Safety in Mines Research Advisory Committee

Final Project Report

Investigation of survey designs to determine full shift exposure of selected personnel in different occupations to respirable dust & radiation in gold, platinum & coal mines

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SIMHEALTH 602 - PHASE 1

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EXECUTIVE SUMMARY

The primary outputs of SIMHEALTH 602 - Phase 1 are as follows:

- A critical literature survey on information presently available on the full-shift exposure of persons in gold, platinum and coal mines to respirable dust and ionising radiation in relation to ***occupation*** and ***work rates***, highlighting areas of incomplete knowledge.

- Results of occupational surveys in the South African gold, platinum and coal sectors to determine the numbers of persons employed in different ***job categories*** and the age and service distributions within each job category.

- A design for full-shift surveys by occupational hygienists in selected gold, platinum and coal mines to measure respirable dust and ionising radiation exposure of selected persons while recording ***occupations*** and ***work rates*** of the subjects.

The literature survey and results of occupational surveys were previously presented in interim reports which are appended. This final report combines the primary outputs contained in the interim reports with the third primary output in terms of considerations and recommendations regarding the design of full-shift surveys based on ***occupation*** and ***job category*** in selected gold, platinum and coal mines to measure respirable dust and radiation.

Following initial focus meetings with key individuals and the SIMRAC committee, the following aspects were agreed with regard to the scope of the project:

- The intended purpose of the study is to design an independent baseline survey, using best practice, the primary intention being to use the generated data for future epidemiological purposes, rather than to evaluate operator compliance, or to assess current regulatory procedures.

- While individual hazardous constituents of respirable dust are not the main focus of the project, this aspect should be given consideration, where practicable.

- Asbestiform materials are to be excluded from the study.

- The radiological aspects of the study should focus on inhalation hazards e.g. radioactive dusts and radon gas. The inclusion of the measurement of external radiation should be considered, if practicable.

- Open cast mines should be included in the study.

The literature review has identified a number of potential knowledge gaps and shortcomings associated with previous surveys and available exposure data relating to respirable dust and radiation which are relevant to any subsequent survey design and which have been considered in the course of the project.

As the project has progressed, a number of key features have emerged which have had a significant influence on the potential scope of the project and the ability to design meaningful surveys to meet the original project mandate. In summary these are:

- There appears to be ***no clear consensus*** with respect to what the ***underlying epidemiological basis*** is and upon which the survey design can be grounded.

- There is ***no clear epidemiological basis*** for defining specific study populations.

- The underlying assumptions regarding ***industry wide occupations and job categories***, upon which sampling populations could be based, have not generally been confirmed.

The effect of these factors has been to seriously limit the potential to design meaningful surveys since:

- It has not been possible to define explicitly the fundamental purpose of the proposed survey. Without such definition, it is not possible to design a meaningful and objective survey strategy; nor would it be possible to determine subsequently if the survey objectives were achieved. At best, any survey design ***might*** produce data which ***may*** subsequently prove to be 'useful'.

- There is a significant danger that any proposed survey design may subsequently dictate the form of any epidemiological studies. This is inherently incorrect. Epidemiology is the study of the distribution and determinants of diseases in populations and it is this which should drive the analysis of potential causal factors not the reverse.

- The hypothetical population basis i.e. ***consistent industry wide occupations and job categories*** which appears to have been originally assumed and from which survey samples could be drawn does not exist.

- In any event, if the hypothetical population hierarchy did exist, the lack of any epidemiological hypothesis and in particular any identified population(s) of interest would require that in theory, to avoid any bias, the survey design would require that the exposure of ***all*** sub-populations would have to be determined. This may not have been the original intention if, for example, the testing of hypotheses arising from studies of disease clustering in specific job categories or occupations is of interest.

These issues are examined and the characteristics of the actual populations are discussed. A survey design on this basis has been evaluated. A design based on DME (1999) job code populations has also been evaluated. However, it is observed that in general these codes are not in widespread use in formal employment records. This has been done with the recognition that neither of these approaches may provide useful or meaningful data for the reasons stated above.

The resource and programme implications of such approaches have been determined and it is concluded that an independent industry wide base line data generation exercise, based on the actual populations, could take many years to complete. The annual cost of the exercise would be determined by the resource commitment. It is concluded that such an approach is unlikely to be useful or practicable. Surveys based on DME codes may perhaps be more practicable if their use becomes widespread, although the usefulness of the resultant data is not confirmed.

An outline strategy to address these issues is discussed and considered in the above context. It is concluded that the issue of dust and radiation exposure assessment for epidemiological purposes should form part of a strategically structured and comprehensive programme developed within the context of a clear and agreed occupational health related policy with associated objectives.

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1. Introduction

1.1 Project aims

The primary outputs of SIMHEALTH 602 - Phase 1 are as follows:

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- Results of occupational surveys in the South African gold, platinum and coal sectors to determine the numbers of persons employed in different job categories and the age and service distributions within each job category.
- A design for full-shift surveys by occupational hygienists in selected gold, platinum and coal mines to measure respirable dust and ionising radiation exposure of selected persons while recording occupations and work rates of the subjects.

1.2 Project reports

The first primary output i.e. the literature survey, was completed and presented in the first interim report in July 1999. The second primary output i.e. results of occupational surveys was completed and presented in the second interim report in February 2000. This final report combines the primary outputs contained in the interim reports with the third primary output in terms of recommendations with regarding the design of full-shift surveys in selected gold, platinum and coal mines to measure respirable dust and radiation.

1.3 Initial scope of the project

Following initial focus meetings with key individuals and the SIMRAC committee, the following aspects were agreed with regard to the scope of the project:

- The intended purpose of the study is to design an independent baseline survey, using best practice - the primary intention being to use the generated data for future epidemiological purposes, rather than to evaluate operator compliance, or to assess current regulatory procedures.
- While individual hazardous constituents of respirable dust are not the main focus of the project, this aspect should be given consideration, where practicable.
- Asbestiform materials are to be excluded from the study.
- The radiological aspects of the study should focus on inhalation hazards e.g. radioactive dusts and radon gas. The inclusion of the measurement of external radiation should be considered, if practicable.
- Open cast mines should be included in the study.

1.4 Key factors affecting the project scope

As the project has progressed, a number of key features have emerged which have had a significant influence on the potential scope of the project and the potential design of surveys. In summary these are:

- The design of any survey of environmental stressors is intimately dependent on the purpose for which it is intended. This primary purpose shapes the types of data collected in the survey, the method used to collect data, the extent of data collection required, the acceptable accuracy of the data and the data analysis methods to be used. Whilst the initial indications from the Simhealth Committee were that the survey data would be primarily for future epidemiological purposes, there appears to be no clear consensus with respect to what the underlying epidemiological basis is and upon which the survey design could be grounded.

- Not withstanding the above, any respirable dust survey must be done on the basis of determining the exposure of a statistical sample of one or more discrete populations. It would appear that the underlying assumption upon which the prospect of designing such respirable dust surveys in specified occupations within mines was that there was a general consistency and conformity with respect to the job categorisation used on mines to describe various jobs. This implies therefore that industry wide populations, based on occupation and job category, existed. This presumably would enable subsequent meaningful statistical analysis of the data in terms of occupations and job categories. Such data could then theoretically be utilised either prospectively or retrospectively in epidemiological studies which focussed on affected populations based on occupation and job category. The evidence collected during the survey of job categories indicates that this is not the case and that little commonality exists between mining sectors, within sectors and even between individual mines within mining groups. It should be noted that in this context the concept of "homogenous exposure groups" as used in certain current exposure assessment regimes does not explicitly refer to groups based on occupation or job category rather to groups who are exposed to similar exposures of a particular hazard.

1.5 Impact of key factors

The effect of these factors has been to seriously limit the potential to design meaningful surveys since:

- It has not been possible to define explicitly the fundamental epidemiological purpose of the proposed survey in terms of populations or specific environmental factors. Without such definition it is not possible to design a meaningful and objective survey strategy; nor would it be possible to determine subsequently if the survey objectives were achieved. At best any survey design *might* produce data which *may* subsequently prove to be 'useful'. A survey design which provides 'all things to all men' is in reality idealistic and impractical. The resource implications of such an approach require serious considerations.

- There is a significant danger that any proposed survey design would subsequently dictate the form of any epidemiological studies. This is inherently incorrect. Epidemiology is the study of the distribution and determinants of diseases in populations and it is this which should drive the analysis of potential causal factors not the reverse.

- The hypothetical population structure which appears to have been originally assumed and from which survey samples could be drawn does not exist.

- In any event, if the hypothetical population structure did exist, the lack of any epidemiological hypothesis and in particular any identified sub-population(s) of interest would require that in theory, to avoid any bias, the survey design would require that the exposure of *all* sub-populations would have to be determined. This may not have been the original intention if for example if the testing of hypotheses arising from studies of disease clustering in specific job categories or occupations is of interest.

These issues are discussed in detail in subsequent sections.

Notwithstanding the above, the characteristics of the actual populations are discussed and an approach to sampling on this basis has been considered. A survey approach based on DME (1999) job codes has also been evaluated. It is recognised that for the above reasons these approaches may not provide useful or meaningful data.

The programme and resource implications of such approaches have been evaluated.

In the light of the above, an outline strategy to address these issues is discussed and considered in this context.

2. Summary of literature survey

2.1 Literature review introduction

A summary of the key sources and findings of a literature survey of information regarding full-shift occupational exposure of workers in gold, platinum and coal mining sectors to respirable dust and ionising radiation is provided in sections 2.2 and 2.3 below. The manner in which the findings of the literature survey have influenced the proposed study are also discussed.

A full report on the literature survey appears in the First Interim Report of SIMHEALTH 602 which is presented in Annex 1 to this final report.

The chief focus of the literature survey was to review and assess survey methods used in local and international literature in order to identify weaknesses, with particular attention being paid to the classification and analysis of data in terms of occupational categories and work rates.

2.2 Literature relating to respirable dust exposure

2.2.1 Summary of key sources

Since the introduction of routine operator sampling programmes in recent decades in many countries, statistically designed independent dust exposure surveys have been fairly rare. Internationally the trend has been to make use increasingly of operator-collected data for dust exposure studies.

While many studies have been conducted in recent years examining trends in such dust exposure data and linking existing exposure rate data to diseases or effects, in most of these studies the accuracy of exposure data is not evaluated, and is generally accepted as a "given", without consideration of how data were obtained, or of confidence limits. Literature detailing actual dust survey methods to obtain statistically accurate and representative exposure data is, on the contrary, limited, and the most useful sources date back to the late 1950's and 1960's.

Key sources identified during the literature survey include the following:

- past and current related SIMRAC projects;
- the South African Corner House Laboratory gold mine surveys;
- various Chamber of Mines surveys;
- the "25-Pit Study" of the British National Coal Board;
- the United States Bureau of Mines surveys on bituminous coal mines, and
- Canadian studies on Ontario mines.

A full list of specific references consulted is provided in the First Interim Report for SIMHEALTH 602.

2.2.2 Summary and influence of key findings relating to respirable dust

2.2.2.1 Need for the study

Issues identified in the literature which lend support to the need for the proposed study include the following:

- Exposure data from outdated studies are being used in South Africa.
- A number of sources identify the need for more thorough occupational exposure assessments in mines in South Africa.
- Operator-collected data in South Africa may be unsuitable for research purposes.

2.2.2.2 Shortcomings in survey methodologies

The following are the chief shortcomings identified in survey methods reported in the literature:

- Due to the fact that equipment which is now outdated, and which involved particle counting techniques, was used in many of the surveys discussed (including the Corner House Laboratory Studies which are still used today by South African epidemiologists as a source of exposure data) limitations on the accuracy of associated exposure data exist. Sampling methods used in such older studies are also likely to have introduced inaccuracies, due to the relatively large distances of samplers from worker breathing spaces.

- Work rates are generally not considered during occupational dust exposure assessments of mines, or in associated epidemiological studies.

- The number of occupational groups used in South African dust surveys tends to be smaller than in the case of overseas surveys, and groups are typically associated with large exposure ranges.

- Groupings used in past South African studies tend to be primarily focussed on white, underground gold miners, and appear to exclude newer jobs.

- Occupational groupings tend to be defined in terms of similarity of work and overall dust levels, rather than on the nature or source of dust.

- In many local and international studies reported in the literature, mines are not selected randomly.

- Past mine dust surveys primarily focussed on the analysis of dust for quartz and ash content. A number of sources indicate, however, that various other airborne constituents (e.g. diesel aerosols, other metallic pollutants) may be of significance to the health of mine workers.

- Mine surveys reported in the literature have also, over the years, focussed increasingly on the measurement of the respirable dust fraction. While the use of respirable dust samples may be appropriate where pollutants such as silica are the primary concern, larger dust fractions may also be relevant to dose-response studies.

The above mentioned shortcomings have important implications for the proposed survey design, and are discussed further in sections 4 and 5. It should be noted that new guidelines (DME 1999) address many of these shortcomings with respect to routine assessment.

2.2.2.3 Occupational groups

With regard to the selection of groupings for the study, the following recommendations arising from the literature survey have influenced the project:

- Besides similarity of work and dust levels, the nature and source of dust should preferably be taken into consideration when deciding on groupings, particularly in surface activities.

- Any proposed study should adopt a survey design which starts with a relatively large number of groups/categories, and then later condenses these, if desired, based on dust results. When selecting the number of occupational groups for the proposed study, it should be kept in mind that the use of a lower number of groups is associated with large exposure ranges, and hence lower confidence limits on group means.

- Information and codes on occupational categories exist in South Africa (as listed by the DME). To facilitate use of any exposure data generated from the proposed study, it is advisable that researchers link selected occupational groups to these existing categories in some manner.

2.2.2.4 Statistical methods

The following further recommendations relating to statistical methods arose from the literature survey, and also influenced the project:

- An iterative survey design should be adopted, to ensure that representative exposure data are obtained. In other words, the results of an initial phase of sampling should be statistically analysed, and further sampling requirements then determined for a second phase, etc.

- Once occupational groups are decided upon, miners should be selected within these groups using a random selection process (e.g. a list of miners' names, used in conjunction with a random number generating system).

- The appointment of a qualified statistician to the research team conducting any future surveys should be considered.

2.2.2.5 Other general findings

During the literature survey it was noted that, although use of operator-collected data overseas is the norm, there is a noticeable lack of use of such data in South Africa, apparently because the information is not in an ideal form, and uncertainties exist with regard to its accuracy.

A final noteworthy finding of the literature survey was that dust exposure data are generally collected for a specific purpose, and that that purpose determines the methods and procedures used during the collection and analysis process. As the proposed survey is being designed in the absence of any defined specific epidemiological study objectives, it was thus recognised that this imposes significant uncertainties on the survey design, and may place limitations on the extent to which the generated data may be used for future epidemiological purposes. These limitations are discussed further in section 4.

2.3 Literature relating to ionising radiation

2.3.1 Summary of key sources

Key sources regarding occupational exposure to ionising radiation in mines included the following:

- Past SIMRAC Studies, in particular GEN 004, Radiation Protection.

- Guidance booklets from International Radiation Protection Agencies such as publications of the International Commission on Radiological Protection, the International Atomic Energy Agency, and the BEIR (Biological Effects of Ionising Radiation) Committee of the US National Research Council.

- Literature on a number of radiation surveys conducted in South Africa and overseas. International literature was primarily from the UK, the USA, the EEC, Germany, France, Poland, Turkey, India and Australia.

A full list of specific references consulted is provided in the First Interim Report of SIMHEALTH 602.

2.3.2 Summary and influence of key findings relating to radiation

2.3.2.1. Need for the study

Three trends were identified in the literature which lend support to the need to include radiation in the proposed study. These are, firstly, the fact that the effects of multiple agents in the mine environment is reported to need more attention; secondly, that radiation exposure in non-uranium mines is generally considered to require closer study and, thirdly, that data from past studies on radiation exposure of miners are not ideal.

2.3.2.2. Shortcomings in surveys

The following were identified as the main shortcomings of ionising radiation surveys discussed in the literature:

- In general, a sound statistical basis to radiation surveys is not evident in the literature.
- The majority of radiation surveys are locality based surveys. As the number of hours spent in the mine and in various locations are frequently not fully documented, this makes the calculation of doses received by individuals difficult.
- The commonly used "grab sampling" methods are associated with a fairly high degree of uncertainty due to temporal variations in radiation levels.
- Work rates are an important consideration when estimating doses from inhalable radioactive constituents, but are not generally mentioned explicitly in radiation studies. Instead work rates tend to be "hidden" e.g. in standard dose conversion calculations which assume universal average values for work rates.
- Ore mining epidemiological studies tend not to consider joint effects of carcinogens, such as silica quartz and radon.
- Most older radiation surveys focussed on radon and radon daughters, and tended not to consider other components of radiation exposure, such as thoron contributions, long-lived ore dust, and external radiation.

The importance of considering other components of radiation exposure besides radon was also noted, but the need for concomitant cost-benefit considerations, was recognised. Thus, when deciding on the radiation components to be included in the proposed study, the likely percentage contribution to overall radiation dose, and the cost of measuring the component in question were taken into consideration. Similar cost-benefit considerations were also applied to decisions regarding the possible inclusion of measurements of the unattached fraction. These issues have been considered further in sections 4 and 5.

2.3.2.4. Other general findings

The following general findings and observations emerged from the literature survey:

- The linking of radiation exposure data obtained in the proposed survey to occupational groupings/categories, will facilitate individual dose estimates in later epidemiological cohort studies. Where possible, the same occupational groups/categories should be used in the proposed dust and radiation surveys, to facilitate the combined use of the data.

- The integration of dust and radiation sampling should be achieved where possible e.g. by using the same sampling pumps and filters.

- As most of the literature focuses on the underground mining environment, possible differences in the prevalence of radiation components on the surface need to be considered.

- Sampling times need to be selected to ensure collection in excess of the minimum detection levels of equipment.

The literature survey also highlighted the broad range of radiological measuring equipment available, and the fact that, when selecting equipment for the survey, factors such as radiation components to be measured, equipment costs, associated errors, intrinsic safety, practicality and convenience should be considered. These issues have been considered in sections 4 and 5.

Finally, it was recognised that, when deciding on the level of detail of the proposed radiological survey, care should be taken to ensure that resource allocation for this aspect of the study is in proportion to the relative hazard posed by radiation (i.e. compared to the hazard posed by dust). The costing in section 5 illustrates such considerations.

3. Summary of occupational surveys

3.1 Occupational surveys introduction

The results of occupational surveys in the South African gold, platinum and coal sectors to determine the numbers of persons employed in different job categories and the age and length of service distributions within each job category are reported.

The survey methodology used is summarised. The findings and a summary of the resulting data are presented. An analysis of the usefulness of the data in assisting in respirable dust survey design or subsequent exposure or epidemiological studies is provided. A full report on the occupational survey appears in the Second Interim Report of SIMHEALTH 602 which is presented in Annex 2 to this final report.

3.2 Summary of occupational survey methodology

A list of all operational gold, platinum and coal mines was obtained from the Department of Minerals and Energy (DME). From this list, randomly selected gold, platinum and coal mines were chosen to participate in the occupational survey.

The selection, in terms of the number of operational mines within each sector was as follows:

- Gold mines: 9 out of approximately 40 operational mines.
- Platinum mines: 3 out of 10 operational mines.
- Coal mines: 9 out of approximately 60 operational mines.

It is estimated that the information requested from the 21 selected mines relates to approximately 200 000 workers, compared with the total number of mine workers which is estimated to be approximately 500 000. Data relating to approximately 100 000 individuals was ultimately received.

Both the personnel departments and the environmental control departments of each of the selected mines were requested to provide the following workforce data for input into the occupational survey:

- Job categories.
- Occupations within job categories.
- Number of workers within job categories and occupations.
- Age and length of service.
- Job category and occupation composition of 'statistical population groups' used in routine dust sampling programmes.

3.3 Key findings from the occupational survey

There does not appear to be any obvious commonality in the use and application of job category and occupational descriptions in the formal employment records of the industry. The data which was received suggests that there is no standard format or methodology for the recording, compilation and presentation of such data.

Although some job category and occupational descriptions used by some personnel departments match those used in some environmental control departments there is no clear systematic connection between the two.

There is no indication that the code system for occupational descriptions proposed by the DME in the draft occupational hygiene programme guideline (DME 1999:57) is being used consistently or on a widespread basis, within the formal employment records of the mining industry. Whilst it is noted that the South African Mines Reportable Accidents Statistics System (SAMRASS), which uses the same code system, has been widely used for some time, this is based on a 'post-event' use of the coding system in relation to limited numbers of identified individuals involved in specific accidents. Therefore this use is significantly different from that which would be involved in widespread use in employment records.

There are indications that medical records kept by the various medical or health centers do not, in all cases, necessarily contain comprehensive information regarding individual job categories and service histories.

The length of service data provided appears to relate only to service on individual mines and in most cases the data provided excludes contractors.

3.4 Conclusions and recommendations from the occupational survey

There is no obvious commonality of job category and occupation descriptions:

- between the Gold, Coal, and Platinum sectors,
- within each of the three sectors,
- between individual mines within a group,

- between mine descriptions and occupational codes used in the DME guidelines.

Due to the lack of commonality in the various systems used to describe job categories and occupations in the formal employment records of the industry, it is not currently feasible to organise these into a common industry wide or sector specific reference data-bases.

In effect the actual discrete population or sampling unit hierarchy/strata consists of that shown in table 3.4(a).

Table 3.4(a): Actual population strata based on job categories and occupations

Population	Employees of the gold, coal & platinum mining industries		
Sub-population/strata	Employees of the gold mining industry	Employees of the coal mining industry	Employees of the platinum mining industry
Sub-sub population/stata	Individual gold mine employees	Individual coal mine employees	Individual platinum mine employees
Sub-sub-sub population/strata	Occupants of individual gold mine specific job categories and occupations	Occupants of individual coal mine specific job categories and occupations	Occupants of individual platinum mine specific job categories and occupations

This is as opposed to the perhaps expected (hypothetical) discrete populations or sampling unit hierarchy/strata as shown in table 3.4(b):

Table 3.4(b): Expected (hypothetical) population strata based on job categories and occupations

Population	Employees of the gold, coal & platinum mining industries		
Sub-population/strata	Employees of the gold mining industry	Employees of the coal mining industry	Employees of the platinum mining industry
Sub-sub population/stata	Individual gold mine employees	Individual coal mine employees	Individual platinum mine employees
Sub-sub-sub population/strata	Occupants of commonly applied job categories and occupations based on an industry wide coding system		

It should be stressed that a population hierarchy based on occupation and job categories is purely relevant to a survey design based on occupation and job category and does not replace or re-define the concept of "homogenous exposure groups" which consist of people who are exposed to similar exposures of a particular hazard.

Over and above the sample unit hierarchy represented in the formal employment records the 'statistical population groups' used for routine dust sampling exist, but also appear not to adopt a common classification or coding system.

Thus there are in general no clearly defined and discrete industry wide or sector specific job categories or occupational groupings that are applied at individual mine level.

Consequentially there does not appear to be any clearly defined industry wide discrete (statistical) populations from which to draw samples, and upon which a survey design could be based. Discrete populations based on job category and occupation exist only at individual mine level. This is particularly relevant should occupation be the basis on which any future individual historic exposure reconstruction is undertaken for epidemiological purposes.

As the sample unit hierarchy is as discussed above, and as there are no clearly stated epidemiological hypotheses upon which the proposed survey design is grounded; the implication is that any survey design would have to either:

- Sample across the mining industry on a random basis; producing a single estimate of the mean exposure and its distribution.

Or

- Sample randomly across each of the gold, coal and platinum sectors; producing estimates of the mean exposure and its distribution in each sector

Or

- Sample at each and every mine; producing estimates of the mean exposure and its distribution at each mine; for mine specific job categories and occupations.

The implications of this are considered in detail in section 5.

As the above survey strategies are unlikely to be practicable or useful, a review should be undertaken of the practicability and desirability of introducing and enforcing a common job categorisation and occupation description system across the industry prior to commissioning any industry wide exposure survey.

Given that industry wide exposure surveys and epidemiological studies often require a period of several years for completion, recognition should be taken of the dynamic nature of the industry and the evolution of new work practices e.g. multi-skilling, mechanisation etc. The effect is that the work content of specific occupations may change radically over relatively short time periods and therefore any common unified coding system is likely to have only a limited period of validity.

The intended use of any industry wide exposure survey data should be clearly specified prior to commissioning any industry wide exposure survey.

As statistical populations exist at an individual mine level, and as individual mines currently generate routine dust sample data, consideration should be given to utilising this for epidemiological purposes. However, it must be ensured that an 'audit trail' linking statistical population group to formal employment records exists.

4 General considerations in respect of design of surveys

4.1 Introduction

This section considers a number of factors relevant to the design of surveys to assess human exposure to environmental stressors, in particular respirable dust and radiation, covering the following areas:

- the general principles of exposure assessment and rationale for any survey and the framework within which it is designed and conducted
- epidemiological considerations
- factors that may be of interest with respect to epidemiology and dust and radiation exposure

- purpose of any future studies
- statistical properties of occupational exposure data

4.2 Exposure assessment – general principles and rationale

Exposure assessment is an integral component of environmental epidemiology. However, all media and routes of exposure should be assessed to determine the relative magnitude of their contribution to overall risk before a more intensive assessment of one specific medium is conducted. (Commission on Life Sciences, 1991:4).

Information on the doses that can cause effects associated with contaminant exposure is vital to the design of an exposure assessment protocol. It is difficult to identify a single effect associated with a single contaminant; it is even more difficult to establish a dose-response relationship. A health outcome often results from a complex situation that includes many factors, and the various associations must be explored and confounding variables controlled or accounted for simultaneously (Commission on Life Sciences, 1991:24).

An accurate assessment of exposure used to test initial epidemiological hypotheses can be employed with health data to establish relationships between exposure and health response. The type of exposure assessment method used, largely determines the applicability of collected data to quantifying the relationship between exposure and biological response and the acceptable level of uncertainty in the data will vary according to whether the assessment is designed to generate or test hypotheses.

In summary exposure assessment is a multidisciplinary endeavor forming an integral part of an overall occupational health management framework and must be undertaken in this context.

4.3 Epidemiological considerations in undertaking exposure assessments.

Given that the underlying stated purpose for any survey designs arising as a result of this project is for 'epidemiological studies' it is necessary to consider briefly the basic science of epidemiology (Supercourse, Epidemiology, the Internet and Global Health), to place exposure assessment in this context and consider how any resultant exposure data might be utilised in subsequent epidemiological studies.

At its most basic, epidemiology is 'the study of how often diseases occur in different groups of people and why' (Coggan, Rose & Barker, 1997:Ch 1, 1).

In general the epidemiological study of occupational diseases is a multistage process:

- the identification of disease clusters; i.e. a perceived excess in disease in time or space
- investigation of disease clusters; i.e. examination of exposure aggregation among individuals in the cluster
- hypothesis generation; i.e. postulate etiological factors and hypotheses
- test etiological hypotheses; i.e. epidemiological studies of populations

A major issue is that any one disease cluster could occur solely due to chance. Furthermore, just because the disease cluster is statistically significant there is still the possibility that this cluster exists only due to chance. Because a particular disease cluster can be due solely to chance, disease clusters can only be hypothesis generating. Therefore, further epidemiological investigations must be made to look for any hypothesised etiologic connection in a new population in time and space. If additional investigations are performed only within the same population, it will be a self-fulfilling prophecy that something will be found since the cluster has already been found. As with all scientific investigations, the hypotheses must be tested elsewhere. An important feature of this hypothesis generation phase is that this specifies the exposure parameters which must be assessed subsequently ***and*** the potential confounding variables which must be accounted for simultaneously.

There are two major analytical epidemiology techniques used to study the determinants of health problems:

- Case control (retrospective) studies; in which the past exposure of individuals exhibiting a disease (cases) to potential risk factors is compared to the exposure of individuals who have not developed the disease (controls). In this type of study disease status is examined ***before*** exposure status.
- Longitudinal or cohort (prospective or retrospective) studies; in which both the exposure and disease status of a group of individuals are examined over a period of time. In this case disease status is examined ***after*** exposure status. However the populations of interest are defined by the epidemiological hypotheses under examination and not the exposure assessment method.

From the above, it can be clearly seen that there are a number of important factors which can be defined only by epidemiological considerations, and which have an important bearing on the design of any surveys to provide exposure data:

- What epidemiological hypotheses are to be examined and what etiological factors are of potential interest with respect to exposure assessment?
- What confounding factors are of interest which must be accounted for at the same time as exposure assessments?
- What are the relevant populations for which exposure assessments are required and how are they defined?
- What exposure parameters and data are required in order to test the epidemiological hypotheses?
- What level of confidence is required in the exposure assessment data?

In this context, it would appear that none of the above have been clearly determined in a structured and holistic fashion prior to commissioning the proposed survey design.

Without a clear definition of these factors any survey design ***might*** at best generate exposure data that ***may*** subsequently prove to be 'useful'. The resource implications of such an approach require serious consideration and must be compared with the consequences of using other sources of data, which may also be non-ideal.

Another important consideration is that any exposure data generated ***now*** is only likely to be useful in prospective studies, since in retrospective studies, the exposure has already occurred; exposure assessments conducted now are unlikely to be an adequate surrogate for historic exposures due to changes in work practices etc. Furthermore, any comprehensive exposure data generated now is likely only to have a short period of validity, also for the above reasons, and may therefore also be of little use in any prospective studies.

For prospective studies perhaps a more useful approach would be the generation of individual exposure assessments conducted on an ongoing basis and recorded in individual health records. It is noted that such an approach is already recommended in the proposed DME guideline (DME, 1999:16)

4.4 General factors that may be of interest with respect to epidemiology and dust and radiation exposure in the mining industry.

Airborne particles which are inhaled may be deposited in the human respiratory tract by inertial impaction, sedimentation and diffusion mechanisms. Certain sizes may be exhaled. Once deposited, however, these particulates may be cleared and expelled quickly (as from the upper airways) or slowly (as from the alveolar regions). Depending on the toxicity and lung residence time of the particulates, cellular responses may occur which lead to pathological damage.

Although inhaled particles are recognised as causative agents in the development of respiratory disease, dose-response relationships tend to be unclear and other issues may confound the problem. Does the exposed worker have a susceptibility to the particles and is his respiratory tract compromised by pre-existing disease, age or a history of cigarette smoking? What sort of exposure history does the worker have? Is exposure 'steady' or are excessive exposures (peaks) commonplace? Does he have sufficient time away from exposure for the clearance mechanisms to function effectively? What sizes of particles constitute the exposure? Are there any other entities being inhaled e.g. gases, vapours, mists, attached and unattached radioactive decay products? Does the work rate (which will affect breathing patterns and depth) play a significant role? Where do TB and HIV feature? Which of these ***might*** need to be included in a given study design?

Hypotheses regarding the effects of exposure to dust and radiation in mining can best be generated through health studies of the affected population, which can subsequently be tested in appropriate epidemiological studies. These studies are influenced, however, by the difficulty of eliminating the effects of confounding factors (e.g., the effects of smoking and exposure to other environmental pollutants such as soot, etc.). Another aspect to be considered in such studies is that prevalence can be influenced by movements in populations, particularly of older miners, leading to inaccurate data gathering due to early retirement, changes in occupation or job loss.

These limitations result in a wide range of estimates of the effects of exposure to dust on the health of the exposed mine workers. To create further problems, monitoring of airborne particulates and other entities is an estimate of the micro-environment being breathed by the worker and it does not reflect his respiratory burden. At best, monitoring gives an indication of high, medium and low concentration micro-environments and these classifications are hardly rigorous. In addition, monitoring results show significant statistical variation and arbitrary 'exposure' categories tend to overlap. In the design of epidemiological studies, any protocol should not be excessively reliant on environmental monitoring of a single entity as an indicator of workers' true doses. By definition, this cannot be the case. When multi-pollutant exposures are being studied the problem complexity increases significantly and often-intricate statistical analyses become *de rigueur*.

To illustrate some of the difficulties encountered in deciding what dust property to measure as part of an exposure-result type study, consider the following. Post-mortem studies of miners' lungs have shown a relationship between the average weight of dust in the lungs and the radiological category of pneumoconiosis (Rivers, et al., 1960; Rossiter, 1972). In animal experiments, injected quartz dusts of different particle sizes produced pathological changes that were more closely related to the mass or surface area of the dust than to the number of particles (King, 1953; Zaidi, 1956). It may be argued that the physiological response to the stimulus differs between animals and humans. However, there seems to be no conclusive evidence one way or another. Furthermore, until such evidence is substantiated, it may be impossible to measure the dust characteristic that is responsible for a specific pathogenic effect.

It should be noted further that, in early studies, cumulative exposure has been identified as one of the most critical factors in the development of pneumoconiosis. Duration of exposure and the amount of airborne respirable dust present in the mining environment have a significant influence upon the prevalence of the disease. It was concluded, (Reisner, 1971), that the development of coal workers pneumoconiosis (CWP) was '***largely due***' to the frequency and severity of exposure. Reisner further suggested that individual large exposures to mixed dust could be important in certain cases. The findings indicated the distinct correlation between a worker's estimated exposure and the risk of developing CWP (Jacobsen et al., 1980; Attfield et al., 1995).

Other studies have shown that the risk of progression to a higher category of pneumoconiosis increases with increasing intensity of exposure, represented by the mean dust concentration (Jacobsen *et al.*, 1970, 1971), and with increasing cumulative exposure, represented by the product of intensity and duration (Jacobsen, 1973, 1979).

However, the results of medical research are inconclusive in identifying in advance individuals who show a greater propensity to developing pneumoconiosis in response to dust exposure. Typically, pulmonary function is measured at the pre-employment and subsequent medical examinations. These tests are not predictive of individuals' susceptibility to dust exposure and therefore only offer a retrospective view of the pathogenesis.

Similar complex issues can be identified with respect to exposure to various sources of radiation forming the basis of extensive research by bodies such as the International Commission on Radiation Protection (ICRP).

The major factors implicated in the pathogenic characteristics of respirable dust in this century (ECSC, 1997) are discussed below:

4.4.1 Dust Type

In the past few decades, several health studies have indicated that dust type plays a crucial role on the miner's health. Toxicity studies have confirmed, for example, that there are pronounced differences in specific risk from different fine coal dusts. Reisner's (1971) study to investigate the cytotoxic effect of different fine coal dusts showed increased cytotoxicity related to higher rank coals.

Reisner (1971) and Jacobsen's (1980) observations in coal miner's data showed that very strong variations existed in the prevalence and progression of CWP between different regions and individual mines, despite similar cumulative exposures and quartz contents of the coal dusts. However, these studies were unable to identify specific factors causing the variation, suggesting that some mines produce coal dust that is more pathogenic than others.

There is no literature relating South African mine workers with various pneumoconiosis levels to coal rank.

The pathogenic effects of dust inhalation can be sub-divided into two broad categories. The first category consists of toxic dusts. The chemical characteristics of toxic dusts have the ability to interfere with the scavenging action of the alveolar macrophages. The second category consists of non-toxic dusts.

Some researchers (Cherrie, 1998) are of the opinion that the retention times of dust in the lungs play, amongst others, an important part in the pathogenic effect of the exposure. In both categories, the inability of the lung scavenger cells or alveolar macrophages to clear the dust, results in the migration of the contaminant particle from the lungs' epithelium to the interstitium (the underlying cellular layer surrounding the blood vessels). Here the dust particle may produce inflammation that may lead to fibrosis and, for some dusts, even cancer.

The production of fibrogenic tissue resulting from the irritation of the alveolar tissue is a known effect. This leads to the irreversible damage of the elastic lung tissue and reduces the oxygen absorption capacity of the lung (Schroeder, 1989). In addition, observations have shown that the presence of irritating material in the interstitium may alter the blood's ability to coagulate and lead to the triggering of heart failure as documented by Seaton (1995) and Schroeder (1989).

4.4.2 Particle Charges

The effect of charged dust particles in the atmosphere results in the coagulation of smaller dust particles into larger conglomerates held together by relatively strong intermolecular Van der Waals forces. It is in the deposition of dust particulate that the electrostatic charge of dust particles plays a part. Previous research has shown that lung deposition of aerosol particles increases directly with the aerosol's charge properties (Melandri, et al., 1983).

In the research study by Organiscak and Page (1998), coal rank and CWP relationship was reported to be related in part to the increase in the dust cloud charging properties of higher rank bituminous coals. Charging of quartzitic dust particles in airflows in tunnels is also common.

4.4.3 Silica Content

Silica is the common name for silicon dioxide (SiO_2). The most common crystalline form of silica is quartz, which occurs as solid crystals from several inches in size down to microscopic dimensions. Other forms of crystalline silica are cristobalite and tridymite.

Quartz was originally believed to be the primary agent in the pathogenesis of CWP. However, it was subsequently found that workers such as dock labourers, who had contact only with the pure coal product, were also susceptible to the disease. Experimental work (Reisner, 1971) has shown that increased quartz content of dust leads to an enhanced pathological effect. A pathological study by Davis (1979) suggested that pulmonary massive fibrosis (PMF) in miners previously employed in low rank coal mines may be induced primarily by the quartz and mineral particles in the dust.

Klosterkotter (1954) showed that silica gel injected intra-trachealy in rats did not cause fibrosis. Schepers et al (1957) observed no fibrosis development in guinea pigs and rabbits exposed to the inhalation of 126 mg/m^3 of silica for two years despite observing macrophage accumulations and mild proliferation of reticulin fibres. In a group of 165 workers exposed to precipitated silica, estimated to be near or below 10 mg/m^3, for an average of 8,6 years (Wilson et al., 1979) no serial changes in pulmonary function nor chest radiographs were observed.

Various studies have related dust exposures of foundry workers to mixed dust fibrosis (Oudiz, 1986; Parkes, 1982). Study of smokers and silica exposure demonstrated the synergistic action of both agents causing chronic obstructive lung disease (Hnizdo and Sluis-Cremer, 1991; Hnizdo, 1990 and Malmberg et al., 1993). There were also studies that reported the association of silica exposure with other lung diseases, such as tuberculosis (Chen and Burnett, 1997; Althouse and Bang, 1995) and lung cancer (Cherry et al., 1998; Costello et al., 1995; Koseka et al., 1994). In 1996, the International Agency for Research on Cancer (IARC) reviewed additional literature and studies published in the intervening decade and recommended that quartz and crystobalite, two polymorphs of crystalline silica, be listed as Group 1, carcinogenic to humans.

The findings of this IARC report (1997) are:

- There is sufficient evidence in studies of humans that show the carcinogenicity of inhaled crystalline silica in the forms of quartz or crystobalite from occupational sources.
- There is sufficient evidence in experimental animal studies confirming the carcinogenicity of quartz and crystobalite.
- There is limited evidence in experimental animal studies of the carcinogenicity of tridymite.
- There is inadequate evidence in studies of humans to confirm the carcinogenicity of amorphous silica.
- There is inadequate evidence in experimental animal studies of the carcinogenicity of synthetic amorphous silica.

4.4.4 Clay Minerals

Clay minerals such as phyllosilicates are present in significant quantities in some mine dust. Individual samples have been found to contain up to 60 per cent illite, muscovite and kaolin (Sabastien, 1989). Some research has suggested that phyllosilicate clay minerals may be able to inhibit the toxic effects of quartz dust in airborne dust sampled from different mines. Inhalation studies on rats (Le Bouffant et al., 1977) suggested the diverse range of natural phyllosilicates found in mixed coal dust might have some protective effect. However, it is difficult at this stage to have an understanding of the protective effect itself as well as to extrapolate the experimental results from rats to represent human exposure. Furthermore, it is hard to assess the protective effect of clay minerals because their variability and diverse geological composition make the gathering of accurate data a complex task even with sophisticated mineral sampling equipment (ECSC, 1997).

4.4.5 Particle Size

Particle size is an important parameter for characterising the behaviour of dust. One of the important measurable factors with regard to health effects on human beings is the particle size as many properties of dust depend on it. The effect of "size" of dust particles on the deposition in the respiratory region of the lungs has been investigated by two methods:

- by inhalation experiments in which the particle concentration is measured on entering and leaving the lungs, and
- by examination of the dust found in lungs at post-mortem.

The dusts liberated typically in the environment during mining operations display a very wide range of particle sizes. There have been a number of experimental studies comparing the lung's response to fine low toxic dusts, some of which are discussed by Soutar and others (Soutar, et al., 1997). All of the ultra-fine dusts were found to produce more damage to the lungs than the same mass of the identical material of fine particles around 250-nm diameter. High concentrations of ultra-fine particles (d_p = 25 – 250 nm) are characterized by relatively large surface areas that interfere with the dust-clearing mechanisms of the lungs as described above.

The MRC selection curve corresponded approximately to lung deposition measured by the inhalation method (Davies, 1952). Post-mortem studies (Cartwright, 1961, 1966; Leiteritz, 1966), have subsequently indicated that the dust found in the lungs of coal miners at death is appreciably finer than would be collected according to this curve. This finding has been questioned and has lead to the creation of an amended new international standard. Rossiter has compared the amounts and composition of dust found in lungs at post-mortem with the pneumoconiosis category. The differences among the categories were identified due to the composition of dust and large differences in the response of individuals.

4.4.6 Particle Shape

Since the beginning of research into dust particle behaviour, scientists have assumed the particle shape to be spherical. It could also be argued that knowledge of the aerodynamics of the dust particle related to its shape could be used in modelling flow patterns and perhaps deposition. There is no evidence to support the theory that different shapes cause different responses.

4.4.7 Individual Susceptibility

Although individual susceptibility is not a pathogenic characteristic of a dust particle, the factor plays an important role in the disease. A study by Maclaren et al., (1989) indicated that there was an increased prevalence of PMF amongst men of aesthetic build than any other group. It was suggested that the increased rate of disease reflects the greater respiratory effort exerted by a tall man working in a restricted environment. Increased respiratory effort could lead to increased dust deposition in the worker's lungs. One remarkable response to coal dust pathogens occurred in individuals who have distinct rheumatoid factor. Caplan's (1960) syndrome, a form of CWP characterized by multiple small lesions, 0.5 to 5 cm in diameter usually originating in the periphery of the lung, highlighted the importance of immunological responses in the development of CWP.

Cherrie (1998) also highlights the fact that individual propensity to asthma can increase sensitivity particularly to ultra-fine dusts. He argues that susceptible individuals may be affected at concentrations up to 100 times less than the accepted exposure limit.

4.4.8 Sampling Methods

Several sampling strategies have evolved over the years and the sampling methods are defined as follows:

4.4.8.1 Personal Sampling

A personal sample consists of the dust sample collected in the breathing zone of a worker while performing occupational duties during a work shift. In this sampling method, the worker wears the sampling train (cyclone, pump, tube, sample filter) for the entire shift. However such sampling does not account for variations in respiration rate due to either individual variations or differing respiratory demand across tasks or occupations.

4.4.8.2 Occupational Sampling

An occupational sample is the dust sample taken during a work shift on individual workers who perform duties in a designated occupation. This method of sampling measures the dust exposure for defined occupations as if one person performed the duties in that occupation for the whole working shift.

4.4.8.3 Area or Environmental Sampling

An area or environmental sample is the dust sample taken at a fixed location at the workplace in an environment or area of interest. The dust sample reflects the average concentration in the area of interest and does not reflect the exposure of any worker in that area.

4.4.8.4 Engineering Sampling

An engineering sample is the dust sample taken to determine the dust concentration near machinery, tipping points, air filters, etc. to characterize the emission source or suppression effectiveness of dust suppression or control measures.

The purpose of personal and occupational sampling is radically different from that of area and engineering sampling. The first two are surrogates for the inhalation of dust and aimed at being representative of worker exposure. In particular, personal sampling may be used for linking exposure to medical records.

The other two methods are aimed at establishing the presence of dust or at characterizing the dust source or dust control measure used in a defined environment.

Studies have indicated that personal sampling provides the best estimate of worker exposures and of the temporal and spatial variability in those exposures (Vincent, 1994). In nearly all the studies where personal and area sampling were compared with clinical measures of occupation-related adverse effects, the personal exposure measurements provided the best correlation (Stopford et al., 1978; Linch et al., 1970; Linch and Pfaff 1971).

From the foregoing it is clear that obtaining any present surrogate exposure data and linking it to a selection of current occupational health outcomes would be misleading in the least. Such an exercise will not give a true reflection of the outcome as a true effect of the exposure.

4.5 Purpose of any future studies

There is no doubt that the prevalence of respiratory system and lung diseases is one of the most serious concerns facing the South African Mining Industry. The pivotal point in this discussion is that there is no certainty as to which dust properties cause the pathologic effects. Concentration, particle size and exposure to short duration high concentrations of various airborne pollutants, either separately or simultaneously, are probably the more likely and better documented.

However, the information is not corroborated by definite data. It is possible that the pathogenicity is the result of a combination of properties of the dust.

Ultimately the purpose of any epidemiological studies is to determine risk factors for specific health effects due to specific agents, which in turn should enable the control of hazards and reduction of risks by focussing of resources on areas which provide the most cost effective return.

This is perhaps illustrated best by considering radiation hazards. The risks associated with exposure to various forms of radiation are the subject of vast amounts of international research which have resulted in well established and internationally accepted systems of risk management and associated exposure limitation standards which are incorporated in regulatory requirements. As such, any further (local) epidemiological studies in this regard can only be justified if there is a strong belief that the identified risk factors are significantly over or under stated or there are specific factors appropriate to local circumstances. In the absence of such justification such studies become of only academic interest.

Not withstanding the above, the extent of the South African mining industry does perhaps present unique opportunities to provide an environment for meaningful occupational epidemiology, containing as it does large exposed populations and the possibility of addressing the problems of small numbers which so often confound studies of disease clusters.

Given the complexity and the seriousness of the situation, any epidemiological studies must be focussed yet comprehensive enough to deliver significant useful information. The first step is in clearly defining the problem area to be examined. This may be obvious initially, but given the above discussion it would be easy to measure exposure to the "wrong" properties.

4.6 Some statistical properties of occupational exposure data

A ***statistical population*** is an entire class of items about which conclusions are to be drawn. Usually it is impossible or impractical to take measurements on all items in the population thus it is usual to take measurements on several items comprising a ***statistical sample***. The findings from the sample are generalised to obtain conclusions about the whole population. In particular there are statistical measures relating to the ***distribution, central tendency*** and the ***dispersion*** of the population. Table 4.6 shows the relevant statistical parameters with respect to certain exposures of interest (Leidel, Busch & Lynch, 1977:12)

Table 4.6(a): Sampling population and statistical parameters for various exposures of interest

Population	Statistical sample used to estimate population parameters	Measure of central location and the distribution	Measure of dispersion	Best distribution model for fitting data
The daily respirable dust exposure averages of all employees in an occupational group of similar expected exposure risk on a similar day	Measured daily respirable dust exposure averages for several employees in the group	(a) Group geometric mean (b) Group arithmetic mean	Geometric standard deviation (GSD)	Log-normal
The daily respirable radioactive dust exposure averages of all employees in an occupational group of similar expected exposure risk on a similar day	Measured daily respirable radioactive dust exposure averages for several employees in the group	(a) Group geometric mean (b) Group arithmetic mean	Geometric standard deviation (GSD)	Log-normal
The monthly radon exposure averages of all employees in an occupational group of similar expected exposure risk on a similar day	Measured monthly radon exposure averages for several employees in the group	(a) Group geometric mean (b) Group arithmetic mean	Geometric standard deviation (GSD)	Log-normal
The monthly external radiation exposure averages of all employees in an occupational group of similar expected exposure risk on a similar day	Measured monthly external radiation exposure averages for several employees in the group	(a) Group geometric mean (b) Group arithmetic mean	Geometric standard deviation (GSD)	Log-normal

Where the true daily or monthly exposure averages are log-normally distributed, the long-term geometric mean (GM) is estimated from the measured daily or monthly exposure averages. The period to period variation of the true daily or monthly averages is estimated by the geometric standard deviation (GSD). Random sampling and analytical errors that contribute to uncertainty in the calculation of any one daily or monthly exposure average contribute relatively little to the uncertainty of a long term average. That is, the dispersion of the distribution of true daily or monthly exposure averages is dominated by period to period environmental fluctuations. Thus the GSD provides a good estimate of the true variations in daily or monthly exposure.

Recognising that the distribution of sample results from a given occupational group is generally log-normal, the exposure averages for groups with typical geometric standard deviations cover a wide range of values, often an order of magnitude. The ratio of a high exposure, such as that of the 95th percentile employee to the group arithmetic average exposure can often be typically 2 or 3 to 1. That is the 95th percentile employee can easily be 200 per cent or 300 per cent of the group average.

Geometric standard deviations commonly occur in the range 1.5 to 2.5 (Leidel, Busch & Lynch, 1997:73). Under most situations, it is incorrect to assign the group average exposure to all employees because the group average can significantly underestimate high exposures. Only when the group GSD is very low (about 1.15 or less) could the group average be assigned to all employees with less than about 20 per cent error.

The above has a number of serious implications if it is assumed that average full shift exposure or monthly radiological data for various occupational groups is somehow useful for epidemiological purposes:

- Even relatively homogenous work groups operating in the same location are often found to have a relatively large GSD. It must be considered how meaningful the determination of an average exposure to an occupational group containing members at different mines, exposed to different source material, using different practices etc might be and how much greater the expected GSD could be.
- Because a knowledge of the dispersion of the sample only arises after analysis of the data, either the above errors would have to be accepted or the groups would have to be refined further following analysis of the data.

It is therefore important to realise that sampling a sub-group and assigning the average exposure obtained to all workers is invalid except under unusual circumstances. As such, the purpose of designation of exposure populations based on, perhaps arbitrary, industry wide definitions of occupation must be questioned. ***However an initial assumption must be that for the purposes of survey design, and until analysis of the data has proved otherwise, sub-groups based on job category or occupation are de-facto homogenous exposure groups.***

Random sampling of homogenous exposure groups and determination of appropriate sample size poses additional problems since little is known in advance regarding any of the parameters of the populations. A method has been developed for determining an appropriate sample (n) from a population (N), based on the confidence (α) of ensuring that a certain upper percentile (τ) of the population is included in the sample. Tables 4.6(a)-(d) illustrates the sample size required (n) for various population size, confidence level, and upper percentile of interest (Leidel, Busch & Lynch, 1997:71).

Table 4.6(b): Sample size for ensuring sampling from top 20 per cent with 90 per cent confidence

Size of group (N)	10	20	50	>100
Required no of measured employees (n)	7	8	11	11

Table 4.6(c): Sample size for ensuring sampling from top 20 per cent with 95 per cent confidence

Size of group (N)	10	20	50	>100
Required no of measured employees (n)	7	10	14	14

Table 4.6(d): Sample size for ensuring sampling from top 10 per cent with 90 per cent confidence

Size of group (N)	10	20	50	>100
Required no of measured employees (n)	9	13	18	22

Table 4.6(e): Sample size for ensuring sampling from top 10 per cent with 95 per cent confidence

Size of group (N)	10	20	50	>100
Required no of measured employees (n)	10	15	21	29

5 Potential survey strategies

5.1 Survey populations

As discussed in section 3.4, discrete populations based on occupation and job category exist in terms of formal employment records only at individual mine level. If exposure parameters *are* required based on occupation and job category, this would of necessity dictate the basis of any industry wide survey strategy and design undertaken at this time.

As discussed above, ***a fundamental underlying assumption of any survey conducted on this basis is that all individuals in a particular occupational group at a particular mine form a discrete population with respect to their exposure, ie are de-facto homogenous exposure groups***.

Section 4.6 identified a means of determining appropriate sample sizes for 'homogenous' groups for varying degrees of confidence.

On this basis it would be possible in theory to:

- Initiate surveys on an individual mine by mine basis
- Examine occupational groups on a mine by mine basis and determine group size and appropriate sample size (n).
- Identify a random sample (n) from each group
- Conduct dust and radiation measurements.

It should be noted that 'common sense' would dictate that not all occupational groups at all mines might be of interest. However there is no definitive basis at present on which to dismiss specific groups from any study.

An alternative would be to base any future study on the DME (1999) occupation codes once these are confirmed as implemented and cross referenced to employment records. Similarly to the above it would be possible to:

- Examine occupational groups on a code by code basis and determine group size and appropriate sample size (n).
- Identify a random sample (n) from each group
- Conduct dust and radiation measurements.

Again the assumption would be that all individuals sharing a particular industry wide code form a discrete population with respect to their exposure.

Again, noting that the DME code list (DME, 1999:57-75) contains almost 1000 different occupation codes, 'common sense' would dictate that not all occupational codes may be of interest. However there is no definitive basis at present on which to dismiss specific groups from the study.

5.2 Environmental parameters to be measured

In the absence of any other identified requirements the following parameters could be assessed:

- Assessment of full shift respirable dust exposure via membrane filter samples of respirable fraction from the 'breathing zone' with gravimetric analysis.
- Assessment of full shift respirable radioactive dust exposure (this assessment could be undertaken on the same physical sample as that for respirable dust)
- Monthly assessment of radon exposure via track etch or similar device (a monthly sample would be required due to the detection limitations of the measuring devices which at the likely exposure levels would not be able to discriminate daily exposures)
- Monthly assessment of external radiation exposure via thermo-luminescent device (a monthly sample would be required due to the detection limitations of the measuring devices which at the likely exposure levels would not be able to discriminate daily exposures)

Clearly there are numerous other exposure parameters which ***could*** be measured.

It should be noted that whilst on this basis, a study of the correlation between respirable dust and respirable radioactive dust would be possible and of the correlation between radon exposure and external radiation exposure should this be considered of interest. However correlation between samples taken on a daily basis and those taken on a monthly basis could not be examined other than on an average basis.

The characteristics of the exposure data could then be examined on a group by group basis.

5.3 Potential survey magnitude

Before proceeding with any exposure assessment survey it is necessary to determine the overall magnitude and likely resource and programme demands of the available strategies.

5.3.1 Potential size of individual mine based survey

There are currently approximately 100 operational gold, coal and platinum mines (=N_{Mines}). These mines are estimated to employ of the order of 500,000 individuals. Therefore each mine employs on average 5000 individuals. Clearly the distribution of the number of employees at individual mines is somewhat skewed with a relatively large number employing significantly less than this and a relatively few mines significantly more; as such this number does not reflect the modal value of the distribution.

Assuming that at each mine there are on average 50 discrete occupational groups (=N_{Gp}) then on average each one would contain 100 individuals. Again the distribution of numbers of occupational groups and number of individuals within groups is likely to be skewed.

Using the factor in section 4.6 for ensuring sampling from the top 10 per cent with 95 per cent confidence would require that, on average, 29 individuals from each group would require to be sampled (=N_{Samp}).

Assuming that on average only 50per cent (=F%) of the occupational groups at each mine would be of interest then the total number of samples required for such a survey would be approximately:

$$(\text{Total number of samples required})_{\text{Mine survey}} = N_{Mines} \times N_{Gp} \times N_{Samp} \times F\%$$

$$= 100 \times 50 \times 29 \times 50\%$$

$$\approx 75\ 000$$

The effect of the above skew distributions i.e. smaller mine populations, fewer occupation groups per mine and fewer individuals per group would tend to cancel out to a certain degree since smaller groups require a proportionately greater fraction of the population to be sampled.

Clearly different sampling confidence requirements would have effects proportionate to the factors shown in tables 4.6(a)-(e).

5.3.2 Potential size of DME code based survey

As above, the gold, coal and platinum industries employ of the order of 500, 000 and the DME code list contains approximately 1000 individual occupation codes (=N_{Codes}). Therefore each individual code contains on average 500 individuals. Again this is likely to be a skewed distribution.

Again using the factor in section 4.6 for ensuring sampling from the top 10per cent with 95per cent confidence would require that on average 29 individuals from each group would require to be sampled (=N_{Samp}).

Assuming again that only 50per cent (=F%) of the occupational groups would be of interest then the total number of samples required for such a would be approximately:

$$(\text{Total number of samples required})_{\text{Code survey}} = N_{Codes} \times N_{Samp} \times F\%$$

$$= 1000 \times 29 \times 50\%$$

$$\approx 15\ 000$$

In this case the skew distribution of numbers of individuals per group would have the effect of increasing the above estimate.

Again different sampling confidence requirements would have effects proportionate to the factors shown in tables 4.6(a)-(e).

5.4 Programme and resource implications of conducting industry wide baseline surveys

5.4.1 Programme implications

Any surveys of the above magnitude are likely to be largely resource driven. Managing such a sampling programme on an industry wide basis is a complex project management task. Even the routine collection of a relatively small number of samples, say 10 per day, requires significant resources.

The potential duration of surveys using the above strategies and generating 10, 20, 50 and 100 dust samples on average per working day and 400, 1000 and 2000 monthly radiological samples are illustrated in table 4.8.3 below

Table 5.4.1 Potential durations of identified survey strategies versus survey resource capability

Survey resource capability	Survey duration			
	Individual mine based survey		DME code based survey	
	Work days	Years	Work days	Years
10 respirable dust samples per day 200 radon and external radiation measurements per month	7500	40	1500	8
20 respirable dust samples per day 400 radon and external radiation measurements per month	3750	20	750	4
50 respirable dust samples per day 1000 radon and external radiation measurements per month	1500	7.5	300	1.5
100 respirable dust samples per day 2000 radon and external radiation measurements per month	750	3.75	150	0.75

5.4.2 Resource implications

Each of the above survey intensity strategies has been assessed in terms of annual operating and capital cost as shown in tables 4.8.4(a) and (b). The details with underlying assumptions are shown in Appendix 1.

Table 5.4.2(a): Annual operating costs of various resource commitment strategies

Cost item	Annual operating cost (Rk/a)			
	10 samples/day	20 samples/day	50 samples day	100 samples day
Manpower	660	660	1425	2350
Travel & Subsistence	155	230	307	465
Analysis costs	489	978	2445	4890
Consumables	10	18	47	92
Equipment maintenance	90	138	340	634
General overheads	140	202	456	843
Sub total	**1544**	**2226**	**5021**	**9273**
Contingency (25%)	386	557	1255	2319
Total operating cost	**1930**	**2783**	**6276**	**11592**

Table 5.4.2(b): Capital costs associated with various resource commitment strategies

Cost item	Initial capital cost (Rk)			
	10 samples/day	20 samples/day	50 samples day	100 samples day
Air samplers and calibrators	272	417	1030	1922
Contingency	68	104	258	481
Total capital cost	**340**	**523**	**1288**	**2403**

5.5 Feasibility of potential strategies

From the above it is apparent that a mine by mine survey strategy is unlikely be practicable or meaningful over such extensive time horizons. However it must be recognised that this reflects the extensive nature of the South African Mining industry. It should also be noted that many of the earlier industry studies reviewed in the literature survey extended in many instances over a number of years.

Whilst a survey based on DME codes is perhaps an order of magnitude smaller it would still require the commitment of significant resources over an extended period, and the real value of the resultant data would have to be considered against this commitment. It should be noted that this resource commitment would be over and above that committed by employers under the Mine Health and Safety Act to link personal exposures to medical records.

Clearly it would be possible to commence such surveys on a limited basis and review the value of the data after a relatively short period of time. However, such an approach could not be considered objective or scientific.

It was noted earlier that extensive industry wide surveys have become increasingly less frequent over recent years, the trend being to rely on operator generated data. In this context it should be noted that the total resources routinely committed collectively by mines to generate exposure data in order to comply with regulatory requirements will in all likelihood be comparable with those identified in the most intensive survey programmes above. Again this highlights the need to carefully consider the possible utilisation of this source of data.

6 Alternative approaches and a way forward

Environmental exposure assessment potentially serves many purposes; to obtain baseline data, to check compliance with standards, to detect if controls are functioning or to test epidemiological hypothesis. However, unstructured collection of data without a clear reason or without a rationale for data interpretation should be challenged vigorously.

It will be clear from the foregoing discussions that, not withstanding their practicability, independent industry wide surveys are considered unlikely to provide meaningful or useful data at this time, much less provide answers to any specific questions.

For many years, the mining industry has been and continues generating extensive environmental data. It is however unclear to what extent this data is reviewed to determine whether the correct information has been collected and whether it is *interpretable* within the context of a clear overall health related policy objective. If this is not the case, the purpose of the data collection exercise should be examined. Fundamentally, can anything be gleaned from existing data?

It should be noted that the current DME (1999) guidelines seek to address many of the issues raised by this project:

- the need for a clear identification and assessment of multiple hazard agents
- the need for exposure assessment based on clearly defined and homogenous exposure populations
- smaller more focussed populations
- the need to keep individual exposure assessments in conjunction with health records.

In theory this data may well meet the requirements of future epidemiological studies provided the quality of the assessment process can be verified or enforced.

Clearly there are many issues to be addressed. However, these ultimately reduce to those of practicality and operational capability. If respiratory disease is prevalent and it is generally accepted that dust is the primary causative agent, what further control measures should be introduced to eliminate or reduce the risk? How stringent should the controls should be? What is an acceptable risk and to whom?

Such a debate is unlikely to be resolved quickly. However, there are likely to be many readily available indicators which can assist in examining the problem. Is there a significant difference in disease prevalence amongst different groups? Why? What is different; geology, mining practice, worker attitude, management control, better medical screening etc?

The initial need is for simple, inexpensive, review processes which can be introduced to categorise workplaces without the need for "full blown", lengthy, difficult-to-interpret epidemiological studies. Criteria for "good mine" status should be defined and non-conforming mines urged to comply within a specific time period where practicable. If they are unable to comply, then specific measures may need to be introduced to protect the health of the workforce.

To address the problem further, given its complexity and magnitude, requires the involvement of all role-players to look at all aspects of the problem, starting with the consideration of the dust properties considered most likely to be significant. Where appropriate, short-term and focussed epidemiological studies need to be undertaken in parallel and on a multidisciplinary basis for each of these properties, but based on the development or examination of specific health related hypotheses. Due cognisance should be taken of other significant factors such as HIV, smoking, and exposure to other airborne pollutants such as diesel emissions. This co-ordinated group of studies should be aimed at identifying the dominant dust property or properties responsible for the incidence of respiratory system or lung disease. This phase may encompass the study of breathing rates and synergism between dust and other pollutants such as diesel exhaust particulate and radon. At the same time the technical details of sampling methods and instrumentation could be reviewed.

Such a co-ordinated group of studies will last a number of years but should yield a more complete understanding of the mechanisms likely at play in disease development. Once these studies are completed, research should focus on the development of monitoring instrumentation and measurement systems to determining worker exposure to relevant factors more accurately.

In the interim, the structured monitoring of worker exposure using full-shift gravimetric sampling as a surrogate for exposure is perhaps an appropriate practice. However, this should involve the recording of occupations along universally accepted classifications of job titles. This data can be used to bench-mark progress in exposure control between mines, in the various occupational categories and within demarcated sections of each mine.

The process outlined above needs to form part of a strategically structured programme developed within the context of a clear and agreed occupational health related policy with associated objectives. Whilst independent industry wide surveys of particular dust and radiation properties *may* form a valuable component of such a programme, to commission such studies in isolation *now* may be premature and result in a less than optimal deployment of available resources.

7 Conclusions and recommendations

Since the introduction of routine operator sampling programmes in recent decades in many countries, statistically designed independent dust exposure surveys have been fairly rare. Internationally, the trend has been to make use increasingly of operator-collected data for dust exposure studies.

While many studies have been conducted in recent years examining trends in such dust exposure data and linking existing exposure rate data to diseases or effects, in most of these studies the accuracy of exposure data is not evaluated, and is generally accepted as a "given", without consideration of how data were obtained, or of confidence limits. Literature detailing actual dust survey methods to obtain statistically accurate and representative exposure data is, on the contrary, limited, and the most useful sources date back to the late 1950's and 1960's.

Due to the fact that equipment which is now outdated, and which involved particle counting techniques, was used in many of the surveys discussed (including the Corner House Laboratory Studies which are still used today by South African epidemiologists as a source of exposure data) limitations on the accuracy of associated exposure data exist. Sampling methods used in such older studies are also likely to have introduced inaccuracies, due to the relatively large distances of samplers from worker breathing spaces.

Although use of operator-collected data overseas is the norm, there is a noticeable lack of use of such data in South Africa, apparently because the information is not in an ideal form, and uncertainties exist with regard to its accuracy.

There is no obvious commonality of job category and occupation descriptions used in formal employment records within the Gold, Coal, and Platinum mining industries and it is not currently feasible to organise these into a common industry wide or sector specific reference data-bases.

There does not appear to be any clearly defined industry wide discrete (statistical) exposure populations from which to draw samples, and upon which a survey design could be based. Discrete populations based on job category and occupation exist only at individual mine level.

Dust exposure data is generally collected for a specific purpose, and that that purpose determines the methods and procedures used during the collection and analysis process. There are thus numerous factors which influence the extent and design of any survey. As such the underlying epidemiological basis for any independent exposure surveys have not been explicitly determined in a structured and holistic fashion such as to enable the objective design of useful or meaningful exposure surveys at this time.

Survey strategies consisting of assessments of exposure of the existing populations to only basic dust and radiation parameters could take many years to complete at significant cost and are unlikely to be practicable or useful.

The possibility exists of undertaking independent surveys based on industry wide job codes once these can be confirmed as in general use. However the resource implications of such an approach are also significant and the potential usefulness of the resultant data has not been established.

A review should be undertaken of the practicability and desirability of introducing and enforcing a common job categorisation and occupation description system across the industry prior to commissioning any industry wide exposure survey.

Given that industry wide exposure surveys and epidemiological studies often require a period of several years for completion, recognition should be taken of the dynamic nature of the industry and the evolution of new work practices e.g. multi-skilling, mechanisation etc. The effect is that the work content of specific occupations may change radically over relatively short time periods and therefore any common unified coding system is likely to have only a limited period of validity.

The intended use of any industry wide exposure survey data should be clearly specified prior to commissioning any industry wide exposure survey.

While operator-collected data in South Africa may be associated with certain limitations, its usefulness for future research should be carefully considered before commissioning any independent surveys. As statistical populations exist at an individual mine level, and as individual mines currently generate routine dust sample data, consideration should be given to utilising this for epidemiological purposes. However, it must be ensured that an 'audit trail' linking statistical population groups to formal employment records exists and that processes are established to verify the quality of the assessment processes.

The issue of dust exposure and radiation exposure assessment for epidemiological purposes should form part of a strategically structured programme developed within the context of a clear and agreed occupational health related policy with associated objectives.

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Appendix 1 Survey cost estimates

Appendix 1a: Costs for surveys generating 10 respirable dust measurements per day and 200 monthly radon/external dose assessments

Cost Item	Assumptions	Unit cost	Units	Units/year	Total cost (R)
Manpower					
Occupational Hygiene Technicians	Assume 2 required @t total employment cost of R200,000 pa	200000	R/y	2	400000
Statistician	Assume required for 20% of time @ total employment cost of R300,000 pa	300000	R/y	0.2	60000
Occ Hygiene professional	Assume required for 20% of time @ total employment cost of R300,000 pa	300000	R/y	0.2	60000
Rad protection specialist	Assume required for 10% of time @ total employment cost of R300,000 pa	300000	R/y	0.1	30000
Project Manager	Assume required for 20% of time @ total employment cost of R300,000 pa	300000	R/y	0.2	60000
Admin Support	Assume required for 50% of time @ total employment cost of R100,000 pa	100000	R/y	0.5	50000
Sub-total manpower					**660000**
Travel and subsistence					
Travel	Assume traveling of 1000 Km/week @ R1.5/Km	1.5	R/k	50000	75000
Accommodation & meals	Assume 4 person-days per week @ R400/day	400	R/day	200	80000
Sub-total travel and subsistence					**155000**
Analysis					
Respirable dust	Assume only gravimetric analysis of respirable dust using services of "AIA"	40	R/analysis	2500	100000
Radioactive dust analysis	Assume total alpha analysis using services of "accredited laboratory"	50	R/analysis	2500	125000
Radon assessments	Assume radon track etch cups issued for 1 month using "accredited laboratory"	85	R/analysis	2400	204000
External dose assessments	Assume SABS TLD badges issued for 1 month	25	R/analysis	2400	60000
Sub-total analysis					**489000**
Consumables					
Filter cassettes	Assume re-used 10 times	6	each	250	1500
Shrink seals		0.45	each	2500	1125
Cyclones	Assume replacement each year	190	each	30	5700
Petri dishes	Assume re-used 5 times	3.6	each	900	1800
Sub-total consumables					**10125**
Equipment					
Equipment replacement/repair	Assume 30% of capital cost				89925
Sub-total equipment					**89925**
Total direct operating costs					**1404050**
General overheads	Assume 10% of operating cost				140405
Sub-total					**1544455**
Contingency	Assume 25%				386113.8
Total					**1930569**

Capital Item	Assumptions	No req'd	Units	Unit cost (R)	Cost
Sample pumps	Assume factor of 3 for charge/calibration and maintenance	30	Each	7000	210000
Flow calibrators		3	Each	11000	33000
Aircell		2	Each	11000	22000
Chargers	Assume 50% unserviceable	15	Each	500	7500
Total					**272500**

Appendix 1b: Costs for surveys generating 20 respirable dust measurements per day and 400 monthly radon/external dose assessments

Cost Item	Assumptions	Unit cost	Units	Units/year	Total cost (R)
Manpower					
Occupational Hygiene Technicians	Assume 2 required @t total employment cost of R200,000 pa	200000	R/y	2	400000
Statistician	Assume required for 20% of time @ total employment cost of R300,000 pa	300000	R/y	0.2	60000
Occ Hygiene professional	Assume required for 20% of time @ total employment cost of R300,000 pa	300000	R/y	0.2	60000
Rad protection specialist	Assume required for 10% of time @ total employment cost of R300,000 pa	300000	R/y	0.1	30000
Project Manager	Assume required for 20% of time @ total employment cost of R300,000 pa	300000	R/y	0.2	60000
Admin Support	Assume required for 50% of time @ total employment cost of R100,000 pa	100000	R/y	0.5	50000
Sub-total manpower					**660000**
Travel and subsistence					
Travel	Assume traveling of 2000 Km/week @ R1.5/Km	1.5	R/k	100000	150000
Accommodation & meals	Assume 4 person-days/nights per week @ R400/day	400	R/day	200	80000
Sub-total travel and subsistence					**230000**
Analysis					
Respirable dust	Assume only gravimetric analysis of respirable dust using services of "AIA"	40	R/analysis	5000	200000
Radioactive dust analysis	Assume total alpha analysis using services of "accredited laboratory"	50	R/analysis	5000	250000
Radon assessments	Assume radon track etch cups issued for 1 month using "accredited laboratory"	85	R/analysis	4800	408000
External dose assessments	Assume SABS TLD badges issued for 1 month	25	R/analysis	4800	120000
Sub-total analysis					**978000**
Consumables					
Filter cassettes	Assume re-used 10 times	6	each	500	3000
Shrink seals		0.45	each	5000	2250
Cyclones	Assume replacement each year	190	each	50	9500
Petri dishes	Assume re-used 5 times	3.6	each	1000	3600
Sub-total consumables					**18350**
Equipment					
Equipment replacement/repair	Assume 30% of capital cost				137775
Sub-total equipment					**137775**
Total direct operating costs					**2024125**
General overheads	Assume 10% of operating cost				202412.5
Sub-total					**2226538**
Contingency	Assume 25%				556634.4
Total					**2783172**

Capital Item	Assumptions	No req'd	Units	Unit cost (R)	Cost
Sample pumps	Assume factor of 2.5 for charge/calibration and maintenance	50	Each	7000	350000
Flow calibrators		3	Each	11000	33000
Aircell		2	Each	11000	22000
Chargers	Assume 25% unserviceable	25	Each	500	12500
Total					**417500**

Appendix 1c: Costs for surveys generating 50 respirable dust measurements per day and 1000 monthly radon/external dose assessments

Cost Item	Assumptions	Unit cost	Units	Units/year	Total cost (R)
Manpower					
Occupational Hygiene Technicians	Assume 4 required @t total employment cost of R200,000 pa	200000	R/y	4	800000
Statistician	Assume required for 50% of time @ total employment cost of R300,000 pa	300000	R/y	0.5	150000
Occ Hygiene professional	Assume required for 50% of time @ total employment cost of R300,000 pa	300000	R/y	0.5	150000
Rad protection specialist	Assume required for 25% of time @ total employment cost of R300,000 pa	300000	R/y	0.25	75000
Project Manager	Assume required for 50% of time @ total employment cost of R300,000 pa	300000	R/y	0.5	150000
Admin Support	Assume required for 100% of time @ total employment cost of R100,000 pa	100000	R/y	1	100000
Sub-total manpower					**1425000**
Travel and subsistence					
Travel	Assume traveling of 2500 Km/week @ R1.5/Km	1.5	R/k	125000	187500
Accommodation & meals	Assume 6 person-days/nights per week @ R400/day	400	R/day	300	120000
Sub-total travel and subsistence					**307500**
Analysis					
Respirable dust	Assume only gravimetric analysis of respirable dust using services of "AIA"	40	R/analysis	12500	500000
Radioactive dust analysis	Assume total alpha analysis using services of "accredited laboratory"	50	R/analysis	12500	625000
Radon assessments	Assume radon track etch cups issued for 1 month using "accredited laboratory"	85	R/analysis	12000	1020000
External dose assessments	Assume SABS TLD badges issued for 1 month	25	R/analysis	12000	300000
Sub-total analysis					**2445000**
Consumables					
Filter cassettes	Assume re-used 10 times	6	each	1250	7500
Shrink seals		0.45	each	12500	5625
Cyclones	Assume replacement each year	190	each	130	24700
Petri dishes	Assume re-used 5 times	3.6	each	2500	9000
Sub-total consumables					**46825**
Equipment					
Equipment replacement/repair	Assume 30% of capital cost				340065
Sub-total equipment					**340065**
Total direct operating costs					**4564390**
General overheads	Assume 10% of operating cost				456439
Sub-total					5020829
Contingency	Assume 25%				1255207
Total					**6276036**

Capital Item	Assumptions	No req'd	Units	Unit cost (R)	Cost
Sample pumps	Assume factor of 2.5 for charge/calibration and maintenance	130	Each	7000	910000
Flow calibrators		5	Each	11000	55000
Aircell		3	Each	11000	33000
Chargers	Assume 25% unserviceable	65	Each	500	32500
Total					**1030500**

Appendix 1d: Costs for surveys generating 100 respirable dust measurements per day and 2000 monthly radon/external dose assessments

Cost Item	Assumptions	Unit cost	Units	Units/year	Total cost (R)
Manpower					
Occupational Hygiene Technicians	Assume 6 required @t total employment cost of R200,000 pa	200000	R/y	6	1200000
Statistician	Assume required for 100% of time @ total employment cost of R300,000 pa	300000	R/y	1	300000
Occ Hygiene professional	Assume required for 100% of time @ total employment cost of R300,000 pa	300000	R/y	1	300000
Rad protection specialist	Assume required for 50% of time @ total employment cost of R300,000 pa	300000	R/y	0.5	150000
Project Manager	Assume required for 100% of time @ total employment cost of R300,000 pa	300000	R/y	1	300000
Admin Support	Assume required for 100% of time @ total employment cost of R100,000 pa	100000	R/y	1	100000
Sub-total manpower					**2350000**
Travel and subsistence					
Travel	Assume traveling of 300 Km/week @ R1.5/Km	1.5	R/k	150000	225000
Accommodation & meals	Assume 12 person-days/nights per week @ R400/day	400	R/day	600	240000
Sub-total travel and subsistence					**465000**
Analysis					
Respirable dust	Assume only gravimetric analysis of respirable dust using services of "AIA"	40	R/analysis	25000	1000000
Radioactive dust analysis	Assume total alpha analysis using services of "accredited laboratory"	50	R/analysis	25000	1250000
Radon assessments	Assume radon track etch cups issued for 1 month using "accredited laboratory"	85	R/analysis	24000	2040000
External dose assessments	Assume SABS TLD badges issued for 1 month	25	R/analysis	24000	600000
Sub-total analysis					**4890000**
Consumables					
Filter cassettes	Assume re-used 10 times	6	each	2500	15000
Shrink seals		0.45	each	25000	11250
Cyclones	Assume replacement each year	190	each	250	47500
Petri dishes	Assume re-used 5 times	3.6	each	5000	18000
Sub-total consumables					**91750**
Equipment					
Equipment replacement/repair	Assume 30% of capital cost				634425
Sub-total equipment					**634425**
Total direct operating costs					**8431175**
General overheads	Assume 10% of operating cost				843117.5
Sub-total					**9274293**
Contingency	Assume 25%				2318573
Total					**11592866**

Capital Item	Assumptions	No req'd	Units	Unit cost (R)	Cost
Sample pumps	Assume factor of 2.25 for charge/calibration and maintenance	250	Each	7000	1750000
Flow calibrators		6	Each	11000	66000
Aircell		4	Each	11000	44000
Chargers	Assume 25% unserviceable	125	Each	500	62500
Total					**1922500**