results Recorded in 1926:

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The dustiness of the underground shift of any occupation would vary with calendar years as the dust levels at the main points, weighted in the proportions of the shift spent at the various dust levels. For the purpose of this investigation, it was assumed that these proportions remained constant over the years at the values arrived at in section 3.5.5. An example of the computation of shift dustiness against calendar years, for non-officials, is given in table 3.5.VII.

((The dust levels for the various underground points were taken from table 3.2.VIII.))

A summary of shift dustiness against calendar years for the various classes of non-officials is given in table 3.5.VIII. An example of the computation of the

shift /

ers	Shift Sinkers
8	298
3	265
0	233
2	202
3	179
9	168
5	161
5	161
5	161
5	161
	161
	161
	161

CUMULATIVE NUMBER OF PARTICLES OVER SIZE

TABLE 3.5, IX
THE "SDM" - NON OFFICIAL GROUP

P.F.O.C.

Year (1)	Miscellaneous Miners (2)	Stoppers (3)	Developers (4)	Total (2+3+4) (5)	Shift Dustiness (5 ÷ 3)
1931	168	238	260	666	222
3	152	203	208	563	188
5	131	170	166	467	152
7	111	142	140	393	131
9	96	123	125	344	115
1941	88	119	116	323	108
3	84	115	111	310	103
5	84	115	109	308	103
7	83	115	106	304	101
9	83	115	104	302	101
1951	83	115	102	300	100
3	82	115	101	298	99
5	82	115	101	298	99

shift dustiness of the
years is given in table
each of the classes in
was computed in a similar
dustiness of the various
calendar years is given
the "expected"
calendar years is determined

3.6.1. Part of the

is a selection

it was decided

part action rather than

decision was made based

the factor as the most

stressed mine workers

The cause of death, age

or from any other cause

only cause of

there were some, which

three sections of the

microscope.

3.5.1. Part

of the

apart from

the cases selected for

they had

1 who were

2 who commenced

3 who worked

Witwatersrand

shift dustiness of the "S.D.M."-class, against calendar years is given in table 3.5.IX. The shift dustiness for each of the classes into which mine officials were cast, was computed in a similar manner. A summary of the shift dustiness of the various classes of officials against calendar years is given in table 3.5.X.

The "spectrum" of shift dustiness against calendar years is depicted graphically in figure 3.8.

3.6 Post Mortem Findings with Respect to Silicosis in a Selected Number of Deceased Mine Workers.

It was decided to base the investigation on post mortem rather than on X-ray findings. This decision was made because medical authorities favoured the former as the more reliable finding. It meant that deceased mine workers only, qualified for selection. The cause of death, whether by accident, from sickness or from any other cause did not matter.

Only cases on whose lungs histological⁶ examinations were done, were included.

⁶ Where sections of the lung are examined under the microscope,

3.6.1 Conditions laid down for the selection of cases:

Apart from the condition laid down above, all the cases selected had to satisfy the following conditions:

They had to be European mine workers:

- .1 who were found free from tuberculosis,
- .2 who commenced underground service after 1925,
- .3 who worked in controlled gold mines of the Witwatersrand and Extensions and the Orange

Free /

Shift
Dustiness
(5 + 3)

222

188

152

131

115

108

103

103

101

101

100

99

99

CUMULATIVE NUMBER OF PARTICLES OVER SIZE

TABLE 3.5.X
MINE OFFICIALS (SUMMARY)

P. P. C. C.

(1) Year	(2) Under- ground fore- men and Engi- neers.	(3) Shift Bosses	(4) Mine Overseers Mine Managers And Miscellaneous Officials	Samplers (4 x 1,3)
1931	118	138	178	220
3	103	170	154	200
5	89	142	129	168
7	77	120	109	142
9	66	105	95	123
1941	61	94	89	116
3	57	84	85	110
5	57	84	84	109
7	57	92	83	108
9	57	91	83	108
1961	57	91	83	108
3	57	90	83	108
5	57	89	81	108

Free State,
4 who did not
service total
5 who accounted
5 years of
6 who became
7 who had more
8 that used to be
The reason
are given below.
Only because
because accurate
Native. Article 6
therefore is better
of citizens. Cases
1911 were excluded
(taken by Government
since 1911 only, and
also underground
died to get this
a number of the
decided on as a
work in
"excluded" mines
of service were, in
only, and because
mines only.
Condition
of service breaks
and death were
to the possible

Free State,§

- .4 who did not have breaks from underground service totalling more than 5 years,
- .5 who continued to work underground up to within 5 years of death,
- .6 who became deceased after 1955,
- .7 who had more than 10 years service.

§ That used to be referred to as "scheduled" mines.

The reasons for laying down the above conditions are given below.

Only European mine workers were considered because accurate service records are not maintained for Natives. Tubercle-cases were excluded because tuberculosis is believed to accelerate the progression of silicosis. Cases with underground service prior to 1926 were excluded because the records of konimeter counts (taken by Government Inspectors of Mines) are available since 1931 only, and a limit had to be placed on the time when underground service commenced. One would have liked to put this limit at 1931 but that would exclude a number of the already small selection and 1926 was decided on as a compromise.

Work in mines that used to be known as "scheduled" mines was necessary because accurate records of service were, in the past, maintained on such mines only, and because the dust determinations refer to such mines only.

Conditions "4" and "5" which limited the periods of service breaks and intervals between stopping of work and death were necessary in order to limit any effect due to the possible progressiveness of silicosis, as well as

to /

CUMULATIVE NUMBER OF PARTICLES OVER SIZE

to reduce the chances of including persons who were subjected to dust conditions about which there was no record.

Condition "6" was enforced by circumstances associated with the provision of facilities to conduct histological examinations on all deceased mine workers as the normal routine.

Cases with less than 10 years underground service were excluded because of the absence of silicosis amongst such cases.

3.6.2 Post Mortem Examinations:

Post mortem examinations were done by pathologists of the Pneumoconiosis Unit of the South African Institute for Medical Research. Permission for access to pathological reports were obtained jointly from the Director of the Pneumoconiosis Bureau and the Superintendent of the Routine Division of the South African Institute for Medical Research. The cases selected were examined by either Dr. I. Webster, Senior Pathologist at the Pneumoconiosis Unit, or else by his Assistant, Dr. C. Wagner.

Full histological examinations were done on all the cases selected.

3.6.3 Classifications with Respect to Silicosis:

At post mortem examinations, the condition of the lungs with regard to silicosis, may be cast into the following broad classifications:

- | | | |
|----------------------------|---|---|
| 0. No dust reticulination, | } | 0 |
| 1. Dust reticulination, | | |

2. /

CUMULATIVE NUMBER OF PARTICLES OVER SIZE

TABLE 3.6.
DETAILS OF THE CASES SELECTED.

Ob- ser- va- tion No.	Years Service	UCD Shifts (1000's)	UCD Hours (10,000's)	Particle Hours (Millions)	P.M. Finding	Bureau Certifi- cation.
1	11.8	2.84	2.27	2.44	0	0
2	21.0	5.26	4.30	6.31	6	III
3	21.1	4.35	3.77	3.22	0	0
4	15.7	3.97	3.17	3.93	4	I
5	12.3	3.02	2.17	2.22	4	I
6	28.9	8.24	6.59	6.82	1	I
7	17.2	4.63	3.71	2.08	1	0
8	20.6	3.18	2.43	1.26	0	0
9	14.9	4.76	3.81	3.65	2	I
10	20.8	5.55	3.76	2.32	0	0
11	19.9	4.56	3.66	3.20	1	0
12	31.8	7.34	4.17	3.86	0	I
13	23.3	6.61	5.29	3.82	2	I
14	26.4	5.99	5.58	5.78	2	I
15	29.0	7.97	5.41	5.24	0	0
16	27.3	7.24	5.79	4.60	1	0
17	23.1	5.41	3.26	2.28	0	0
18	12.6	3.20	2.55	2.66	0	0
19	16.9	4.45	3.66	4.01	4	I
20	28.8	8.20	6.56	5.39	3	I
21	17.9	4.21	2.95	1.49	0	0
22	13.8	3.42	2.73	2.41	0	0
23	15.0	4.11	3.28	2.95	0	0
24	19.6	5.77	4.60	4.54	3	I
25	21.0	4.56	3.65	4.03	3	I
26	25.1	5.67	5.33	6.68	4	I
27	15.4	3.36	2.69	2.79	4	I
28	20.4	5.71	4.55	4.03	4	I
29	16.9	4.54	3.59	4.22	2	I
30	17.5	4.94	3.93	3.78	3	I
31	14.7	3.48	2.76	2.86	0	0
32	27.5	7.88	5.52	3.45	1	I

2. Dust retin
3. Occasional
4. Few isolate
5. Moderate
6. Large mass
7. Conglomerate
In the ad
demonstrated mine work
Permanents Act
according to the r
the above table, w
"I" indicates
"II" indicates
"III" indicates
"IV" indicates
The eff
permanents of
1.5 million to
seen, the above
where a person w
than what he is
certification res
compensation con
A Dr. P. J. V
Phonograph
57 Co
open to their
with respect
service etc.

- | | | |
|--|---|-----|
| 2. Dust reticulinisation with collagenisation, | } | I. |
| 3. Occasional islet, | | |
| 4. Few islets, | | |
| 5. Moderate number of islets, ... | | II |
| 6. Large number of islets, ... | | III |
| 7. Conglomeration. | | IV |

In the absence of pulmonary disability, a deceased mine worker will, after the introduction of the Pneumoconiosis Act, 1956, be certified for "pneumoconiosis" according to the roman figures on the right hand side of the above table, where:

- "O" indicates no pneumoconiosis,
- "I" indicates pneumoconiosis in the first stage,
- "II" indicates pneumoconiosis in the second stage,
- "III" indicates pneumoconiosis in the third stage, and
- "IV" indicates pneumoconiosis in the fourth stage.

The official certifications with respect to pneumoconiosis of the cases selected, are given in table 3.6 adjacent to the post mortem finding. As will be seen, the above correlation is confirmed, except that where a person was in life certified in a stage further than what he is at post mortem found to be in, the official certification remains at the more advanced stage - compensation once paid can not be recalled again.

Dr. P.J. Erasmus, formerly Deputy Director, Pneumoconiosis Bureau (now resigned).

57 Cases were selected. The details with respect to their post mortem finding, Bureau certification with respect to pneumoconiosis, years of underground service etc. are given in table 3.6.

((The /

CUMULATIVE NUMBER OF PARTICLES OVER SIZE

TABLE 3.6 (CONTINUED)

Ob- ser- va- tion No.	Years Ser- vice	UGD Shifts (1000's)	UGD Hours (10,000's)	Par- ticle Hours (Mil- lions)	P.M. Finding.	Bureau Certifi- cation.
33	14.9	3.90	3.11	3.25	0	0
34	16.5	4.47	3.21	3.34	0	0
35	21.7	7.23	4.80	5.20	0	0
36	27.6	6.84	2.74	3.73	4	I
37	19.8	5.52	4.32	4.09	4	I
38	19.0	4.32	3.46	3.82	0	0
39	18.3	4.32	3.45	3.91	4	I
40	14.1	3.69	2.87	2.76	4	I
41	13.8	3.13	2.51	2.64	3	I
42	19.5	4.23	2.67	2.67	I	0
43	15.0	3.39	2.00	1.99	I	0
44	25.7	6.80	5.44	5.38	5	II
45	15.2	5.45	4.36	2.34	2	I
46	26.2	8.71	6.97	5.50	2	I
47	21.0	6.21	4.50	3.83	I	0
48	21.5	4.65	3.33	4.29	2	I
49	25.7	7.00	4.90	3.69	0	0
50	22.8	5.40	2.58	2.77	0	II
51	25.8	5.68	4.09	5.23	0	0
52	19.7	3.76	3.01	3.31	5	II
53	27.0	7.57	6.06	7.39	6	IV
54	27.2	6.97	5.58	7.76	5	II
55	30.3	7.83	6.15	8.76	5	II
56	20.3	5.43	3.60	3.60	5	II
57	23.1	6.04	4.85	6.38	5	III

(The Bureau
has no relationship
between persons in
3.6.4 The
The company

respect to class of
such as that of the
account of the limited
cases to qualify for
competition does not
not concern the entire
paid labor force, the
signature of a parent
statute, the fact that
could cause the company
existing European labor
will be considered by

(a) There was the
death but not murder.
for criticism. A
large is, therefore,
on the more dangerous
where, probably after
than other underground
mining class of murder
portion of the sample
present underground
(b) The second
composition of the
existing underground
following:

((The numbers of the cases given in the table bear no relationship to any numbers attached to the deceased persons in life.))

3.6.4 The Composition of the Sample Selected:

The composition of the sample selected with respect to class of mine worker, is most probably not the same as that of the underground European labour force on account of the limitations that had to be laid down for cases to qualify for inclusion. However, a difference in composition does not matter because the investigation does not concern the silicosis incidence of the present European labour force, but the relationship between the dust exposure of a person and his degree of silicosis. Nevertheless, the factors and the direction in which they could cause the composition to deviate from that of the existing European labour force are of interest, and they will be considered here.

(a) Death was the prime selector! " of death did not matter. It could be anything. one died from silicosis. A bias with respect to condition of the lungs is, therefore, excluded, but the workers employed on the more dangerous occupations, e.g. the actual miners, probably stood a better chance of being included than other underground workers. Hence, the actual mining class of worker may possibly form a larger proportion of the sample selected than it forms of the present underground European labour force.

(b) The second factor which could cause the composition of the sample to deviate from that of the existing underground European labour force is the following:

The /

Bureau
Certifi-
cation.

CUMULATIVE NUMBER OF PARTICLES OVER SIZE

O
O
O
I
I
O
I
I
I
O
O
II
I
I
O
II
O
II
IV
II
II
II
III

The next of kin may receive increased (but not decreased) compensation as a result of post mortem examinations where the deceased was in life not yet certified to be in the *second stage*, and the consent of the next of kin must be obtained for such examinations. Decreased compensation is not possible, because even if the deceased is at post mortem found in a stage less advanced than he was in life certified to be, the compensation rate remains the same for the more advanced stage. The "better off" next of kin, such as the next of kin of Mine Officials may, therefore, be less readily prompted to agree to post mortem examinations than the next of kin of ordinary mine workers, and this could further reduce the proportion of mine officials being included in the sample.

(c) The compensation factor also acted in another way. viz., on account of the possibility of increased compensation to the next of kin, preference is given to post mortem examinations on cases who were in life not in the second* stage of pneumoconiosis. This is done to cause the least possible delay in the payment of increased compensation where due.

* Full compensation is paid to the next of kin from the second stage onwards.

As far as the author can judge, factors "b" and "c" are the ones which could affect the composition of the sample with respect to class of worker.

Factors "b" and "c" were probably also responsible for the stage reached during the investigation that, when 51 cases qualified for inclusion, only two cases were beyond the stage described as "few islets."

It /

CUMULATIVE NUMBER OF PARTICLES OVER SIZE

It was then decided to specially select from there onwards, only cases beyond this stage. Only six cases could be found within the period available to the author, which satisfied also the other conditions previously laid down.

Other factors which have a bearing on whether or not post mortem examinations are conducted, are the following:

- (i) Certain religious groups invariably refuse consent,
- (ii) In other cases post mortem examinations are not possible on account of the condition in which the lungs arrive at the Bureau.

These two factors can, however, only act in a random fashion on the composition of the sample with respect to class of worker.

Of interest also, is the legislation in existence to encourage the conducting of post mortem examinations in all cases except where such examinations are specifically refused.

In this respect, the following extract from Section 29 of the Pneumoconiosis Act of 1956 is of interest:

'A medical practitioner who attended a deceased person at the time of his death or who has opened the body of such person and who knows or has reason to believe that the person worked in a controlled mine, shall remove his cardio-respiratory organs and send the organs to the bureau No medical practitioner shall conduct a post mortem examination without the consent of the widow or an adult near relative, if such person can readily be consulted.'

3.7 /

CUMULATIVE NUMBER OF PARTICLES OVER SIZE

NAME : "X"

TABLE 3.7.

Bureau No. "Z".

BLASTING CERTIFICATE NO. "Y".

Mine	Nature of Employment:	Shifts per Occupation.	From	To	Shifts per mine.
1	Lnr. Sampler Lnr. Machines. Timberman Pipes & Tracks. Trammer.	78 127 86 98 223	23. 7.36.	30. 8.38.	612
2	A.M.T. & W/Pkr. A.M. & Timberman	26 43	31. 6.38.	21.11.38	65
3	A.M.T. & A.M.S.O.W. Mach. Stoper	147 90	29.11.38.	6.10.39	237
4	Trammer Tracks. Mach. Developer.	152 6 182	18.10.39.	27.12.40	340
5	Temp. Gen. Miner. Timberman Stoper	150 841	31.12.40.	26. 7.44.	991
6	A.M. & Trammer Developer	155 32	2. 8.44	31. 3.45.	188
7	Temp. Gen. Miner	126	9. 4.45.	10. 9.45.	126
8	Trammer Stoper	72 22	17. 9.45.	28. 1.46.	94
9	Sinker Sinkers Helper Shaft Timberman	202 3 29	29. 3.46.	3. 2.47.	234
10	Sinker Sinking, Banksman Developer	329 4 20	13. 3.47 1.12.47.	31. 7.48.	353
11	Stoper	11	10. 8.48.	26. 8.48.	11
12	Woolagoman S.V. Banksman Sinkers Helper Sinker Developer Shaft Timber	36 50 5 266 26 90	7. 1.40.	20. 8.50.	473
13	Timberman	39	24. 6.50.	9. 8.50.	39.
14	Sh/Timberman Sinker	2 26	11. 8.50.	12. 9.50.	26
15	Shaft Timber Shaft Sinker	221 14	15. 9.50. 21. 6.51.	29. 7.51.	235
16	Stage Hand	-	3. 8.51.	12.11.51.	69
17	Banksman	-	12. 8.53.	2. 9.53.	-
18	Banksman Gang Controller	134 -	4.10.54. 1. 4.55.	20. 9.56.	124

3.7 Records of Ser

At the outset

obtained the permission

er¹ to study the copies

workers dealt with by his

Department's Committee

of service of mine work

and that only the records

they qualified for full

benefits to a

workers who did not con

compensation portions of

workers where each part

this investigation.

The problem

sion of the Commission

Mines for access to the

employees.

Table 3.7 is

extracted from the rec

which known as the

3.8 The Total Fi

selected:

The mine was

every type of work th

of shifts that he wor

From the es

duration of the under

an estimate could be

each occupation. A

record of service of

3.7 Records of Service:

At the outset of the investigation, the author obtained the permission of the Pneumoconiosis Commissioner* to study the copies of records of service of mine workers dealt with by him. It transpired that the Pneumoconiosis Commissioner only had copies of the records of service of mine workers who qualified for compensation, and then only the records of service up to the time when they qualified for full compensation.

Needless to say, the records of service of mine workers who did not contract silicosis as well as the post compensation portions of the records of service of mine workers where such portions existed, were essential to this investigation.

The problem was solved by obtaining the permission of the Transvaal and Orange Free State Chamber of Mines for access to their records of service of mine employees.

Table 3.7 is an example of the information extracted from the records of service.

* Then known as the Chairman of the Silicosis Board.

3.8 The Total Time Spent Underground by Each Case Selected:

The mine workers' record of service reveals every type of work that he was employed on and the number of shifts that he worked in each occupation.

From the estimates, made in section 3.4 of the duration of the underground shift of each class of work, an estimate could be made of the time spent underground on each occupation. As can be seen from Table 3.7, the record of service details the following information:

3.8.1 /

	Shifts per mine.
8.	612
8	65
9	237
0	340
4.	221
5.	188
5.	126
6.	94
7.	234
8.	353
8.	11
0.	473
3.	39.
0.	28
1.	235
1.	69
3.	
0.	124

CUMULATIVE NUMBER OF PARTICLES OVER SIZE

TABLE 3.8.1.
SHIFTS, HOURS AND PARTTOL - HOURS.
P. P. C. C.

1	2	3	4	5	6	7	8	9
Occ.n No.	Se.	Pr. P Se. S	H.p. Occ.n (2x4) + 100	Pr. Hrs. (6+5) + 100	P.O. C.C.	P.p. Occ.n (5x7) + 10000	Pr. Ps. (9 8) + 10000	
1	528	528 8	42.6	42.6	231	98.4	98.4	
2	169	695 8	13.5	56.1	234	31.6	130.0	
3.1	201	896 8	16.1	72.2	159	25.6	155.6	
.2	29	925 8	3.3	74.5	211	4.9	160.5	
.3	331	1256 8	26.5	101.0	147	39.0	199.5	
4	266	1524 8	21.4	122.4	133	28.5	228.0	
5.1	114	1638 8	9.1	131.5	125	11.4	239.4	
.2	94	1733 8	7.5	139.0	121	9.1	248.5	
.3	95	1827 8	7.6	146.6	118	9.0	257.5	
.4	13	1840 8	1.0	147.6	159	1.6	259.1	
6.1	330	2170 8	26.4	174.0	131	34.6	293.7	
.2	294	2464 8	23.4	197.4	100	23.4	317.1	
.3	42	2517 8	3.9	201.3	126	4.9	322.0	
.4	24	2537 8	1.9	203.2	95	1.8	323.8	
.5	69	2606 8	5.5	208.7	94	5.2	329.0	
7.1	178	2784 8	14.2	222.9	111	15.8	344.8	
.2	134	2918 8	10.7	233.6	119	12.7	357.5	
8.1	833	3751 8	66.6	300.2	87	57.9	415.4	
.2	30	3781 8	2.4	302.6	116	2.8	418.2	
9.1	282	4063 8	22.5	325.1	84	18.9	437.1	
3	23	4086 8	1.8	328.0	64	1.3	438.3	
.3	29	4116 6	1.7	328.6	91	1.5	439.8	
.4	1	4116 8	.1	328.7	116	0.1	439.9	
10.1	271	4387 8	21.7	350.4	83	18.0	457.9	
.2	6	4393 6	.4	350.8	90	0.4	458.3	
11.1	9	4402 8	.7	351.5	83	0.6	458.9	
.2	46	4448 8	3.7	355.3	83	3.1	462.0	
12.1	131	4579 8	10.5	365.7	83	8.7	470.7	
.2	109	4688 8	8.7	374.4	83	7.2	477.9	
.3	46	4734 8	3.7	378.1	83	3.1	481.0	
.4	282	5016 8	22.6	400.7	83	18.8	499.8	
.5	1983	6979 8	157.0	557.7	50	72.5	578.3	

3.8.1 The
ignored for the purpose
that each mine was at
the
the
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occupations
the
and stopped on each
the
occupation.

From his re
mine surface agent and
of its years and in sh
estimate is also given
be spent underground
the time spent underground
table 3.8.1.

The first
occupation, the second
in each occupation,
number of shifts work
number of hours spent
(according to the ear
column the product of
the estimated hours
and the sixth column
underground.

((Column)
counts and are exple
3.9 Time Under
Of importance

3.8.1 The name of the mine (this column was ignored for the purpose of this investigation, except that each mine was given a number);

.2 the nature of employment;

.3 the number of shifts employed in each occupation;

.4 the dates when employment was started and stopped on each mine; and

.5 the number of shifts worked in each occupation.

From his record of service, the period that a mine worker spent underground can be computed and expressed in years and in shifts. A reasonably accurate estimate is also possible of the number of hours which he spent underground. An example of a computation of the time spent underground is given in columns 1 to 6 of table 3.2.1.

The first column contains the number of the occupation, the second column the number of shifts worked in each occupation, the third column the progressive number of shifts worked underground, the fourth column the number of hours underground per shift in each occupation (according to the estimates made in section 3.4), the fifth column the product of the second and fourth columns i.e., the estimated hours spent underground in each occupation and the sixth column the progressive number of hours underground.

((Columns 7, 8 and 9 deals with konimeter counts and are explained in Section 3.10.))

3.9 Time Underground versus Silicosis:

Of importance to the present investigation is
the /

CUMULATIVE NUMBER OF PARTICLES OVER SIZE

the relationship between the degree of silicosis and the total time underground, in order to form a basis of comparison for the relationship between degree of silicosis and konimeter-hour particles.

In order of accuracy, estimates of the time underground are:

- a. years of underground service,
- b. underground shifts, and
- c. underground hours.

The "years", the shifts and the hours that each of the 57 cases selected spent underground are given in table 3.6.

The relationship between silicosis and "years" is depicted in figure 3.9(a). As can be seen, there is practically no association between the two measures.

The relationship between silicosis and underground shifts is depicted in figure 3.9(b). As can be seen, the association does not appear to be any better than that between silicosis and underground years.

The relationship between silicosis and hours underground is depicted in figure 3.9(c). Again no improvement can be detected.

The total time underground is an estimate of a person's dust exposure but as the dust exposure per unit of time varies with different occupations and with different calendar periods, the total time underground is a poor estimate of a person's dust exposure.

A more accurate estimate may be his "konimeter count" exposure and the method of estimating the konimeter count exposures of the cases selected, is described in the next section.

TABLE 3.10.1.

Occupation.		DATES *		Corresponding		Mean
No.	Group	From	To	Dust	Levels	v.p.c.o.
1	SDM	30.1	31.10	242	212	227
2	DM	31.12	32.7	250	218	234
3.1	M	32.7	33.2	163	155	159
.2	S	33.2	33.3	211	211	211
.3	M	33.3	34.6	154	139	147
4	M	34.6	35.6	139	127	133
5.1	M	35.6	35.11	127	122	125
.2	M	35.11	36.3	122	119	121
.3	M	36.3	36.7	119	116	118
.4	S	36.7	36.8	159	159	159
6.1	SDM	36.8	37.12	138	124	131
.2	M	37.12	39.2	103	96	100
.3	S	39.2	39.4	127	125	126
.4	M	39.4	39.5	95	95	95
.5	M	39.5	39.8	95	93	94
7.1	SDM	39.8	40.4	112	110	111
.2	S	40.4	40.10	120	118	119
8.1	M	40.10	43.12	89	84	87
.2	S	43.12	44.1	116	116	116
9.1	M	44.1	45.2	84	84	84
.2	Tr	45.2	45.3	64	64	64
.3	SE	45.3	45.4	91	91	91
.4	S	45.4	45.5	116	116	116
10.1	M	45.5	46.11	83	83	83
.2	SE	46.11	46.11	90	90	90
11.1	M	46.11	46.22	83	83	83
.2	M	46.12	47.2	83	83	83
12.1	M	47.2	47.8	83	83	83
.2	M	47.8	47.12	83	83	83
.3	M	47.12	48.2	83	83	83
.4	M	48.2	49.5	83	83	83
.5	Sh	49.5	56.6	50	50	50

* For "36.5" read : May 1936.

3.10 The following
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3.10 The Konimeter Count Exposure of Each Case:

The estimation of the konimeter count exposure entailed the following assumptions:

- .1 That all working places of the same class had the same dust count irrespective of the mine or the position in the mine,
- .2 that the dustiness per shift of all mine workers of the same occupational group was the same and equal to the mean for that group,
- .3 that the occupational groups were subjected to the mean dust counts recorded during routine inspections by Government Inspectors of Mines, weighted in the proportions given in section 3.5.5, for the various types of working places.

In view of the above, the estimates of dust exposures have very wide confidence limits.

The dust exposure of any underground career is equal to the sum of the exposures of the various occupational periods constituting the career. The exposure of each occupational period is the product of:

underground shifts,
hours per shift and
dustiness per shift.

The dustiness per shift of every occupation varied with calendar time and, therefore, it was necessary to know the calendar period of occupation to estimate the dust exposure of a specific occupational period. In order to facilitate the assessment of the mean dustiness per shift of each period of occupation of a mine worker, tables of which No. 3.10.I is an example, were drawn up for each case.

The /

Mean
v.p.c.c.

CUMULATIVE NUMBER OF PARTICLES OVER SIZE

The following columns were incorporated in these tables:

- .1 In the first column was recorded the number of every occupation,
- .2 in the second column the symbol corresponding to the occupational group,
- .3 in the third column the dates corresponding to the beginning and the end of each occupation,
- .4 in the fourth column the dust levels corresponding to the terminal dates for the particular occupation, and
- .5 in the last column, the mean dust level.

The records of service revealed the dates of employment and of discharge on every mine.

The dates when a change was made from one occupation to another within the same mine were, as a rule, not recorded unless the change was a major one such as when a daily paid worker became an official. However, the various occupations and the number of shifts worked in every occupation, were recorded consecutively and from these details the dates of change of occupation within the same mine could be estimated fairly accurately. The dates of change so estimated were made to the nearest calendar month.

3.10.1 Accumulation of underground shifts per unit of calendar period:

In order to estimate the terminal dates of occupational periods rapidly where needed, graphs were constructed of underground shifts against period of service for the various underground occupations. (See figure 3.10).

The /

TABLE 3.10.II

APPROXIMATE RATES AT WHICH UNDERGROUND SHIFTS
ARE ACCUMULATED.

Occupation	Underground shifts per		
	Week	Year	5 Year period
Miners	6	280	1400
Shift Bosses	6	280	1300
Mine Overseers	5	240	1100
Miscellaneous Officials.	5	240	1100
Underground Managers	4	190	850

The graphs in
table 3.10.II.

The number of
per 5 year period were
(The leave privilege of
Secretary of the United
States Commission.

3.10.12

amount to get 12 days

12 - 12 = 312 4

+ 7 given of work

+ 7 given 12" and

5 shifts and

Day, Sundays Day and

shifts per year and, the

period, 12 days 1,400

3.10.13

Officials were secured

7 days accumulated leave

of days leave and

Officials, 80 for shift

117 for Underground

a day a very small

become officials

3

allowance for Shift 3

30 days every 7

7 days accumu

80 days every 7

Therefore, underground

The graphs were constructed from the data in table 3.10.II.

The number of underground shifts per year and per 5 year period were arrived at as explained below. (The leave privilege figures were obtained from the Secretary of the Underground Officials Association in a private communication).

3.10.1.1 Non-Officials: Miners were assumed to get 30 days leave per year.

365 - 30 = 335 days per working year;
+ 7 gives 48 weeks per working year;
x 6 gives 287 shifts per working year.

5 Shifts subtracted for Good Friday, Christmas Day, Dingaans Day and 2 Medical Bureau days, leaves 282 shifts per year and, therefore, 5 x 282 shifts per 5 year period, i.e. say, 1,400 shifts per 5 year period.

3.10.1.2 Officials:^{*} All Underground Officials were assumed to get 30 days leave per year plus 7 days accumulated leave in addition to a certain number of days long leave which may be assumed at 65 for Junior Officials, 80 for Shift Bosses, 103 for Mine Overseers and 117 for Underground Managers.

* Only a very small number of the cases included became officials - none became managers.

3.10.1.2.1 Shift Bosses: Leave allowance for Shift Bosses were assumed as:

30 days every year, plus
7 days accumulative leave per year, plus
80 days every fifth year.

Therefore, underground shifts per year = $(365 - 30) \times 5/7$
= 287.

Less /

Less 2 public holidays and 2 medical Bureau days = 283.
∴ Underground shifts per 5 year period = 1,415
less the shifts absorbed by long leave allowance viz.
 $80 + 5 \times 7 \text{ days} = 115 \text{ days.}$
 $(115 + 7) \times 6 \text{ shifts} = 99 \text{ shifts.}$
∴ Underground shifts per 5 years = 1,415 - 99
= 1,300.

3.10.1.2.2 Mine Overseers and Under-
ground Engineers: Leave

allowances were assumed at 30 days per year plus 7 days
accumulative per year, plus 103 days every 5 years.

(It was assumed that Mine Overseers went under-
ground 5 days per week).

Therefore, number of shifts per year = $(365 - 30) \times 5/7$
= $335 \times 5 + 7$
= 240
and number of shifts per 5 years = 1,200 less the
shifts absorbed by the long leave period of $(5 \times 7 + 103 =)$
138 days, i.e.,

less $(138 \times 5/7 \text{ shifts}) = 100 \text{ shifts.}$

Therefore, number of underground shifts per 5 years =
 $1,200 - 100 = 1,100 \text{ shifts.}$

3.10.1.2.3 Miscellaneous Officials:

For the purpose of estimating dates from the number of
underground shifts, this group was assumed the same as
Mine Overseers.

3.10.1.2.4 Underground Managers:

(Such cases were not received but the relative number of
shifts are of interest.)

Leave allowances may be assumed at 30 days per
year plus 7 days accumulative leave per year plus 117

days /

days every 5 years.

(It may also be assumed that Underground Managers go down 4 days per week, on an average.)

Therefore, number of underground shifts per year =

$$(365 - 30) \times 4/7 = 190$$

and number of underground shifts per 5 year period =

$$5 \times 190 = 950 \text{ less}$$

the number of shifts absorbed by the long leave period
viz. $(117 + 5 \times 7)$ days,

i.e. $152 \times 4 + 7 = 89$ shifts.

Therefore, number of underground shifts per 5 year period =

$$950 - 90 = 860$$

= 850 say.

As stated before, the graphs were used in cases where the deceased worked on the same mine for many years as a result of which few dates, to mark off occupational periods, appeared on his record of service.

In cases where the deceased shifted frequently from one mine to another his record of service had many date checks and in such cases reference to the graphs were not necessary. Such cases also confirmed that the graphs were sufficiently accurate to estimate the occupational period from the number of shifts worked.

3.10.2 The dust exposures of the various occupational periods:

This was computed from the number of shifts worked during each occupational period and the mean dustiness per shift of the period.

The mean dustiness per shift of each occupational period was computed from the curves of dustiness per shift against calendar years.

Figure /

Figure 3.8 depicts the variation in shift dustiness of the various occupations with calendar years. The computation of mean dustiness per shift for the various occupational periods is shown in table 3.10.I. The second column of the "3.10.I" tables gives the occupational group and the third column gives the calendar period of occupation. From figure 3.8, the shift dustiness for the various occupations could be read for any calendar month. The shift dustiness so read, was entered in the fourth column of the "3.10.I" tables. The number of readings taken per unit of calendar period varied according to the nature of the change in shift dustiness.

If the change in shift dustiness was non linear with time, readings were taken at sufficiently short calendar intervals for the change in dustiness to be assumed linear, so that the arithmetic mean of the computed dust levels gave sufficient accuracy.

The mean dust levels so calculated were then transferred to the seventh column of the "3.8.II tables" opposite the corresponding occupational hours. The product of hours underground and mean dust level gave the dust exposure (expressed in konimeter particle-hours).

The estimated dust exposure of each occupational period was entered in the eighth column of table 3.II and the ninth column gave the cumulative dust exposure.

3.11 Konimeter count exposure versus Silicosis:

The relationship between silicosis and konimeter count exposure is depicted in figure 3.11. There is still a very wide scatter but the relationship between the two measures does seem to be better than that depicted in

figures /

figures 3.9(a), (b) and (c).

In order to test the association between silicosis and each of the four measures of dust exposure viz. "years", shifts, hours and konimeter-particle-hours, the results were analysed statistically.

3.12 Statistical Analysis:

3.12.1 Random Theory:

A question that arises in connection with the sample selected is whether random theory holds. To provide the answer to this question, the method of obtaining the sample will be restated briefly. The author set up a "screen" for a certain period. All the cases which passed the screen were included. This gave cases No. 1 to 51. Only 2 out of these 51 cases were beyond classification "4" on the Pathologists' scale. The screen was then altered so as to include only cases beyond this stage from there onwards. This produced the final six cases viz., Nos. 52 to 57.

As explained before, the sample selected is probably not representative of the underground European labour force, neither with respect to class of worker nor with respect to the prevalence of silicosis.

However, the sample may be classified into certain classes with respect to silicosis, and as far as the author can judge, the dust exposures in each class is a random sample of the population of dust exposures of that class. ((There are four measures of dust exposure viz.:

- (1) "Years" of underground service,
 - (2) underground shifts,
 - (3) underground hours, and
 - (4) konimeter particle-hours.))
- ln /

In view of the above, random estimation theory was assumed to hold and the association between silicosis and each of the four measures of dust exposure, was tested. The variance ratio test was selected.

3.12.2 Variance Ratio Test(50): The variance ratio test gave the results (see below) for the association between degree of silicosis and each of the four measures of dust exposure. (For the actual calculations, see annexure "A").

The variance ratio test compares the variance between classes with the variance within classes. As there are 57 observations that could be cast into 7 classes, there are 50 degrees of freedom within classes, and 6 degrees of freedom between classes.

- (a) For underground years of service, the variance between classes, came to 28.7, and the variance within classes, came to 26.8. The variance ratio, therefore, equals 1.07. For 6 and 50 degrees of freedom, the variance ratio is 0.903 for the 50% level and 1.24 for the 70% level(51). The variance ratio, therefore, reaches about the 60% level, which is not significant, i.e., there is no evidence that average number of years of service differed between the seven classes of degree of silicosis.

- (b) For underground shifts, the variance between classes, came to 3.08, and the variance within classes, came to 2.48. The variance ratio, therefore, equals 1.24. For 6 and 50 degrees of freedom, the variance ratio is 1.24 for the

70% /

70% level.⁽⁵¹⁾ The variance ratio, at this level is better than that obtained for "years" but not yet significant as it is less than 95% i.e., there is no marked evidence connecting condition of the lungs with the number of shifts.

- (c) For underground hours, the variance between classes, came to 3.29, and the variance within classes, came to 1.37. The variance ratio, therefore, equals 2.40. For 6 and 50 degrees of freedom, the variance ratio is 2.29 for the 95% level and 2.67 for the 97.5% level.⁽⁵¹⁾ The variance ratio, therefore, reaches about the 96% level, and may be considered significant. At this stage it would appear reasonable to judge that the greater the damage done to the lungs the greater the number of hours underground.

- (d) For konimeter-particle-hours, the variance ratio between classes, came to 8.47, and the variance ratio within classes, came to 1.78. The variance ratio is, therefore, 4.76. For 6 and 50 degrees of freedom the variance ratio is 4.51 for the 99.9% level and 4.93 for the 99.95% level. The variance ratio, therefore, reaches beyond the 99.9% level which is very significant.

Thus, there is strong evidence that the greater the damage to the lungs the greater the number of konimeter-particle-hours.

Summary:

Summary:

The results of the statistical analysis suggest that there is:

- (a) No association between given degree of silicosis and years of underground service;
- (b) very little if any association between given degree of silicosis and underground shifts;
- (c) some association between given degree of silicosis and underground hours;
- (d) a strong association between given degree of silicosis and konimeter-particle-hours.

3.12.3 Distribution of years, shifts, hours and particle-hours within classes:

The distribution within classes, of the four measures referred to above, were examined by expressing the cumulative proportions of cases above and below certain class limits and by plotting the cumulative proportions on percent probability paper.* The points lie on a reasonably straight line, in all cases. Examples of the plots obtained are depicted in figures 3.12(a), (b), (c) and (d). The results suggest, therefore, that the four measures are normally distributed within classes.

* For the purpose of this examination, grouping of the sample into four main classes with respect to silicosis, viz., X₀, X₁, X₂₊₃₊₄ and X₅₊₆, suggested itself. The suffixes refer to the pathological classification given in section 3.6.3 and used in table 3.6.

3.12.4 The t-test:

In view of the reasonably normal distribution of the four measures of dust exposure within classes, the t-test⁽⁵²⁾ was used to test differences between mean dust

exposures /

exposures of the main classifications made with respect to silicosis. The following results were obtained:

- (i) The difference between X_{2+3+4} and X_0 reached:
 - (a) the t97.5 level for particle-hours,
 - (b) the t92 level for hours,
 - (c) less than the t75 level for shifts,
 - (d) less than the t50 level for "years"

(X_{2+3+4} was less than X_0).
- (ii) The difference between X_{5+6} and X_{2+3+4} reached:
 - (a) the t99.3 level for particle-hours,
 - (b) the t88 level for hours,
 - (c) the t88 level for shifts, and
 - (d) the t99.0 level for "years".*

* This is the exception and although the difference reaches a significant level, it is lower than that for particle-hours.

- (iii) The difference between X_{5+6} and X_0 reached:
 - (a) beyond the t99.9 level for particle-hours,
 - (b) the t99.5 level for underground hours,
 - (c) the t96.1 level for underground shifts, and
 - (d) the t97.4 level for "years".

Summary:

The results suggest that for two given degrees of silicosis, the particle-hours will, in the majority of cases, be separated further apart than any of the other three measures.

The t-test, therefore, confirms the findings of the variance ratio-test viz., that there is a stronger association between degree of silicosis and konimeter-particle-hours than between degree of silicosis and any of the other three measures of dust exposure. The /

The relationship between degree of silicosis and mean dust exposure is depicted graphically in figures 3.13 to 3.16, for each of the four methods of expressing dust exposure.

The main classifications made with respect to silicosis are given as ordinates on an arbitrary scale, whilst the four measures of expressing the dust exposures are given as abscissae.

4. DISCUSSION:

4.1 The Question of Bias:

4.1.1 Post Mortem Findings:

When the Pathologist examines the lungs he has a record of the deceased's service as reported verbally by the deceased to the Bureau during periodical examinations. The Pathologist, therefore, has an idea of what the person was employed on and for how long.

However, the Pathologist does not know the deceased's number of shifts, or his number of underground hours and least of all, his number of particle-hours.

4.1.2 Particle-hours:

The author's original intention was to estimate the dust exposures without prior knowledge of the post mortem findings and many exposures were so estimated but, unfortunately, this could not be persisted with due to practical difficulties. These difficulties were mainly associated with the elimination of cases that were found to have tuberculosis, as well as with the special selection of cases in an advanced stage, towards the end of the investigation.

However, the author can vouch that prior knowledge of the post mortem findings were not allowed to influence /

influence the estimation of particle-hours of cases.

4.2 Factors which would tend to obscure an association between the two measures:

(a) Any inaccuracies associated with the estimation of the measures, will tend to obscure the functional relationship between the measures. The inaccuracies associated with the konimeter-particle-hours have been dealt with.

It has also been indicated that only broad classifications, based on the terms used by pathologists, of the degree of silicosis are possible.

(b) Any variation in the personal susceptibility to contract silicosis would also tend to obscure the functional relationship. Some factors which may have a bearing on the personal susceptibility are:

- (i) General physique,
- (ii) Age range of occupation,
- (iii) Mode of living, eg., heavy or light smoker, excessive or moderate drinking, etc., etc.

(c) The possibly progressiveness of silicosis. All the cases investigated did not accumulate their dust exposure at the same rate, nor over the same period, nor in the same pattern. (By the same "pattern" is meant an initial high rate followed by a low rate as against an even rate over the whole period or as against an initial low rate followed by a high rate.)

These factors were completely ignored.

In view of the above, it seems logical to expect a better agreement between degree of silicosis and konimeter count exposure than that obtained with the results /

influence the estimation of particle-hours of cases.

4.2 Factors which would tend to obscure an association between the two measures:

(a) Any inaccuracies associated with the estimation of the measures, will tend to obscure the functional relationship between the measures. The inaccuracies associated with the konimeter-particle-hours have been dealt with.

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(b) Any variation in the personal susceptibility to contract silicosis would also tend to obscure the functional relationship. Some factors which may have a bearing on the personal susceptibility are:

- (i) General physique,
- (ii) Age range of occupation,
- (iii) Mode of living, eg., heavy or light smoker, excessive or moderate drinking, etc., etc.

(c) The possibly progressiveness of silicosis. All the cases investigated did not accumulate their dust exposure at the same rate, nor over the same period, nor in the same pattern. (By the same "pattern" is meant an initial high rate followed by a low rate as against an even rate over the whole period or as against an initial low rate followed by a high rate.)

These factors were completely ignored.

In view of the above, it seems logical to expect a better agreement between degree of silicosis and konimeter count exposure than that obtained with the results /

results used by the author, if it were possible to allow for the medical factors which may affect the onset of silicosis and if the true konimeter count exposure were available.

4.3 Composition of the Sample of Cases:

The composition of the sample selected, with respect to class of worker, could unfortunately, not be studied scientifically due to lack of time, but the author hopes to be able to do so at a later date.

5. CONCLUSION:

There appears to be a strong association between degree of silicosis and konimeter-particle-hours. Hence, there is no need to change the konimeter or the sampling technique, before a significantly closer agreement can be established between degree of silicosis and dust exposure, as based on the results recorded during routine dust sampling with another instrument.

6. APPLICATION:

What is really needed is the association between given dust exposure and degree of silicosis, but this cannot be obtained in practice. However, as a given degree of silicosis has been found to be strongly associated with the konimeter-particle-hours, the opposite must follow viz., that a given number of konimeter-particle-hours must be strongly associated with the degree of silicosis.

In view of the wide scatter of the konimeter-particle-hours associated with a given degree of silicosis, it will not be of much practical use to attempt the prediction of the degree of silicosis in a person from his
konimeter- /

konimeter-particle-hour exposure as estimated in this investigation.

Nevertheless, the mean konimeter-particle-hours associated with a given degree of silicosis, may serve as a useful guide to aim at, in order to keep the mean degree of silicosis in a population of workers below a certain level, eg. from the relationship between degree of silicosis and konimeter-particle-hours (see figure 3.16) it can be seen that if it is required to prevent the mean degree of silicosis in a body of men from getting beyond that at which the mean certification is likely to be for pneumoconiosis in the first stage, their mean dust exposure should not get beyond about 4 million konimeter-particle-hours.

Example:

An example calculated from the figure of 4 million hour particles to contract pneumoconiosis in the first stage is of interest.

Take developers. The estimated mean dustiness per shift of a developer (by 1955), is about 100 p.p.c.c.

At 8 hours per day and at 290 shifts per year, it will, therefore, take a developer, under present day conditions, about $4,000,000 \div (100 \times 8 \times 290)$ years i.e. about 17 years to accumulate 4 million konimeter-hour-particles (if he always remains on development).

A person cannot start as a developer right from the first shift, because experience in the "miscellaneous" class of work is essential, where the dust exposure is less than that as a developer. This will lengthen the period to accumulate 4 million particle-hours of dust exposure towards, say, 20 and more years, which figure compares /

compares favourably with that found in practice. As can be seen in figure 2.5 ((curve (2))) 20 - 25 years was the most common underground service at which silicosis in the first stage was contracted.

7. RECOMMENDATIONS:

7.1 Records of Service:

As there is no association between degree of silicosis and years of service or number of shifts, which are the two measures of dust exposure obtainable from the records of service as compiled at present, and as strong association can be obtained if only two additional items were recorded, which are: the hours per shift and the shift dustiness, it is recommended that they be added to all future records of service of employees on mines where regular dust sampling is done.

7.2 Recorded Dust Counts:

7.2.1 As pointed out in section 3.2.1.1, the dust counts recorded suffer from the disadvantage that they include some observations which were taken where conditions were suspected or known to be bad and others, which were taken to verify that conditions had been improved. To eliminate the bias introduced hereby, it is recommended that these two classes of observations are kept separate from those taken at random.

7.2.2 The dust records also suffer from the disadvantage that individual dust samples are not recorded; so that, with the method used, it is not possible to arrive at the distribution function of dust levels in mine air, and hence, it is not possible to fix confidence limits to mean dust counts. In view of the

above /

above, it is recommended that records of dust samples be so compiled that the frequency distribution of dust levels may be computed therefrom.

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ANNEXURE : A.1 :

YEARS OF SERVICE.

(a) ORDINARY CLASSIFICATION.

P.M. Classification.	Years of Service	n	$\sum Ex$	$\bar{x}$	$\sum Ex^2$	$\sum nx^2$	$\sum (x-\bar{x})^2$	s^2
0	11.8 15.0 21.1 14.7 20.6 14.9 20.8 16.5 31.8 21.7 29.0 25.7 23.1 22.9 12.6 25.8 17.9 19.0 13.8	19	378.6	19.93	8110.13	7644.10	566.02	31.44
1	28.9 27.5 17.2 19.5 19.9 15.0 27.3 21.0	8	176.3	22.04	4070.85	3685.21	189.64	27.09
2	14.0 15.2 23.3 26.2 26.4 21.5 16.9	7	144.4	20.63	3127.20	2978.17	148.43	24.74
3	28.6 19.6 21.0 17.5 13.8	5	100.7	20.14	2151.29	2028.10	123.19	30.80
4	15.7 20.4 12.3 27.6 16.9 19.6 25.1 18.3 15.4 14.1	10	195.6	19.56	3654.22	3444.74	209.48	23.28
5	25.7 30.3 19.7 20.3 27.2 23.1	6	146.3	24.38	3652.21	3567.26	84.93	16.99
6	21.0 27.0	2	48.0	24.00	1170.00		18.00	18.00
		57	1172.9	20.70 $\pm .69$	26935.89	24423.93	1339.69 1511.96	

	S.S.D.	A.f.	s^2
Between classes	172.27	6	28.71
Within classes	1339.89	50	26.79
Total	1511.96	56	= 5.17 ²
	$\sqrt{s^2} = 1.078$		

Practically unity; somewhere near 60% sig. level;
No evidence whatever of differences in the means.

* For "s" read "sigma".

ANFEXURE : A.1 : YEARS OF SERVICE

(b) CONDENSED CLASSIFICATION.

	n	Σx	$\bar{x}$	Σx^2	$n\bar{x}^2$	$\Sigma (x-\bar{x})^2$	s^2
0	19	378.6	19.93	8110.13	7544.10	566.02	31.44
1	6	176.3	22.04	4070.85	3885.21	189.64	27.09
2+3+4	22	430.7	19.58	8932.71	8431.93	500.78	23.65
5+6	8	194.3	24.28	4822.21	4719.06	103.15	14.73
	57	1179.9	20.70	25935.89	24423.93	1359.59 1511.96	27.00

	S. S. D.	df	s^2
Between classes	152.37	3	50.79
within classes	1359.59	53	25.65
Total	1511.96	56	

$\chi^2 = 1.980$; at 3 53 df,
somewhere near 85% level.

ANNEXURE : A.2 : UNDERGROUND SHIFTS.

(a) ORDINARY CLASSIFICATION.

P.M. Classification.	Under ground shifts (1000's)	n	Σx	$\bar{x}$	Σx^2	$n\bar{x}^2$	$\Sigma(x-\bar{x})^2$	s^2
0	2.84 3.20 4.47 4.35 4.21 7.23 3.18 3.42 4.32 5.55 4.11 7.00 7.34 3.48 5.40 7.97 3.90 5.68 5.41	19	93.06	4.90	499.779	456.190	43.59	2.42
1	8.24 7.24 3.39 4.63 7.88 6.21 4.56 4.23	8	46.38	5.80	292.589	269.120	23.47	3.35
2	4.76 4.54 4.65 6.61 5.45 6.99 8.71	7	41.71	5.96	263.010	248.651	14.36	2.39
3	8.20 4.56 3.13 5.77 4.94	5	26.60	5.32	155.627	141.512	14.01	3.50
4	3.97 3.36 4.2 3.02 5.71 3.59 4.46 6.84 6.67 5.62	10	47.45	4.75	241.873	226.625	16.25	1.81
5	6.80 6.97 5.43 3.76 7.83 6.04	6	36.83	6.14	236.274	226.198	10.04	2.01
6	7.57 5.28	2	12.85	6.43	65.183	82.690	2.49	2.49
All Classifications		57	304.88	5.35	1774.195	1637.482	124.31 142.71	

Between classes
Within classes
Total

47
5
50
56

S.S.D.
18.50
124.31
142.71

3.08
2.48

$$\sqrt{s^2} = 1.24 \text{ (70\% level)}$$

APPENDIX : A.2 : UNDERGROUND SHIFTS.

(b) Condensed Classification.

P.H. Classification.	n	Σx	$\bar{x}$	Σx^2	$n\bar{x}^2$	$\Sigma (x-\bar{x})^2$	s^2
0	19	93.06	4.90	499.779	456.190	43.59	2.42
1	8	46.38	5.80	293.580	269.120	23.47	3.35
2,3+4	22	115.76	5.26	660.410	608.512	51.76	2.46
5+6	8	49.68	6.21	321.417	308.513	12.90	1.84
All classifications.	57	304.88	5.35	1774.195	1631.482	131.68 142.71	

	df.	S.S.D.
Between classes	3	11.03 3.68
Within classes	53	131.68 2.46
Total	56	142.71

$$\chi^2 = 1.48 \text{ (about 75\% level)}$$

((for (3,53) 1.25 = 70% and 2.12 = 90%))

ANNEXURE : A.3 : HOURS UNDERGROUND

(a) ORDINARY CLASSIFICATION.

P.M. Classification.	Hours Under ground in 10000's	n	Σx	$\bar{x}$	Σx^2	$n\bar{x}^2$	$\Sigma (x-\bar{x})^2$	s^2
0	2.27 2.55 3.21 3.77 2.95 4.80 2.43 2.73 3.46 3.76 3.28 4.90 4.17 2.78 2.58 5.41 3.11 4.09 3.26	19	65.51	3.45	240.220	236.147	14.07	0.78
1	6.59 5.79 2.00 3.71 5.52 4.50 3.65 2.67	8	34.44	4.31	165.961	148.609	17.35	2.48
2	3.81 3.59 3.33 5.29 4.35 5.88 6.97	7	32.93	4.70	165.204	154.630	10.57	1.76
3	6.55 3.65 2.51 4.60 3.93	5	21.25	4.25	99.261	90.312	8.95	2.24
4	3.17 2.69 3.45 2.17 4.55 2.87 3.56 2.74 5.33 4.32	10	34.85	3.49	130.088	121.601	8.39	0.92
5	5.44 5.58 3.60 3.01 6.15 4.85	6	28.63	4.77	144.095	136.517	7.58	1.52
6	6.06 4.22	2	10.28	5.14	54.532	52.832	1.69	1.69
All Classification		57	227.89	4.00	999.361	911.088	88.50 88.27	

	<u>df.</u>	<u>S.S.D.</u>	
Between classes	6	19.77	3.29
Within classes	50	68.50	1.37
Total	56	88.27	

$v^2 = 2.40$ (about 96% level)
 ((for (6,50) 2.20 = 95% and 2.67 = 97.5% (50)))

ANNEXURE : A. 3 : HOURS UNDERGROUND.

(b) Condensed Classification.

F.M. Classi- fifi- cations.	n	Σx	$\bar{x}$	Σx^2	$n\bar{x}^2$	$\Sigma(x-\bar{x})^2$	s^2
0	19	65.51	3.45	240.230	236.147	14.07	0.78
1	9	34.44	4.31	165.961	148.609	17.35	2.48
2+3+4	22	89.03	4.05	394.553	360.855	33.70	1.60
5+6	8	38.91	4.86	198.627	188.957	9.67	1.38
All Classifi- cations.	57	227.89	4.00	999.361	911.088	74.79	88.27

	<u>df</u>	<u>S.S.D.</u>
Between classes	3	13.48 4.49
Within classes	53	74.79 1.41
Total	56	88.27

$$\chi^2 = 3.18 \text{ (about 95\% level)}$$

((for (3,53), 3.17 = 95% and 3.37 = 97.5% (52)))

ANNEXURE : A.4 : PARTICLE- HOURS.

(a) Ordinary Classification.

P.M. Class- ifica- tion.	Particle hours in millions	n	Σx	$\bar{x}$	Σx^2	Σnx^2	$\Sigma (x-\bar{x})^2$	s^2
0	2.44 5.24 2.95 3.83 3.32 2.28 2.86 3.69 1.26 2.86 3.25 2.77 2.32 1.49 3.34 5.23 3.86 2.41 5.20	19	60.49	3.184 $\pm .61$ with 95%	215.9299	192.5811	23.3488	1.297
1	6.82 2.67 2.98 1.99 3.20 3.83 4.60 3.45	5	29.51	3.693 $\pm .95$	124.4632	109.0765	15.3767	2.1967
2	3.55 5.50 3.82 4.29 5.78 4.22 2.34	7	29.50	4.204 ± 1.02	132.5414	124.8214	8.2200	1.370
3	5.39 2.64 4.54 4.03 3.78	5	20.38	4.076 ± 1.18	87.1626	83.0699	4.0937	1.0234
4	3.93 4.03 2.22 3.73 4.01 4.09 6.68 3.91 2.79 2.76	10	38.15	3.815 $\pm .84$	158.6475	145.5423	13.1052	1.456
5	5.28 3.60 3.31 6.38 7.76 8.76	6	35.00	5.848 ± 1.08	229.4541	205.2180	24.2361	4.047
6	7.39 6.31 2	13.70	6.850 ± 1.88	94.4282	93.8450	.5832	.583	
		57	226.85	3.980	1042.6169	902.8232	88.0637 139.7937	

df	S.S.D.	s^2
6	Between classes	50.8300
50	within classes	88.9637
56	Total	139.7937

$\chi^2 = 4.762$ (6,50 d.f.)
(compare with 4.93 at 99.95% level
and 4.51 at 99.9% level).

ANNEXURE : A.4.(b)

CONDENSED CLASSIFICATION.

F.M. Classification.	n	Σx	$\bar{x}$	Σx^2	Σx^2	$\Sigma (x-\bar{x})^2$	s^2
0	19	60.49	3.184 $\pm .60$ 95%	215.9299	192.5811	23.3488	1.297
1	8	29.54	3.693 $\pm .93$	124.4532	109.0765	15.3767	2.1967
2+3+4	22	88.03	4.001 $\pm .56$	378.3515	352.2405	26.1110	1.243
5+6	8	48.79	6.098 $\pm .93$	323.8823	297.5580	26.3243	3.761
	57	226.85	3.989	1042.6169	908.8232	91.1608 139.7937	

S.S.U.

d.f.

Between classes 48.5329 3 16.211

Within classes 91.1608 53 1.720
= 1.311²

Total 139.7937 56

$\chi^2 = 9.43$

((With 3,95 for (3,53) df
significance at 99.95% level.))

ANNEXURE B.

SIGNIFICANCE TESTS USING "t"

1. $\bar{X}_{234} - \bar{X}_0$:

1.1 PARTICLE-HOURS:

$$\bar{X}_{234} = 4.00 \quad s_{234}^2 = 1.24 \quad n_{234} = 22$$

$$\bar{X}_0 = 3.18 \quad s_0^2 = 1.30 \quad n_0 = 19$$

$$\therefore \bar{X}_{234} - \bar{X}_0 = 0.82 \pm t_{95} \sqrt{\frac{s_{234}^2}{n_{234}} + \frac{s_0^2}{n_0}} \quad (f = 39)$$

$$= 0.82 \pm 2.02 \sqrt{\frac{1.24}{22} + \frac{1.30}{19}}$$

$$= 0.82 \pm 2.02 \sqrt{0.0564 + 0.0684}$$

$$= 0.83 \pm 2.02 \sqrt{0.1248}$$

$$= 0.82 \pm 2.02 \times 0.354 \quad (0.82 + 0.352 = 2.31;$$

$$= 0.82 \pm 0.71 \quad \text{for } f = 39, 2.31 = t_{97.5})$$

Conclusion: The difference is significant.

1.2 HOURS:

$$\bar{X}_{234} = 4.05; \quad s_{234}^2 = 1.60; \quad n_{234} = 22$$

$$\bar{X}_0 = 3.45; \quad s_0^2 = 0.780; \quad n_0 = 19$$

$$\therefore \bar{X}_{234} - \bar{X}_0 = 0.60 \pm t_{95} \sqrt{\frac{1.60}{22} + \frac{0.780}{19}} \quad (f = 39)$$

$$= 0.60 \pm 2.02 \sqrt{0.0726 + 0.0410}$$

$$= 0.60 \pm 2.02 \sqrt{0.1136}$$

$$= 0.60 \pm 2.02 \times 0.337 \quad (0.60 + 0.337 = 1.78;$$

$$= 0.60 \pm 0.68 \quad \text{for } f = 39, 1.76 = t_{92})$$

Conclusion: The difference is not significant.

1.3 SHIFTS:

$$\bar{x}_{234} = 5.26; s^2 = 2.46; n = 22$$

$$\bar{x}_0 = 4.90; s^2 = 2.42; n = 19$$

$$\begin{aligned} \therefore \bar{x}_{234} - \bar{x}_0 &= 0.36 \pm t_{95} \sqrt{\frac{s^2_{\bar{x}_{234}}}{n} + \frac{s^2_{\bar{x}_0}}{n_0}} \quad (f = 39) \\ &= 0.36 \pm 2.02 \sqrt{\frac{2.46}{22} + \frac{2.42}{19}} \\ &= 0.36 \pm 2.02 \sqrt{0.112 + 0.127} \\ &= 0.36 \pm 2.02 \sqrt{0.239} \\ &= 0.36 \pm 2.02 \times 0.489 \quad (0.36 + 0.49 = 0.74) \\ &= 0.36 \pm 0.99 \quad (\text{For } f = 39, 0.74 = t_{75}) \end{aligned}$$

Conclusion: The difference is not significant.

1.4 YEARS:

N.B. $\bar{x}_{234}$ is less than $\bar{x}_0$!

$$2. \quad \bar{X}_{5+6} - \bar{X}_{2+3+4} :$$

2.1 PARTICLE-HOURS:

$$\bar{X}_{5+6} = 6.10, \quad s_{5+6}^2 = 3.76, \quad n_{5+6} = 8$$

$$\bar{X}_{2+3+4} = 4.00, \quad s_{2+3+4}^2 = 1.24, \quad n = 22$$

$$\begin{aligned} \therefore \bar{X}_{5+6} - \bar{X}_{2+3+4} &= 2.10 \pm t_{95} \sqrt{\frac{s_{5+6}^2}{n_{5+6}} + \frac{s_{2+3+4}^2}{n_{2+3+4}}} \quad (f=28) \\ &= 2.10 \pm 2.05 \sqrt{\frac{3.76}{8} + \frac{1.24}{22}} \\ &= 2.10 \pm 2.05 \sqrt{0.47 + 0.056} \\ &= 2.10 \pm 2.05 \sqrt{0.526} \\ &= 2.10 \pm 2.05 \times 0.725 \\ &= 2.10 \pm 1.49 \end{aligned}$$

$$\begin{aligned} (2.10 + 0.725 &= 2.90; \\ \text{for } f = 28, \quad 2.90 &= t_{99.3}) \end{aligned}$$

Conclusion: The difference is significant.

2.2 HOURS

$$\bar{X}_{5+6} = 4.86, \quad s_{5+6}^2 = 1.38, \quad n_{5+6} = 8$$

$$\bar{X}_{2+3+4} = 4.05, \quad s_{2+3+4}^2 = 1.60, \quad n_{2+3+4} = 22$$

$$\begin{aligned} \therefore \bar{X}_{5+6} - \bar{X}_{2+3+4} &= 0.81 \pm t_{95} \sqrt{\frac{1.38}{8} + \frac{1.60}{22}} \\ &= 0.81 \pm 2.05 \sqrt{0.172 + 0.073} \\ &= 0.81 \pm 2.05 \sqrt{0.245} \\ &= 0.81 \pm 2.05 \times 0.495 \\ &= 0.81 \pm 1.01 \end{aligned}$$

$$\begin{aligned} (0.81 + 0.495 &= 1.64; \\ \text{for } f = 28, \quad 1.64 &= t_{89}) \end{aligned}$$

Conclusion: The difference is not significant.

The difference between the means of the "particle-hours" reaches a higher level of significance than the means of the "hours".

Therefore, "particle-hours" is a better measure of the condition of the lungs than "hours".

3.3 SHIFTS:

$$\bar{X}_{5+6} = 6.21, \quad s_{5+6}^2 = 1.84, \quad n_{5+6} = 8$$

$$\bar{X}_{2+3+4} = 5.26, \quad s_{2+3+4}^2 = 2.46, \quad n_{2+3+4} = 22$$

$$\begin{aligned} \therefore \bar{X}_{5+6} - \bar{X}_{2+3+4} &= 0.95 \pm 2.05 \sqrt{\frac{1.84}{8} + \frac{2.46}{22}} \\ &= 0.95 \pm 2.05 \sqrt{0.230 + 0.112} \\ &= 0.95 \pm 2.05 \sqrt{0.342} \\ &= 0.95 \pm 2.05 \times 0.585 \\ &= 0.95 \pm 1.20 \end{aligned}$$

$$\begin{aligned} (0.95 + 0.585 &= 1.62; \\ \text{for } f = 28, \quad 1.62 &= t_{88}^*) \end{aligned}$$

Conclusion: The difference is not significant.

2.4 YEARS.

$$\bar{X}_{5+6} = 24.3, \quad s_{5+6}^2 = 14.7, \quad n_{5+6} = 8$$

$$\bar{X}_{2+3+4} = 19.6, \quad s_{2+3+4}^2 = 23.8, \quad n_{2+3+4} = 22$$

$$\begin{aligned} \bar{X}_{5+6} - \bar{X}_{2+3+4} &= 4.7 \pm 2.05 \sqrt{\frac{14.7}{8} + \frac{23.8}{22}} \\ &= 4.7 \pm 2.05 \sqrt{1.84 + 1.08} \\ &= 4.7 \pm 2.05 \sqrt{2.92} \\ &= 4.7 \pm 2.05 \times 1.71 \\ &= 4.7 \pm 3.51 \quad (4.7 + 1.71 = 2.75; \\ &\quad \text{for } f=28, 2.75 = t_{99}) \end{aligned}$$

Conclusion: The difference is significant, but reaches a lower level than that for Particle-hours viz. 2.75 as against 2.90.

$$3. \quad \bar{X}_{5+6} - \bar{X}_0 :$$

3.1 PARTICLE-HOURS

$$\bar{X}_{5+6} = 6.10, \quad s_{5+6}^2 = 3.76, \quad n_{5+6} = 8$$

$$\bar{X}_0 = 3.18, \quad s_0^2 = 1.30, \quad n_0 = 19$$

$$\begin{aligned} \therefore \bar{X}_{5+6} - \bar{X}_0 &= 2.92 \pm 2.06 \sqrt{\frac{3.76}{8} + \frac{1.30}{19}} \quad (f=25) \\ &= 2.92 \pm 2.06 \sqrt{0.470 + 0.068} \end{aligned}$$

$$\begin{aligned}
 &= 2.92 \pm 2.06 \sqrt{0.538} \\
 &= 2.92 \pm 2.06 \times 0.734 \\
 &= 2.92 \pm 1.51
 \end{aligned}$$

$$\begin{aligned}
 &(2.92 + 0.734 = 3.98; \\
 &\text{for } f = 25, 3.72 = t_{99.9})
 \end{aligned}$$

Conclusion: The difference is very significant.

3.2 UNDERGROUND HOURS:

$$\bar{X}_{5+6} = 4.86, s_{5+6}^2 = 1.38, n_{5+6} = 8$$

$$\bar{X}_0 = 3.45, s_0^2 = 0.78, n_0 = 19$$

$$\begin{aligned}
 \therefore \bar{X}_{5+6} - \bar{X}_0 &= 1.41 \pm 2.06 \sqrt{\frac{1.38}{8} + \frac{0.78}{19}} \quad (f = 25) \\
 &= 1.41 \pm 2.06 \sqrt{0.173 + 0.041} \\
 &= 1.41 \pm 2.06 \sqrt{0.214} \\
 &= 1.41 \pm 2.06 \times 0.465 \\
 &= 1.41 \pm 0.93 \quad (1.41 + 0.465 = 3.05; \\
 &\quad \text{for } f = 25, 3.05 = t_{99.5})
 \end{aligned}$$

Conclusion: The difference is very significant.

3.3 UNDERGROUND SHIFTS:

$$\bar{X}_{5+6} = 6.21, s_{5+6}^2 = 1.84, n_{5+6} = 8$$

$$\bar{X}_0 = 4.90, s_0^2 = 2.42, n_0 = 19$$

$$\begin{aligned}
 \bar{X}_{5+6} - \bar{X}_0 &= 1.31 \pm 2.06 \sqrt{\frac{1.84}{8} + \frac{2.42}{19}} \quad \frac{3.42}{19} \\
 &= 1.31 \pm 2.06 \sqrt{0.230 + 0.127} \\
 &= 1.31 \pm 2.06 \sqrt{0.357} \\
 &= 1.31 \pm 2.06 \times 0.598 \\
 &= 1.31 \pm 1.24 \quad (1.31 + 0.598 = 2.18; \\
 &\quad \text{for } f = 25, 2.06 = t_{95} \\
 &\quad \text{and } 2.38 = t_{97.5}) \\
 \therefore 2.18 &= t_{96.1}
 \end{aligned}$$

Conclusion: The difference is significant.

3.4 YEARS:

$$\bar{x}_{5+6} = 24.3, \quad s_{5+6}^2 = 14.7, \quad n_{5+6} = 8$$

$$\bar{x}_0 = 19.9, \quad s_0^2 = 31.4, \quad n_0 = 19$$

$$\therefore \bar{x}_{5+6} - \bar{x}_0 = 4.4 \pm 2.06 \sqrt{\frac{14.7}{8} + \frac{31.4}{19}}$$

$$= 4.4 \pm 2.06 \sqrt{1.84 + 1.65}$$

$$= 4.4 \pm 2.06 \sqrt{3.49}$$

$$= 4.4 \pm 2.06 \times 1.87$$

$$= 4.4 \pm 3.85$$

$$(4.4 + 1.87 = 2.36;$$

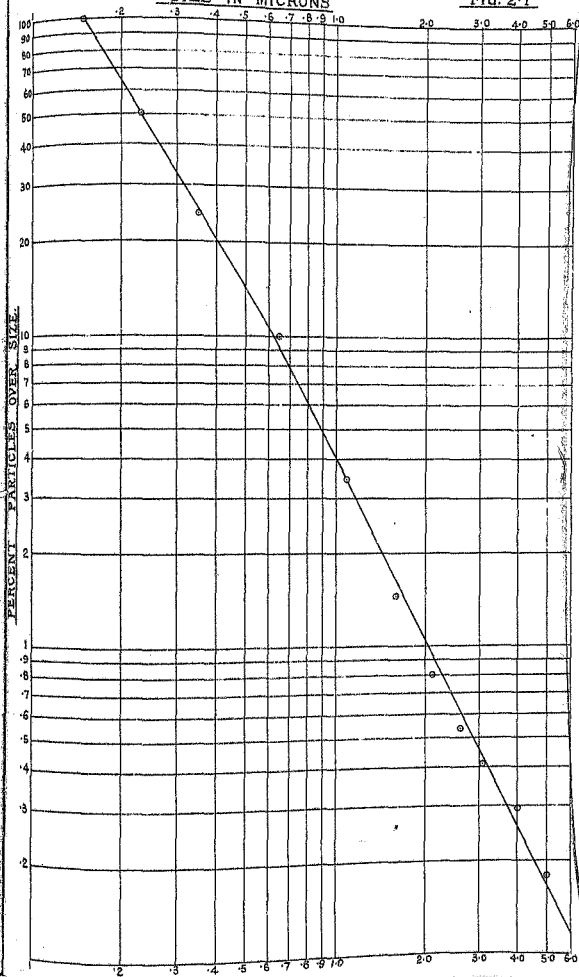
for $f = 25, 2.38 = t_{97.5}$)

$$\text{and } 2.06 = t_{95})$$

Conclusion: The difference is significant but reaches a lower level than in the case of "particle-hours"

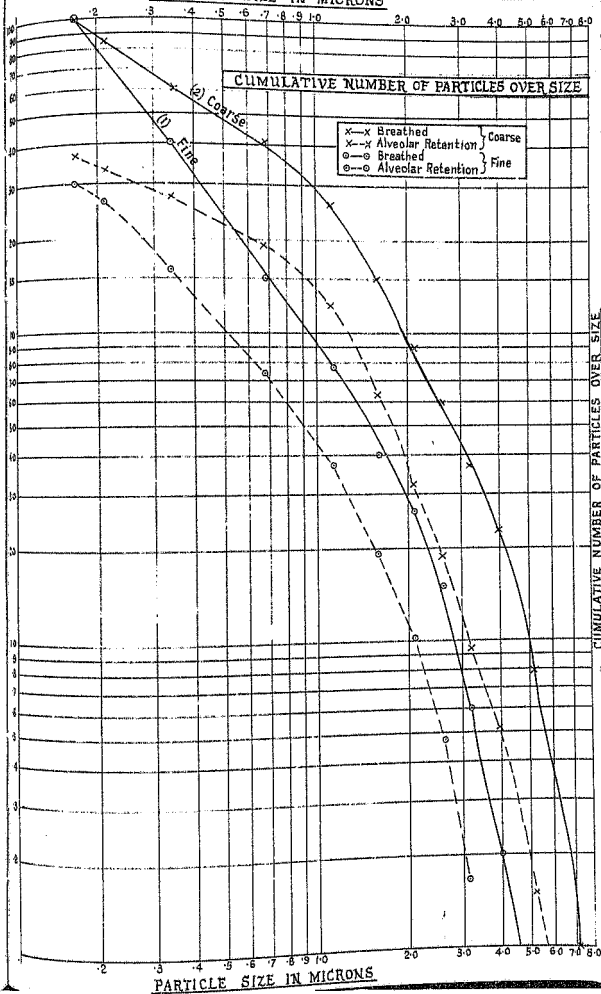
SIZE IN MICRONS

FIG. 2-1



PARTICLE SIZE IN MICRONS

FIG. 2-2



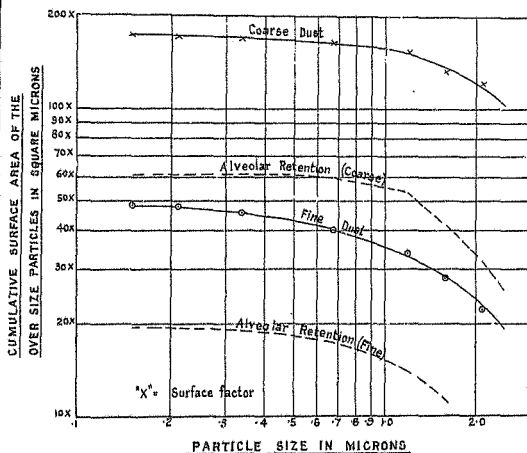
CUMULATIVE NUMBER OF PARTICLES OVER SIZE

FIG. 2-2

PARTICLE SIZE IN MICRONS

FIG. 2-3

CUMULATIVE SURFACE AREA



CUMULATIVE VOLUME (MASS)

FIG. 2-4

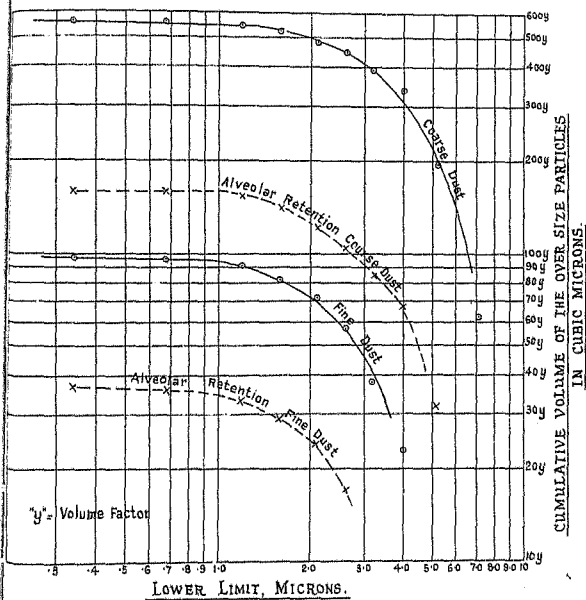


FIG. 2-5

NEW CASES OF SILICOSIS;

(1) 1924-25 to 1928-29

(2) 1946-47 to 1950-51

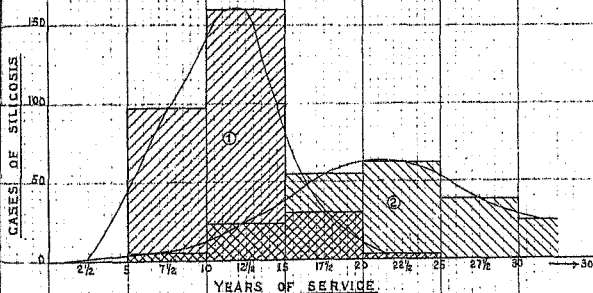
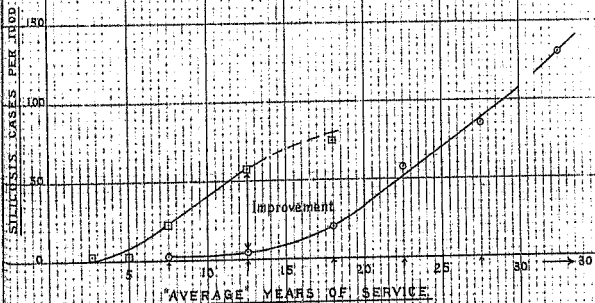


Fig. 2-6

SILICOSIS RESPONSES

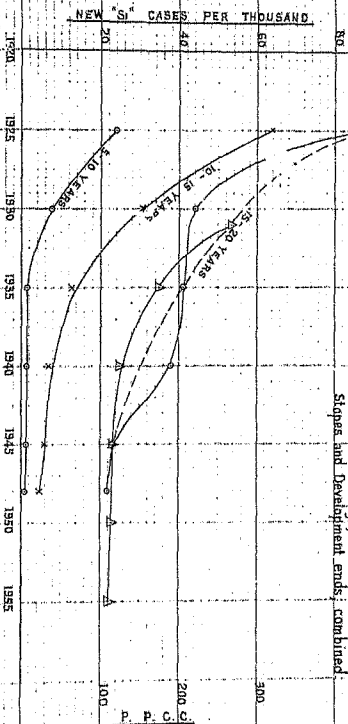
- 1924-25 to 1928-29 Silicosis cases per 1000
- 1946-47 to 1950-51 Silicosis cases per 1000



Silicosis response against calendar years.

Fig. 2-7

Δ Mean of courts: At bottom of intake shafts,
Men take air-ways,
Stops and Development ends, combined



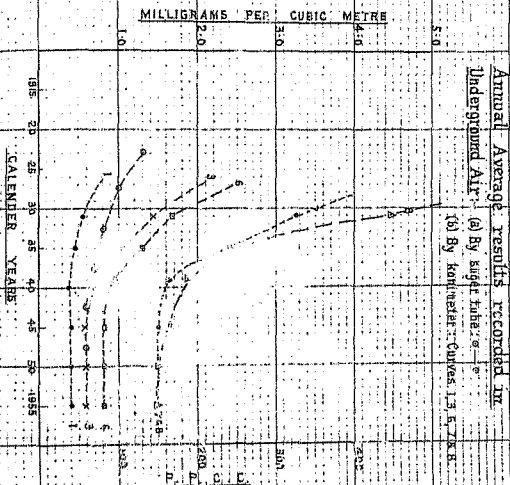


Fig. 28

Fig. 3-2

Dust count and number of spots taken at top of Downcast Shafts.

FIG. 3-1

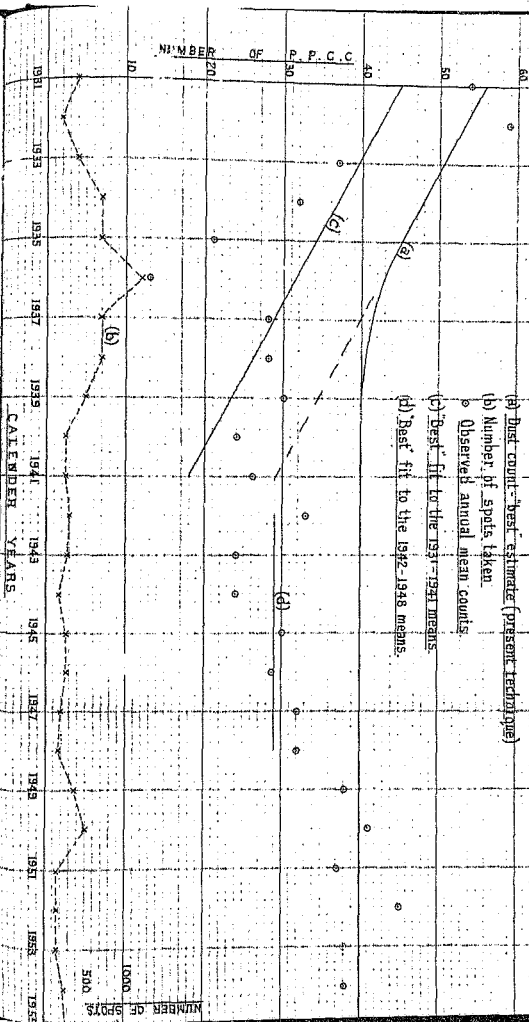


Fig. 3-2

Dust count and number of spots taken at the bottom of Downcast Shafts.

- (a) Dust count "best" estimate (present technique)
- (b) Number of spots taken
- (c) Observed annual mean counts
- (d) Best fit to the means for 1931-1941.

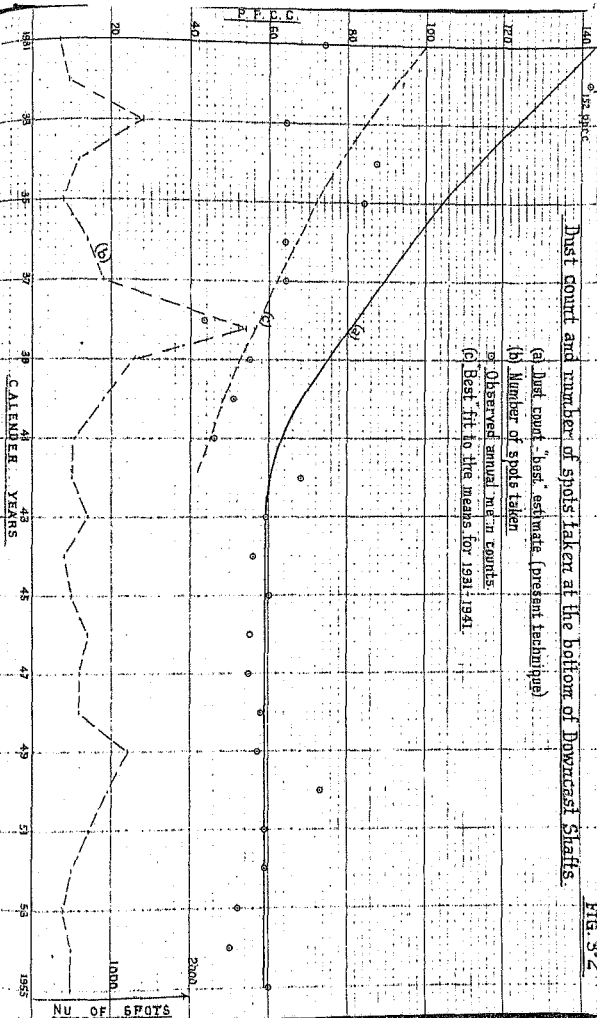


FIG. 3-3

Dust count and number of spots taken in train airways away from Downcast Shafts.

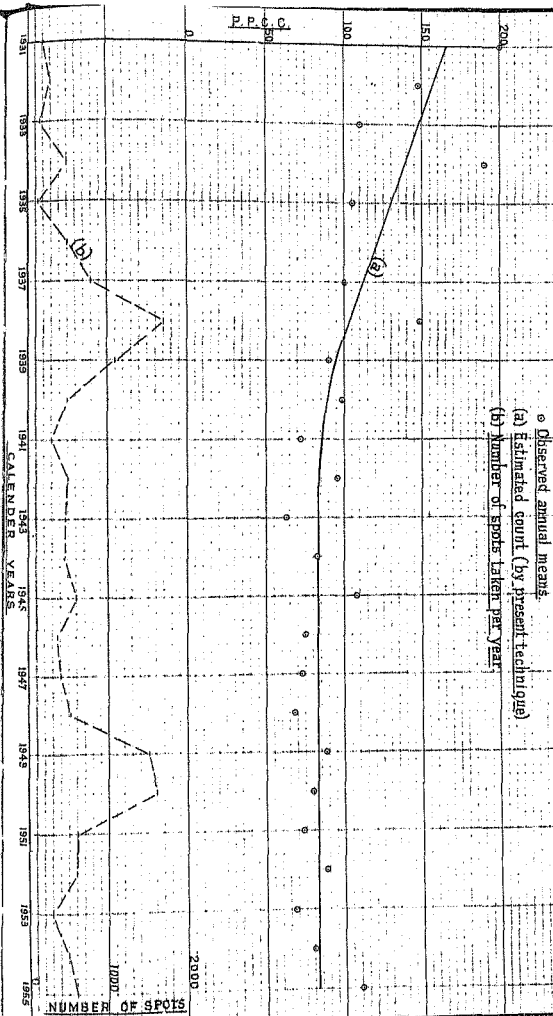
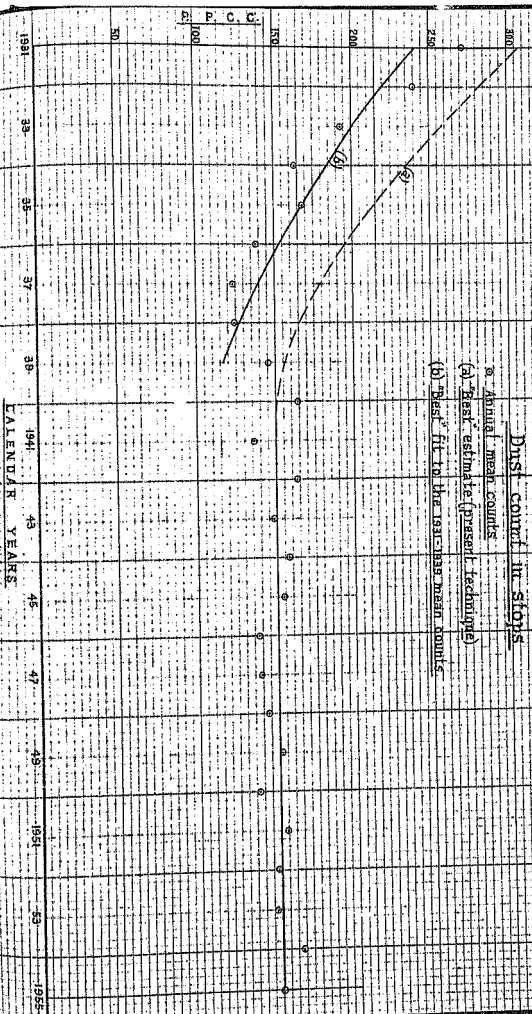


FIG. 3-40



LOGARITHMS OF MEAN SLOPE COUNTS VERSUS CALENDAR YEARS

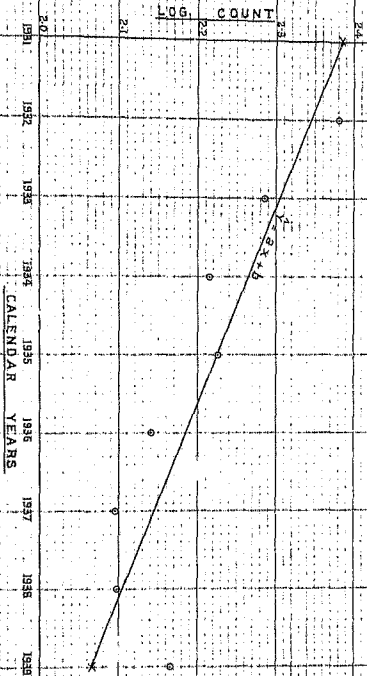
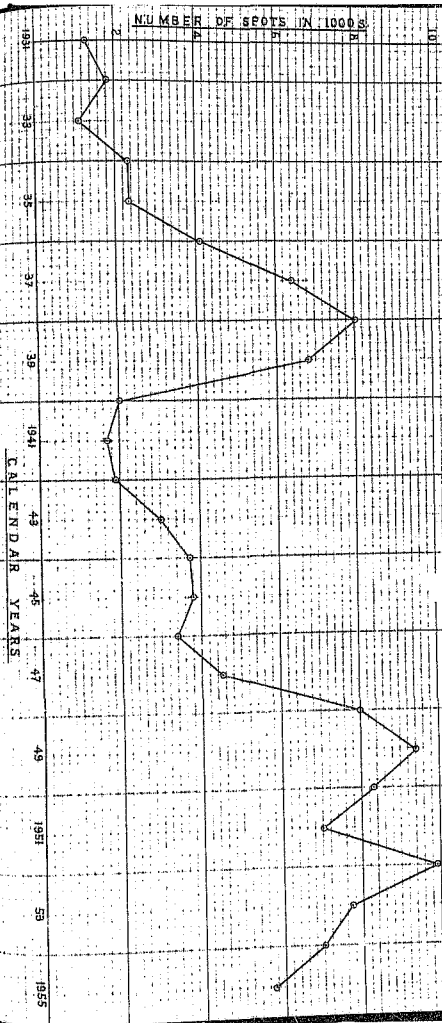


FIG. 34(0)



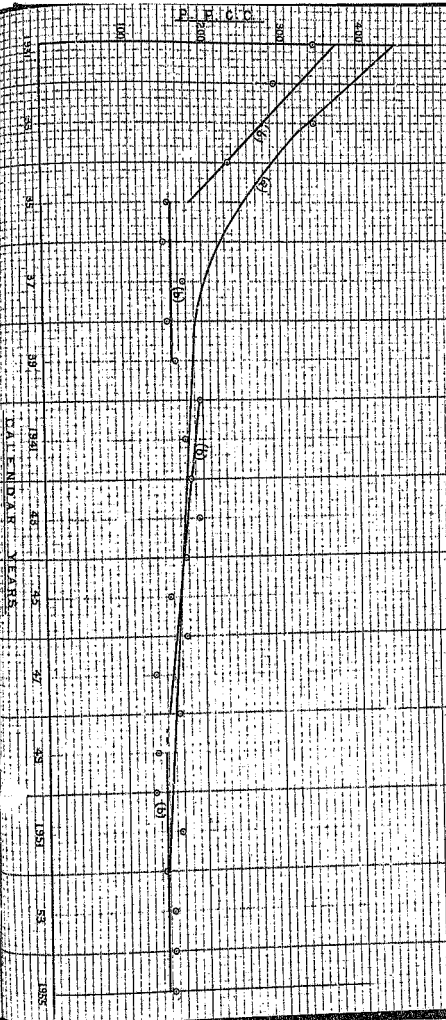
NUMBER OF SPOTS TAKEN IN STOPES

FIG. 3.4 (III)

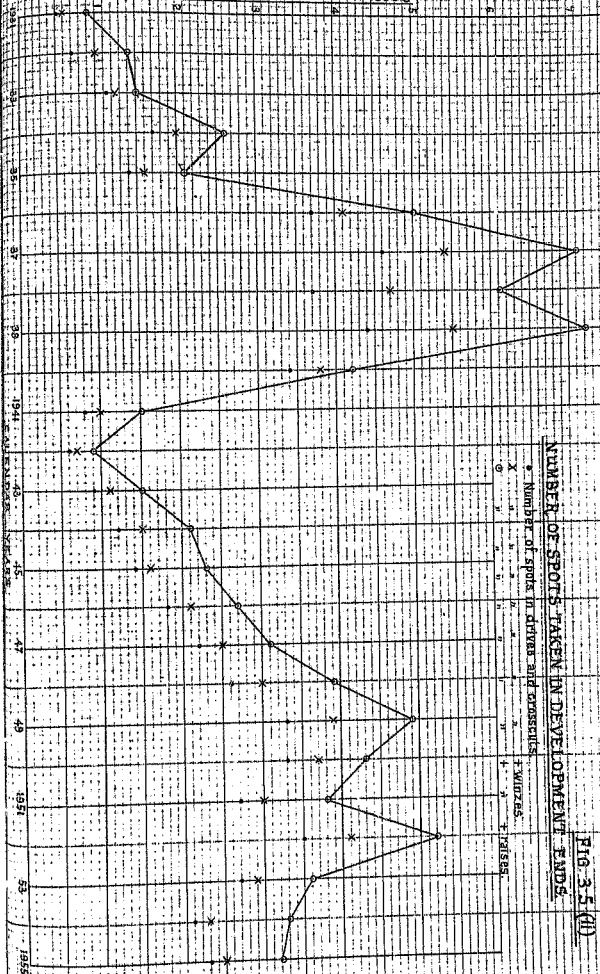
Fig. 3-5-0

ANNUAL MEAN COUNTS IN DEVELOPMENT ENDS

- o Annual mean counts
- (a) Best estimate (present technique)
- (b) Best fit to annual mean counts



NUMBER OF SPOTS IN 1000'S



NUMBER OF SPOTS TAKEN IN DEVELOPMENT - ENDS

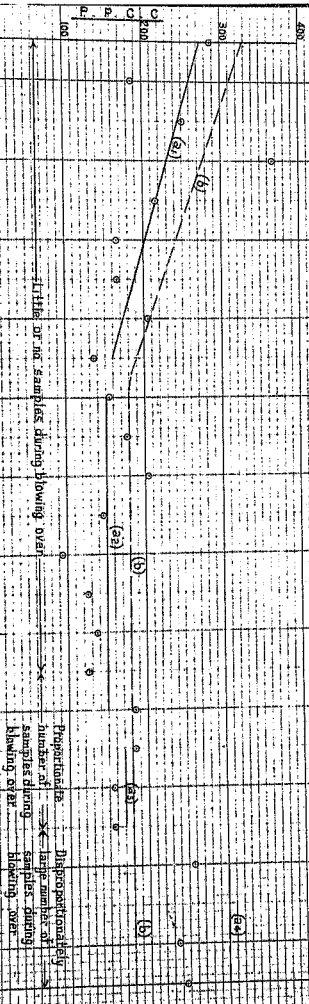
FIG. 3-5 (II)

DUST COUNTS IN SINKING SHAPTS

FIG. 3.6 (a)

(1) $\bar{a}, \bar{a}_2, \bar{a}_{22}, \dots$ Observed means.

(2) b Adjusted mean (blowing over allowed for in the correct proportion)



Number of spots per year in sinking shafts

○ = Number in Vertical shafts
 — = " " and Inclined shafts.

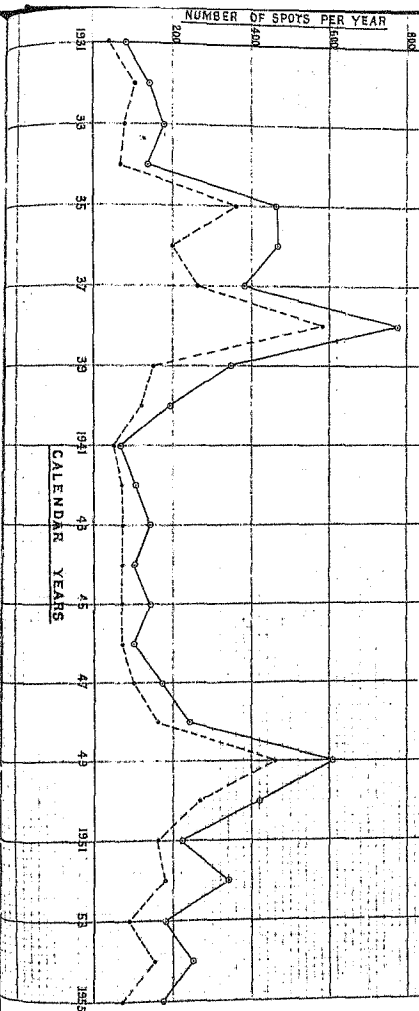
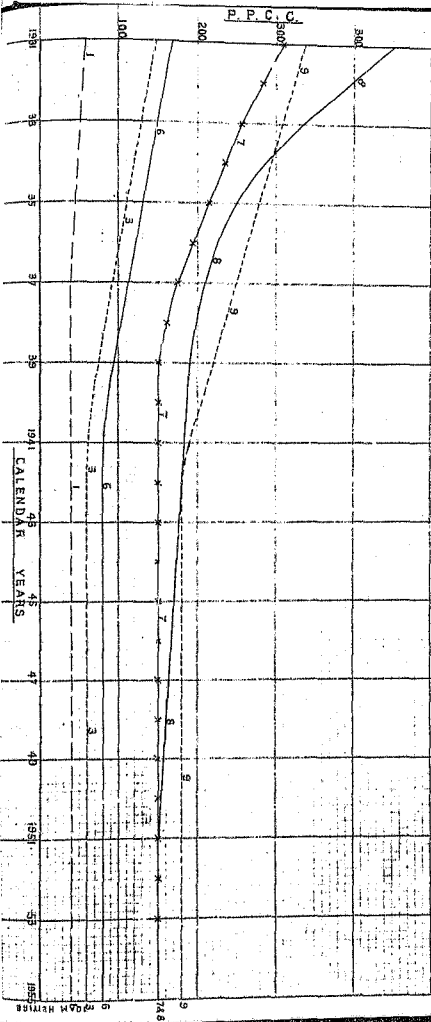


FIG. 3-6(b)

FIG. 3-7

SUMMARY OF DUST LEVEL VARIATIONS AT: 1 Top of Downcast Shafts.

- 2 Bottom of "
- 3 Main intake airways.
- 4 Stope faces.
- 5 Development and faces.
- 6 Shaft bottoms.



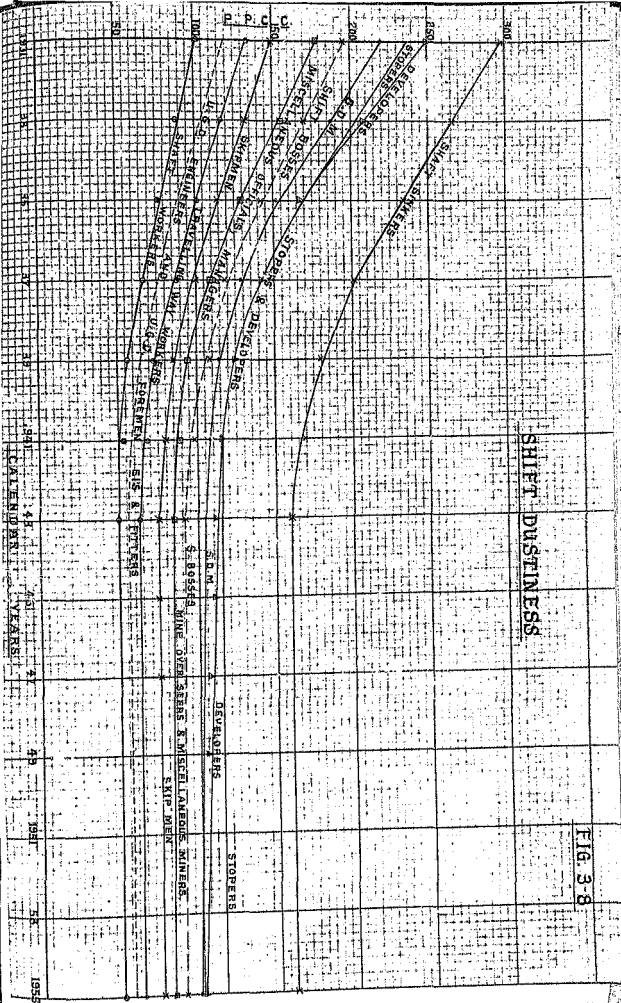


FIG. 3-8

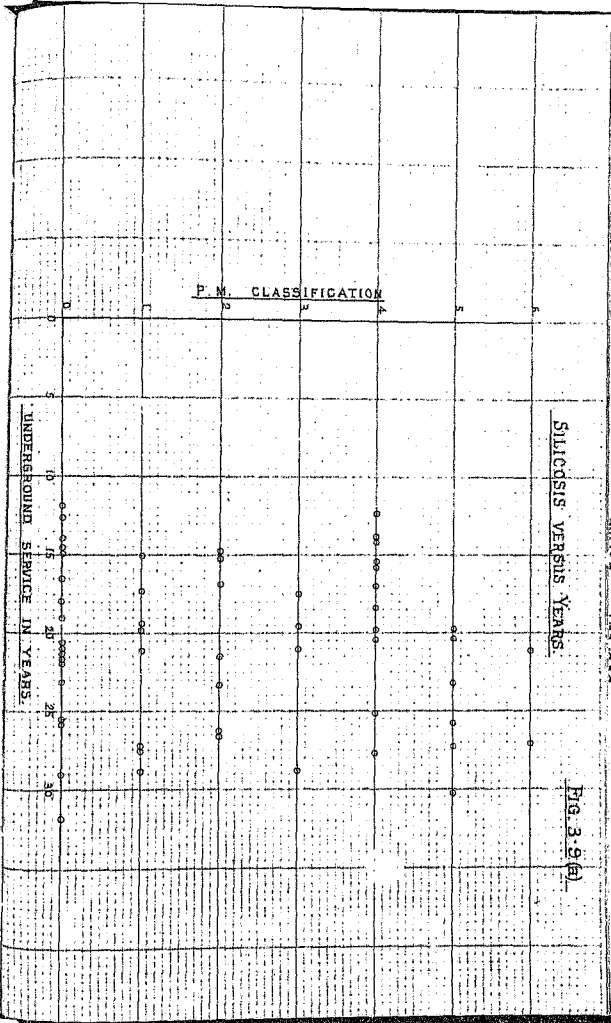
SILICOSIS VERSUS YEARS

FIG. 3.9(a)

P. M. CLASSIFICATION

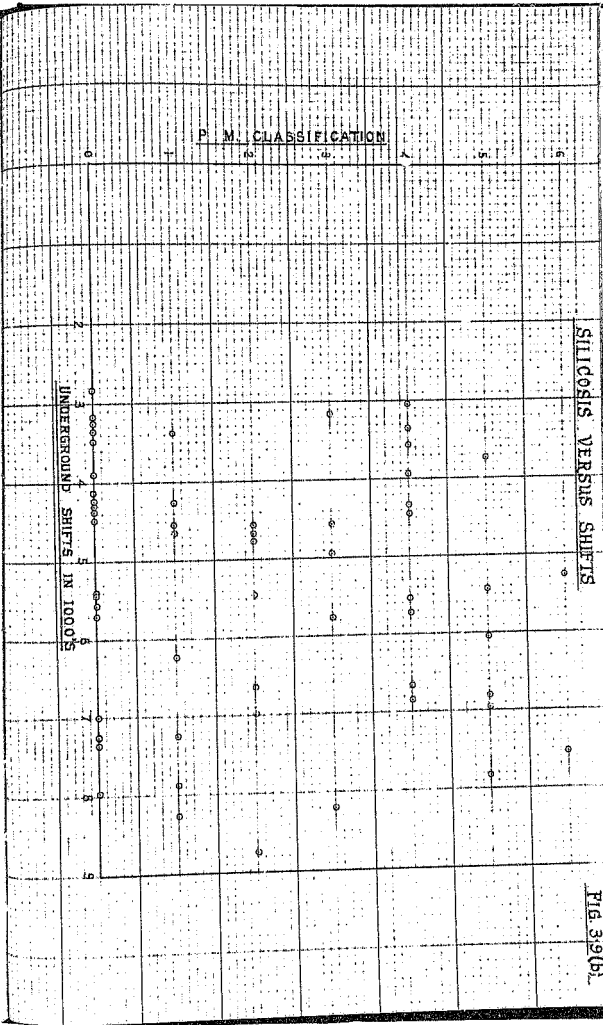
UNDERGROUND SERVICE IN YEARS

10 15 20 25 30



SILICOSIS VERSUS SHIFTS

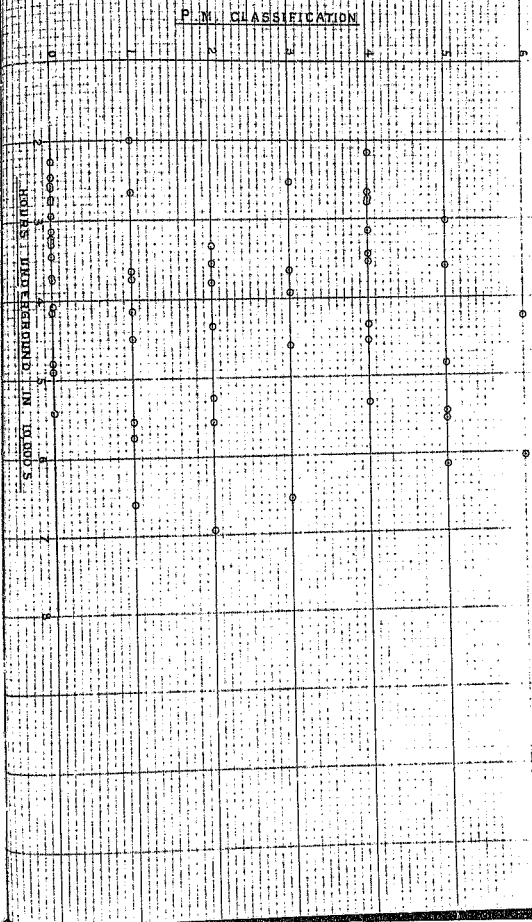
FIG. 39(b)



NOTED INCREAS

SILICOSIS VERSUS HOURS UNDERGROUND

FIG. 3-9 (C)



NORMAL RATE OF ACCUMULATION OF UNDERGROUND SHIFTS

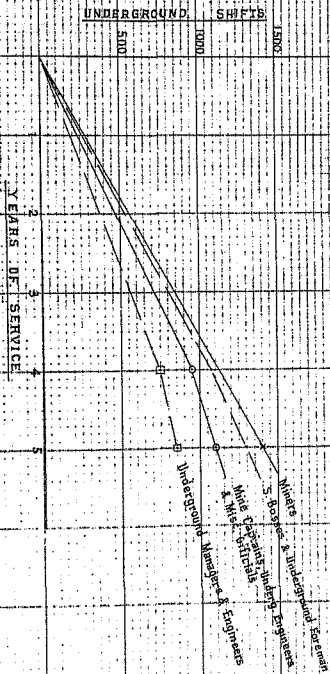


FIG. 310

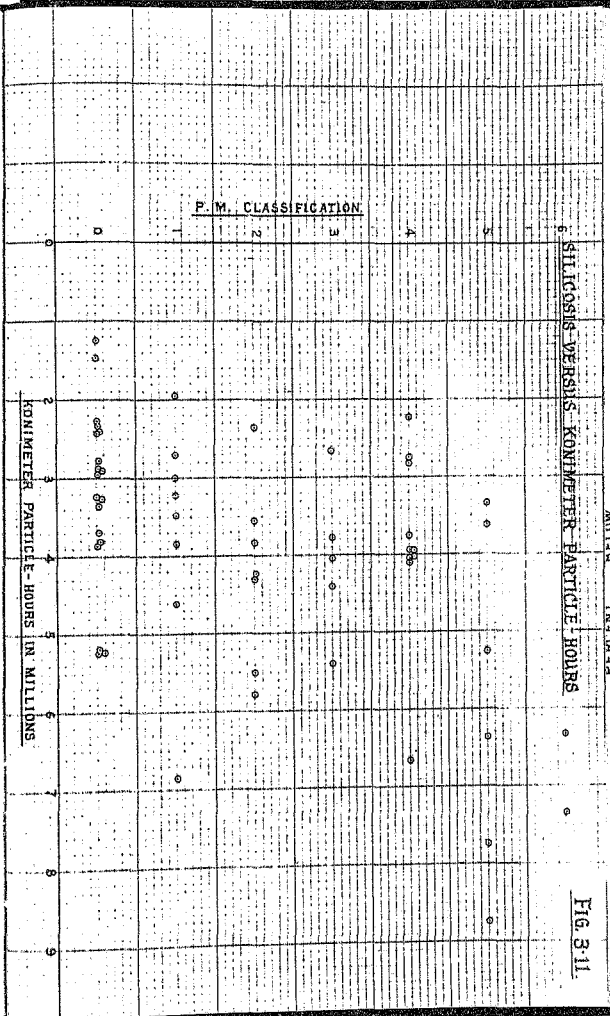


Fig. 3-11.

FIG. 3-12(a)

DISTRIBUTION OF UNDERGROUND YEARS OF SERVICE

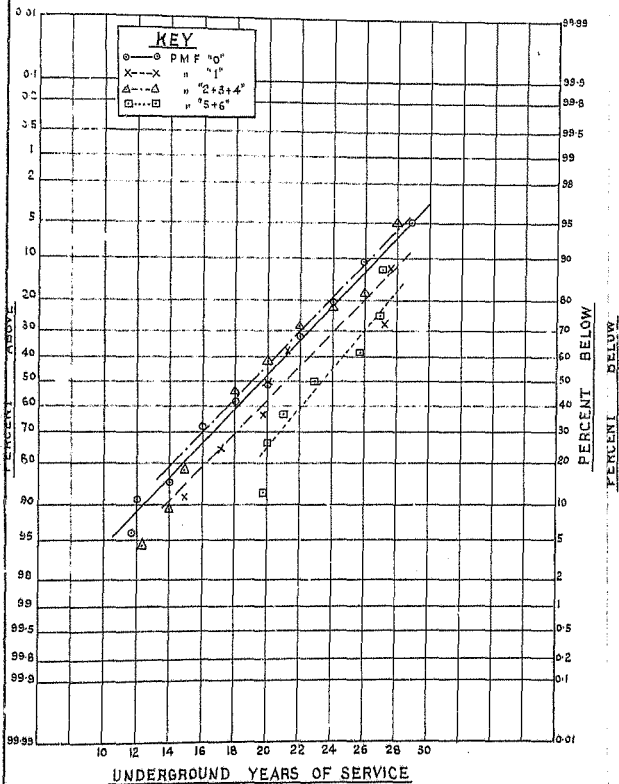


FIG. 3-12(b)

DISTRIBUTION OF SHIFTS.

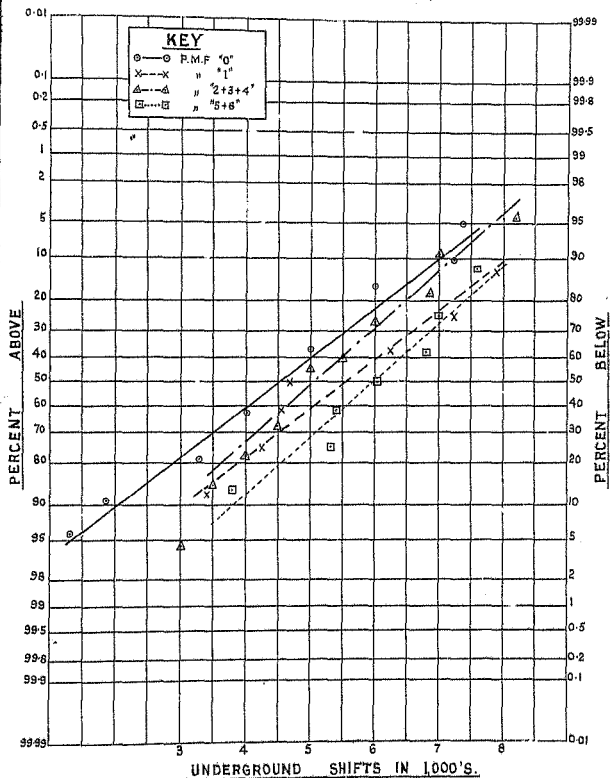


FIG. 3-12(c)

DISTRIBUTION OF UNDERGROUND HOURS.

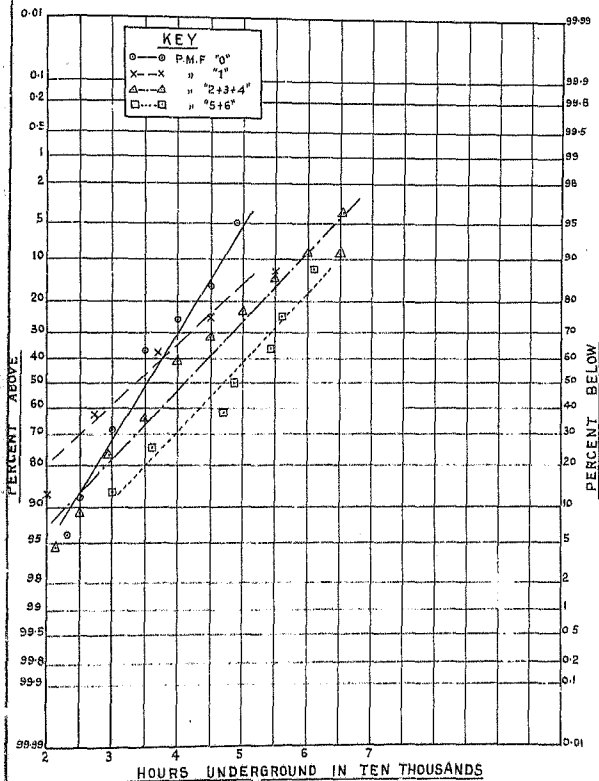
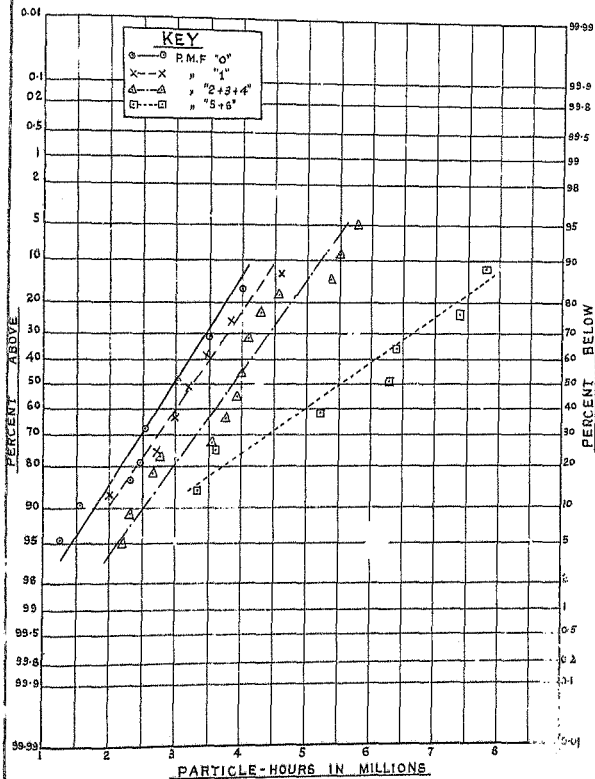


FIG. 3-12 (d)

DISTRIBUTION OF PARTICLE-HOURS.



SILICOSIS

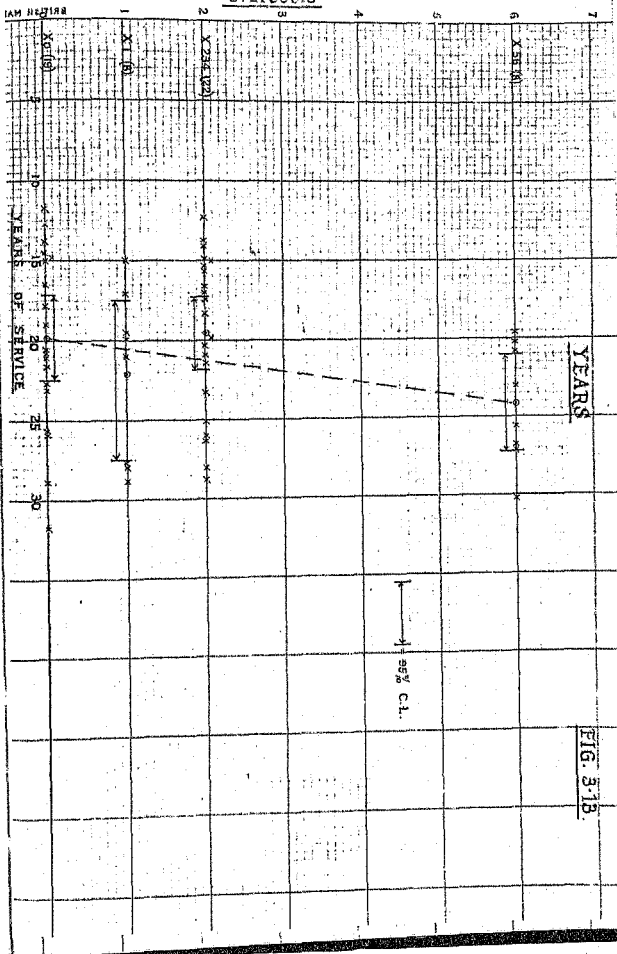
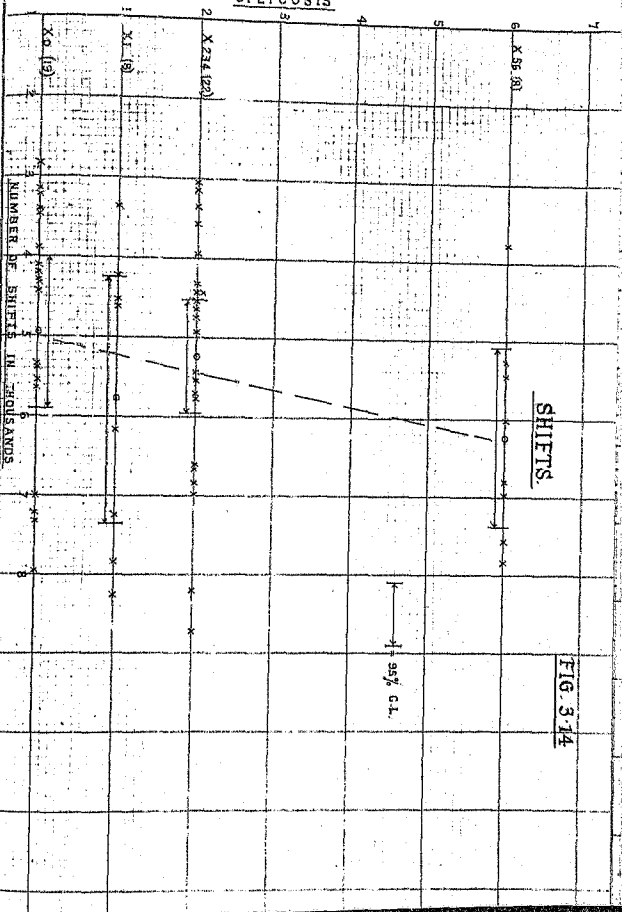


FIG. 3-13

SILICOSIS



SILICOSIS

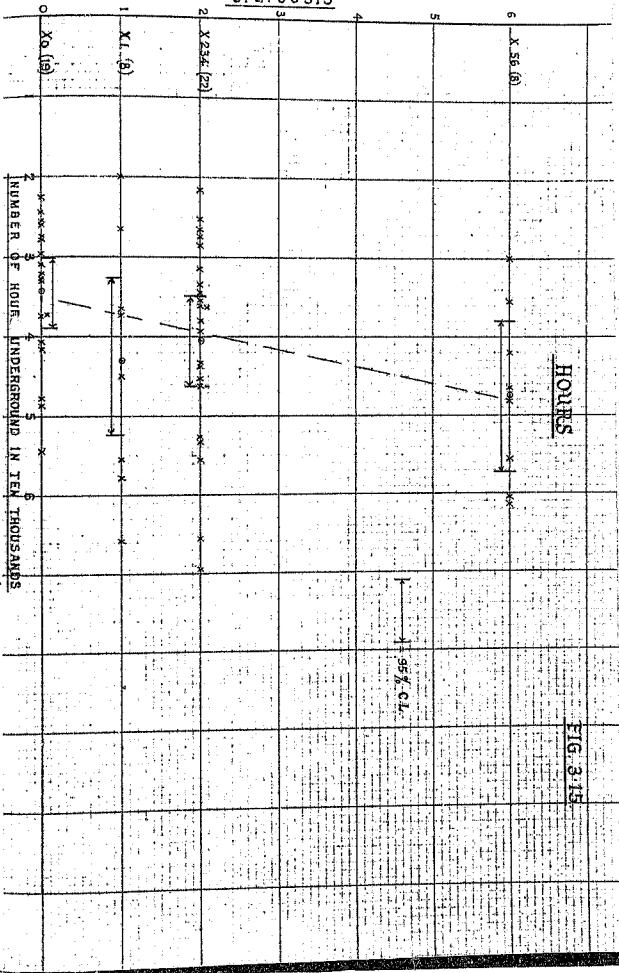
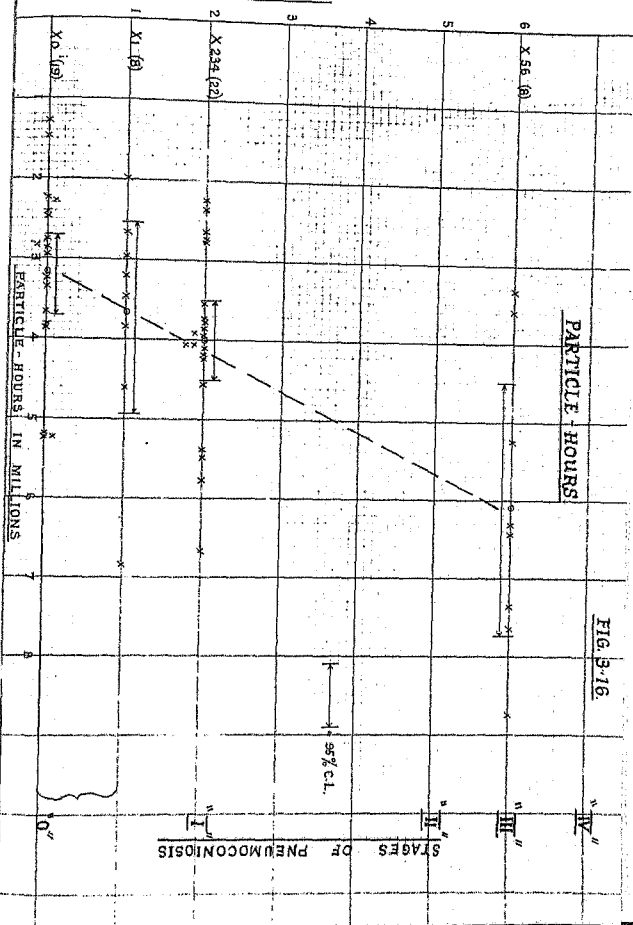


FIG. 3-15

SILICOSIS



Author Du Toit Rudolph Stefanus Jacobus

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