Retrospective case-control study of cancer incidence associated with vanadium pentoxide exposure in the mineral processing industry

by

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Submitted in partial fulfilment of the requirements for the degree

MSc (Epidemiology)

at the School of Health Systems and Public Health

University of Pretoria

September 2009

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DECLARATION

I, MH Fourie, hereby declare that the work which I hereby submit as partial fulfilment for the degree **MSc (Epidemiology)** is original (except where acknowledgements indicate otherwise) and that neither the whole work nor any part of it has been submitted, or is being submitted for another degree at this or any other university.

Signed: Date: 1 September 2009

Acknowledgements

This study and the dissertation flowing there from would not have been possible without the following people and institutions:

1. Vanitec for support and part funding of the project;
2. The cooperation, time and patience of various employees of the SA and USA vanadium processing plants;
3. Information on the current and historical chemical processes, physical structure and work organisation at the plants, patiently supplied by various engineers and managers at the processing plants;
4. Data on personal air sampling and analysis results supplied by the two processing plants;
5. Lists of current and previous employees supplied by the two processing plants and by the retirees' club of the USA processing plant;
6. The cooperation of all study participants or their next-of-kin;
7. The ethics review by the University of Pretoria Ethics Committee;
8. Prof Kuku Voyi, the academic study leader, for her direction, patience, support and encouragement;
9. Dr Zeleke Worku for direction on the statistical analyses;
10. Greta Mouton and Samantha Hodgson for technical support during the preparation of the manuscript;
11. INFOTOX for allowing me to spend time on the project, and
12. The Lord God; by His grace all have been possible.

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Acronyms and abbreviations

AMV	Ammonium metavanadate
CCD	Counter current decantation
DME	Department of Minerals and Energy
DNA	Deoxyribonucleic Acid
FeV	Ferrovanadium
HEGs	Homogenous exposure groups
IARC	International Agency for Research in Cancer
ICP/MS	Inductively Coupled Plasma/Mass Spectrometry
MVO	Modified vanadium oxide, or vanadium trioxide: V_2O_3
Nitrovan	Nitrovan is the trade name of the product, and the participating company has stipulated that the chemical composition of the product may not be clarified in more detail, except a statement that it does not contain V_2O_5
NTP	National Toxicology Program
OEL	Occupational exposure limit
RO	Reverse Osmosis
SABS	South African Bureau of Standards
SRP	Sulphate recovery plant
SX	Solvent extraction
USEPA	United States Environmental Protection Agency

Abstract

Background

Vanadium is an economically important mineral that is mined and processed at several international locations, including South Africa and the USA. Vanadium exists in several oxidative states, of which the pentavalent compounds are usually the most toxic. Vanadium pentoxide (V_20_5) is pentavalent and is generated during various processing and metal alloy manufacturing processes. Occupational exposure may occur via inhalation of V_20_5 fumes and particles, resulting primarily in adverse effects to the respiratory system. Currently, there is no evidence that vanadium is carcinogenic in humans, and it has never been reported in exposed humans. The International Agency for Research in Cancer (IARC) has classified V_20_5 as possibly carcinogenic to humans, based on the increased incidence of bronchiolo-alveolar neoplasms observed in male and female mice and male rats in a study by the National Toxicology Program (NTP) of the US Department of Health and Human Services. The NTP study has prompted the international vanadium industry, embodied by Vanitec, the international association of vanadium producers, to request an epidemiological study with the aim of determining the potential association between cancer and occupational V_20_5 exposure.

Aim

The aim of the study was to conduct a pilot retrospective case-control study to investigate the relationship between cumulative occupational exposure to V_2O_5 and the risk of developing cancer at two representative vanadium processing plants, one in SA and one in the USA.

Methods

All cases and controls were sourced from the industry's current and past employee corps. Employees that could potentially have been exposed to V_2O_5 in the workplace for a period of at least 5 years were included in the study.

Ethics approval for the study was obtained from the Ethics Committee of the University of Pretoria. Participation was on a voluntary basis, and all potentially eligible current workers were invited to participate. As many retirees and former employees as possible were traced and invited to participate, and eligible deceased employees that conformed to the inclusion and exclusion criteria were identified from lists provided by

the companies involved. Potential participants were asked to grant informed consent to participate in the study. Health and lifestyle information, information on fuel use in the family home, and a personal job history were obtained by use of a structured questionnaire during a personal interview with a trained interviewer. Interviews were conducted from April to July 2004.

The main inclusion criterion for both cases and controls was current or previous employment at the South African, or the USA vanadium processing facility included in the study. The disease case definition was histologically confirmed cancer. Exclusion criteria were: refusal of interview; less than 5 years in employment when V_2O_5 was produced at the plant; cause of death not ascertained, employment elsewhere in the vanadium industry, and exposure to a known carcinogenic agent during a period of employment elsewhere. Males and females were included and participants were not excluded on the basis of race or ethnicity. Employees of all ages were eligible.

Exposure assessment at both plants was based on recorded V_2O_5 concentrations in personal air samples, the participant's job history, the history of vanadium processing, the physical structure and work organisation at the processing plants. Historical V_2O_5 concentrations in air in the workplace were retrospectively estimated for those periods during which personal air sampling was not conducted. Historical concentrations were estimated by extrapolation from current (known) air concentrations, in conjunction with data on annual production volumes, personal experiences of occupational hygienists and plant managers at the plant, and historical records of plant upgrades, controls on emissions, changes in production processes and industrial incidents and accidents, where available at the plants. Exposure was expressed as the cumulative exposure (mg-years/m^3) and the mean air concentration (mg/m^3) of V_2O_5 to which participants had been exposed. Study participants were also classified into exposure categories based on their mean exposure concentrations.

Results

In total, 196 questionnaires were collected from eligible participants. The majority (94.4 per cent) were males. Smoking and the consumption of alcohol was fairly common amongst the study group, with 61 per cent of the participants being current or previous smokers, and 59.5 per cent indicating that they were drinking alcoholic drinks or beverages. The mean age ($\pm$ SD) of the study group was 52.4 $\pm$ 10.2. The annual mean exposure of the study group during the period of employment was 0.02 $\pm$ 0.03 mg/m^3 V_2O_5, and the mean cumulative exposure to V_2O_5 was 0.17 $\pm$ 0.46 mg-years/m^3.

Four (4) cancer cases were confirmed at the South African plant, and 6 at the USA plant: four adenocarcinomas (three each in the prostate and one in the colon); three squamous cell carcinomas (two each in the lung and one skin cancer); one renal cell cancer of the kidney, one seminoma of the testis, and one papillary urothelial cancer of the bladder. The occurrence of prostate and lung cancers were not unusual, giving the presence of risk factors such as relatively advanced age (for prostate cancer) and smoking (for lung cancer). The other types of cancer, and the ages at which cancer was most frequently diagnosed (the mean age at diagnosis of cancer was 58.5) were not remarkably different from those that were prominent in the cancer literature. An unusual cluster of specific types of cancer, or of any prominent and unusual organ involvement not associated with known non-occupational risk factors, was therefore not found in the case group.

Conclusion

The results of this study fail to indicate a statistically significant association between cancer and various indices of exposure to vanadium pentoxide. This conclusion is subject to a number of limitations and uncertainties arising from the small number of cases available for study, and limited follow-up of some participants. The potential association between exposure and cancer should be tested in a larger study group with more cancer cases, allowing more powerful statistical analyses, ideally multivariate logistic regression analysis.

The study has confirmed the feasibility of the retrospective assessment of exposure to vanadium compounds in the vanadium processing industry, providing that the processing plant history covers detail of processing methodologies, physical structures, production volumes and work organisation, and providing that a detailed job history should be available for all potential participants. Confirmation of the cause of death and cancer status of previous employees was not practical in the South African scenario. An open case-control design nested in a prospective cohort should be more successful in the South African scenario, but also more expensive and results will only be available after an extended follow-up period. In the USA scenario tracing of previous employees, and access to cancer registries and death certificates should be more practical, and a retrospective case-control study should be possible.

Keywords: vanadium, vanadium pentoxide, cancer, exposure assessment, mineral processing, occupational health, case control, epidemiology.

Chapter 1: Introduction

1 Vanadium

Vanadium is an economically important mineral that is mined and processed at several international locations, including in South Africa. The vast majority of vanadium is used as ferrovanadium or as vanadium carbide in the production of high-resistance carbon steels. Nonferrous alloys that contain vanadium are used in jet aircraft, space technology, and the atomic energy industry. Vanadium compounds are used as catalysers in the petroleum and chemical industry, for the purification of exhaust gases, as accelerators for the drying of paint, colouring agents in the manufacture of glass, ceramics and inks and are used in the production of fluorescent lights, batteries and coloured phosphorus.[1,2] Vanadium is also a frequent constituent of steel used for orthopaedic implants.[3]

Elemental vanadium does not occur in nature; however, vanadium compounds exist in over 50 different mineral ores and in association with fossil fuels. It has six oxidation states (1^-, 0, 2^+, 3^+, 4^+, and 5^+) of which the 3^+, 4^+, and 5^+ valency states are the most common. The most stable oxidation state is the quadrivalent state (V^{4+}, VO^{2+}, vanadyl). Pentavalent (V^{5+}, vanadate) salts include metavanadate (VO_3^-), orthovanadate ($H_2VO_4^-$), and pyrovanadate ($V_2O_7^{4-}$).[1,4] Protonation of vanadium occurs in acidic solutions; below pH 3.5, it becomes a monovalent cation (VO_2^+). In basic solutions, the element occurs as VO_4^{3-}, with chemistry similar to that of one of the physiological phosphates (PO_4^{3-}). In neutral solutions, vanadium occurs as H_2VO_4[1,5].

The toxicologically significant compounds are vanadium pentoxide (V_20_5), sodium metavanadate ($NaV0_3$), sodium orthovanadate (Na_3V0_4) and ammonium metavanadate (NH_4V0_3) (all pentavalent (5^+) vanadium) and vanadyl sulphate ($V0S0_4$) (tetravalent (4^+) vanadium).[1,4] The metavanadate form (VO_3^-) is the most common state in extracellular body fluids whereas the quadrivalent form vanadyl (VO^{2+}) predominates intracellularly. The toxicity of vanadium increases with higher valences and the pentavalent compounds are usually the most toxic. Acidification tends to reduce the toxicity of vanadium compounds.[1]

2 Sources of exposure to vanadium

Anthropogenic sources account for about two-thirds of the atmospheric vanadium. These sources include the combustion of petroleum, coal and heavy oils during the generation of electricity and heat and vanadium-processing activities in the metallurgy industry. Typical air concentrations range from 1 to 60 ng V/m^3 in rural areas and 0.011 to 1.4 μg V/m^3 in urban areas, depending on the presence of industrial sources and the levels of consumption of fossil fuel during the production of electricity and heat.[1] Vanadium levels in air near metallurgical industries usually average about 1 μg V/m^3.[6] Drinking water is not an important source of exposure to vanadium for the general population with typical vanadium concentrations less than 1 μg/litre drinking water. Food is the major source of exposure to vanadium for the general population, even though most foods contain low concentrations of vanadium (less than 1 ng V/g).[6]

Occupational exposure occurs via inhalation of vanadium dust or fumes, particularly the pentoxide form in the course of mining the ore, the various manufacturing processes and also during maintenance on oil-using boilers, as many heavy oils used for energy generation contain vanadium.[2, 7] During these cleaning operations, environmental concentrations of 10 to 100 mg V/m^3 are frequently encountered and concentrations as high as 500 mg V/m^3 have been reported.[6, 8, 9]

3 Pharmacokinetics of vanadium

The absorption of vanadium compounds depends on their solubility and the route of entry. Vanadium is most easily absorbed by the pulmonary route.[10] It has been estimated that the rate of absorption of soluble vanadium compounds (e.g. V_2O_5) through the pulmonary route is about 25 per cent.[6] Inhalation of dusts and fumes is the major route of exposure of workers to vanadium.

Animal studies suggest that the rate of absorption of vanadium by the gastrointestinal tract is less than 1 to 2 per cent, even in the case of soluble vanadium salts. Dietary vanadium occurs either as vanadyl (4+) or as vanadate (5+), with the latter being absorbed about 3 times more effectively by the gastrointestinal tract than the former.[1] The dermal absorption is likely to be extremely small[11], although local contact irritation does occur.[2]

In blood, approximately 90 per cent of circulating vanadium occurs as vanadyl bound to plasma transferring and albumin. Following transport in plasma, the distribution of vanadium from blood is rapid, with a half-life of about 1 hour. Some VO^{3-} enters cells via anion transport systems where glutathione reduces vanadate (5+) to vanadyl (4+). Vanadyl is relatively non-reactive as a result of its complexing with proteins and with other small molecules. Vanadium generally does not combine with organic compounds. The highest concentrations of vanadium initially appear in the kidney, liver and lungs. In the long term, the bones and teeth retain the highest concentrations of vanadium.[1, 11]

As explained previously, most ingested vanadium is not absorbed and is eliminated in the faeces. Absorbed vanadium is rapidly excreted in the urine with a biological half-life of 20 to 40 hours. Some data suggest slow accumulation in the body in the course of chronic exposure.[1]

4 Health effects of vanadium

4.1 Respiratory effects

The toxicity of vanadium compounds depends on a variety of factors including the route of administration and the inherent toxicity of the particular compound. In general, the toxicity of vanadium compounds is low, and the toxicity is least following ingestion and greatest following parenteral administration. Inhalation produces intermediate toxicity.[1] Inhalation exposures to vanadium and vanadium compounds result primarily in adverse effects to the respiratory system. In studies on workers occupationally exposed to vanadium, the most clearly documented effects of vanadium dust are upper respiratory tract irritation characterised by mucus discharge (resulting in rhinitis), bronchospasm (resulting in wheezing), nasal haemorrhage, conjunctivitis, cough, pharyngitis, and chest pain. Such respiratory effects become evident at air concentrations between 0.01 and 0.52 mg V/m^3.[1, 2, 12] Exposure to high concentrations of V_2O_5, as experienced during maintenance of boilers, is prominently associated with rhinitis and cough. In these circumstances, symptoms are often referred to as “boilermakers bronchitis”.[13] Other upper airway symptoms are typically nasal congestion/irritation and throat irritation. Lower airway symptoms reported include chest tightness, wheeze, cough, and sputum production. Symptoms may be delayed a few days and recovery usually occurs within 2 to 5 days. Following more severe exposure, an acute bronchitis with dyspnoea and expiratory wheezes may develop along with gastrointestinal symptoms and fatigue.[1, 9]

Bronchitis and pneumonitis may occur after prolonged exposure.[1] Case studies suggested that asthma might develop after heavy exposure to vanadium compounds.[14] However, a prospective study of boilermakers exposed for 4 weeks failed to demonstrate a relationship between the vanadium concentration and the change in forced expiratory volume in the first second (FEV_1) adjusted for age and smoking. Similarly, there was no correlation between the vanadium concentration and airway responsiveness as measured by methacholine challenge.[15]

A South African study on vanadium plant workers showed that vanadium induces bronchial hyper responsiveness and asthma in some previously well individuals and that abnormal bronchial reactivity may persist for up to 23 months after cessation of exposure.[2] Another cross-sectional survey of 333 employees at a vanadium plant in South Africa revealed a threefold increase in asthma-like symptoms in current workers compared to a reference population not exposed to vanadium or other major respiratory irritants.[16]

4.2 Other systemic effects

Although workers exposed to vanadium compounds have reported non-specific symptoms (e.g. headache, palpations, weakness, tinnitus, dizziness), neurological symptoms are generally not well documented in the medical literature.[1] Recently, however, it has been shown that vanadium concentrations around 14.2 µg/litre in urine is associated with reduced neurobehavioral abilities, particularly visuospatial abilities and attention.[17] Vanadium seams to interfere with haeme synthesis, as a significantly positive and dose related correlation was observed between serum vanadium and zinc protoporphyrin in a study on workers exposed to vanadium. Erythrocyte zinc protoporphyrin is a valuable indicator of abnormal haeme synthesis, resulting from the incorporation of Zn^{2+}, instead of the missing Fe^{2+}, into the protoporphyrin molecule.[18]

Skin irritation may be associated with exposure to concentrations as low as 0.03 mg V/m^3 and eye irritation with concentrations as low as 0.018 mg V/m^3. A green discoloration of the tongue is associated with relatively heavy exposure to vanadium. Vanadium is a weak sensitising agent of skin at high concentrations, causing symptoms of dermatitis.[1]

There are no data on reproductive abnormalities in humans. Reproductive effects of vanadium have been reported in male rats and mice.[1, 19, 20] Experimental fetotoxicity and teratogenic effects were reported in hamsters and mice exposed to vanadium, vanadium pentoxide, orthovanadate or metavanadate. Vanadium is also embryotoxic.[21] With regard to the effects of vanadium on reproduction, gestation and lactation, it is now well established that the degree of vanadium toxicity depends on a series of factors such as the chemical form of the specific vanadium compound, the oxidation state of vanadium, the route of exposure, and the period of dosing, as well as the dose of vanadium administered.[20]

While there is a lack of information on the reproductive and developmental toxicity of vanadium following inhalation exposure, vanadium has been shown to be a reproductive and embryo/foetal toxicant when given orally. However, toxic effects of vanadate and vanadyl were observed only at dose levels remarkably higher than the amounts of vanadium usually ingested through diet and animal studies indicate that maternal toxicity occurs before the appearance of teratogenic effects.[1, 20, 60] Consequently, it was concluded that vanadium would not pose a risk for adverse effects in people under common environmental and nutritional conditions of exposure.[20]

4.3 Carcinogenicity

4.3.1 Toxicological studies

Currently, there is no evidence that vanadium is carcinogenic in humans, but the possibility remains, because vanadium interferes with mitosis and chromosome distribution.[1] Although positive genotoxicity results[1, 4, 21] and tumour promoting data[24] have been published for V_20_5, cancer has never been reported in exposed humans. The American Conference of Governmental Industrial Hygienists has decided that V_2O_5 is not classifiable as a human carcinogen.[25] The International Agency for Research in Cancer (IARC) has classified V_20_5 as possibly carcinogenic to humans (Group 2B)[26], based on the increased incidence of bronchiolo-alveolar neoplasms observed in male and female mice and male rats in the NTP study[27] discussed below. The overall evaluation was reached on the basis of *sufficient evidence* as to the carcinogenicity of vanadium pentoxide in experimental animals, in the absence of data on human cancer. The USEPA[28] have not yet classified vanadium or vanadium pentoxide according to its carcinogenicity.

In vitro studies indicate that V_2O_5 is not cytotoxic.[1,4] It is not clastogenic and is only weakly mutagenic[1, 12] or not at all, even when induced rat or hamster liver S9 enzymes are incorporated in the assay conditions. [27] The majority of *in vitro* studies on genotoxicity and possible neoplastic transforming activity of vanadium show positive effects in test systems using bacteria, yeast, hamster and mouse cells in culture for end points such as recombination repair, gene mutation, or DNA synthesis.[1, 4, 22] The NTP study[27] evaluated mice exposed through the inhalation route for an intermediary period (3 months), but evidence of *in vivo* genotoxicity of V_2O_5 was not found.

At least one study of the exposure of human leukocytes to vanadate showed DNA strand breaks.[23] Ivancsits and co-workers[3] showed that *ortho*-vanadate (Na_3VO_2) induced DNA fragmentation in cultured (isolated) fibroblasts at concentrations relevant to occupational exposure, but that *in vitro* exposure of whole blood leukocytes and lymphocytes to similar concentrations did not induce DNA fragmentation. The application of vanadium salts at low concentrations (less than 0.l pM) stimulated colony formation in fresh human tumour cells, but high concentrations (more than 0.l pM) inhibited growth.[24] These in vitro data indicate that vanadium has the potential for genotoxicity and tumour-induction in humans, although the tumour-inducing properties are apparently concentration-dependent.

Ivancsits and co-workers[3] also studied the *in vivo* effects of vanadium exposure in exposed workers showing significant vanadium uptakes (serum median of 5.38 µg V/litre, range of 2.18 to 46.35 µg V/litre). No increase in cytogenic effects or oxidative DNA damage could be demonstrated in leukocytes retrieved from these subjects. [3]

Evidence of genotoxicity of various vanadium compounds, in various oxidative states of vanadium, are therefore presented in some reports of *in vitro* studies employing various test systems, although other studies had negative outcomes and failed to confirm the DNA-damaging effects. In general, *in vivo* animal and human studies are lacking, except for the studies published by Invancsits and colleagues[3] and by the NTP[27], which failed to show DNA damage in leukocytes[3] or eruthrocytes[27] respectively. Therefore, it is currently not possible to draw unequivocal conclusions regarding the genotoxic potential of vanadium in its various oxidative states.

In vitro studies suggest that some vanadium compounds (vanadocene dichloride, peroxovanadates with or without a heteroligand) possess some anti-tumour properties[29]. V^{5+} might cause apoptosis in some types of cells, whereas V^{5+} may be anti-apoptotic in other types of cells. Cell apoptosis (controlled self-destruction of cells) was originally viewed as a normal process that maintained correct functional cellular population dynamics through the apoptotic loss of cell populations carrying abnormal genetic information. It is known that metals under certain circumstances are apoptotic, but it is not known whether this apoptotic process induced by metals is a perfect or an imperfect process. An imperfect apoptotic process might result in the escape of cells that would be potentially carcinogenic. Thus, increased apoptosis under the conditions of chronic metal exposure would possibly increase the number of cells carrying damaged but replication-competent genetic information. Conversely, chronic and lower dose exposure of cells or tissues to metals may perturb or even inhibit appropriate apoptosis, leading to the accumulation of cells with carcinogenic potential.[21, 30] It appears that further research on the tumourogenic potential of vanadium, specifically V_2O_5, is needed to clarify this topic.

The National Toxicology Program (NTP) of the US Department of Health and Human Services released a Technical Report on toxicology and carcinogenesis studies of vanadium pentoxide inhalation in rats and mice. Groups of 50 male and 50 female rats were exposed to atmospheres containing aerosols of 0.5, 1, or 2 mg of vanadium pentoxide particles per cubic meter of air. Groups of 50 male and 50 female mice were also exposed to atmospheres containing 1, 2, or 4 mg vanadium pentoxide per cubic meter. Animals were exposed six hours per day, five days per week for two years. Tissues from more than 40 sites on each animal were examined. Male rats exposed to vanadium pentoxide had greater than normal incidences of lung neoplasms, and some lung tumours also occurred in exposed female rats. It was concluded that exposure to vanadium pentoxide particles caused lung neoplasms in male rats and possibly in female rats, and in male and female mice.[27]

The most important point of critique against the NTP study is that the air concentrations translate into doses that would cause intolerable irritation effects in humans and would therefore never be experienced by workers in the processing plants. A literature search on the Medline database1 failed to raise any studies of the potential relationship between cancer in humans and any of the vanadium compounds, whether in the environmental or occupational exposure scenario. The key-words used were

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[1] MEDLINE was chosen since it is the primary source of global information from international biomedicine literature, and the primary such source available at the University of Pretoria.

vanadium/ vanadium compounds/ pentoxides/ cancer/ neoplasms/ disease/ kidney diseases/ gastrointestinal diseases/ respiratory tract diseases/ heart diseases/ bone diseases/ central nervous system diseases/ epidemiology/ occupational medicine.

The results of the NTP study prompted the international vanadium industry, embodied by Vanitec, the international association of vanadium producers, to request an epidemiological study with the aim of determining the association between cancer and occupational vanadium exposure.

4.3.2 Extrapolation of toxicological results to human cancer risks

The principle underlying the extrapolation of toxicological results of animal tests to inferred human risks is often referred to as the principle of phylogenetic continuity. According to this principle, prediction of human risks based on results of animal tests is valid because of the biological and biochemical similarities between species, including cell structure, energy metabolism, and transmission of genetic information. In most cases, animal findings may accurately predict effects in humans. However, researchers have also pointed out various instances of interspecies differences in metabolism of some substances, which had resulted in the conclusion that animal-to-human interpretation was found to be unreliable. Amongst these are predictions of carcinogenesis based on positive results in rodents that were later found to be invalid for humans.[71, 72]

One of the problem areas identified is the use of the maximum tolerated dose in animal toxicology studies. High doses are often used in animal cancer studies, because it is not economically feasible to test chemicals at low doses, which would require very large numbers of animals to detect statistically significant increases in cancer incidence. The use of high doses to assess human risks in the NTP V_2O_5 study[27] was probably unavoidable not only for this reason, but also since the range of doses to which workers are exposed in the case of occupational exposure to V_2O_5 is not readily available for extrapolation of relevant animal doses in toxicity studies. However, the practice is not without problems and has frequently been debated.

Some toxicologists are of the opinion that "testing for carcinogenicity in animals at near toxic doses does not give enough information to predict the excess number of cancers from low doses typically experienced by humans," according to Dr Lois Gold, director of the Carcinogenic Potency Database Project at Lawrence Berkeley Laboratory. Dr Gold was also of the opinion that high dosing may increase the number of tumours, because increased cell division, stimulated by cell toxicity at high doses and consequent cell replacement, may result in increased rates of mutations and tumors. If this is true, effects at low doses are likely to be much less than a linear model would predict and may often be zero, which would invalidate extrapolation of high dose effects to low doses presumably experienced by humans.[71, 72]

In response to criticism of the continued use of the MTD in long-term carcinogenesis bioassays, it has been argued that doubts about the perfection of the MTD should not lead to the abolishment of the experimental identification and measurement of potential human risks using animal models. Instead, such concerns should be taken into account when applying the results during the preliminary stages of the risk assessment process while also using all other available data on the chemical, according to Dr James Huff of the Environmental Carcinogenesis Program at the USA National Institute of Environmental Health Sciences (NIEHS).[71]

Oberdorster[73] raised an issue specifically related to chronic inhalation studies in rats with highly insoluble non-fibrous particles of low cytotoxicity. Concerns were expressed that lung conditions, amongst others also lung tumours, observed in such inhalation studies were due to excessive particulate lung burdens, and the term "particle overload" was coined to characterize these conditions. Accumulation of excessive particulate burdens is typically caused by impairment of alveolar-mediated lung clearance, which has been demonstrated under experimental conditions. Cytotoxic particles also cause impaired alveolar-mediated lung clearance, but at a much lower lung burden which does not qualify as particle overload. Species differences with respect to the induction of adverse chronic effects in response to lung overload were noted by Oberdorster[73] and further evidence of species differences became available in a more recent studiy.[75] Mice were less prone to the development of lung tumours and lung tumours in rats were observed only under conditions of a lung burden having caused impaired particle clearance. Evidence in humans suggest that particle-overloaded lungs, e.g. in coal workers, respond with fibrosis, but not with increased incidences of lung tumours.[73, 74] Oberdorster cautioned that it cannot be excluded that other types of chronically inhaled particles may have a carcinogenic potential in the human lung if accumulating to very high lung burdens. However, lung tumours observed in chronic rat studies at high particulate exposure concentrations may not be relevant for human extrapolation to low-exposure concentrations.[73, 74]

In vitro studies thus far indicated that V_2O_5 is not cytotoxic[1,4], but the NTP study reported that vanadium pentoxide appears to be slightly soluble in the lung, and as such, may be cytotoxic.[27] With regard to potential conditions of lung overload in the NTP study, data was presented to substantiate the conclusion that lung clearance rates did not reflect saturation kinetics in rats and mice,[27] and it may therefore be deduced that occurrence of lung overload was not likely under the experimental conditions. It was noted that mice cleared vanadium much faster from their lungs than did rats, although in rats and mice the clearance half-times under conditions of chronic exposure (2-year study) were much longer than under subchronic conditions (16-day study). [27]

From the above information it appears that extrapolation of carcinogenicity from the NTP mice and rat studies to humans is probably not invalidated by potential lung overload issues. However, the question remains whether tumours observed at the relatively high concentrations used in the animal studies are relevant under the conditions of very low exposure concentrations presumably experienced by humans in the occupational setting. This question is even more important when the focus is shifted to comparability of dose. In the chronic 2-year NTP studies, V_2O_5 exposure caused a more pronounced neoplastic response in mice than in rats, which the authors suggested may at least in part be explained by the fact that, on a body weight basis, mice received considerably more vanadium that rats. [27] If differences in the received dose is a possible explanation of the observed differences between mice and rats, the question of potential differences in the carcinogenic response to inhaled V_2O_5 between rodents and humans begs to be answered with a dose-based methodology.

4.3.3 Motivation for occupational epidemiology studies of V_2O_5 exposure

Human exposure to V_2O_5 is primarily an issue of occupational exposure. The most valuable application of the above studies is therefore in the occupational scenario, particularly in the vanadium processing industry, where V_2O_5 is produced. The above discussion highlights the general limitations and uncertainties associated with extrapolation of results of animal cancer studies to humans. Specifically, it serves to emphasise that assessment of the potential carcinogenicity of V_2O_5 in the occupational scenario cannot reach an unequivocal conclusion if only animal data, however complete and convincing with regard to animal experiments, are not complimented and extended by valid human epidemiological studies. In addition, it is clear that extrapolation from animal data of the relevant dose at which carcinogenesis in humans may be expected is subject to uncertainty and might not be as accurate as determination of this dose in an occupational epidemiology study.

The number of vanadium processing industries that produce V_2O_5 as an intermediary product is small. Therefore, the number of workers potentially exposed to V_2O_5 internationally is small. However, even if smaller numbers of workers are potentially effected, cancer has an intense impact on personal levels of health, emotional anxiety, quality of life, expendable income and employability, and on the public and private health systems of both developed and developing countries. This is a relevant motivation to conduct a pilot study of the potential association between cancer and exposure to V_2O_5 in the occupational setting.

5 Common sources of cancer risk in industrial workers

During the last decades, a considerable body of scientific evidence of the causative association between occupational exposure and different types of cancer has emerged. Common examples are benzene and leukaemia; formaldehyde and cancers of the nasal sinuses and nasopharynx; ionising radiation and leukaemia; and hexavalent chromium and lung cancer. It is therefore important to identify all known potential sources of cancer present in the occupational and social environment of the study participants in this pilot study aiming to examine the potential association between cancer and exposure to V_2O_5 in the vanadium processing industry. Because of the long lag period associated with cancer, past exposures of study participants in previous occupations were also considered.

The occupational environment in the vanadium processing industry is characterised by a limited variety of less complex chemical exposures, as is clear from the process descriptions in Sections 3.6 and 4.6 in the Methodology chapter. Very few chemicals are used: sodium sulphate, sodium carbonate, sulphuric acid, sodium chloride and ammonium sulphate. Besides the vanadium compounds generated during the various processes, the only other potential air-borne chemical compound is ammonia. Of these chemicals, none are known carcinogens. However, sulphuric acid mist is a known cancer-causing agent in humans, resulting in increases in lung, nasal and larynx cancers.[78] An acid mist is a suspension of acid droplets in air. Skin or eye contact with sulphuric acid, while dangerous, does not appear to cause increased rates of cancer.

Although sulphuric acid is used in the South African processing plant, an acid mist is not generated and this is therefore not regarded as a potential source of cancer amongst study participants. Mixtures of sodium sulphate, sodium carbonate, sulphuric acid, sodium chloride, ammonium sulphate and ammonia are not known carcinogenic agents. There is a general lack of information regarding the potential carcinogenic properties of vanadium, and nothing is currently known regarding the carcinogenic potential of mixed exposure to vanadium and each of, or a combination of, the other compounds noted in the process description.

Literature reports that asbestos is a cause of lung cancer and it has been classified as carcinogenic by IARC[31] and the USEPA[28] (last revised 1993). Asbestos workers have increased chances of getting two types of cancer: cancer of the lung tissue itself and mesothelioma, a cancer of the thin membrane that surrounds the lung and other internal organs. Numerous reports from several countries have described cases or series of pleural and peritoneal mesotheliomas in relation to occupational exposure to various types and mixtures of asbestos (reviewed by IARC[31]). Environmental exposure either in the houses of asbestos workers or in the neighbourhood of asbestos mines or factories has been noted in some of the cases and it has been estimated that a third of the mesotheliomas occurring in the USA may be due to nonoccupational exposure.[32] Adenocarcinomas of the lung were also reported in a number of studies.[33, 34]

In epidemiological studies, an interaction between two risk factors is generally defined as a "*departure from an additive or multiplicative model of relative risks when both risk factors are present*".[35] With respect to lung cancer, some studies indicate that the interaction between asbestos and smoking is greater than additive.[36, 37] Other studies have found that smoking increases the risk of lung cancer from asbestos exposure more than predicted by additivity, but often less than predicted by a multiplicative model.[38, 39] The mechanism by which smoking and asbestos interact to increase the risk of lung cancer is not known, but several hypotheses have been suggested. One possible mechanism is a smoking-induced decrease in clearance of fibers from the lung, perhaps by interference with ciliary action or macrophage activity,[40] leading in turn to increased penetration of the respiratory epithelium by fibers.[41]

It is commonly known that smoking increases the risk of developing lung cancer. Smoking has a strong effect on lung cancer risk, because smokers have about 10 times the risk of lung cancer as non-smokers.[42] It is therefore necessary to investigate the smoking habits of the study group.

Bagnardi et al.[43] conducted a meta-analysis of alcohol drinking and cancer risk on a total of 235 studies in which 117 471 cases were identified. Three levels of alcohol consumption were examined: 25 g a day, 50 g a day and 100 g a day (25 g corresponds to approximately 2 drinks a day). Associations were found between each level of alcohol consumption and cancers of the oral cavity and pharynx, oesophagus, larynx, breast, liver, colo-rectum and stomach. Associations were also found between alcohol consumption and cancers of the ovary and prostate, but only for 50 g and 100 g a day. No associations were found between alcohol consumption and cancers of the lung, small intestine, bladder, kidney, pancreas and endometrium. For melanoma and cancers of the gallbladder and cervix, no studies examined the effects of 100 g a day and no associations were observed at the other levels.

A cohort study on 13 064 men and 11 459 women participants, aged between 20 to 98 years, from Copenhagen examined the effect of wine, beer and spirits on death from all causes, coronary heart disease and cancer.[44] Wine drinkers were at lower risk for all-cause mortality than non-wine drinkers. Light drinkers who avoided wine had a 10 per cent reduced risk of all-cause mortality; those who included wine had a 34 per cent reduced risk. Light to moderate wine consumption (1 to 21 glasses a week) reduced mortality from all causes, coronary heart disease and cancer. Consuming more than 22 alcoholic drinks a week (excluding wine) was associated with a 63 per cent increased risk of cancer; if consumption included wine the risk dropped to 24 per cent. Consuming more than 21 beer or spirit drinks a week was associated with an increased risk of mortality.

Alcohol consumption, and both the dose and type of alcohol consumed, is therefore associated with the development of at least some types of cancer, or with mortality due to cancer. It is thus necessary to obtain information characterising the drinking habits of the study group.

6 Case-control studies of cancer in the occupational scenario

6.1 Strengths and weaknesses

Efficiency with regard to time and costs is one of the greatest strengths of the case-control study design.[79] A case-control study starts with an outcome (in this case cancer) and then traces back to investigate exposures, therefore it may be conducted in a shorter time-span than, for example, a prospective cohort study, in which time must pass to allow the occurrence and collection of cases. Since the diagnosis is already available at the outset of the investigation, resources may be focused on the known cases and the selected controls, which may require assessment of a smaller sample than, for example, a cohort study.

Cohort studies are usually large enterprises that require relatively large populations for follow-up, in order to obtain a substantial number of cases of the disease, that will allow stable estimates of incidence. Lengthy studies of large populations are by definition expensive. Most of the expense derives from the need to establish a continuing system for monitoring disease occurrence in a large population. This is especially true if the disease in question involves a long induction (lag) time, as may be the case with an investigation of cancer. Such cohort studies are expensive in relation to the amount of information returned, resulting in inefficiency in terms of the spent resources.[80]

One of the disadvantages of a case-control study is that the precision of the generated estimate of the incidence rate ratio is less that that from a cohort study of the same population.[80] Case-control studies are also subject to bias (e.g. recall bias with regard to exposures that are not on record, such as dietary habits), and it is difficult to obtain reliable information if record keeping is either inadequate or unreliable. An important limitation of case-control studies is that associations between the disease of interest and an exposure may be generated, but that causality is not demonstrated. [79]

6.2 Occupational case-control studies of cancer illustrated in the literature

Case-control studies of occupational risk factors for cancer are often hospital-based and examine a specific cancer, e.g. lung cancer,[81] laryngeal and hypopharyngeal cancer[82]. Case-control studies may also be focused on specific industries, e.g. textile workers (several studies reviewed by IARC[83]), a study of lung cancer amongst the pulp and paper workers,[84] and respiratory cancer within a cohort of nickel mining and refining workers.[85] Studies focused on specific industries select the cases and controls amongst the workers in these specific industries. Some of these are nested within a cohort, that is cases and controls are selected from amongst a defined cohort of workers in the industry.

7 Historical perspectives on vanadium processing

7.1 The South African processing plant

7.1.1 History

The South African company owning the current processing plant had historically operated a smaller vanadium processing plant (referred to as SA Plant A), which was gradually phased out and replaced by a larger and more modern facility some 50 to 60 km from the first plant (referred to as SA Plant B). There was, therefore, a period during which both plants were simultaneously in operation. V_2O_5 was the primary product at SA Plant A from 1966 until 1978, at which time V_2O_5 production was terminated and production was switched to V_2O_3 and Nitrovan[¶]. The plant was finally closed down in 1984, after which many of the SA Plant A employees were transferred to SA Plant B. Production of V_2O_5 had started at SA Plant B in 1976. V_2O_5 production at SA Plant B continued until August 1994, when production was switched to V_2O_3, Nitrovan and ferrovanadium (FeV). Therefore, since 1994, V_2O_5 has not been

[¶] Nitrovan is the trade name of the product, and the participating company has stipulated that the chemical composition of the product may not be clarified in more detail, except a statement that it does not contain V_2O_5.

produced at SA Plant B. The timeline relevant to exposure assessment of employees at the South African processing plant is summarised in Figure 1 below.

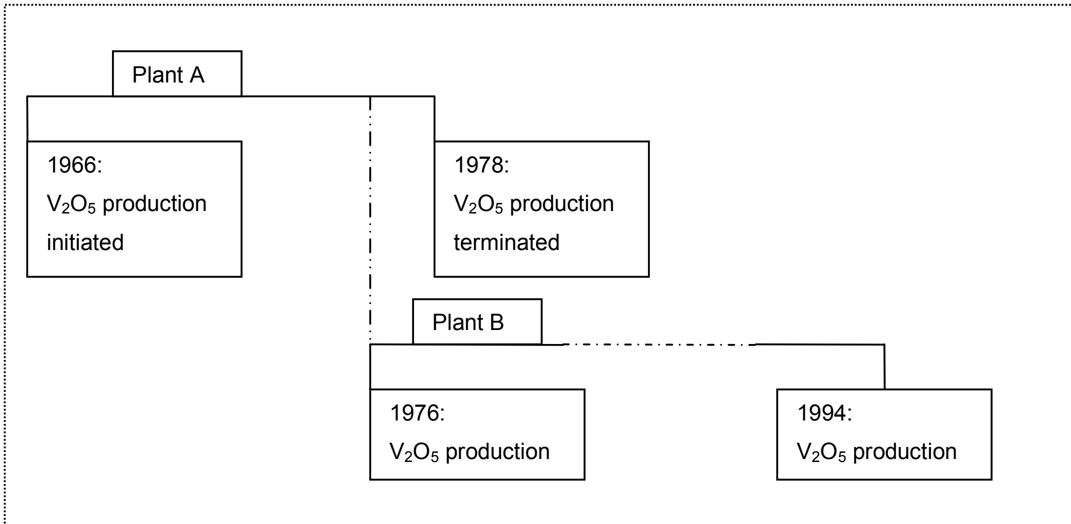

Figure 1: Timeline relevant to exposure assessment of employees at the South African processing plant.

7.1.2 Process description

The world-wide vanadium market is cyclical and therefore processing plants must be able to adapt to the product demands of the international market. The South African plant is therefore capable of producing a range of vanadium products from a number of starting materials. The facility is able to utilise vanadium-bearing magnetite ore, vanadium-bearing slag (purchased from other suppliers), or a combination of both. The range of products that may be produced includes V_2O_5, V_2O_3 (vanadium trioxide, also known as MVO – modified vanadium oxide), FeV (ferrovanadium), FeV slag or Nitrovan. The process is discussed below (information supplied by Bob Halland[48] – the South African processing plant).

The magnetite is concentrated from ore through crushing, screening, milling and finally magnetic separation (magnetic magnetite is separated from finely milled ore using magnets). The material left after magnetite has been removed is referred to as magnetite tailings.

After concentration, the next process is extraction, which takes place in two steps, namely roasting and leaching. Magnetite tailings (which are used as a carrier), magnetite, vanadium-bearing slag, sodium sulphate and sodium carbonate are mixed and fed to the pulverised coal-fired rotary kiln. The mixture is roasted to render the vanadium water-soluble. The kiln product is water-leached. The solids are wet milled, and washed in a counter-current process over a large belt filter. The magnetite tailings are disposed of on a tailings dump. The vanadium-bearing liquor (principally composed of sodium sulphate and sodium metavanadate) is pH adjusted with sulphuric acid before being pumped to the precipitation plant.

At the precipitation plant, AMV (ammonium metavanadate (NH_4V0_3)) is precipitated from the de-silicated solution (also called the pregnant solution) by addition of ammonium sulphate. Precipitated ammonium metavanadate (AMV) is separated from solution and is washed on a belt filter before being dried in a rotary drier. AMV is containerised, sampled and analysed prior to being fed to the vanadium trioxide (MVO) reactors or to the calciner, depending on the particular vanadium product to be produced.

The barren solution left over after precipitation is pumped to the sulphate recovery plant (SRP), where sodium sulphate is recovered from the solution, for re-use in the kiln (roasting).

Refining in the period prior to August 1994 (V_2O_5, V_2O_3 and Nitrovan production)

Following precipitation of AMV, two routes of refining were available: production of V_2O_5 or production of vanadium trioxide (MVO).

Production of V_2O_5 involves two steps, namely *de-ammoniation* and *fusion*. Dry AMV is converted to V_2O_5 powder by de-ammoniation in a calciner. V_2O_5 powder is fused to a melt that is tapped from the fusion furnace onto a water-cooled wheel, where V_2O_5 solidifies and is scraped off in the form of V_2O_5 flakes.

V_2O_5 flake may be sold as a final product or used to produce FeV. Ferro-vanadium (FeV) is produced in an electric arc furnace. The FeV metal is crushed to customer requirements, blended, packaged and shipped.

The production of MVO (modified vanadium oxide, or vanadium trioxide: V_2O_3) involves the following sections: the MVO reactor, the mix plant and the Nitrovan furnace. V_2O_5 is not present in these sections. Due to sensitivities around industrial intellectual property, more detail regarding this process cannot be given. The Nitrovan product is blended, packaged and shipped to customers.

Refining since August 1994 (V_2O_3 and Nitrovan production)

Dried ammonium metavanadate (AMV) from the precipitation area is fed to the vanadium trioxide (or MVO) reactors, in which AMV is reduced to V_2O_3 (MVO – modified vanadium oxide). MVO is drummed and is the raw material for both the ferro-vanadium and the Nitrovan plants. At the ferro-vanadium plant, ferro-vanadium (FeV) is produced in an electric arc furnace. The FeV metal is crushed to customer requirements, blended, packaged and shipped. Nitrovan is produced in the Nitrovan facility. V_2O_5 is not present in these sections. Nitrovan product is blended, packaged and shipped to customers. V_2O_5 is not present at the MVO reactors, in the FeV plant or in the Nitrovan facility.

Process summary

A summary of the process, the relevant activity area in the processing plant and the vanadium compounds involved in each step are presented in Table 1 below.

Table 1: Summary of mineral processing at the South African processing plant.

Process heading		Area in plant	Vanadium compounds
Concentration		Crushing, milling and separation	Very little exposure, vanadium compounds typically in inert state
Extraction: Roasting		Kiln feed	
Extraction: Leaching		Kiln discharge and leach	Sodium metavanadate ($NaV0_3$)
Refining prior to August 1994: V_2O_5 route	Precipitation, deammonation and fusion together in one area	Precipitation	1. Sodium metavanadate ($NaV0_3$) 2. AMV – ammonium metavanadate (NH_4V0_3)
		Calciner	1. AMV wet powder in 2. V_2O_5 formed
		Fusion furnace	1. Vanadium pentoxide (V_2O_5) powder into furnace 2. V_2O_5 flake moved out of fusion area in drums, already sealed
Refining prior to August 1994: V_2O_3 route	Reduction	MVO reactor	Vanadium pentoxide (V_2O_5) not present
	Mix and Nitrovan furnace	Mix plant Nitrovan furnace	Vanadium pentoxide (V_2O_5) not present
	Ferro-vanadium arc-furnace	Ferro-vanadium Only since September 1993	Vanadium pentoxide (V_2O_5) not present
Refining since August 1994	Reduction	MVO reactor	Vanadium pentoxide (V_2O_5) not present
	Ferro-vanadium arc-furnace	Ferro-vanadium	Vanadium pentoxide (V_2O_5) not present
	Nitrovan	Nitrovan facility	Vanadium pentoxide (V_2O_5) not present
Sulphate Recovery		Sulphate Recovery Plant	None

7.2 The USA processing plant

7.2.1 History

Production of V_2O_3 at the USA processing plant started in 1968. Processing of V_2O_5 started in 1985 and had continued since then. Processing of V_2O_3 also continued, but since 1985 the processing of V_2O_3 was slowly reduced and currently more V_2O_5 is produced. Since 1985/6 until the earlier part of 1992, the production proportions were approximately 90 per cent V_2O_3 and 10 per cent V_2O_5. Since 1992, production of V_2O_5 increased gradually until 1995, at which time the proportions were approximately equal (50 per cent V_2O_3 and 50 per cent V_2O_5). Production of V_2O_5 has increased at a slow pace after 1995, until the production of V_2O_5 (60 per cent) exceeded that of V_2O_3 (40 per cent) since 1999 (historical information obtained from Robert Elliott and André Breytenbach (USA processing plant)). Assuming linear increases in production of V_2O_5, estimates may be made of the percentages of V_2O_5 produced during each year.

7.2.2 Process description

Prior to 1989, vanadium rich ore was the major feed source and extraction was done by roasting and extrusion. Feed materials were fed through a hammer mill, dried, and mixed with salt (NaCl). The mixture was extruded to form pellets and roasted in a kiln. The calcined material was cooled and mixed with counter current decantation (CCD) liquor in the CCD circuit. From there the process continued in the product recovery circuit. The barren solids were fed to the tailings dam or settling pond.

Since 1989, vanadium bearing slags, ashes and petroleum cokes became the major feed sources and were fed directly to the extraction process. Labourers handled unloading and stacking of feed materials, while the feed operator delivered the material into the grinding mill with a front-end loader. The feed material went into a ball mill where the lumps were broken up and were then pumped to the leach tanks. Vanadium was converted to a soluble vanadium compound in the leach circuit, which maximised extraction.

The slurry from the leach circuit was pumped to the counter-current decantation (CCD) circuit where the soluble vanadium was washed from the leached solids. The barren solids were slurried and then pumped to the tailings pile. The liquor from this pile was recovered and recycled as process wash water in the CCD circuit, thereby eliminating a discharge. The vanadium containing liquor from the CCD circuit was fed to the product recovery circuit, where the vanadium containing liquor from the CCD circuit was upgraded and purified utilising solvent extraction (SX) and crystallisation technology. After crystallisation, vanadium oxides V_2O_5 and V_2O_3 were produced in rotary calciners.

In the reverse osmosis circuit, reverse osmosis was used to recycle ammonia streams, to improve process efficiency and to conform to environmental requirements related to effluent discharge. Liquid vanadium (vanadyl solutions) was prepared for direct sale to customers in the mixing tank in the liquid vanadium chemicals reaction circuit. All products were packaged at product packaging before being shipped to the customers.

7.2.3 Process summary

A summary of the process, the relevant activity area in the plant and the vanadium compounds involved in each step is presented in Table 2 below.

Table 2: Summary of mineral processing at the USA processing plant.

Process heading	Area in plant	Vanadium compounds
Feed	Feed pad	Very little exposure, vanadium compounds typically in inert state
Extrusion (before 1989)	Mill and extrusion	
Roasting (before 1989)	Kiln	
Grinding (since 1989)	Feed	
	Grinding (ball) mill	
Leaching	Leach circuit	Sodium metavanadate ($NaV0_3$)
	Decantation	Sodium metavanadate ($NaV0_3$)
Product Recovery Circuit – all areas under one roof – all exposed to V_2O_5 dust	Liquid ion exchange (SX – solvent extraction)	Sodium metavanadate ($NaV0_3$) Ammonia vanadium salts
	Crystallisation	Ammonia vanadium salts
	Drying and calcination (calcination in reactor) – MVO calciner area	Ammonia vanadium salts, MVO and V_2O_5
Reverse Osmosis (RO) Circuit (Since December 1995, RO personnel spent approximately 40 per cent of their time in the MVO-SX area)	AMV thickener	Ammonia vanadium salts
Discharge	Raffinate thickener	None
Gypsum precipitation	Gypsum precipitation tanks and centrifuge	None
Liquid vanadium chemicals circuit (manned by RO operators since 2003)	Vanadyl solutions process	MVO and V_2O_5, vanadyl solutions
Packaging	Packaging	V_2O_5, AMV ($NHV0_3$) and MVO

7.3 Dust sampling in the vanadium processing industry

7.3.1 Methodology

The toxicity and the deposition characteristics of air-borne particles in the respiratory tract are determined by the size characteristics of airborne particulates. Smaller particles will tend to deposit deep into the gas exchange region of the lung.[49] To more appropriately assess the possible health effects of airborne particulate matter, exposure guidelines have typically been issued for different sizes of particles. Workplace exposure guidelines have traditionally been expressed as total dust and respirable dust.

Total dust is collected by using a filter of a type and pore size appropriate to the particulate being sampled. The filter is loaded into a cassette and connected to a sampling pump that has been calibrated to a specific flow rate. Samples are collected in an area or in the breathing zone of workers (in which case it is referred to as a personal sample).[50]

Some regulations require the measurement of respirable dust. Respirable dust can penetrate the lung defense mechanisms of the human body and penetrate deep into the gas exchange (alveolar) region of the lung. Respirable dust is collected onto a filter of a type and pore size that is appropriate for the particulate being sampled. Preceding the filter, however, is a particle size-selective device, typically a cyclone, that will separate the respirable fraction from the non-respirable fraction when connected to a pump sampling at the designated flow rate.[50] When taking a respirable sample, a small cyclone with a collection efficiency of 100 per cent for submicron particles, decreasing to an efficiency of 50 per cent for 4 µm particles and an efficiency of 1 per cent for 10 µm particles, is used. Typically the respirable fraction is about 20 per cent of the total ambient dust.

New workplace exposure guidelines have been adopted by several international agencies for inhalable particulate mass, thoracic particulate mass and respirable particulate mass. Inhalable dust is a term used to describe dust that is hazardous when deposited anywhere in the respiratory tract including the nose and mouth. Inhalable dust has a 50 per cent cut-off point of 100 µm and includes the larger and the smaller particles. Thoracic particulates are dust particles having a 50 per cent cut–off point of 10 µm. These particles may be hazardous when deposited in the pulmonary region.[50]

When taking an inhalable sample, a sampler similar to the one in Figure 2 is used. This is calibrated to a collection efficiency of 100 per cent for submicron particles, decreasing to 50 per cent at 100 µm, but with no upper size limit. The entire cassette and filter is weighed before and after sampling, with the result that material that has collected on the lip of the cassette is included in the inhalable sample. Typically this is 80 percent or more of the total ambient dust.[51]

Figure 2: Sampling cassette for collecting inhalable samples.

Source: Woolery[51]

7.3.2 Sampling and analysis at the South African processing plant

Dust sampling in mines and processing plants is performed according to the occupational hygiene regulations of the Department of Minerals and Energy (DME). Processing plants are sub-divided into activity areas as per the activity area code list found in the guideline document of the DME. Statistical populations of persons generally supposed to be exposed to similarly dusty environments (also referred to as homogenous exposure groups (HEGs)) are subsequently identified in each activity area (work area). A predetermined percentage of workers belonging to the HEG group is then selected randomly and monitored on a regular basis.[52]

At the South African processing plant, personal respirable dust samples are collected and dust concentrations are determined for individual samples and averaged for the homogenous exposure groups. A composite sample of the individual dust samples is prepared and the vanadium concentration in the composite dust sample is determined and expressed as a percentage weight of the dust sample. The method determines both pentavalent ($V(5^+)$) and tetravalent ($V(4^+)$) vanadium. The contribution of tetravalent ($V(4^+)$) vanadium varies and may reach 33 per cent of the reported result. The result is not reported as either vanadium (5^+) or vanadium (4^+), but as vanadium pentoxide (V_2O_5), the vanadium substance that is regulated by the South African DME.

Analysis occurs according to a confidential in-house method developed by the South African Bureau of Standards (SABS), referred to as the "*caustic dissolution"* or "*0.1N NaOH soluble vanadium*" method (confirmed by Pat Carr , Tel. +27-12-428 7096).

The V_2O_5 percentage by weight in dust, reported by the analytical laboratory, is multiplied with the average of the personal airborne dust concentrations and the resulting V_2O_5 concentration (in personal air) is assigned to each individual in the particular exposure group. The calculations are illustrated in Table 3 below.

Table 3: Illustration of the calculation of the vanadium (5+ and 4+) concentration (expressed as V_2O_5), in personal air.

Individual sample concentrations in HEG: mg dust/m^3 air	Average of HEG: mg dust/m^3 air	Analysis of composite dust sample: % V_2O_5	mg V_2O_5 /m^3 air
A	**B**	**C**	**D = B x C**
0.04	0.140	5.96 %	0.008
0.05			
0.06			
0.03			
0.52			

Since all forms of vanadium(5$^+$) and vanadium(4$^+$) present in the dust sample are reported together and expressed as V_2O_5, the result cannot be directly applied to the vanadium pentoxide compound. The paradox therefore exists that the results of personal sampling might indicate a significant concentration of V_2O_5 in a particular section of the processing plant, while the probability of V_2O_5 compound (that is, excluding other vanadium compounds) being present is almost none, because V_2O_5 is simply not the major vanadium compound involved in or emitted by the chemical process occurring in that section of the plant.

The current epidemiological study is aimed at the V_2O_5 compound in particular (referred to as V_2O_5) and excludes other vanadium compounds. Assessment of exposure to the V_2O_5 compound can therefore not use the V_2O_5 concentrations reported by the analytical laboratory or reported in the occupational hygiene records, since the method of analysis measures all forms of vanadium(5$^+$) and vanadium(4$^+$) present in the dust sample. Although the occupational hygienists and the DME compares the result from the analytical laboratory (expressed as concentrations of V_2O_5) to the occupational exposure limit (OEL) proclaimed by DME regulations, exposure assessment in the current epidemiological study must be based on the estimated air concentration of the V_2O_5 compound. The air concentration of the V_2O_5 compound is estimated from the occupational hygiene monitoring results, by taking into account the particular chemical processes that occur in the particular section of the processing plant, as will be explained later.

7.3.3 Sampling and analysis at the USA processing plant

The USA processing plant granted access to sampling results of the gravimetric dust sampling programme conducted since March 1988 to June 2004. The information extracted from the personal dust monitoring records for use in the study is given in Annexure 6. Personal samples were individually analysed at the USA plant, and exposure information for individuals was available. Dust samples were chemically analysed using the Inductively Coupled Plasma/Mass Spectrometry (ICP/MS) method for determining the vanadium concentration of dust samples.[55] This method assessed all oxidation states of vanadium. Results were earlier reported as concentrations of vanadium (all oxidation states) and since around 1991, as concentrations of V_2O_5. The formula for the conversion of the reported vanadium concentration into an equivalent concentration of V_2O_5 (regardless of whether V_2O_5 was actually present or not) is:

Equation 8

$$\text{Concentration } V_2O_5 = \frac{\text{Reported concentration vanadium}}{0.56}$$

Since all oxidation states of vanadium present in the dust sample are detected by the method of analysis, the monitoring results cannot be directly applied to vanadium pentoxide compound, even though the result is expressed in terms of V_2O_5. The paradox therefore exists that the results of personal sampling might indicate a significant concentration of V_2O_5 in a particular section of the processing plant, while the probability of V_2O_5 being present is almost none, because V_2O_5 is simply not the major vanadium compound involved in or emitted by the chemical process occurring in that section of the plant.

The current epidemiological study is aimed at the V_2O_5 compound in particular and excludes other vanadium compounds. Assessment of exposure to V_2O_5 can therefore not use the V_2O_5 concentrations reported by the analytical laboratory or reported in the occupational hygiene records, since the method of analysis measures all oxidation states of vanadium present in the dust sample. Exposure assessment in the current epidemiological study must be based on the estimated air concentration of the V_2O_5 compound. The air concentration of the V_2O_5 compound is estimated from the occupational hygiene monitoring results, by taking into account the particular chemical processes that occur in the particular section of the processing plant, as will be explained later.

Prior to 1998, total dust was sampled, but this practice was changed in January 1998, after which only respirable dust was sampled. It is necessary to convert concentrations of total dust to concentrations of respirable dust, in order for exposure data from different periods and different processing plants to be comparable to guidelines and amongst each other. The mean V_2O_5 concentration amongst plant workers reported for the period 1996 to 1997 was compared to the mean V_2O_5 concentration reported for 1998 to 1999. The conversion factor, for converting concentrations of total dust to concentrations of respirable dust, was calculated as follows:

Conversion factor (V_2O_5 Concentration$_{\text{total dust}}$ to V_2O_5 concentration$_{\text{respirable dust}}$)

$$= \frac{\text{Mean } V_2O_5 \text{ concentration}_{\text{total dust}} \text{ 1998 to 1999}}{\text{Mean } V_2O_5 \text{ concentration}_{\text{respirable dust}} \text{ 1996 to 1997}}$$

$$= \frac{0.026}{0.152}$$

$$= 0.171$$

The conversion factor was used to convert all V_2O_5 concentrations of total dust, reported prior to 1998, to V_2O_5 concentrations of respirable dust.

8 Aim and objectives of the study

Epidemiological studies of the potential association between occupational exposure to vanadium pentoxide (V_2O_5) and the risk of cancer have not been reported in the literature. Since the potential incidence of cancer amongst adults is relatively small (in comparison with other chronic diseases, e.g. cardiorespiratory diseases) a retrospective case-control study was identified as the least expensive design that may yield a result within a relatively short period of time.

The aim was to conduct a pilot retrospective case-control study to investigate the relationship between cumulative occupational exposure to V_2O_5 and the risk of developing cancer at two representative vanadium processing plants, one in SA and one in the USA. The pilot study was a vital opportunity to test the exposure assessment strategy in the vanadium industry

The specific objectives of the study were:

1. To obtain specific detail concerning the personal lifestyle, health and job history of current and previous employees from the processing plants chosen to participate in the study.
2. To assess historical exposure to vanadium pentoxide in the workplace at the two participating processing plants.
3. To identify and confirm cancer cases amongst current and previous employees by collecting information from pathology reports or from death certificates.
4. To attempt statistical analysis of the results, in order to confirm the null hypothesis that the risk of developing cancer, associated with occupational exposure to V_2O_5, is not significantly different from the risk of developing cancer amongst those not exposed to V_2O_5.

Chapter 2: Methodology

1 Terminologies referring to vanadium pentoxide

The occupational hygiene records of both the South African and the USA vanadium producing industries report the results of their monitoring programme as concentrations of V_2O_5 in air. V_2O_5 concentrations in the workplace are regulated in both countries. However, the methods of analysis of dust samples in both countries are not specific for the V_2O_5 compound. In South Africa, all forms of vanadium(5^+) and vanadium(4^+) present in the dust sample are indicated by the method of analysis. The result of the analysis is reported as the concentration of V_2O_5, but is actually the sum of the concentrations of all forms of vanadium(5^+) and vanadium(4^+), that is expressed as the concentration of V_2O_5. The result of the laboratory does therefore not reflect the concentration of the vanadium pentoxide compound. The paradox therefore exists that the results of personal sampling might indicate a significant concentration of V_2O_5 in a particular section of the processing plant, while the probability of V_2O_5 compound (that is, excluding other vanadium compounds) being present is almost none, because V_2O_5 is simply not the major vanadium compound involved in or emitted by the chemical process occurring in that section of the plant.

This is also true in the USA, where all oxidation states of vanadium present in the dust sample are detected by the method of analysis. The result of the laboratory does therefore also not reflect the concentration of the vanadium pentoxide compound. The paradox therefore again exists that the results of personal sampling might indicate a significant concentration of V_2O_5 in a particular section of the processing plant, while the probability of V_2O_5 compound being present is almost none, because V_2O_5 is not the major vanadium compound involved.

The current epidemiological study is aimed at the V_2O_5 compound in particular (referred to as V_2O_5 compound) and excludes other vanadium compounds. The results of the occupational hygiene programmes, as found in the company reports, are referred to as concentrations of *reported* V_2O_5. In all other instances, the term "V_2O_5" refers to the V_2O_5 compound in particular.

2 Study design

A retrospective case-control study design was used. The study was based in the vanadium processing industry and all cases and controls were sourced from the industry's current and past employee corps.

The study was conducted at two representative vanadium processing plants, one in South Africa and one in the United States of America (USA). Exposure to V_2O_5 potentially occurs at those vanadium processing plants where V_2O_5 is produced, either as an intermediate or as a final product. The South African plant was chosen because V_2O_5 was previously produced at the plant for a significant number of years, therefore potentially lengthy exposure periods were expected for those older workers relocated from plant A to plant B (as explained in Section 7.1.1 of the Introductory chapter). The USA plant was included because of the international interest in the outcome of the study, and it was a convenience selection because V_2O_5 was previously produced at the plant. The methodology followed at the plants is presented separately in this chapter.

3 The South African vanadium processing plant

3.1 The study population: inclusion and exclusion criteria

The target population included all persons potentially exposed to V_2O_5 in the workplace. The study population included all individuals who have ever been or were still in employment at the South African processing plant.

The following groups were identified:

- Active employees potentially exposed to V_2O_5 in the workplace, and
- Former employees potentially exposed to V_2O_5 in the workplace.

Three distinct groups were identified amongst the former employees:

- Employees that had left the service of the company prior to their retirement date, that were either unemployed or employed elsewhere (not at the vanadium processing plant) at the time of the study;

- Employees that had left the service of the company and had entered retirement, and
- Deceased former employees that had either died while in service at the company, or had died after retirement, or had died after having left the service of the company to be employed elsewhere.

The lag period between exposure and the occurrence of cancer may cover a period of at least five years. For this reason, only employees that could potentially have been exposed to V_2O_5 in the workplace for a period of at least 5 years were included in the study. In other words, all persons employed at the processing plant for at least 5 years during the period in which V_2O_5 was produced at the plant were eligible for inclusion in the study group, regardless of the work area in which they had worked.

Employees who had worked less than 5 years during the period in which V_2O_5 was produced at the plant were not eligible and were excluded from participation in the study. Current or former employees that had started working at the plant after 1994 were not invited to participate, since V_2O_5 production at the plant had been terminated in 1994. Deceased employees were excluded if the cause of death could not be confirmed.

Participants with a diagnosis of cancer were excluded from the study if a causal factor associated with employment in other companies, either before or after the period of employment at the SA company, could be identified. Examples of such causal factors would be employment in the uranium industry or employment in a chemical or mineral processing industry associated with the risk of cancer (e.g. sulphuric acid – H_2SO_4, or hexavalent chromium - Cr(6+)). Participants who had been employed at other vanadium processing companies were also excluded, regardless of whether they were diagnosed with cancer or not. This exclusion criterion was established because exposure assessments at other vanadium processing companies were outside the scope of the pilot study, and exposure classification in those participants would have failed.

3.2 Case and control definition

The NTP study of cancer in exposed rodents[27] was the only literature source available to inform the case definition to be applied in the pilot study of V_2O_5-exposed workers in the vanadium processing industry. IARC has classified V_20_5 as possibly carcinogenic to humans[26], based on the increased incidence of bronchiolo-alveolar neoplasms observed in male and female mice and male rats in the NTP study[27]. However, studies of the association between occupational V_20_5 exposure and cancer have not yet been published and sufficient information is not available to exclude other cancers.

A precise case definition is desirable, since this would focus the allocation of resource such as time and money on the ascertainment of the relevant health endpoint, and would allow more precise definition of potential confounders such as other occupational exposures or lifestyle factors. In the context of limited information on the specific cancer that might develop in exposed humans, a wider case definition limits the risk that a cluster may be overlooked because it was not identical to the type of cancer identified in the rodent study. This risk is not insignificant, because of the limitations inherent in the extrapolation of results in rodent studies to humans (discussed in Introductory Section 4.3.2). In consideration of these arguments, the case definition was not limited to one target organ, e.g. lung cancer. Admittedly, this decision may result in imprecise definition of and inadequate adjustment for confounders in the statistical analyses models.

In summary, the case definition was as follows:

- Disease case definition: histologically confirmed cancer.
- Main inclusion criterion: current or previous employment at the specific South African, or the specific USA vanadium processing facility included in the study.
- Exclusion criteria:
  - Refusal of interview;
  - Less than 5 years in employment when V_2O_5 was produced at the plant;
  - Cause of death not ascertained;
  - Employment elsewhere in the vanadium industry;
  - Cancer cases for whom exposure to a known carcinogenic agent was identified during period of employment elsewhere.
- Gender: male or female.
- Race/ethnicity: none excluded.
- Age: case definition not limited to any age group, although indirectly excluding school-aged persons.
- Geographic locations: vanadium processing facility in South Africa and in the USA.

In summary, the control definition was as follows:

- Control selection criteria:
    - Not diagnosed with cancer;
    - Current or previous employment at current or previous employment at the specific South African, or the specific USA vanadium processing facility included in the study.
- Matching variables: not applied.
- Exclusion criteria
    - Refusal of interview;
    - Less than 5 years in employment when V_2O_5 was produced at the plant;
    - Cause of death not ascertained;
    - Employment elsewhere in the vanadium industry;
    - Exposure to a known carcinogenic agent identified during period of employment elsewhere.
- Gender: male or female
- Race/ethnicity: none excluded.
- Age: control definition not limited to any age group, although indirectly excluding school-aged persons.
- Geographic locations: vanadium processing facility in South Africa and in the USA.

3.3 Recruitment of participants

Ethic approval for the study was obtained from the Ethics Committee of the University of Pretoria (reference number S34/2004 - Annexure 1). Participation was on a voluntary basis. All currently active employees that had started working at the plant before 1994 were invited to participate. Participants were recruited through personal interviews with the active employees.

The South African company provided a list of names, addresses and sometimes telephone numbers of former employees who had worked at the processing plant in 1994 or before. An effort was made to trace as many of these retirees and former employees as possible. A list of employees that had died while in service was also provided. Eligible deceased employees that conformed to the inclusion and exclusion criteria were identified from this list.

3.4 Qualitative methods

Personal interviews were conducted with the potential participants, during which the purpose of the study as well as issues related to confidentiality, the protection of privacy and the participant's rights to refuse to take part and to withdraw from the study were explained. Potential participants were asked to grant informed consent to participate in the study. Informed consent was also requested to contact the participant's medical doctor or clinic if deemed necessary by the investigators. Persons who declined to participate or who refused to sign the informed consent documents were not included in the study. A copy of the informed consent document is available in Annexure 2.

Interviewers at the South African processing plant were sourced from the community and were trained on the intent of the questionnaire, the rights of the subjects and the importance and technique of unbiased interviewing.

"Snowballing" was also used to trace previous employees, meaning that traced participants were asked to refer interviewers to other previous employees that they were aware of or had contact with.

Questionnaires and informed consent forms were available in English, Afrikaans and Setswana. The questionnaires and informed consent forms were reviewed by culturally sensitive sociologists and subjected to trial runs with persons with cultural and educational backgrounds expected to be similar to that of potential participants. A copy of the questionnaire is available in Annexure 3.

Health information obtained from study participants via the questionnaire included the following:

- Smoking history;
- Use of snuff (smokeless tobacco);
- Alcohol use;
- A limited medical history regarding potential previous diagnoses of cancer;
- Names and contact details of medical practitioners and specialists consulted by the potential participant; and
- Family cancer history.

Environmental information obtained from the study participants included information on fuel use in the family, *e.g.* the use of coal or wood in the home. Participants were asked for informed consent to contact their medical doctor or clinic if deemed necessary by the investigators.

Retrospective assessment of smoking status typically involves questions such as:[45]

- whether any tobacco products were ever used;
- whether cigarettes, cigars, pipes or chewing tobacco were used;
- detailed information about the duration of smoking, and
- the average amount that the person smoked per day or week.

The questionnaire used in the pilot study obtained information on both the current and previous smoking status of participants. Participants were questioned on whether they smoked (or had smoked) tobacco or dagga (marijuana). With regard to tobacco products, participants were questioned on whether they smoked cigars, hand-rolled or commercial cigarettes or the pipe. If so, they were questioned on the number of cigarettes or cigars smoked per day and for how long they were smoking (or had been smoking before giving up the habit). An attempt was also made to gauge the severity of their smoking habits by questioning participants on their reactions (e.g. coughing) when smoking.

Participants were also asked whether they used snuff, and how often, since the habit of snuffing is also known to cause cancer.[61, 62]

During retrospective assessment of smoking status, the question usually arises whether a person smoking one pipe a day for only two months of his lifetime should have the same smoking status classification as a person smoking 20 cigarettes per day for duration of 20 years. The classification of the “overall smoking status” of a subject as positive followed the guidelines of Woo and Pinney[45], who classified a subject as a smoker if one or more of the following criteria were met in a lifetime:

- smoked at least 400 cigarettes;
- smoked at least one cigar per week for a year or longer;
- smoked at least one pipe per week for a year or longer, or
- used chewing tobacco at least once a week for a year or longer.

Questions on alcohol use focused on the type of alcohol consumed most often (*e.g.* beer from a shop, homemade beer, wine, homemade spirits or commercial spirits). Participants were also questioned on how many years they had been using alcohol. The CAGE Alcohol Abuse Screener was used to identify participants who were probably abusing alcohol.[46, 47] The questions asked were:

- Do you ever feel you should cut down on your drinking;
- Do you ever get annoyed by people criticizing your drinking;
- Do you feel bad or guilty about your drinking; and
- Do you drink early in the morning to steady your nerves or to get rid of a hangover?

Participants were asked general questions concerning their health, *e.g.* whether they suffered from, or had ever suffered from, shortness of breath, heart disease, high blood pressure (hypertension), lung cancer, diabetes or any other form of cancer. If the participant indicated a history of any type of cancer, they were questioned on the date of diagnosis. Information on other diseases besides cancer were not used for data analysis, but were included in an effort to prevent unnecessary concerns and anxiety about cancer or the occurrence of cancer amongst the employees of the processing plants. Participants were also questioned to determine if a family history of cancer was present.

With regard to fuel use in the home, participants were asked about the combustion of coal, firewood or paraffin as an energy source in the home.

Asbestos exposure in the mining industry is an easily identifiable cause of lung cancer and thus a potential confounder among mine- and mineral processing workers. Explicit enquiries on previous asbestos exposures were not made during the personal interviews with participants and are therefore not available from the personal questionnaires. It was, however, assumed that historical exposure to asbestos exposure could be inferred from the job history.

3.5 Medical information

Medical practitioners were contacted to confirm the diagnosis of cancer, if the study participant had indicated that he/she had been diagnosed with cancer. A pathology report giving the diagnosis of the organ- and cell type involved and the type of cancer was accepted as confirmation. A statement concerning cancer as the cause of death on death certificates was also acceptable.

The feasibility of using South African death certificates to confirm the cause of death of deceased participants as a source of information was tested by initially requesting death certificates from the Department of Home Affairs for a sample of only eight of the deceased former employees that had been active at the South African processing plant. Death certificates for the remainder of the deceased were requested at a later stage. In cases where next-of-kin of deceased former employees were traced, death certificates were requested from the next-of-kin.

3.6 Classification of cases and controls

Participants were classified as cases and controls according to the case definition and control selection criteria given in Section 3.2 in this chapter. A small number of participants had indicated the diagnosis of cancer during the personal interview, but the relevant pathology reports subsequently indicated other benign diseases, such as benign prostatic hyperplasia, instead of prostate cancer, or sun damage to the skin (solaris keratosis), in stead of skin cancer. These participants had already been included in the study population on the basis of the inclusion- and exclusion criteria, and were classified as controls.

3.7 Quantitative methods: exposure assessment

3.7.1 Estimation of historical air concentrations of V_2O_5 in the workplace: 1976 to 1989

The ideal approach would be to base exposure of employees on actual monitoring information (mg V_2O_5 per m^3 air), but this level of detail was not available prior to 1989. In cases where actual monitoring data were not available, historical levels of V_2O_5 in the workplace were estimated by extrapolation from current (known) air concentrations, in conjunction with the following parameters:

- Annual production volumes;
- Detailed information about controls on emissions as determinants of atmospheric vanadium concentrations in the workplace;
- Personal experiences of occupational hygienists and plant managers at the plant;

- Historical records of plant upgrades, and industrial incidents and accidents, where available at the plants; and,
- Historical records of changes in production processes.

This approach is similar to that used by Camus et al.[53] to estimate historical exposure to environmental asbestos. Two current employees of the processing plant, namely a plant foreman and a chemical engineer, acted as assessors of the historical exposure in the workplace. The assessors were knowledgeable about the historical chemical processes in the plant and confirmed that the most significant exposure to V_2O_5 was expected at the fusion furnace and the calciner, which were both housed in the precipitation area. Small percentages of V_2O_5 were also expected in the shipping area and in the laboratory. The expected percentages were of such small order of magnitude in comparison to percentages in the precipitation area that, in order to simplify calculations, it was assumed that historical concentrations of V_2O_5 in the shipping area and in the laboratory were similar to that in the precipitation building. Historical concentrations of V_2O_5 in only the precipitation building were therefore estimated. In the other areas, where V_2O_5 compound was not expected, historical concentrations of V_2O_5 had not been estimated.

The two assessors had been active in the processing plant during the period in question and were able to recollect and judge the historical levels of dust present in the workplace air. Assessors were asked to estimate historical V_2O_5 concentrations and to express the results of their estimations in the same manner as currently measured levels of exposure, that is as concentrations of vanadium (5^+) and vanadium(4^+) reported together as V_2O_5.

It was not practical to blind assessors to the calendar year of the estimation, or to the identity of the plant, but assessors were blinded to each other. Each assessor considered evidence independently, without consulting each other, and estimated a range of historical exposure by using the following 2 steps:

Step 1: qualitative assessment

Milestones for plant development; upgrade and emissions control (Table 4-1, Annexure 4) were used in a qualitative assessment of the dust exposure intensity in Plants A and B. Assessors were asked to score the dust exposure intensity on the following scale:

- Extreme
- Very high

- Not acceptable
- Acceptable
- Low
- None

Step 2: quantitative assessment

The dust exposure intensity assessed in Step 1 was fed into the exposure matrix presented in Table 4-2, Annexure 4. The exposure matrix contained data relevant to potential exposure concentrations of V_2O_5, *e.g.* the visibility of dust contamination in workplace air, which was also estimated by the assessors, and the annual production tonnage, which was supplied by the company owning the processing plant. The data were pertinent to those periods in which personal exposure data were not available at the South African processing plant.

Assessors were asked to score the visibility of dust exposure on the following scale:

- Extreme
- Very bad
- Not acceptable
- Acceptable
- Very light
- None

The assessors used the exposure matrix to estimate a quantitative range of historical V_2O_5 concentrations that could have been prevalent in the precipitation area. The mean of the midpoints of the two individual ranges, in mg/m^3, was used for exposure assessment calculations.

In areas where V_2O_5 compound was not expected, the concentration of V_2O_5 compound would logically be zero (0) and historical concentrations of V_2O_5 had not been estimated.

The percentage of reported V_2O_5 presented by V_2O_5 compound (excluding other vanadium-containing compounds) could therefore be estimated from the process description, the particular chemical processes occurring in that particular section of the processing plant and historical work practices applicable to the specific activity area. For example, the V_2O_5 product was always in the form of V_2O_5 flakes, which did not generate considerable amounts of dust. V_2O_5 flakes were drummed and sealed in the fusion area (in the precipitation area), before being moved to the shipping area. Employees in the shipping area were therefore exposed to only small quantities of V_2O_5. The percentage reported V_2O_5 present as the V_2O_5 compound was assumed to be zero if the monitored worker had worked in an area of the plant in which V_2O_5 releases were not expected, even if the occupational hygiene report indicated a result expressed as V_2O_5 for that particular worker. The only activity area in the processing plant in which significant V_2O_5 exposure was possible during the monitoring period was at the fusion furnace. The assessors had estimated that V_2O_5 compound represented approximately 80 per cent of the total reported V_2O_5 dust load in that area. Operations at the furnace were discontinued in August 1994, when production of V_2O_5 was terminated. However, it is important to note that the fusion furnace and the calciner were situated in the precipitation area. People working in any of those activity areas would therefore have experienced exposure to the V_2O_5.

The estimates of the mean percentages of workplace V_2O_5 were provided by the two assessors. These percentage estimations are applicable to both the estimated historical concentrations (prior to 1990) and to the measured V_2O_5 concentrations recorded in the occupational hygiene records. The information extracted from the personal dust monitoring records for use in the study is given in Annexure 5.

3.7.2 Retrospective assessment of individual exposures according to individual occupational histories available until 1989

The mean cumulative concentration of V_2O_5 to which each individual participant had been exposed must be calculated in order to classify study participants in various exposure categories. Since the occupational hygiene programme had only started in 1990, V_2O_5 exposure of individual employees prior to 1990 was never assessed and exposure concentrations were derived from the estimated historical air concentration of V_2O_5 (see methodology in section 3.7.1 above). Concentrations of V_2O_5 in air, to which individual employees had been exposed, were derived based on the occupational history, particularly the occupational titles and the work areas in which the study participant had been active.

If the individual occupational history indicated that the employee had been active in **only one** specific work area, the concentration of V_2O_5 was calculated by multiplying the estimated historical air concentration of V_2O_5 with the estimated percentage of V_2O_5 compound present in the specific area. This calculation is presented in equation 1.

Equation 1

Concentration V_2O_5 compound in area	=	Historically estimated V_2O_5 concentration	x	% of V_2O_5 compound estimated to be present in that area

As previously explained, historical concentrations of V_2O_5 had only been estimated for the precipitation building, since this was the only area of significant exposure to V_2O_5. In areas where V_2O_5 was not expected, the concentration of V_2O_5 would logically be zero (0) and historical concentrations of V_2O_5 had not been estimated. Also, the expected percentages of V_2O_5 in the shipping area and in the laboratory were of such small order of magnitude in comparison to percentages in the precipitation building that, in order to simplify calculations, it was assumed that historical concentrations of V_2O_5 in the shipping area and in the laboratory were similar to that in the precipitation building.

If the occupational title held by an employee indicated that the employee might have been active in **more than one** specific work area, including potentially the precipitation building, the exposure concentration was derived by weighting. The concentrations V_2O_5 calculated with Equation 1 for the precipitation building was weighted according to the probability that the employee would have been active in the area. This is illustrated with Equation 2:

Equation 2:

Weighted concentration V_2O_5	=	Concentration V_2O_5 in precipitation building	X	Probability of employee having been active in the precipitation building

The probability that employees would have been active in the precipitation building was estimated as explained below.

A number of occupational groups, such as fusion or crusher attendants, could be assumed to have spent their entire workday in one specific activity area. In these cases, the probability of being active in that area would be equal to 1 (100 per cent), regardless of whether exposure to V_2O_5 was possible or not. Other occupational groups had probably spent their workday in various activity areas. For the sake of convenience these occupational groups were referred to as “rovers”. Examples of “rovers” are:

- “Leave reliefs”: personnel that temporarily occupy positions vacated by personnel on leave;
- Roving operators;
- Electricians;
- Mechanics;
- Plant managers;
- Plant foremen;
- Engineers;
- Occupational hygienists;
- Welders, and
- Boilermakers.

The probability of these workers being active in the precipitation building was estimated with input provided by the two assessors, relying on personal experience. Since the precipitation building was by far the area with the highest concentration of V_2O_5 in air (in comparison to the shipping area); since "rovers" were expected to spend far more time in the precipitation building than in the shipping area, and since roving personnel were not expected to be active in the laboratory, only the probability of being active in the precipitation building was considered for "rovers".

3.7.3 Retrospective assessment of individual exposures for the period 1990 to 1994

The South African processing plant granted access to results of the occupational hygiene programme’s gravimetric sampling programme conducted since January 1990 to December 2003. The records indicated the periods of monitoring, the personnel numbers and/or names and/or occupations and/or activity area(s) and/or the homogenous exposure group of monitored personnel. As explained previously, selected individuals believed to represent specific homogenous exposure groups were monitored, therefore a complete record of dust monitoring for each individual employee was not available. The results of the laboratory analysis was reported as V_2O_5, which included both vanadium (5^+) and vanadium(4^+), as explained in Section 7.3.2 in the Introductory chapter.

Concentrations of V_2O_5 for occupational categories appearing in the occupational hygiene records during the period 1990 to 1994 were derived from recorded V_2O_5 concentrations (which included both vanadium (5^+) and vanadium(4^+)). If a specific activity area was named in the occupational hygiene records, the recorded concentration of V_2O_5 (obtained from records) was multiplied with the estimated percentage of V_2O_5 present in the activity area, to obtain the derived concentration of V_2O_5.

Exposure to V_2O_5 present in the activity area was therefore calculated as follows:

Equation 3:

Concentration V_2O_5 in area	=	Recorded V_2O_5 concentration in activity area	x	Percentage of V_2O_5 estimated to be present in that area

In some cases, the activity area was indicated as "plant" in the occupational hygiene records, or the activity area was omitted entirely, and only the occupation of the monitored employee was given. This was mostly noted if the employee had been a "rover". In these cases, the employee could have been active in **more than one** specific work area, including potentially the precipitation area.

The exposure concentration was therefore derived by weighting. The derived concentration of V_2O_5 was weighted according to the probability that an individual would have been active in the precipitation building. This is illustrated with Equation 4:

Equation 4:

Weighted concentration V_2O_5	=	Reported V_2O_5 concentration (occupational hygiene records)	x	% V_2O_5 estimated to be present in the precipitation building	x	Probability that occupational group had been active an area of exposure to V_2O_5

In a few cases, "rovers" were monitored only in areas where exposure to V_2O_5 had not been possible. In these cases, the exposure concentration was given as zero (0.0), even if the occupational hygiene records had indicated a result greater than 0. These are indicated in the results presented in Annexure 5.

Mean concentrations of V_2O_5, to which each occupational category was exposed during a specific monitoring period, were subsequently calculated.

An example of the calculation of the mean air concentration of V_2O_5 applicable to a specific occupation is shown in Table 4 below.

Table 4: Example of the calculation of the mean air concentration of V_2O_5 applicable to fusion attendants in the South African processing plant.

Step	Type of data used or calculation performed	Example of data or result
1	Occupation identified in the South African processing plant occupational hygiene report	Fusion attendants
2	Activity area indicated in the South African processing plant report, or assumed by author from process description	Fusion
3	Time weighted dust concentration (mg/m^3): result of laboratory analysis given in the occupational hygiene report	0.18
		0.54
		1.40
4	% V_2O_5 in sampled dust: result of laboratory analysis given in the occupational hygiene report	10.00
5	Calculation of the concentration of V_2O_5 (vanadium(5^+) and vanadium(4^+) reported together as V_2O_5) in sampled dust (mg/m^3)	0.18 x 0.1
		0.54 x 0.1
		1.40 x 0.1
6	Estimated % reported V_2O_5 present as V_2O_5 compound (Table 9, Results chapter)	80.00 %
7	Probability that fusion attendant would have been active in the fusion area	1.0
8	Calculation of the concentration of V_2O_5 in sampled dust (mg/m^3)	0.18 x 0.1 x 0.8 x 1 = 0.014
		0.54 x 0.1 x 0.8 x 1 = 0.043
		1.40 x 0.1 x 0.8 x 1 = 0.112
9	Calculation of the mean air concentration of V_2O_5 (mg/m^3)	0.056: Mean of 0.014, 0.043 and 0.112

The mean exposures calculated for occupational categories and for specific 6-month monitoring periods, were subsequently assigned to individuals that had been active in the plant during the monitoring period, on the basis of the occupational history. These assigned concentrations were used to calculate the mean exposure per year of occupational service of each individual from the study population.

3.7.4 Assessment of the duration of exposure

The number of years that each eligible participant had potentially been exposed to V_2O_5 was calculated based on the information provided in the job history section of the questionnaire. In cases where participants had worked at other vanadium processing plants (e.g. a third plant in South Africa), the participant was not included in the study, since exposure assessments were not done for other plants and therefore periods of exposure to V_2O_5 at those plants were not known. This was not applicable to any potential cases identified in the study.

3.7.5 Calculation of cumulative exposure and mean exposure per year of occupational service

To predict the risk of cancer according to the risk model, the cumulative exposure to V_2O_5 compound is estimated for each individual in the sample population. The cumulative exposure in a specific exposure period with a relatively stable air concentration is the product of the duration and the intensity of exposure (Equation 5).

Equation 5

$$\text{Cum exp}_i = c_i y_i$$

Where: Cum $\exp_i$ is the cumulative exposure over period i,in mg-year/m^3;
c_i is the mean calculated or estimated air concentration of V_2O_5 in mg/m^3, during period i, and
y_i is the duration of that exposure period in number of years.

The cumulative exposure over the period of occupation is calculated by summing the cumulative exposures in all exposure periods (Equation 6). This approach is justifiable, since workers may move around and are exposed to different V_2O_5 concentrations during their careers.

Equation 6

$$\text{Cum exp}_{occupation} = \text{Cum exp}_{1} + \text{Cum exp}_{2} + \ldots\ldots + \text{Cum exp}_{n}$$

Where: Cum $\text{exp}_{occupation}$ is the cumulative exposure over the period of occupation, and Cum $\text{exp}_{1\text{ to }n}$ are the cumulative exposures over periods i = 1 to n

For the purpose of classification of workers into exposure categories, the mean exposure per year of occupational service is calculated (Equation 7).

Equation 7

$$\text{Mean exp.} = \frac{\text{Cum exp}_{occupation}}{y_{occupation}}$$

Where: Cum $\text{exp}_{occupation}$ is the cumulative exposure over the period of occupation in the vanadium industry, and

$y_{occupation}$ is the total number of years of potential occupational exposure to V_2O_5 in air.

The total number of years of potential occupational exposure to V_2O_5 in air ($y_{occupation}$ in Equation 7) was not equal to the total period of occupation of an individual in the vanadium industry. The total number of years was equal to the number of years occupied in the industry, while working in a processing plant where V_2O_5 was produced, regardless of whether the employee was working in an activity area where V_2O_5 was present, or in an area where V_2O_5 was most likely not present, e.g. in offices.

3.7.6 Classification of study participants into exposure categories

Not exposed

This exposure category represented all personnel or occupational groups for whom the monitored or estimated mean air concentration was zero (0 mg/m^3). Personal air V_2O_5

concentrations were sometimes not monitored for this group, because they were considered as unexposed by industrial hygienists. Examples of occupational groups for whom this would have been the case included office workers, security personnel, messengers, caterers and health practitioners working within the boundaries of the processing plant.

Low levels

The mean exposure per year of occupational service ranged from any concentration greater than 0.000 up to 0.049 mg V_2O_5 compound per m^3 air. The upper limit for this exposure category was chosen not to exceed the strictest limit, including the South African occupational exposure limit (OEL), which is 0.05 mg/m^3 for V_2O_5 fume and respirable particulate.[54] According to the method used by the laboratory contracted by the South African processing plant, the OEL would include vanadium(4+) and vanadium(5+) compounds.

Intermediate levels

The mean exposure per year of occupational service ranged from 0.05 up to 0.5 mg V_2O_5 compound per m^3 air. These limits were chosen to include the South African OELs for both inhalable and respirable vanadium pentoxide particulate and fume.[54] According to the method used by the laboratory contracted by the South African processing plant, the OELs would include vanadium(4+) and vanadium(5+) compounds.

High levels

The mean exposure per year of occupational service exceeded 0.5 mg V_2O_5 compound per m^3 air. According to the method used by the laboratory contracted by the South African processing plant, the OELs would include vanadium(4+) and vanadium(5+) compounds.

4 The United States vanadium processing plant

4.1 The study population: inclusion and exclusion criteria

All persons employed for at least 5 years during the period in which V_2O_5 was produced at the plant were eligible for inclusion in the study group, regardless of the work area in which they had worked. Active and former employees were considered, as for the South African study.

The exclusion criteria were the same as for the South African study (Section 3.1 above), except that all employees who had retired or had left the service of the company prior to 1985 were excluded, since V_2O_5 production at the USA plant had only started in 1985.

Similarly to the South African study, participants with a diagnosis of cancer were excluded from the study if a causal factor associated with employment in other companies, either before or after the period of employment at the USA company, could be identified. Participants who had been employed at other vanadium processing companies were also excluded.

4.2 Recruitment of participants

Participation was on a voluntary basis and recruitment was as for the South African study (Section 3.3 above). All currently active employees at the USA plant were invited to participate, because production of V_2O_5 started in 1985 and continues until the present day.

The company provided a list of the names and addresses of former employees. The retiree's club of the USA processing plant also provided a list. Eligible deceased employees that conformed to the inclusion and exclusion criteria were identified from this list.

4.3 Qualitative methods

Personal interviews were conducted using the same procedures as for the South African study (Section 3.4 above) and the informed consent document (Annexure 2) was once again used. A trained South African interviewer interviewed personnel of the USA processing plant, and "Snowballing" was also used to obtain references to other previous employees.

Questionnaires and informed consent forms were available in English and were subjected to trial runs with persons with cultural and educational backgrounds expected to be similar to that of potential participants. The questionnaire was in the same format as the English version used in the South African study (Annexure 3). Health and environmental information, the smoking and alcohol use habits, and the medical and family history of participants were obtained as for the South African study (Section 3.4 above). The classification of the smoking status of USA participants was done using the same criteria as for the South African study (Section 3.4 above).

Even though it was not expected that the USA population would use fuels such as firewood or paraffin in the home, these questions were not removed from the questionnaire used in the USA, in order to confirm any potential differences in fuel use between the South African and the USA group. Similar to the South African study, explicit enquiries on previous asbestos exposures were not made, but it was assumed that historical exposure to asbestos exposure could be inferred from the job history.

4.4 Medical information

Confirmation of the diagnosis of cancer was done as for the South African study (Section 3.5 above). In cases where next-of-kin of deceased former employees were traced, death certificates were requested from the next-of-kin to confirm the cause of death. Death certificates were not requested from the USA authorities, due to limitations in the time and money available for completion of the project.

4.5 Classification of cases and controls

Classification of cases and controls was based on the same criteria as for the South African study (Sections 3.2 and 3.6 above).

4.6 Quantitative methods: exposure assessment

4.6.1 Estimation of historical V_2O_5 air concentrations in the workplace: 1985 to 1988

The ideal approach would be to base exposure of employees on actual monitoring information (mg V_2O_5 per m^3 air), but this level of detail was not available prior to the last months of 1988. A limited number of hygiene records were available for 1988, but the results of the historical exposure assessment for 1988 were used to supplement the occupational hygiene records.

Actual monitoring data for the period 1985 to 1988 were not available and historical levels of V_2O_5 in the workplace were estimated by extrapolation from current (known) air concentrations, using the parameters as described for the South African study (Section 3.7.1). These parameters were, in summary, the historical records of annual production volumes, plant upgrades, changes in production processes and controls on emissions, and personal experiences of occupational hygienists and plant managers.

Two engineers currently active at the processing plant were used as assessors of the historical exposure in the workplace. The assessors were knowledgeable about the historical chemical processes in the plant and confirmed that the MVO building and the packaging area were the only activity areas where exposure to V_2O_5 was expected. These two employees had been active in the processing plant during the period in question and were able to recollect and judge the levels of dust historically present in the workplace air. Assessors were asked to estimate historical V_2O_5 concentrations and to express the results of their estimations in the same manner as currently measured levels of exposure, which is as all oxidation states of vanadium reported together as concentrations of V_2O_5.

It was not practical to blind assessors to the calendar year of the estimation, or to the identity of the plant, and the assessors chose to conduct the assessment during a panel discussion, and estimated a range of historical exposure. Estimations were done using the same steps as outlined for the South African study (Section 3.7.1). In the first step, a qualitative assessment of the dust exposure intensity was done with reference to the milestones for plant development; upgrade and emissions control at the USA processing plant (Table 4-1, Annexure 4). The dust exposure intensity was fed into the exposure matrix presented in Table 4-2 (Annexure 4), which provided the same types of data as the exposure matrix used in the South African study. For the purposes of the exposure matrix, assessors were asked to score the visibility of dust exposure on the same scale as for the South African study (Section 3.7.1). The data were pertinent to those periods in which personal exposure data were not available at the USA processing plant. The assessors used the exposure matrix to estimate the historical V_2O_5 concentrations that could have been prevalent in the precipitation area. In areas where V_2O_5 was not expected, the concentration of V_2O_5 would logically be zero (0) and historical concentrations of V_2O_5 had not been estimated.

4.6.2 Retrospective assessment of personal exposure: periods prior to 1988

Since the occupational hygiene programme had only started in late 1988, personal V_2O_5 exposure prior to 1989 had never been measured and was estimated. Concentrations of V_2O_5 in air, to which employees had been exposed, were therefore derived based on the occupational history, particularly the occupational titles and the work areas in which the study participant had been active.

If the individual occupational history indicated that the employee had been active in **only one** specific work area, personal exposure was calculated as follows:

The estimated historical air concentration of V_2O_5 was multiplied with the estimated percentage of V_2O_5 present in the specific area. According to the process description (Table 4), V_2O_5 was expected in the MVO building, sometimes also referred to as the MVO/SX building, and in the product packaging area. The percentages of V_2O_5 compound in each of these areas were assumed to be equal to the estimated production of V_2O_5 in a specific calendar year, expressed as a percentage of the total production. In the other areas, where V_2O_5 was not expected, the percentage would logically be zero (0).

Exposure to V_2O_5 was therefore calculated as follows (Equation 9) if the employee had been active in only one specific work area:

Equation 9:

Concentration V_2O_5 in area	=	Historically estimated V_2O_5 concentration in that area	x	Percentage of V_2O_5 estimated to be present in that area

In areas where V_2O_5 was not expected, the concentration of V_2O_5 would logically be zero (0) and historical concentrations of V_2O_5 had not been estimated.

If the occupational title indicated that the employee might have been active in **more than one** specific work area, including potentially the MVO/SX building and/or the product packaging area, the exposure concentration was derived by weighting. The concentrations V_2O_5 compound calculated with Equation 9 for respectively the MVO/SX building and the product packaging area was weighted according to the probability that the employee would have been active in each of these areas. This is illustrated with Equation 10:

Equation 10:

Weighted concentration V_2O_5	=	Concentration V_2O_5 in MVO/SX building	X	Probability of individual having been active in MVO/SX building	+	Concentration V_2O_5 in product packaging area	X	Probability of individual having been active in product packaging area

The probability that workers of a particular occupation would have been active in each of the MVO/SX building and the product packaging area was estimated as explained below.

Some occupational groups could be assumed to have spent their entire workday in one specific activity area. In these cases, the probability of being active in that area, regardless of whether V_2O_5 compound was present or not, would be equal to 1 (100 per cent).

Other occupational groups had probably spent their workday in various activity areas. For the sake of convenience these occupational groups were referred to as "rovers". Examples of "rovers" are:

- Labourers;
- Maintenance personnel;
- Electricians;
- Mechanics;

- Plant managers;
- Plant foremen;
- Engineers;
- Occupational hygienists;
- Oilers, and
- Welders.

The probability of those workers being active in the MVO/SX building and in the product packaging area was estimated as explained below.

Gr. 1 employees are expected to be active in the processing plant for approximately 60 per cent of their workday, spending the rest of the workday outside the processing area. Gr. 2 employees spent practically all of their workday in an office; it was estimated that they would spend only approximately 10 per cent of their time in the processing plant, if at all.

Prior to 1989, there were 7 areas in the plant where any Group 1 or Group 2 employee was likely to spend a significant amount of his time. The probability of working in the MVO/SX building was therefore 1/7 prior to 1989. The probabilities of working in the product packaging area were presumed to be the same. These probabilities were subsequently multiplied with the probability of spending time in the processing plant (0.60 for Gr. 1 and 0.10 for Gr. 2).

Prior to 2003, labourers spent approximately 30 per cent of their time (that is a probability of 0.30) in the product packaging area, but this was only considered when the activity area was not given in the hygiene records. The balance of their time (probability of 0.70) could be spent in various areas of the plant, including the MVO/SX building, where they would also be exposed to V_2O_5. Prior to 1989, there were 6 such other areas and the probability of working in the MVO/SX building was therefore 1/6 prior to 1989, and this was multiplied with the probability of spending time in various areas of the plant (0.7).

A “miscellaneous” operator could move around all the buildings in a plant performing various tasks. As stated previously, prior to 1989, the plant consisted of 7 separate buildings, therefore the probability of working in the MVO/SX building was 1/7 prior to 1989. The probabilities of working in the product packaging area were presumed to be the same.

A chemical engineer that had worked in the USA processing plant during the period in question estimated the probability of spending time in the MVO/SX building and the product packaging area (Table 14 in the Results chapter), as applicable to the following occupations:

- Painters and shift foremen (employed before 1992);
- Artisans;
- Electricians, mechanics, welders, master mechanics and maintenance personnel;
- Instrument and other technicians;
- Technical supervisors;
- Safety and other managers;
- Plant superintendent;
- Engineers, assistant engineers, and
- Oilers.

4.6.3 Retrospective assessment of personal exposure: 1989 to 2004

The USA processing plant granted access to results of the occupational hygiene programme conducted since January 1990 to December 2003. The records indicated the periods of monitoring, the names and occupations or activity area(s) of monitored personnel. Selected individuals believed to represent specific exposure groups were monitored, therefore a complete record of dust monitoring for each individual employee was not available. The results of the laboratory analysis were reported as V_2O_5, which included all vanadium compounds, as explained in Section 7.3.3.

Reported V_2O_5 concentrations (representing all vanadium compounds), were used to derive the concentrations of V_2O_5 compound. If a specific activity area was named in the occupational hygiene records, the reported concentration of V_2O_5 (obtained from records) was multiplied with the estimated percentage of V_2O_5 compound present in the activity area, to obtain the derived concentration of V_2O_5 compound. According to the process description V_2O_5 compound was expected in the MVO building, and in the product packaging area. The percentages of V_2O_5 compound in each of these areas were assumed to be equal to the estimated production of V_2O_5 compound in a specific calendar year, expressed as a percentage of the total production. In the other areas, where V_2O_5 compound was not expected, the percentage would logically be zero (0).

Exposure to V_2O_5 present in the activity area was therefore calculated as follows:

Equation 11:

Concentration V_2O_5 in area	=	Reported V_2O_5 concentration in activity area	x	Percentage of V_2O_5 compound estimated to be present in that area

In some cases, the activity area was indicated as "plant" in the occupational hygiene records, or the activity area was omitted entirely and only the occupation of the monitored employee was given. This was mostly noted if the employee had been a "rover". In these cases, the employee could have been active in **more than one** specific work area, including potentially the MVO/SX building and the product packaging area. The exposure concentration was therefore derived by weighting. The derived concentration of V_2O_5 was weighted according to the probability that an individual would have been active in each of the MVO/SX building and the product packaging area. This is illustrated with Equation 12:

Equation 12:

Weighted conc. * V_2O_5	=	Recorded V_2O_5 conc. X % V_2O_5 compound in MVO/SX building X Probability of working in MVO/SX building	+	Recorded V_2O_5 conc. X % V_2O_5 compound in product packaging X Probability of working in product packaging area

*conc. = concentration

The probability of "rovers" being active in the MVO/SX building and in the product packaging area was estimated as explained below, and the annual mean concentrations of V_2O_5, to which each occupational category was exposed, were subsequently calculated.

As explained previously, Group 1 (Gr. 1) employees were expected to be active in the processing plant for approximately 60 per cent of their workday, spending the rest of the workday outside the processing area. Group 2 (Gr.2) employees spent practically all of their workday in an office; it was estimated that they would spend only approximately 10 per cent of their time in the processing plant, if at all. Since 1989 there were 5 areas in the plant where any Gr.1 or Gr. 2 employee was likely to spend a significant amount of his time, and the probability of working in the MVO/SX building was therefore 1/5 since 1989. The probabilities of working in the product packaging area were presumed to be the same. These probabilities were subsequently multiplied with the probability of spending time in the processing plant (0.60 for Gr. 1 and 0.10 for Gr. 2).

Prior to 2003, labourers spent approximately 30 per cent of their time (that is a probability of 0.30) in the product packaging area, but this was only considered when the activity area was not given in the hygiene records. The balance of their time (probability of 0.70) could be spent in various areas of the plant, including the MVO/SX building, where they would also be exposed to V_2O_5. Since 1989 (but prior to 2003), there were 4 such areas and the probability of working in the MVO/SX building was therefore 1/4 since 1989, and this was multiplied with the probability of spending time in various areas of the plant (0.7).

Since 2003, product packaging operators were permanently appointed and this decreased the time labourers spent in the packaging area. Since 2003, there was one permanent labourer, in addition to the operators, in the packaging area and other labourers were utilised in this area on an *ad hoc* basis as needed (this was indicated in the hygiene records). If not working in the packaging area, labourers could therefore have worked in four areas of the plant since 2003. The probability of a labourer having worked in the MVO/SX building was therefore 1/4 since 2003.

A “miscellaneous” operator could move around all the buildings in a plant performing various tasks. As stated previously, the plant consisted of 5 separate buildings since 1989. The probability of working in the MVO/SX building was therefore 1/5 since 1989. The probabilities of working in the product packaging area were presumed to be the same.

A chemical engineer that had worked in the USA processing plant during the period in question estimated the probability of spending time in the MVO/SX building and the product packaging area (Table 14 in the Results chapter), as applicable to the following occupations:

- Painters and shift foremen (employed before 1992);
- Artisans;

- Electricians, mechanics, welders, master mechanics and maintenance personnel;
- Instrument and other technicians;
- Technical supervisors;
- Safety and other managers;
- Plant superintendent;
- Engineers, assistant engineers, and
- Oilers.

An example of the calculation of the mean air concentration of V_2O_5 applicable to a specific occupation is shown in Table 5.

Table 5: Example of the calculation of the mean air concentration of V_2O_5 applicable to a plant labourer in the USA processing plant, for a particular year during the monitoring period (*e.g.* 1989).

Step	Type of data used or calculation performed	Example of data or result
1	Occupation identified in the USA processing plant occupational hygiene report	Labourers
2	Activity area indicated in the USA processing plant report	Plant
3	Estimation of % reported V_2O_5 present as V_2O_5 compound, based on processing plant production figures	40%
4	Estimation of the probability that labourers were active in area of exposure to V_2O_5 (Table 14, Results chapter)	MVO/SX: 0.175 + Product packaging: 0.30 = 0.475
5	V_2O_5 (mg/m^3) reported in sampled dust, or calculated from the reported vanadium concentration (V) (mg/m^3). This V_2O_5 concentration represents all V compounds. V_2O_5 (mg/m^3) = $\frac{V}{0.56}$	V = 0.61; V_2O_5 = 1.09 V = 0.33; V_2O_5 = 0.59
6	<u>Calculation of the derived concentration of V_2O_5 in sampled dust (mg/m^3):</u> Derived V_2O_5 (mg/m^3) = V_2O_5 (mg/m3) (in occupational hygiene records, or calculated from V) **x** % estimated V_2O_5 (40%) **x** Probability that labourers were active in area of exposure to V_2O_5	1.09 x 0.4 x 0.475 = 0.207 0.59 x 0.4 x 0.475 = 0.112
7	Calculation of the mean air concentration of V_2O_5 (mg/m^3) for a labourer working in the plant, for a specific calendar month (*e.g.* June 1989).	0.160: Mean of 0.207 and 0.112

The mean exposures calculated for occupational categories and for specific exposure periods, were subsequently assigned to individuals that had been active in the plant during the monitoring period, on the basis of the occupational history. These assigned concentrations were used to calculate the mean exposure per year of occupational service of each individual from the study population.

4.6.4 Calculation of cumulative exposure and mean exposure per year of occupational service

Estimation of cumulative and mean exposures was done as described for the South African processing plant participants in Section 3.7.5 above.

4.6.5 Classification of study participants into exposure categories

Definitions of exposure categories were as described for the South African processing plant participants in Section 3.7.6, and participants were classified accordingly.

5 Statistical analyses

5.1 Descriptive statistics and strength of associations with cancer and with exposure

Data were captured in a Microsoft Office Excel 2003 spreadsheet. Statistical analysis was performed using the Stata software package, version 9.0. Frequency tables were obtained for each discrete variable, e.g. *gender*, *smoking status* and *cancer diagnosis*. Summary parameters, including the mean, standard deviation, median and range, were determined for continuous variables, e.g. the *total number of years exposed to* V_2O_5 and the *cumulative* V_2O_5 *exposure*.

The outcome of interest was the occurrence of cancer, which is a dichotomous variable. The Pearson chi-square test of association was used to test the strength of association between the outcome variable of study (cancer) and several dichotomous variables of study related to cancer. This method is valid only for cases with expected cell frequencies of five (5) or more. In cases where the expected cell frequencies were less than five, the Fisher's exact test was valid and was performed. The Pearson chi-square test was also used to test the strength of association between several dichotomous variables of exposure to V_2O_5, and variables that were potential confounders in the study.

5.2 Binary logistic regression analysis

Only two values were possible for the outcome (or dependent) variable (cancer), because cancer could be either present (1) or absent (0). The outcome variable was therefore dichotomous, and binary logistic regression analysis was appropriate to investigate the relationship between the outcome variable and predictor variables.

In binary logistic regression analysis, the number of predictor variables that can be included in the logistic regression model is determined on the basis of the following requirement:

minimum {number of ones, number of zeros} = 10k

In the above relationship, k denotes the number of predictor (X) variables that can be used for regression.[57]

The outcome variable of study (cancer) has 10 “ones” (cancer cases) and 186 “zeros” (non-cases). The smaller of the two is 10. That is,

min{10, 186} = 10 = 10(k)

Hence, k=1.

Therefore, only 1 predictor variable could be used for binary logistic regression analysis, because the number of respondents with cancer is only 10.

The selection of a predictor variable for binary logistic regression analysis depends on epidemiological relevance of the predictor variable to the research question, the presence of a significant relationship between the outcome variable of study or both. Table 23 shows variables selected for a series of 8 binary logistic regression procedures. This is a retrospective case-control study design, without matching, therefore the most suitable epidemiological measure of effect in this study is the odds ratio. In each procedure, the strength of relationship between the likelihood of cancer and the predictor variable was assessed based on an odds ratio.

The outcome variable Y is dichotomous, and has only 2 categories. That is,

$$Y = \begin{cases} 1 & if \;\; respondent \;\; has \;\; cancer \\ 0 & otherwise \end{cases}$$

X denotes the predictor variable used for binary logistic regression analysis. The statistical model for each binary logistic regression procedure is given as follows:

$$\log it(p) = \ln\left(\frac{p}{1-p}\right) = \hat{\beta}_0 + \hat{\beta}\; X$$

The above model was used 8 times for each of the 8 predictor variables selected for binary logistic regression analysis.

A series of 8 binary logistic regression procedures were performed, using the above statistical model, with cancer as the outcome variable and each of 8 potential predictor variables related to cancer. In binary logistic regression analysis, the epidemiological measure of effect is the odds ratio, and Table 23 shows the crude odds ratios obtained from a series of 8 binary logistic regression procedures.

However, crude odds ratios (Table 23) are inadequate because of the presence of confounding variables. The conditions for a factor to be a potential confounder[59] in the pilot study of the association between cancer and V_2O_5 exposure are that the confounder:

- Must be a risk factor for the outcome (cancer);
- Must be associated with exposure to V_2O_5;
- Must not be an intermediate step in the (potential) causal path between exposure to V_2O_5 and the development of cancer; and
- Should not be a surrogate for exposure to V_2O_5.

Potential confounders were therefore identified on the basis of a known association with cancer, or a significant association with exposure to V_2O_5, or on the basis that most of the study participants had the same outcome or value for these variables.

Stratified binary logistic regression analysis was used to adjust for confounding in the analysis stage of the study.

Effect modification may be recognized when different relationships between exposure and cancer occur in subgroups of the population, e.g. at different levels of the variable "age". This was assessed by obtaining stratum specific odds ratios for each of the potential effect modifiers. Data were stratified according to each of the potential confounding variables or effect modifiers and stratum-specific estimates of odds ratios were obtained. The results are summarised in Table 24.

5.3 Assessment of the validity of pooling data from the South African and USA groups

The study was conducted at two vanadium processing plants, one in South Africa and the other in the USA. Data collected from the two countries were pooled for the purposes of the statistical analysis. The validity of this approach was investigated by assessing the similarity of results from South Africa and the USA. Statistical tests used were the Bartlett's test for the equality of variances, the two-sample unpaired t-test for cases of unequal variances and the Mann-Whitney test for discrete variables.

Chapter 3 - Results

1 Introduction

In total, 196 questionnaires were collected from eligible current, previous and retired employees of the South African and USA vanadium processing plants. This chapter summarises the collected data, the results of the exposure assessment at both plants, and the results of the statistical analyses of data.

2 The South African vanadium processing plant

2.1 Participation in the study

One hundred and eighty two (182) active employees at the South African processing plant, who had 10 years or more of service, were eligible and were approached to participate in the study. Twelve (12) of the employees invited to participate and scheduled for interviews were not available on the days on which interviews were scheduled, either because they had fallen ill, or were on leave, or had been moved to a night shift on short notice. One hundred and seventy (170) active employees were therefore available for the interviews. Five (5) of the invited employees did not respond to the invitation and did not present themselves for the scheduled interviews. One hundred and sixty five (165) active employees were therefore interviewed, of which 2 refused to participate. One hundred and sixty three (163) active employees with more than 10 years of service at the South African processing plant had therefore completed questionnaires. Amongst the active employees potentially eligible and available for the study, 4 per cent (7 out of 170) of those available to be interviewed had either refused to attend the interviews (5 persons) or had indicated their refusal during the interview (2 persons). The participation rate amongst the active employees at the South African processing plant, who had 10 years or more of service, had therefore been 90 per cent (163 out of 182).

The South African processing plant provided a list of former employees who had worked at the plant for 10 years or more, before retirement or before leaving the service of the company. This totalled 63 in number. Of these, 45 (76 per cent) were traced, of which 3 refused to complete a questionnaire. The retirees referred the investigators to 9 additional retirees or former employees that were not on the list provided by the South African processing plant. Of these, all were traced and 8 agreed to participate. Fifty (50) retirees and former employees had therefore completed questionnaires.

Amongst the total of 213 current, former and retired employees that had completed questionnaires, 80 were not eligible for the study, since they had worked for less than 5 years at the South African processing plant during the years prior to 1994, when V_2O_5 was being produced; or since occupational histories were incomplete; or since they had been employed at a third South African vanadium processing plant not included in the exposure assessment. One hundred and thirty three (133) completed questionnaires had therefore been collected at the South African processing plant from eligible active, former and retired employees, who had satisfied the exclusion and inclusion criteria. Of these, 98 were active employees, and 35 were former or retired employees.

The plant provided a list of 51 employees that had died while in service. The cause of death of these employees could not be ascertained in all cases, and tracing of next-of-kin to obtain a personal and health history was not attempted.

2.2 Estimation of historical air concentrations of V_2O_5 in the workplace: 1976 to 1989

Step 1: qualitative assessment

The results of the qualitative assessment by two assessors of the dust exposure intensity in Plants A and B are given in Table 6.

Table 6. Qualitative assessment of the dust exposure intensity in Plants A and B. Milestones for plant development, upgrade and emissions control are described in the shaded areas.

Period	Relevant Information	Exposure intensity (qualitative)	
		Assessor A	Assessor B
1966 - 1973	Production of V_2O_5 at SA Plant A.	Not employed	Acceptable to very high
Milestone 1	Phase I constructions at SA Plant B: installation of crushers and ball mills.		
1973 - 1976	Production of V_2O_5 at SA Plant A continues.	Not employed	Acceptable to very high
Milestone 2	Phase II constructions at SA Plant B: installation of ball mills, a kiln, leach and precipitation plant, as well as a sulphate plant. Production of V_2O_5 starts at SA Plant B.		
1976 - 1978	Production of V_2O_5 continues at SA Plant A.	Acceptable	Acceptable to very high
Milestone 3	V_2O_5 production terminated at SA Plant A.		
1978 - 1980	Production of V_2O_3 and Nitrovan[¶] continues at SA Plant A. SA Plant B produces V_2O_5, and dry AMV for transport to SA Plant A.	Acceptable	Not acceptable
Milestone 4	SA Plant A kiln leach and precipitation plant closed.		
1980 - 1984	SA Plant A processes metavanadate to Nitrovan	Acceptable	Acceptable to not acceptable
Milestone 5	SA Plant A operation closes down. V_2O_3 and Nitrovan equipment moved from SA Plant A to SA Plant B.		
1984 - 1986	V_2O_3 and V_2O_5 produced at SA Plant B. No Nitrovan production.	Acceptable	Acceptable to not acceptable
Milestone 6	An international company buys SA Plant A. Nitrovan plant erected at SA Plant B		
1986 - 1993	V_2O_5, V_2O_3 and Nitrovan produced at the South African processing plant (SA Plant B)	Acceptable	Acceptable to not acceptable
Milestone 7	V_2O_5 production terminated at the South African processing plant (Aug 94). Ferrovanadium plant commissioned (Sep 93).		

Step 2: quantitative assessment

The intensities of air contamination by dust, that could have been prevalent in the precipitation area, as estimated by the two assessors, are given in Table 7. The ranges of historical V_2O_5 concentrations that could have been prevalent are given in Table 8.

[¶] Nitrovan is the trade name of the product, and the participating company has stipulated that the chemical composition of the product may not be clarified in more detail, except a statement that it does not contain V_2O_5.

Table 7: Intensity of air contamination by dust at the fusion furnace and calciner in the precipitation area of the South African processing plant.

Period for estimation	Annual V_2O_5 production (tonnage)	Exposure intensity (qualitative)		Estimated range of mg V_2O_5 per m^3 air (quantitative)
		Assessor A	Assessor B	
1966 - 1973	Not shown, considered as confidential trade date by the company	Not employed	Acceptable to very high	Refer to Table 8
1973 - 1976		Not employed	Acceptable to very high	
1976 - 1978		Acceptable	Acceptable to very high	
1978 - 1980		Acceptable	Not acceptable	
1980 - 1984		Acceptable	Acceptable to not acceptable	
1984 - 1986		Acceptable	Acceptable to not acceptable	
1986 - 1993		Acceptable	Acceptable to not acceptable	

Table 8: Historical estimations of the range of reported V_2O_5 concentrations in air at the fusion furnace and calciner in the precipitation area of the South African processing plant.

Period for estimation	Assessor A mg V_2O_5 per m^3 (reported)	Assessor B mg V_2O_5 per m^3 (reported)	Mean of the midpoints: mg V_2O_5 per m^3 (reported)
1976	0.5 - 1.0	0.5 - 1.0	0.75
1977	0.5 - 1.0	0.5 - 1.0	0.75
1978	0.5 - 1.0	0.5 - 1.0	0.75
1979	0.4 - 0.8	0.5 - 1.0	0.70
1980	0.4 - 0.8	0.5 - 1.0	0.70
1981	0.4 - 0.8	0.5 - 1.0	0.70
1982	0.4 - 0.8	0.5 - 1.0	0.70
1983	0.2 - 0.4	0.5 - 1.0	0.55
1984	0.2 - 0.4	0.5 - 1.0	0.55
1985	0.2 - 0.4	0.5 - 1.0	0.55
1986	0.2 - 0.4	0.5 - 1.0	0.55
1987	0.2 - 0.4	0.5 - 1.0	0.55
1988	0.2 - 0.4	0.5 - 1.0	0.55
1989	0.2 - 0.4	0.5 - 1.0	0.55

2.3 Percentages of estimated historical V_2O_5 present as V_2O_5 compound in specific activity areas

The percentages of the estimated historical concentrations of reported V_2O_5 presented by V_2O_5 compound (excluding other vanadium-containing compounds) as estimated by the two assessors from the process description applicable to the specific work area, are summarised in Table 9.

Table 9: Mean percentages of reported V_2O_5 presented by V_2O_5 compound, estimated by the South African assessors.

Activity area or occupation	Mean percentages of reported V_2O_5 in the workplace presented by V_2O_5 compound
Admin Crusher Front end loader driver Kiln Leaching Mill Mine MVO reactor Nitrovan furnace Press attendant Security Stores Sulphate recovery plant Tailings dump	0
Shipping	1
Laboratory	5
Press cleaner in precipitation area	10
Fusion Precipitation	80

2.4 Probability of roving personnel being active in the precipitation area

The probability that a “rover” would potentially have been active in the precipitation building was estimated and the probabilities are summarised in Table 10 below:

Table 10: Probability that a "rover" would potentially have been active in the precipitation building, estimated from experience by the South African assessors.

Occupation	Probability that a "rover" would potentially have been active in the precipitation building
Assistant engineer Chemical engineer Engineering manager Manager services Operational manager Section engineer Service operations manager Technical supervisor	0.05
Production manager	0.05 – 0.10
Artisan Artisan assistant Assistant engineer Development technical Plant superintendent Plant technician Leave relief	0.10

2.5 Occupational hygiene records for 1990 to 1994

The results of the exposure assessment for 1990 to 1994, including the results extracted from the gravimetric sampling programme conducted since January 1990 to August 1994, is available in Annexure 5. The occupational hygiene records presented the monitoring results for successive 6-month monitoring periods. Results of V_2O_5 assessments during January to December 1991 were incomplete and could not be used for exposure assessment. Due to changes in the sampling protocol, no data were available for the period January to June 1992. Since the production process had not changed during this period, the missing concentrations in specific activity areas were assumed to be the mean of those recorded during the previous year (January to December 1990) and the following year (July 1992 to June 1993).

3 The USA vanadium processing plant

3.1 Participation in the study

The entire staff (69 active employees) at the USA processing plant was approached to participate in the study. Four (4) of those did not show up for interviews, of which one potential participant was on leave. Eleven (11) of the active employees were interviewed, but refused to participate in the study. The participation rate amongst the active employees at the USA processing plant had therefore been 78 per cent (54 out of 69). Of these, 8 were not eligible for the study, since they had not completed 5 years of employment at the USA processing plant, since the initiation of V_2O_5 production in 1985. At the conclusion of the study, 46 completed questionnaires were therefore available from eligible active employees.

The USA processing plant's personnel department and the processing plant's retiree's club each contributed to a list of retirees from the plant. This totalled 95 in number. Of these, 37 were traced (39 per cent), of which 34 agreed to participate in the study. The number of traced retirees is very limited, due to limitations in time and the expenses involved. Nineteen (19) of the retirees that had agreed to complete a questionnaire were not eligible for the study, because they had not completed 5 years of employment at the plant, since the initiation of V_2O_5 production in 1985. At the conclusion of the study, 15 completed questionnaires were therefore available from eligible retired employees.

The personnel department provided a list of 77 former employees (not retirees) that had left the service of the company, or had died while in service. One of the 77 former employees presented for participation in the study and was included, since he satisfied the exclusion and inclusion criteria for the study. Another was confirmed to have died while in service at the processing plant. His next-of-kin was traced and was willing to complete a questionnaire on the deceased's health and lifestyle, and also provided a copy of the death certificate showing the cause of death. An effort was not made to trace the other former employees, due to restrictions in time and the restricted budget that was available. At the conclusion of the study, 63 questionnaires were therefore available from eligible current, previous and retired USA processing plant employees.

3.2 Estimation of historical V_2O_5 air concentrations in the workplace: 1985 to 1988

Step 1: qualitative assessment

The results of the qualitative assessment by two assessors of the dust exposure intensity in the USA processing plant are given in Table 11.

Table 11: Qualitative assessment of the dust exposure intensity in the USA processing plant for the period 1985 to 1989.

Period for estimation	Relevant information	Dust exposure intensity (qualitative)	
		Assessor A	Assessor B
1985 - 1989	Processing of **V_2O_5** starts Both V_2O_3 and V_2O_5 processed	Acceptable	Low to moderate

Step 2: quantitative assessment

The visibility of air contamination by dust, that could have been prevalent in the precipitation area, as estimated by the two assessors, and the historical V_2O_5 concentrations that were estimated are given in Table 12.

Table 12: Estimated reported V_2O_5 concentrations in air in the MVO Building and in Product Packaging in the USA processing plant.

Work area	Period for estimation	Annual V_2O_5 production (tonnage)	Exposure intensity phase (Qualitative)	Visibility of air contamination by dust	Reported V_2O_5 estimated by panel (mg/m^3 air)
MVO Building	1985	Not shown due to confidentiality restrictions	Acceptable	Acceptable	0.10
MVO Building	1986		Acceptable	Acceptable	0.13
MVO Building	1987		Acceptable	Acceptable	0.15
MVO Building	1988		Acceptable	Acceptable	0.20
Product Packaging	1985		Acceptable	Acceptable	0.05
Product Packaging	1986		Acceptable	Acceptable	0.07
Product Packaging	1987		Acceptable	Acceptable	0.08
Product Packaging	1988		Acceptable	Acceptable	0.10

3.3 Retrospective assessment of individual exposures according to individual occupational histories for periods prior to 1988

3.3.1 Estimated percentages of V_2O_5 present in the MVO/SX building and the product packaging area

The estimated percentages of V_2O_5 produced at the USA vanadium processing plant from 1985 to 2004 are presented in Table 13, below. These percentages were presumed to be equal to the percentages of V_2O_5 present in the MVO building and in product packaging. In all other activity areas, the percentage V_2O_5 would be zero (0).

Table 13: V_2O_3 and V_2O_5 production as percentages of the total production at the USA processing plant from 1985 to 2004.

Year	Percentage V_2O_3	Percentage V_2O_5
1985 - 1991	90	10
1992	80	20
1993	70	30
1994	60	40
1995	50	50
1996	47	53
1997	45	55
1998	42	58
1999 - 2004	40	60

3.3.2 Probability of workers being active in an area of exposure to V_2O_5

The probability of "rovers" being active in either the MVO/SX building or in the product packaging area was estimated with input provided by the two assessors. The results of the estimations are summarised in Table 14.

Table 14: Probability that a "rover" would potentially have been active in an area where exposure to V_2O_5 was possible.

Occupation	Probability of being active in MVO/SX building	Probability of being active in product packaging
Gr. 1 employees prior to 1989	0.085	0.085
Gr. 1 employees since 1989	0.120	0.120
Gr. 2 employees prior to 1989	0.014	0.014
Gr. 2 employees since 1989	0.020	0.020
Labourers prior to 1989	0.117	0.30
Labourers since 1989, but prior to 2003	0.175	0.30
Labourer since 2003	0.250	0.00, unless otherwise indicated in hygiene records
Product packaging operators since 2003	0.0	1.0
Miscellaneous operator prior to 1989	0.143	0.143
Miscellaneous operator since 1989	0.200	0.200
Employed only before 1992: Painters Shift foremen	0.075	0.075
Artisan Artisan assistant Development technical Plant superintendent Plant technician	0.05	0.05
Electricians Mechanics Welders Master mechanics Maintenance personnel Engineers (not specified)	0.20	0.20
Safety managers	0.075	0.075
Oilers	0.15	0.15
Instrument technicians	0.25	0.00
Assistant engineer Production manager	0.025 – 0.05	0.025 – 0.05
Chemical engineer Engineering manager Manager services Operational manager Section engineer Service operations manager Technical supervisor	0.025	0.025

3.4 Occupational hygiene records for 1988 to 2004

The information extracted from the results of the personal dust monitoring records for use in the study is given in Annexure 6, as well as the results of the exposure assessment for 1988 to 2004.

3.5 Asbestos exposure

Asbestos has been used throughout large sections of the USA processing plant since it was started up in the mid sixties. A large amount of it was used in the kiln preheater and off-gas duct installations, which required regular maintenance. Most of this asbestos was removed in 1996 when the kiln, preheater and fine ore building were demolished. Asbestos cladding and other asbestos products were also used on the lake pumps, leach pipes, SX pipes, SX tanks and flocculation tanks and were used in gasket rope. The job categories with potentially significant exposure to these would have been the mechanics and their aides, and the operators attending to the roaster, the neutralization process and to the SX and MVO areas. In 2002 a small amount of asbestos was found on (and removed from) the crystallisers. Therefore, mechanics and SX operators could have experienced a lesser exposure to asbestos fibres during this period.[56]

4 Cases identified in the study

4.1 South Africa

A summary of the cases identified at the South African processing plant is presented in Table 15. The potential cases amongst the deceased are not included in this report, since deceased employees were not exhaustively followed up in the pilot study.

4.2 USA

A summary of the cases identified at the USA plant is presented in Table 16.

Table 15: Summary of the exposure classification of cases identified at the South African processing plant.

Questionnaire number	Age when diagnosed (years)	Site of cancer	Type of cancer	Occupation	Work area	Number of years of exposure*	Cumulative exposure mg-year/m^3 V_2O_5	Mean exposure mg/m^3 V_2O_5	Exposure classification	Smoking status
155	61	Bladder	Papillary urothelial	Trainer	Mechanical Training	16	0.602	0.038	Low	Previous; unknown number of years @ 25 cigars/day
156	60	Prostate	Adeno-carcinoma	Leave relief/operator	Roving	3	0.180	0.040	Low	Previous; 2 years @ 20 cigarettes/day
				Leave relief	Roving	10	0.343			
158	51	Colon	Adeno-carcinoma	Human Resources Manager	Admin	7	0.000	0.000	Not exposed	Previous; 20 years @ 30 cigarettes/day
261	58	Lung	Squamous cell	Operator	Roving	5	0.300	0.046	Low	Current; 33 years @ 7 cigarettes/day
				General foreman/supervisor	Roving	18	0.753			

*The number of years of exposure includes years under previous ownership of the facility.

Table 16: Summary of the exposure classification of cases identified at the USA plant.

Questionnaire number	Age when diagnosed (years)	Site of cancer	Type of cancer	Occupation	Work area	Number of years of exposure*	Cumulative exposure mg-year/m^3 V_2O_5	Mean exposure mg/m^3 V_2O_5	Exposure classification	Smoking status
171	31	Testicular	Seminoma	Labourer	Plant	1	0.032	0.032	Low	Never smoked
				Reverse osmosis operator	Reverse osmosis	6	0.189			
231	55	Prostate	Adeno-carcinoma	Technician	Instrument shop	10	0.188	0.019	Low	Never smoked
				Master mechanic	Maintenance	4	0.086			
233	63	Prostate	Adeno-carcinoma	Maintenance	Plant	15	0.317	0.021	Low	Previous; 4 years @ 20 cigarettes/day
235	70	Lung	Squamous cell	Welder	Plant maintenance	8	0.089	0.011	Low	Previous; 30 years @ 10 - 15 cigarettes/day
236	74	Skin	Squamous cell	Operator	Mill	5	0.000	0.000	Not exposed	Previous; 10 years @ 1 cigar/week
237	62	Kidney	Renal cell	Safety director	Plant/Mine	5	0.007	0.001	Low	Previous; 9 years @ 20 cigarettes/day

*The number of years of exposure includes the years before the current owner had owned the facility.

5 Results of the statistical analyses

5.1 Descriptive statistics

The original dataset consisted of a total of 50 variables of study (1 outcome or dependent variable of study and 49 independent or predictor variables). Frequency tables were obtained for each discrete variable as shown in Table 17 below.

Table 17: Summary statistics of the discrete variables in the study.

Variable name	Total observations *n*	Variable category	*n*	Percentage*
Gender	196	male	186	94.9
		female	10	5.1
Country	196	SA	133	67.9
		USA	63	32.1
Employed	196	active	144	73.5
		retired	44	22.5
		former	8	4.1
Smoking status	196	never	77	39.3
		current	57	29.1
		previous	62	31.6
Tobacco product predominantly used	196	none	76	39.0
		commercial cigarettes	113	58.0
		cigars	5	2.6
		pipe	1	0.5
		handrolled cigarettes	0	0.0
		dagga	0	0.0
		not answered	1	0.5
Cough when smoking	196	no	166	84.7
		yes	29	14.8
		not answered	1	0.5
Frequency of cough when smoking	196	cough not reported	166	85.1
		seldom	16	8.2
		often	13	6.7
		not answered	1	0.5

Table 17 (continued): Summary statistics of the discrete variables in the study.

Variable name	Total observations *n*	Variable category	*n*	Percentage*
Use of snuff	196	no	179	91.3
		yes	17	8.7
Type of snuff used	196	none	179	91.3
		powder	17	8.7
		liquid	0	0.0
Daily frequency of snuff use	196	never	179	91.3
		seldom	16	8.2
		often	0	0.0
		not answered	1	0.5
Consumption of alcohol	196	no	79	40.3
		yes	116	59.2
		not answered	1	0.5
Consumption of commercial beer	196	no	105	53.6
		yes	89	45.4
		not answered	2	1.0
Consumption of homebrewed beer	196	no	191	97.4
		yes	3	1.5
		not answered	2	1.0
Consumption of commercial wine (sold in bottles)	196	no	173	88.3
		yes	21	10.7
		not answered	2	1.0
Consumption of commercial wine (sold in boxes)	196	no	194	99.0
		yes	0	0.0
		not answered	2	1.0
Consumption of homebrewed spirits	196	no	194	99.0
		yes	0	0.0
		not answered	2	1.0
Consumption of commercial spirits	196	no	158	80.6
		yes	34	17.3
		not answered	4	2.0
Probable alcohol abuse	196	no	177	90.3
		yes	17	8.7
		not answered	2	1.0
Ever diagnosed with cancer	196	no	186	94.9
		yes	10	5.1

Table 17 (continued): Summary statistics of the discrete variables in the study.

Variable name	Total observations *n*	Variable category	*n*	Percentage*
Type of cancer	196	none	186	94.9
		bladder	1	0.5
		prostate	3	1.5
		colon	1	0.5
		skin	1	0.5
		testicular	1	0.5
		lung	2	1.0
		kidney	1	0.5
Family history of cancer	196	no	143	73.0
		yes	33	16.8
		probably	3	1.5
		don't know	17	8.7
Household energy source: coal or wood	196	no	186	95.0
		yes	10	5.0
Household energy source: paraffin	196	no	157	80.1
		yes	39	19.9
Considerable indoor pollution	196	no	169	86.2
		yes	27	13.8
V_2O_5 exposure classification	196	not exposed	103	52.6
		low	82	41.8
		intermediate	11	5.6
		high	0	0.0

*Percentages may not add up to 100, due to rounding off of decimals

Summary statistics were compiled for the continuous variables of study and these are shown in Table 18.

Table 18: Summary statistics of the continuous variables in the study.

Variable name	Total observations *n*	Mean ± SD	Median (inter-quartile range*)	Range**
Age	196	52.4 ± 10.2	53 (46 - 59)	22 - 76
Period smoking (years)	192	11.3 ± 13.3	5 (0 - 20)	0 - 52
Commercial cigarettes smoked daily	193	8.6 ± 12.9	3 (0 - 15)	0 - 90
Pack-years smoked	189	3155.8 ± 5834.3	438.3 (0 – 3835.1)	0 – 49308.8
Cigars smoked daily	195	0.2 ± 1.9	0 (0 - 0)	0 - 25
Pipes smoked daily	195	0.03 ± 0.3	0 (0 - 0)	0 - 4
Hand-rolled cigarettes smoked daily	194	0.04 ± 0.34	0 (0 - 0)	0 - 2
Dagga smoked daily	195	0.03 ± 0.24	0 (0 - 0)	0 - 3
Period snuff used (years)	193	1.4 ± 6.4	0 (0 - 0)	0 - 55
Period alcohol used (years)	153	12.3 ± 14.9	0 (0 - 27)	0 - 46
Volume commercial beer per week (ml)	192	1657.6 ± 3076.4	0 (0 - 2040)	0 - 18750
Volume homebrewed beer per week (ml)	190	126.3 ± 1015.7	0 (0 - 0)	0 - 12000
Volume bottled wine per week (ml)	189	46.9 ± 180.5	0 (0 - 0)	0 - 1500
Volume “boxed” wine per week (ml)	192	0 ± 0	0 (0 - 0)	0 - 0
Volume homebrewed spirits per week (ml)	191	0 ± 0	0 (0 - 0)	0 - 0
Volume commercial spirits per week (ml)	188	19.4 ± 89.9	0 (0 - 0)	0 - 1000
Number of years followed up after end of exposure***	196	7.5 ± 4.6	10 (3.5 – 10)	0 - 22
Total number of years exposed***	196	13.4 ± 5.7	12.6 (9 - 17)	5 - 36
Cumulative exposure*** (mg-years.m-3)	196	0.17 ± 0.46	0 (0 - 0.22)	0 - 5.51
Mean exposure*** (mg.m-3)	196	0.02 ± 0.03	0 (0 - 0.03)	0 - 0.35

* 25^{th} to 75^{th} quartile

** Smallest – largest value

*** Exposure to V_2O_5

6 List of variables of study and their levels

Table 19 shows the list of variables assessed in the pilot study along with their possible values. The outcome of interest was the occurrence of cancer, which is a dichotomous variable (yes, no, depicted as 1 and 0 respectively).

Table 19: List of variables of study, with their possible values.

Variables	Reference category	*n*	Test category	*n*
Age	< 53 years	94	≥ 53 years	102
Employment status	Active employees	144	Retired and former employees	52
Smoking status	Never smoked	77	Current and previous smokers	119
Tobacco product predominantly used	None	77	All other products	119
Period smoking (years)	< 5 years	95	≥ 5 years	101
Commercial cigarettes smoked daily	< 1	83	≥ 1	113
Pack-years smoked	0	80	> 0	116
Cigars smoked daily	< 1	190	≥ 1	6
Pipes smoked daily	< 1	193	≥ 1	3
Hand-rolled cigarettes smoked daily	< 1	190	≥ 1	6
Dagga smoked daily	< 1	192	≥ 1	4
Frequency of cough when smoking	Not reported	182	Seldom and often	13
Type of snuff	None	179	Powder and liquid	17
Daily frequency of snuff use	Never	179	Seldom and often	16
Period snuff used (years)	≤ 20 years	183	> 20 years	13
Period alcohol used (years)	< 1	79	≥ 1	117
Volume commercial beer per week (ml)	< 2040	102	≥ 2040	94
Volume homebrewed beer per week (ml)	<3000	186	≥ 3000	10
Volume bottled wine per week (ml)	< 1	170	≥ 1	26
Consumption commercial spirits: Volume commercial spirits per week (ml)	< 1	158	≥ 1	38
Type of cancer	None	186	All other types	10
Family history of cancer	No	143	Yes and probably*	36
Vanadium pentoxide exposure classification	Not exposed	103	Low, intermediate and high	93

Table 19 (continued): List of variables of study, with their possible values.

Variables	Reference category	*n*	Test category	*n*
Total number of years exposed**	$\leq$ 9	57	> 9	139
Cumulative exposure** (mg-years.m^{-3})	0	110	> 0	86
Mean exposure** (mg.m^{-3})	0	103	> 0	93

*: “don't know” values were treated as missing values

** Exposure to V_2O_5

Summary statistics of the variables *age, pack-years smoked, total number of years potentially exposed to V_2O_5 cumulative exposure to V_2O_5* and *mean exposure to V_2O_5* amongst the cases and controls are shown in Tables 20 and 21 respectively.

Table 20: Descriptive statistics of the variables of interest potentially related to cancer in the control group (*n* = 186).

Variables	Total observations *n*	Mean $\pm$ SD	Median (inter-quartile range*)	Range**
Age	186	51.9 $\pm$ 9.86	52.5 (45 - 59)	22 - 75
Pack-years smoked	186	2 983 $\pm$ 5 810	319.9 (0 - 3 652)	0 - 49 307
Total number of years exposed***	186	13.6 $\pm$ 5.67	12.6 (9 - 17)	5 - 36
Cumulative exposure*** (mg-years.m^{-3})	186	0.18 $\pm$ 0.470	0 (0 - 0.198)	0 - 5.51
Mean exposure*** (mg.m^{-3})	186	0.017 $\pm$ 0.033	0 (0 - 0.03)	0 - 0.35

* 25th to 75th quartile

** Smallest – largest value

*** Exposure to V_2O_5

Table 21: Descriptive statistics of the variables of interest potentially related to cancer in the case group (n = 10).

Variables	Total observations *n*	Mean $\pm$ SD	Median (inter-quartile range*)	Range**
Age	10	61.8 $\pm$ 12.23	63 (59 – 70)	32 - 76
Pack-years smoked	10	4 166 $\pm$ 4 816	2 374.1 (0 – 8 218)	0 - 12 783
Total number of years exposed***	10	12.0 $\pm$ 5.98	11.8 (7 – 15)	5 – 24.1
Cumulative exposure*** (mg-years.m-3)	10	0.09 $\pm$ 0.140	0.005 (0 – 0.24)	0 – 0.369
Mean exposure*** (mg.m-3)	10	0.012 $\pm$ 0.018	0.002 (0 – 0.025)	0 – 0.044

* 25^{th} to 75^{th} quartile

** Smallest – largest value

*** Exposure to V_2O_5

7 Pearson's chi-square and Fisher's exact tests of association

The Pearson chi-square test of association (valid for expected cell frequencies of five or more) and the Fisher's exact test (cell frequencies less than five) were used to test the strength of association between cancer and the dichotomous variables of study related to cancer. Tables 22 and 23 show summaries of the results of the two tests. The Pearson chi-square test was also used to test the strength of association between dichotomous variables of exposure to V_2O_5, and potential confounders. The results are summarised in Table 24.

Table 22: Results of the Pearson's chi-square test of association with cancer.

Independent variable	P-value	Strength of association
Volume commercial beer per week (ml)	0.895	Insignificant
Volume commercial spirits per week (ml)	0.012	Significant
Total number of years exposed*	0.135	Insignificant

* Exposure to V_2O_5

Table 23: Results of the Fisher's exact test of association with cancer.

Independent variable	P-value	Strength of association
Age	0.019	Significant
Gender	1.000	Insignificant
Country	0.079	Insignificant
Employment status	0.023	Significant
Smoking status	0.092	Insignificant
Tobacco product predominantly used	0.092	Insignificant
Pack-years smoked	0.532	Insignificant
Cigars smoked daily	0.273	Insignificant
Pipes smoked daily	1.000	Insignificant
Hand-rolled cigarettes smoked daily	1.000	Insignificant
Dagga smoked daily	1.000	Insignificant
Cough when smoking	1.000	Insignificant
Frequency of cough when smoking	1.000	Insignificant
Use of snuff	1.000	Insignificant
Type of snuff used	1.000	Insignificant
Period snuff used (years)	1.000	Insignificant
Consumption of alcohol	1.000	Insignificant
Period alcohol used (years)	1.000	Insignificant
Volume homebrewed beer per week (ml)	0.415	Insignificant
Volume commercial wine (sold in bottles) per week (ml)	0.625	Insignificant
Probable alcohol abuse	0.605	Insignificant
Family history of cancer	0.009	Significant
Household energy source: coal or wood	1.000	Insignificant
Household energy source: paraffin	0.216	Insignificant
Considerable indoor pollution	0.363	Insignificant
Cumulative exposure* (mg-years.m^{-3})	0.339	Insignificant
Mean exposure* (mg.m^{-3})	0.522	Insignificant
V_2O_5 exposure classification	0.522	Insignificant

* Exposure to V_2O_5

Table 24: Results of the Pearson's chi-square test of the association between potential confounders and exposure.

Variable significantly associated with cancer	P-value: association with V_2O_5 exposure variable			
	Total number of years exposed*	**Cumulative exposure* (mg-years/m^3)**	**Mean exposure* (mg/m^3)**	**V_2O_5 exposure classification***
Age (years)	0.249	0.944	0.863	0.863
Consumption commercial spirits	0.984	0.115	0.072	0.072
Family history of cancer	0.527	0.189	0.146	0.146
Employment status	0.689	0.019	0.018	0.018

* Exposure to V_2O_5

Associations of significant strength ($P < 0.05$) are shaded.

8 Binary logistic regression analysis

A series of 8 binary logistic regression procedures were performed with each of 8 potential predictor variables related to cancer, and with cancer as the outcome variable. Table 25 shows the odds ratios, the epidemiological measures of effect, obtained from these procedures.

Table 25: Summary of results from the binary logistic regression analyses.

Outcome variable: cancer						
Predictor variable	**Crude OR**	**P-value**	**95% CI of OR**	**% Overall correct classification**	**% Sensitivity**	**% Specificity**
Age	9.0	0.039	1.12 - 72.47	94.9	0.00	100.0
Employment status	4.6	0.023	1.23 – 16.89	94.9	0.00	100.0
Smoking status	6.2	0.086	0.77 – 50.10	Not determined		
Consumption commercial spirits	4.6	0.020	1.27 - 16.93	94.9	0.00	100.0
Total number of years exposed	0.39	0.147	0.108 - 1.396	Not determined		
Cumulative exposure* (mg-years.m^{-3})	1.99	0.300	0.543 – 7.278	Not determined		
Mean exposure* (mg.m^{-3})	1.70	0.419	0.466 - 6.248	Not determined		
V_2O_5 exposure classification	1.76	0.419	0.466 - 6.248	Not determined		

* Exposure to V_2O_5

Associations of significant strength are shaded.

9 Estimation of stratum-specific odds ratios from binary logistic regression analysis

The suitable epidemiological measure of effect in the pilot study is the odds ratio, but crude odds ratios (Table 25) were inadequate because of the presence of confounding variables or effect modifiers. Data were stratified according to each of the potential confounding variables and stratum-specific estimates of odds ratios were obtained, as summarised in Table 26.

Table 26: Summary of results from the stratified binary logistic regression analyses.

Predictor variable	Crude OR for cancer	Strata of potential confounders or effect modifiers	Stratified OR for cancer	95% CI of adjusted OR
Age	9.0	Employment status: Active	4.7778	[0.4845 - 47.1149]
		Employment status: Retired and former	OR indeterminable, since “age < 53 years” not found amongst cases in this stratum	
Consumption commercial spirits*	4.6364	Age > 53 years	5.2083	[1.2692 - 21.3723]
		Age < 53 years	OR indeterminable, since “Consumption commercial spirits > 1ml” not found amongst cases in this stratum	
		Years exposed < 9	1.0500	[0.10556 – 10.4443]
		Years exposed > 9	19.3043	[2.0616 - 180.7597]
		Employment status: Active	4.3846	[0.5900 - 32.5836]
		Employment status: Retired and former	5.5714	[0.9291 - 33.4085]
Years exposed to V_2O_5	0.3881	Age > 53 years	0.3873	[0.0956 – 1.5692]
		Age < 53 years	OR indeterminable, since “Years exposed > 9” not found amongst cases in this stratum	
		Consumption commercial spirits < 1ml	0.0946	[0.0103 - 0.8708]
		Consumption commercial spirits > 1ml	1.7391	[0.1720 – 17.5848]
		Employment status: Active	0.4141	[0.0564 - 3.0401]
		Employment status: Retired and former	0.3143	[0.0553 - 1.7866]

* Volume commercial spirits consumed per week.

Associations of significant strength are shaded.

10 Comparison of variables from the South African and USA data

10.1 Bartlett's test for the equality of variances

Bartlett's test for the equality of variances was used to assess the similarity of results from South Africa and the USA, by comparing the variances of several variables of interest. Table 27 shows that the observed variation in a number of important variables studied in processing plant workers in South Africa differ significantly from those in the USA.

Table 27: Bartlett's test for the equality of variances from South Africa and the USA

Variable	P-value	SD USA group *n* = 63	SD SA group *n* = 133	Significance of difference
Age	0.0000	13.74	7.78	Significant
Pack-years smoked	0.0001	4148.5	6494.8	Significant
Consumption commercial spirits (ml per week)	0.0052	69.9	97.7	Significant
Total number of years exposed*	0.011	6.79	5.20	Significant
Cumulative exposure* (mg-years.m^{-3})	0.0000	0.19	0.54	Significant
Mean exposure* (mg.m^{-3})	0.0066	0.026	0.035	Significant

SD Standard deviation in the sample

* Exposure to V_2O_5

10.2 The two-sample unpaired t-test for continuous variables

The two-sample unpaired t-test with unequal variances was used to compare the means of the South African and American groups with regards to continuous variables of study. Results are shown in Table 28 below:

Table 28: Results of the two-sample unpaired t-test for continuous variables: comparison of means of participants from South Africa with those from the USA.

Variable	P-value	Mean [CI] USA group *n* = 63	Mean [CI] SA group *n* = 133	Significance of difference
Age	0.0532	49.90 [46.44 -53.37]	53.55 [52.22 - 54.88]	Not significant
Pack-years smoked	0.1282	2361 [1316.63 – 3406.187]	3553 [2407.9 - 4698.2]	Not significant
Consumption commercial spirits (ml per week)	0.811	17.28 [-1.11 - 35.66]	20.28 [3.33 - 37.24]	Not significant
Total number of years exposed*	0.699	13.16 [11.45 - 14.87]	13.53 [12.65 - 14.43]	Not significant
Cumulative exposure* (mg-years.m^{-3})	0.0591	0.11 [0.06 - 0.15]	0.21 [0.11 - 0.30]	Not significant
Mean exposure* (mg.m^{-3})	0.662	0.018 [0.011 - 0.024]	0.016 [0.0099 - 0.022]	Not significant

* Exposure to V_2O_5

10.3 The Mann-Whitney test for discrete variables

Results of the Mann-Whitney test used to compare South African and American samples with regard to the means of discrete variables of study are shown in Table 29 below:

Table 29: Results of the unpaired Mann-Whitney test for discrete variables: comparison of the South African sample with the USA sample.

Variable	P-value	USA group *n* = 63	SA group *n* = 133	Significance of difference
Gender	0.0087	Females = 7 (11%)	Females = 3 (2.2%)	Significant
Cancer	0.053	Cases = 6	Cases = 4	Not significant
Employment status	0.921	Current = 46	Current = 98	Not significant
Smoking status	0.310	Current = 35	Current = 84	Not significant
Consumption of alcohol	0.368	Current = 34	Current = 82	Not significant
Vanadium pentoxide exposure classification	0.000	Not exposed = 18 (28%) Exposed = 45	Not exposed = 85 (64%) Exposed = 48	Significant

10.4 Comparison of follow-up periods for cases and controls

10.4.1 Bartlett's test for the equality of variances

It is accepted that the period between exposure to a carcinogen and the presentation of cancer may cover several years. Potential cancer cases might therefore present after the investigation, and might be missed if the number of years that elapse from the last potential exposure to V_2O_5 up to the time of the investigation (the follow-up period) is not sufficient. It is therefore possible that the follow-up period in the control group might have been too short to allow the presentation of cancer cases. Bartlett's test for the equality of variances was used to compare similarity of variance in the follow-up period from the case and control groups. Table 30 shows the results.

Table 30: Tests of equality of variances from the case and the control groups

Variable	P-value	SD control group *n* = 186	SD case group *n* = 10	Significance of difference
Number of years of follow-up	0.9089	4.6	4.3	Not significant

SD Standard deviation in the sample

10.4.2 The two-sample unpaired t-test for continuous variables

The two-sample unpaired t-test with equal variances (the Bartlett's test failed to indicate significant differences in variance between cases and controls) was used to compare the follow-up period from the case and control groups. Results are shown in Table 31.

Table 31: Results of the two-sample unpaired t-test: comparison of the period of follow-up of the case and control groups.

Variable	P-value	Mean [CI] control group *n* = 183	Mean [CI] cancer group *n* = 10	Significance of difference
Number of years of follow-up	0.0532	7.5 [6.83 – 8.16]	7.4 [4.3 – 10.5]	Not significant

Chapter 4 - Discussion

1 Summary of the study group

The study group or participants who had satisfied the exclusion and inclusion criteria consisted of 98 active and 35 former or retired employees from the South African processing plant, and 46 active and 17 former or retired employees from the USA processing plant. The majority (94.4 per cent) were males. The mean age ($\pm$ SD) of the study group was 52.4 $\pm$ 10.2. The mean cumulative exposure to V_2O_5 was 0.17 $\pm$ 0.46 mg-years.m^{-3}. Amongst the participants, 4 cancer cases were identified at the South African plant, and 6 at the USA plant. Various types of cancers were reported in various organs. Four adenocarcinomas were confirmed, three each in the prostate and one in the colon. Three squamous cell carcinomas were confirmed, two each in the lung and the third was a skin cancer. The other cancers were one renal cell cancer of the kidney, one seminoma of the testis, and one papillary urothelial cancer of the bladder. Smoking and the consumption of alcohol was fairly common amongst the study group, with 61 per cent of the participants being current or previous smokers, and 59.5 per cent indicating that they were drinking alcoholic drinks or beverages.

2 Vanadium pentoxide exposure and cancer

Although positive genotoxicity results and tumour promoting data have been published for vanadium pentoxide, cancer has never been reported in exposed humans. The National Toxicology Program (NTP) of the US Department of Health and Human Services released a report with the conclusion that there was some evidence of carcinogenic activity of vanadium pentoxide in male rats and equivocal evidence of carcinogenicity in female rats, based on the occurrence of alveolar/bronchiolar neoplasms; and clear evidence of carcinogenic activity in male and female mice, based on increased incidences of alveolar/bronchiolar neoplasms. [27]

The NTP report suggested that the generation of reactive oxygen species (ROS) was a potential mechanism for the carcinogenesis of vanadium pentoxide, resulting in DNA damage and the mutations noted in lung carcinomas taken from mice exposed to vanadium pentoxide.[27] A mechanism involving ROS formation is plausible, since the ability of V_2O_5 to induce ROS formation has been demonstrated in human lung fibroblasts.[70]

Environmental exposure to vanadium pentoxide is limited to the localities close to anthropogenic sources, such as industries involved in the generation of electricity and heat, and vanadium-processing activities in the metallurgical industry. Occupational exposure occurs via inhalation of vanadium dust or fumes during various activities, particularly the pentoxide form in the course of ore processing. The inhalation route of exposure used in the NTP study was therefore relevant to the occupational exposure scenario in humans. Reports of low-level exposure in humans are not available, and the associated effects are currently unknown.

Vanadium processing is an economically important activity in South Africa and in the USA and the potential for the development of cancer due to occupational exposure is therefore of interest to the workforces of both countries. Occupational exposure to vanadium pentoxide in the mineral processing industry presents a practical setting in which to study a potential link between exposure and cancer in humans. Such a study is of interest to the industry, since it concerns the health of their workforce, and because the demand for the product might be seriously limited if it is classified as carcinogenic. In addition, one of the main points of critique against the NTP study is that the upper range of air concentrations to which the rodents were exposed would have caused intolerable irritation effects in humans and would therefore never be experienced by workers in the processing plants. These factors have prompted the international vanadium industry, embodied by Vanitec, the international association of vanadium producers, to request an epidemiological study with the aim of determining the association between cancer and occupational vanadium exposure.

Whether the appearance of lung tumours and neoplams in exposed rodents implies a potential for carcinogenicity in exposed humans obviously depends on whether results in rodents may be extrapolated to humans. Amongst others, similarity in pharmacokinetics and the biochemical mechanisms of biotransformation are some of the important premises for valid extrapolation between species. Cancer is a rare disease and internationally the number of workers potentially exposed to V_2O_5 is not large, therefore opportunities to study pharmacokinetics, biotransformation and potential mechanisms of genotoxicity in humans are limited. Current knowledge concerning these mechanisms is not sufficiently complete to allow extensive and fully comprehensive comparisons between rodents and humans, or to allow final conclusions regarding potential associations between V_2O_5 exposure and cancer. This situation is a motivation for investigation of the potential association in settings of occupational exposure.

Food is the major source of exposure to vanadium for the general population, even though most foods contain low concentrations of vanadium (less than 1 ng V/g), and drinking water is not an important source of exposure, with typical vanadium concentrations less than 1 µg/litre[6]. The most plausible higher-than-background exposures in humans therefore occur through inhalation near industrial sources and in the occupational scenario. The inhalation route of exposure studied in the NTP study is therefore relevant and comparable to that in humans. However, due to differences in body mass (70 kg average weight for humans[63] and 0.40 kg average rat weight[27]) and differences in the air ventilation rate (1.4 m^3/hr for humans doing light exercise[64] and 225 ml/min[65], or 0.0135 m^3/hr for rats), volumes of air inhaled per kg body mass are not comparable (0.020 m^3/kg-hr for humans and 0.034 m^3/kg-hr rats). Therefore, when humans and rodents are exposed to the same air concentrations of a compound, the dose inhaled by rats might be almost twice that inhaled by humans. This simplified comparison does not consider potential differences in rates of deposition of the chemical compound on the nasal surface, or differing rates of uptake from the nasal epithelium.

Vanadium levels in air near metallurgical industries (approximately 1 µg V/m^3)[6] are orders of magnitude lower than those employed in the NTP study, which was clearly designed to test relatively high levels of intermittent exposure, mimicking occupational exposure over the long term (2 years).[27] The current study in the vanadium processing industry has shown that the highest estimated historical concentration of reported V_2O_5 at any time since 1976 was 0.75 mg/m^3 (Tables 8 and 12 in the Results chapter), while the estimated mean individual exposure during the period of occupation did not exceed 0.5 mg/m^3 V_2O_5 in any of the study participants (Table 18), and the mean of the study group was 0.02 $\pm$ 0.03 mg/m^3 V_2O_5 (Table 18). The estimated occupational exposure to V_2O_5 was lower than that employed in the NTP study, which ranged from 0.5 to 2 mg/m^3. [27]

The above discussion indicates that both the air concentrations of V_2O_5 and the administered doses used in the NTP study were not comparable to the estimated occupational exposure scenario. Despite these differences, the occurrence of a cluster of cancers in the occupationally exposed groups would be a significant finding. Figure

7 indicates that the confirmed cancers occurred in seven different organs, and Tables 15 and 16 shows that most cases (3 of 10) were diagnosed with prostate cancer, and two were diagnosed with lung cancer. Those with prostate cancer were diagnosed at relatively advanced ages (55, 60 and 63 years of age) and those with lung cancer were or had been smoking for 30 years or more, and were diagnosed at ages 58 and 70 respectively. The occurrence of cancer in these cases are therefore not unusual, giving the presence of risk factors such as relatively advanced age (for prostate cancer)[66] and smoking (for lung cancer)[67].

Those with prostate cancer were all diagnosed with adenocarcinoma, the most common type of prostate cancer[66] and those with lung cancer with squamous cell carcinoma, which occurs in approximately 25 to 30 per cent of lung cancer cases[67]. The colon cancer case was diagnosed with adenocarcinoma, the most common type of colon cancer[68] and the skin cancer case was diagnosed at age 74 with squamous cell carcinoma, the most common tumour arising on sun-exposed sites in older people.[69] The types of cancer most frequently diagnosed, and the ages at which cancer was most frequently diagnosed (the mean age at diagnosis of cancer was 58.5) were therefore not remarkably different from those that were prominent in the cancer literature. The presence of an unusual cluster of specific types of cancer, or of any prominent and unusual organ involvement not associated with known non-occupational risk factors, was therefore not found in the case group.

Most of the cancer cases (8 of 10) had given their primary work areas or occupation as “plant” or “roving” and therefore it was not possible to identify one specific activity area which might potentially be associated with the occurrence of cancer.

3 Limitations in the statistical analysis

The number of respondents with cancer was only 10, and limits the repertoire of statistical techniques that may be applied. Due to the limited number of cancer cases, logistic regression analysis with multiple variables could not be conducted to test the association between cancer and the other variables of study. The only available option was the use of binary logistic regression analysis, with only one predictor variable in one each of the iterations. It must therefore be noted that the statistical results were based on a series of one-on-one binary logistic regression procedures, and not on a collective (multivariate) binary logistic regression procedure. The result was theoretically weak and this limits the confidence in the results of the study.

4 Potential confounders and effect modifiers in the study

4.1 Confounding

A confounder is another (extraneous) exposure in the study population that is associated both with the disease and the exposure being studied. Confounders lead to bias that distorts the magnitude of the relationship between the disease and the exposure. The extraneous exposure would be a risk factor for the health outcome, and may lead to incorrect conclusions about the association between an exposure and an outcome.[58]

The conditions for a factor to be a potential confounder[59] may be applied to this pilot study of the association between cancer and V_2O_5 exposure as follows. The confounder:

- Must be a risk factor for the outcome (cancer);
- Must be associated with exposure to V_2O_5;
- Must not be an intermediate step in the (potential) causal path between exposure to V_2O_5 and the development of cancer; and
- Should not be a surrogate for exposure to V_2O_5.

A confounder in the pilot study would lead to bias that distorts the magnitude of the relationship between, e.g., exposure to V_2O_5 and cancer. Potential confounders identified in the study on the basis of their known association with cancer were age, smoking or the use of other tobacco products such as snuff, asbestos exposure, alcohol use, other occupational exposures known to be associated with the risk of cancer, and a family history of cancer. Other variables were identified as potential confounders since most of the study participants had the same outcome or value for these variables, namely employment status (most participants were active employees), and the number of years potentially exposed to V_2O_5 (more than 70 per cent of the participants were exposed for more than 9 years). Since the number of years potentially exposed to V_2O_5 was one of the exposure variables of interest, this variable could technically not be a confounder.

Amongst the other variables, only age, employment status, the consumption of commercial spirits, and a family history of cancer were significantly associated with cancer (results of the Pearson's chi-square and Fisher's exact tests of association, Tables 22 and 23, respectively). Of these variables associated with cancer, only the employment status was significantly associated with exposure to V_2O_5 (results of the Pearson's chi-square test, Table 24). Table 24 shows that the employment status was significantly associated with more than one of variables reflecting exposure to V_2O_5, but not to the number of years exposed to V_2O_5. One of the criteria for confounding states that the confounder should not be a surrogate for exposure. The employment status could not be a surrogate for exposure, since participants in both categories of the employment status (Table 24) had been exposed to V_2O_5. Based on these results, the employment status was the only variable that met the criteria for confounding. This conclusion was further investigated by one of the methods commonly used to adjust for confounding in the analysis stage of a study, namely stratified binary logistic regression analysis.

4.2 Effect modification

When the degree of association between an exposure variable (e.g. age or the number of years of exposure to V_2O_5) and a disease outcome (cancer), changes according to the value or level of a third variable, the third variable is called an "effect modifier", because it modifies the "effect" of exposure on cancer. Effect modification may therefore be recognized when different relationships between exposure and cancer occur in subgroups of the population, e.g. at different levels of the variable "age". The correct action in this case was to obtain stratum specific odds ratios for each of the potential effect modifiers, as demonstrated in the next sections.

4.3 Interpretation of the raw odds ratios

Significant predictor variables are characterized by estimated odds ratios that differ from 1; P-values that are smaller than 0.05, and 95 per cent Confidence Intervals (CIs) of odds ratios that do not contain 1. Accordingly, the following variables were not influential over cancer, as judged by the crude odds ratios (Table 25):

- Smoking status;
- Total number of years exposed;
- Cumulative exposure;
- Mean exposure, and
- Vanadium pentoxide exposure classification.

The crude odds ratios indicated that the following variables were influential over cancer at the 5 per cent level of significance (Table 25):

- Age;
- Employment status, and
- The volume of commercial spirits consumed per week.

It must be noted that this result was based on a one-on-one binary logistic regression procedure, and not on a collective (multivariate) binary logistic regression procedure. The result was theoretically weak. Nevertheless, it indicated the presence or absence of a significant relationship with cancer.

Without considering confounding and effect modification, the following interpretations may be made from the raw odds ratios. The estimated odds ratio of age was 9, showing that as age varied from low to high, the likelihood of cancer increased by a factor of 9. That is, older processing plant workers were 9 times as likely to have cancer in comparison with younger processing plant workers. The estimated odds ratio for a retired or former employee was 4.6, the same as that for a person consuming commercial spirits. This implies that retired or former employees are 4.6 times as likely to have cancer in comparison with active employees and that the consumption of commercial spirits increases the likelihood of cancer 4.6 times above that of a person who does not consume commercial spirits.

4.4 Interpretation of the stratified odds ratios

The crude odds ratio (Table 25) for the consumption of commercial spirits with cancer was significant. The odds ratios for the association of the consumption of commercial spirits with cancer within the different strata for employment status (Table 26) were not significant, since the confidence intervals for the stratified odds ratios included 1. Taken together, these results confirm that employment status was a confounder of the effect of the consumption of commercial spirits on cancer, and that the apparent association between the consumption of commercial spirits and cancer seen in the crude odds ratio was actually caused by the confounder, employment status.

The potential confounding effect of employment status on the association of age with cancer could not be tested, since the odds ratio for the stratum “Employment status:

Retired and former" could not be determined (Table 26). The comparison of the raw and stratified odds ratios was therefore not possible.

More than one of the significant models derived from the stratified binary logistic regression analysis included the variable "volume of commercial spirits consumed per week". The first model indicated that, in older people (age $\geq$ 53 years) the odds ratio for cancer associated with the increased consumption of commercial spirits was equal to 5.21. This could be interpreted as showing that the likelihood of cancer, in older people consuming commercial spirits, was increased by a factor of 5.21.

The second model including the variable "volume of commercial spirits consumed per week" showed that in people with longer periods of potential exposure to vanadium pentoxide (more than 9 years) the odds ratio for cancer associated with the consumption of commercial spirits was equal to 19.3, which means that the odds of contracting cancer in people with longer periods of exposure and consuming commercial spirits (more than 1 ml per week) were 19.3 times that of people not consuming commercial spirits.

The conclusions based on these two models were however not valid, since the statistical analyses indicated that employment status was a confounder of the association of cancer with the consumption of commercial spirits. It is therefore likely that this would also be true within the strata of to the variables "age" and "period of potential exposure to vanadium pentoxide". However, since only 1 predictor variable could be used for a one-on-one binary logistic regression analysis, a collective binary logistic regression analysis with multiple variables could not be conducted to test these assumptions.

The third model appeared to show that abstinence from the consumption of commercial spirits was an effect modifier of the association between longer periods of exposure to vanadium pentoxide and the development of cancer. The stratified odds ratio was 0.09, apparently indicating a protective effect of longer periods of exposure to vanadium pentoxide against the development of cancer, but only in people consuming less than 1 ml of commercial spirits per week. However, the potential modifying effect could not be fully investigated, since the odds ratio for the stratum "Consumption commercial spirits $\geq$ 1ml" could not be determined (Table 26). The comparison of the raw and stratified odds ratios was therefore not possible. Effect modifications were not observed through the comparison of other raw and stratified odds ratios.

Other indices of vanadium pentoxide exposure used in the pilot study were the cumulative exposure (mg-years.m^{-3}), the mean exposure (mg.m^{-3}), and the vanadium pentoxide exposure classification. None of these variables were statistically significantly related to the occurrence of cancer in employees working in the vanadium processing industry, and effect modification by any variable of study was not observed for any of these vanadium pentoxide exposure variables.

It is possible that the study lacked sufficient power to detect a potential association between vanadium pentoxide exposure and cancer, because of the small number of cases (n = 10). However, it is also possible that an association does not exist, as indicated by the stratified odds ratios.

5 Uncertainties and limitations of the study

5.1 The validity of the study group

The inclusion and exclusion criteria ensured that only workers that had potentially been exposed to vanadium pentoxide for a period of at least 5 years were included in the study. The mean period of potential exposure was 13.4 years (median 12.6 years), with a minimum of 5 and a maximum of 36 years. This presents reasonably extended periods of exposure, which should be sufficient for the development of cancer. However, the exclusion of subjects with less than 5 years of service during the period in which V_2O_5 was produced at the plant was a limitation of the study. This criterion potentially resulted in the exclusion of subjects with long follow-up periods, who could have contributed significantly to the study. The mean follow-up period from the end of exposure to the time of enquiry was 7.5 years. This is a relatively short period in terms of the presentation of cancer, is a limitation of the study and probably requires further follow-up for a period of up to 25 years.

The sampled group was a valid representation of the study group in so far as the chemical exposures in the workplace (including V_2O_5), the gender of the workforce and the representation of both a developed and a developing country was concerned. Exposure to vanadium pentoxide was estimated by use of the entire available occupational hygiene record of reported vanadium pentoxide concentrations analysed in personal air samples of active workers. The air monitoring programmes at the two processing plants were planned by the occupational hygienists in charge according to occupational hygiene guidelines aimed at achieving a representative result of exposure in the workplace, and should therefore be a valid representation of the exposure experienced by workers at the two processing plants.

The representivity of smoking habits and general health amongst the active South African vanadium-processing workforce should be substantial, since the participation rate amongst the active employees at the South African processing plant was 90 per cent. The participation rate amongst the active employees at the USA processing plant was 78 per cent, therefore the confidence in the representivity of smoking habits and general health amongst the active USA workforce is not as high as for the South African processing plant. A statistical analysis of the representivity could not be done, since data on the non-participants were not available.

The sampled group was not fully representative of the potential periods of exposure in the workplace, since a significant percentage of retired, former and deceased employees were not traced and did not participate in the study. Sampling of persons that had died since leaving the employment of both the USA and the South African company was not complete, especially in South Africa. In South Africa, major difficulties were encountered in the process of death certificate retrieval. In addition it was necessary to contact the medical practitioner that had filed the original death certificate, since the cause of death was not specified on the death certificate received from the SA Department of Home Affairs. This proved to be a fruitless endeavour in many cases. In this regard the sampled group therefore failed as a valid representation of the study group.

In retrospect, the decision to exclude cancer cases for whom exposure to a known carcinogenic agent was identified during the period of employment elsewhere was a flaw in the study design, since selection of cases or controls cannot be based on exposure, regardless of whether this is the exposure of interest or not. This should be acknowledged as a shortcoming of the study design.

5.2 Validity of pooling data from the South African and USA groups

The study was conducted at two vanadium processing plants, one in South Africa and the other in the USA. Data collected from the two countries were pooled for the purposes of the statistical analysis. The results of the Bartlett's tests (Table 27) shows that the variation in processing plant workers observed in South Africa differed significantly from those in the USA with regard to the variables *age*, *pack-years smoked, consumption of commercial spirits, cumulative exposure to* V_2O_5*, total number of years of exposure* and the *mean exposure concentration*. Results from two-sample unpaired t-tests and Mann-Whitney tests indicated that the means of only two variables were statistically significantly different, namely *gender* and the V_2O_5 *exposure classification*. The USA group had a larger proportion of females and a larger proportion of participants classified as exposed to vanadium pentoxide. It is therefore concluded that the South African and the USA groups were significantly different with regard to the variation of the important variables of study, but that both groups gave statistically similar estimates for the means of all variables of study, except *gender* and *exposure classification*.

In summary, the workforces from the two countries were not comparable with regard to the following characteristics:

- Proportion of participants classified as exposed to V_2O_5;
- Gender distribution of the workforce;
- Ethnic group to which the majority of the workers belong, and
- The US is a developed or first-world country, whereas South Africa is a developing or third-world country. The education status of the two workforces would therefore probably not be comparable, although data to support this was not collected.

The study group is therefore not strictly homogenous and country of origin might be a confounder in the study. However, the statistical analysis showed that this could not be the case, since there was not a statistically significant association between the country of origin of the participant and the occurrence of cancer (P=0.079, Table 23). In addition, the statistical analysis showed that the South African and the USA groups gave statistically similar estimates for the means of all variables of study, except gender and exposure classification. These findings provides a valid ground for the pooling of data with regard to the other important variables, including age, smoking and drinking habits, and other variables of exposure (total number of years exposed; cumulative exposure, and mean exposure).

5.3 Limited traceability of former and deceased employees

A fully comprehensive follow-up of all former and deceased employees is a critical element contributing to the validity of a study of cancer in the occupational scenario, for two reasons, namely the potentially prolonged lag time and the avoidance of the healthy worker effect. The lag time between the exposure event and the development of cancer may be substantial, therefore it is possible that few cancer cases associated with V_2O_5 exposure might be seen amongst the employed, while the majority might be found amongst retirees or other former employees. The healthy worker effect is a valid concern if follow-up is limited to in-service employees, due to the expected low probability that seriously ill cancer patients will continue working. A significant percentage of retired, former and deceased employees were not traced in both countries. The cancer statuses of these are therefore not known and this is a substantial limitation of the study.

5.4 Validity of the methods of exposure assessment

5.4.1 Variables of exposure used in the study

Accurate and comprehensive exposure assessment is the cornerstone of any epidemiological study aiming to describe the association between an exposure of interest and the potentially related outcome. In the pilot study, a number of variables were used to describe the duration or intensity of exposure to V_2O_5, which was hypothesised to be associated with the development of cancer amongst exposed individuals.

One of the variables chosen was the number of years of potential exposure (duration of exposure) and this was defined as the number of years that the participant had worked in the plant, while V_2O_5 was in production. The calculation of the duration of exposure was based on the participant's job history and on the plant history and could be done with considerable accuracy, since the plant history may be confirmed by referral to official company documents and reports.

The other three variables describing the intensity of exposure were based on the estimation of concentrations of V_2O_5 from occupational hygiene records of reported V_2O_5, which was analysed by a method detecting concentrations of vanadium(5+) and vanadium(4+) (in South Africa), or by a method detecting concentrations of all oxidation states of vanadium (in the USA).

5.4.2 Estimation of reported V_2O_5 concentrations

Experienced engineers and other personnel that had been active in the relevant plant during the specific time period estimated the historical reported V_2O_5 concentrations, in cases where occupational hygiene records of reported V_2O_5 were not available. These estimates were based on secondary data such as production volumes and process methodology, but were also dependent on personal and subjective recollections of workplace circumstances, and therefore particularly vulnerable to recall and observer bias.

Comparison of the estimates of reported V_2O_5 concentrations for the years prior to the introduction of occupational hygiene monitoring (Table 8 for the SA processing plant and Table 12 for the USA plant) with reported V_2O_5 concentrations (Annexure 5 for the SA plant and Annexure 6 for the USA plant) indicates that it is likely that the intensity of earlier exposure to V_2O_5 had been overestimated. This can be concluded since estimates of reported V_2O_5 concentrations were orders of magnitude higher than the reported V_2O_5 concentrations given in the occupational hygiene records, even when estimated values in the year prior to the introduction of occupational hygiene monitoring is compared with values reported during the first year of monitoring. An overestimation of historical exposure appears likely, since historical accounts of developments at the processing plant do not give any reason to expect a sudden decrease in the V_2O_5 concentrations during the first year of the occupational hygiene-monitoring period.

5.4.3 Confidence in V_2O_5 concentrations estimated from reported V_2O_5 concentrations (reported by analytical laboratories)

The degree of confidence in the reported V_2O_5 concentrations was comparable to other similar analytical methods, but the exposure assessment was complicated by the fact that the laboratory reports, although reporting V_2O_5 concentrations, were in fact reporting concentrations of both vanadium(5+) and vanadium(4+) (in South Africa), or of all oxidation states of vanadium (in the USA). The ratio of vanadium(5+) to other oxidation states was not expected to remain constant under all circumstances and in all activity areas of the processing plant, but relevant data that could be used as a basis for the calculation of expected vanadium(5+) concentrations in the various areas of the processing plant and under various production conditions are unfortunately not available. Expected vanadium(5+) concentrations were therefore estimated based on secondary data such as V_2O_3 and V_2O_5 production as percentages of the total production at the USA processing plant, and based on production and chemical engineers' knowledge of the production process and their estimations of the maximum percentages of reported V_2O_5 concentrations that might have been present as V_2O_5 compound in the various activity areas of the plants.

A further source of uncertainty in the exposure assessment of the South African and USA participants was the estimation of V_2O_5 concentrations for groups of workers, based on the assumption that workers with similar patterns of movement through various areas in the processing plant would be exposed to similar concentrations of V_2O_5, regardless of the types of activities that they engaged in, and regardless of whether they were mainly active during production or maintenance shifts (which could have a significant effect of the intensity of exposure). An attempt was made to control this inaccuracy by grouping maintenance workers together, and separately from managerial workers, although this was not always possible. However, the accuracy could also potentially have been improved by weighting of exposure in relation to the potential for exposure associated with different activities (e.g. supervision and inspection as opposed to maintenance activities, that are potentially associated with higher exposure concentrations).

Prior to 1998, total dust was sampled at the USA processing plant, but this practice was changed in January 1998, after which only respirable dust was sampled. Only respirable dust was sampled at the South African processing plant, therefore it was necessary to convert results of vanadium concentrations sampled as total dust to concentrations in respirable dust, in order for exposure data from different periods and different processing plants to be comparable to guidelines and amongst each other. The conversion factor needed was developed by comparing average total V_2O_5 concentrations reported at the USA plant for the period 1996 to 1997 to the average respirable V_2O_5 concentration reported for the period 1998 to 1999. The ratio of the average respirable to the average total concentrations was used as a conversion factor and used to calculate estimated respirable concentrations from all V_2O_5 concentrations reported prior to 1998.

It is possible that differences in concentrations reported pre- and post 1998 might not only be due to changes in the sampling methodology, but also to changes in vanadium processing methods applied in the plant. The discussion of the mineral processing methods used at the USA plant (Section 7.2.2 in the Introductory chapter), indicates that changes in process methodology had occurred in 1989, but not after that. The changes had also occurred only in areas in which vanadium compounds were typically in the inert state (Table 4), therefore these changes could not have influenced the dust concentrations in areas of V_2O_5 exposure. It is therefore not likely that changes in processing methods applied in the processing plant could have influenced dust concentrations around 1998. The discussion of the historical perspective on vanadium processing at the USA plant (Section 7.2.1 in the Introductory chapter) indicates that production of V_2O_5 had increased at a slow pace since 1995 (when V_2O_5 production had constituted approximately 50 per cent of the total product), until the production of V_2O_5 (60 per cent) exceeded that of V_2O_3 (40 per cent) since 1999. This did not represent a large-scale or comprehensive change in processing methodology and was not expected to influence the validity of the developed conversion factor to a significant degree. A third factor that justifies consideration is increased total production in the plant, but this may unfortunately not be discussed, as production figures are considered privileged information and therefore not available for publication in this report.

The uncertainties discussed here were introduced mainly by the absence of complete records of exposure expressed in consistent concentration terms, preferably in concentrations of respirable V_2O_5 only, excluding other vanadium compounds. It must unfortunately be concluded that these uncertainties limited confidence in the accuracy of the final estimation of prevailing concentrations of the V_2O_5 compound. This potential inaccuracy impacted on all variables of V_2O_5 exposure, of which the calculation of the final value incorporated the estimated air concentrations of V_2O_5 compound, namely the variables cumulative exposure, mean exposure, and vanadium pentoxide exposure classification.

5.4.4 The validity of the definition of exposure categories for the classification of participants

The exposure classification was based on a division of categories according to the various South African occupational exposure limits (OEL) for vanadium in air, regulated by the South African Department of Minerals and Energy.[54] The OELs were developed for application to reported concentrations of V_2O_5 (which would include pentavalent (5+) and tetravalent (4+) compounds). The categories were therefore based on concentrations of reported V_2O_5, but in this study were not applied to the reported or estimated reported V_2O_5 concentrations, but to concentrations of V_2O_5 derived from reported V_2O_5 concentrations. This does not challenge the conclusion of the pilot study or the validity of the exposure assessment, since the objective of the study was an investigation of the carcinogenic potential of specifically the V_2O_5 compound. The exposure assessment and the classification of participants in the pilot study supported close adherence to this aim. However, any comparison of the results of the pilot study with the current occupational hygiene scenarios requires that the reported V_2O_5 concentrations obtained from such a scenario must be converted to estimated concentrations of the V_2O_5 compound, as explained in the study methodology, prior to any such comparisons.

Based on this discussion and the results of the study, it is concluded that a significant risk of cancer at V_2O_5 concentrations within the “low” exposure category defined in the pilot study (V_2O_5 less than 0.05 mg/m^3) is not confirmed by the current results. Since the V_2O_5 concentration is a stricter and more conservative estimate of the pentavalent vanadium concentration than the reported V_2O_5 concentration, which might include other valence states, the “low” V_2O_5 concentration category in the pilot study would probably include a number of cases in at least the “intermediate” category as defined by the SA DME (2005) in terms of reported V_2O_5. It may therefore be concluded that there is currently not any evidence suggesting that occupational exposure at “low” concentrations of reported V_2O_5 (SA DME classification), is potentially associated with cancer.

5.5 Cancer and exposure to vanadium compounds other than V_2O_5

The pilot study focussed on exposure to V_2O_5, since this vanadium compound was investigated in the NTP study that had motivated the epidemiological study.[27] The exposure assessment was therefore, by design, limited to the concentrations of V_2O_5 compound experienced in the workplace. However, V_20_5 is not the only toxicologically significant vanadium compound present in air in the processing plants included in the study. As discussed in the process descriptions, the other vanadium compounds that might be present at various concentrations in air include sodium- and ammonium metavanadate ($NaV0_3$ and NH_4V0_3), vanadium trioxide (V_2O_3), Nitrovan and ammonia vanadium salts. Since the toxicity of vanadium increases with higher valences and the pentavalent compounds are usually the most toxic, sodium- and ammonium metavanadate (both compounds with vanadium in the pentavalent state) are candidates for an association with cancer.[1,4]

The exposure assessment did not include an assessment of the air concentrations of metavanadate compounds and this is a limitation of the study. Inclusion of concentrations of metavanadate would also open the possibility of relating the occurrence of cancer to concentrations of pentavalent vanadium, which might produce a more accurate assessment of the relationship between cancer and toxic vanadium compounds, rather than limiting the cancer assessment to exposure to V_2O_5, as was done in the pilot study.

5.6 Potential sources of bias in the study

A potential source of bias in the study is the estimation of the historical reported V_2O_5 concentrations, which was dependent on personal and subjective recollections of workplace circumstances, and therefore particularly vulnerable to recall and observer bias. This was controlled by involving two assessors in the estimations at each of the participating plants, in an endeavour to ensure a more balanced approach.

A second potential confounder is follow-up time, since an extended follow-up time in the cases, versus an insufficient follow-up time in the controls, might result in a random selection bias against the inclusion of cancer cases. However, the comparison of the follow-up period between the case and control groups failed to confirm the presence of such a bias. Tables 30 and 31 show that the variation and the estimate of the mean in the number of years elapsed during the follow-up period did not differ significantly between the case and control groups, therefore a lack of sufficient follow-up time cannot be invoked as a potential bias in the study.

Selection of the two companies from which participants were sourced might introduce selection bias into the study, but this is unlikely, since the chemical operations at the two companies were broadly representative of the vanadium processing industry, except with the necessary requirement that V_2O_5, the compound of interest in this study, must be produced at the plant. The two companies do present different ethnic profiles and levels of socio-economic development, which might be sources of bias, but this was shown not to be case, as explained in Section 5.2.

Another type of bias is observation bias, which occurs when the investigator looks harder for an outcome in one group, or questions one group more closely than the other, resulting in a biased identification of cases and controls, or a biased assessment of exposure factors in the groups in question. The personal interviews that were conducted in English or Afrikaans were conducted by the same interviewer in South Africa and in the USA, using a questionnaire asking the same questions about cancer and the various exposure and lifestyle factors. The Setswana interviewers trained together and were instructed on the use of the questionnaire by the interviewer of the South African and USA participants. Questionnaires in Setswana were translated from English, were reviewed by culturally sensitive sociologists and subjected to trial runs with persons with cultural and educational backgrounds expected to be similar to that of potential participants.

All cancer cases were confirmed by a pathology report. Interviews were also conducted “blindly”, in that the interviewer was not aware of the participant’s status as a case or a control prior to the personal interview, and only knew whether a participant suffered from cancer after the personal and lifestyle history had been taken. Considering all of these controls and precautions, it is therefore unlikely that observer bias played a role in the interviewer’s approach in either the South African or the USA participant groups.

6 Strengths of the study

It is to be admitted that the statistical power of the study is not very large, mainly because a relatively small sample size was available to study cancer, which is a relatively rare disease. This was compounded by incomplete follow-up amongst the deceased and former employees.

However, certain strengths of the study may be pointed out. The exposure assessment was thorough and based in part on available personal monitoring results. Historically, monitoring was not conducted for a significant number of years, and in these cases exposure was estimated through consideration of historical plant developments, upgrades and improvements in emissions control, and organisation of production activities. Estimated historical air concentrations were broadly equivalent to results that might have been obtained through static air sampling and analysis in the workplace. These historical concentrations were the basis for the estimation of personal exposures according to job descriptions. This was done through consideration of the activity areas in which employees with specific job descriptions would have worked, and the specific chemical substances to be expected in individual activity areas, as determined by the organisation of production activities in the processing facility. This study is the first of its kind conducted in the vanadium industry to document estimation of historical personal exposure prior to the advent of exposure monitoring through personal air sampling and analysis.

The study sample was pooled from two countries with different ethnic profiles and different levels of socio-economic development. Despite these differences, there was not a statistically significant association between the country of origin of the participant and the occurrence of cancer. The design of the study therefore excluded ethnicity and socio-economic development as a source of bias in the potential association between cancer and occupational exposure to V_20_5. It may also be concluded that the current results do not support a potential gene-environment interaction that might facilitate the development of cancer upon exposure to V_20_5, although larger sample sizes are needed to study this aspect.

7 Implications of the study for occupational hygiene practices in vanadium processing plants

Vanadium concentrations in air in the workplace were historically expressed as concentrations of V_2O_5, apparently because a mixture of oxidation states of vanadium is possible, especially in processing plants, while the technology to differentiate various valence states of vanadium has not been widely available. This probably informed the decision to regulate V_2O_5, and also because compounds of the pentavalent state are usually most toxic, compared with other compounds of lower valence, e.g. the tetravalent form vanadyl (VO^{2+}). The method of analysis currently used in South Africa detects both pentavalent and tetravalent ($V(4^+)$) vanadium. The contribution of tetravalent ($V(4^+)$) vanadium varies and may reach 33 per cent of the reported result. The method used by the participating country from the USA assessed all oxidation states of vanadium, and the potential contribution by other valence states except the pentavalent vanadium had not been determined.

The result of the current analytical and regulatory practices is that the underestimation of pentavalent vanadium concentrations in the workplace is unlikely, although overestimations of various degrees are probably common. This situation might not satisfy the analytical puritan, since the reported concentrations are usually higher than the true air concentrations of V_2O_5 in the workplace, but is a practical approach in the absence of more specific analytical techniques, that measure concentrations of specific valences of vanadium routinely, reliably and fairly inexpensively. From an ethical point of view, this practice is satisfactory, since it is a conservative approach that ensures adequate protection of the worker, under all circumstances of exposure to all mixtures of vanadium compounds, by assuming that all vanadium compounds are pentavalent (and thus more toxic). It is therefore not recommended that this method of evaluation should be changed, unless more specific analytical techniques, that measure concentrations of specific valences of vanadium routinely, reliably and fairly inexpensively, become available. However, this state of affairs should be approached with caution in experimental toxicological studies aimed at investigating the association between cancer and specific vanadium compounds (such as V_2O_5). Such studies often use concentrations relevant to current regulations as a point of reference. In the case of V_2O_5, however, it should be taken into consideration that the regulations are in fact based on concentrations of reported V_2O_5, that are highly likely to exceed the true concentrations of V_2O_5. If the regulatory guidelines are interpreted as true concentrations of V_2O_5, and laboratory animals exposed to those concentrations, this could potentially result in the overestimation of cancer risks in such experimental studies.

8 The feasibility of a retrospective case control study of cancer at vanadium processing plants

A judgement on the feasibility of a retrospective case control study of cancer at vanadium processing plants should consider the feasibility of retrospective assessment of exposure in the workplace, but also of lifestyle factors, health and occupational histories.

The confidence in the expert assessments of historical exposure, for those periods during which personal dust monitoring records were not available, was judged to be reasonable, although concentrations were probably over- rather than underestimated. Employees involved in the expert assessments operated under time constraints and were not available for repeat estimates, therefore confidence in the assessment process could not be judged statistically. The probability of underestimating exposure is therefore low and there is no danger of misclassifying exposed persons as unexposed. The probability of misclassifying unexposed persons as exposed is also low, provided that a strict and consistent exposure classification protocol is followed. The cornerstone of the classification protocol would be the strict criterion that only employees that could not have experienced exposure to V_2O_5, according to their job history and according to the plant history, are classified as unexposed.

Retrospective assessment of exposure to vanadium compounds in the vanadium processing industry is therefore possible, firstly provided that only two categories of exposure classification are used, namely exposed *versus* unexposed. Secondly, a complete and dependable plant history must be available, covering detail of processing methodologies, physical structures, production volumes and work organisation, and all potential historical changes to these parameters. Thirdly, a detailed occupational history should be available for all potential participants, giving detail of the specific periods during which participants were involved in specific job descriptions in specific activity areas in and around the plant.

The retrospective assessment of personal lifestyle factors, health and occupational history of the participants was found to be possible. Confirmation of the cause of death and cancer status of previous employees was not practical in all cases, specifically not in the South African scenario. Death certification practices in South Africa were recently altered, with the result that the death certificate made available to the family of the deceased, and for which copies may be obtained upon request from the South African Department of Health, does not list the cause of death as a medical diagnosis. In stead, cause of death is listed as only one of two options, namely either due to natural or due to unnatural causes. The medical diagnosis is listed on a so-called "second page" of the death certificate, that is submitted to the Official South African Government Statistical Service (StatsSA). Access to this page, giving details of the cause of death, and hence to the diagnosis in case of a natural cause of death, was denied to the researchers. The appropriate steps would therefore be to firstly obtain permission from the next-of-kin to contact the medical practitioner that had filed the death certificate, in order to ascertain the cause of death. Secondly, the medical practitioner must then be requested to disclose the cause of death from the medical files of the deceased. This was attempted in three cases, but no response was received from the medical practitioners, despite repeated requests for information. Although a sample of three is clearly not enough for a conclusion on the feasibility of obtaining the cause of death, this does indicate the potential difficulties that can be expected. These difficulties would impact on the time and effort needed to confirm causes of death, and will clearly have a negative cost implication.

The major obstacle in the South African scenario was difficulty in following up previous employees, in order to ensure sufficiently long follow-up periods to confirm the presence or absence of cancer as a cause of death. If this cannot be confirmed, it would be practically impossible to exclude a diagnosis of cancer over the long term, which would make it very difficult to validate the findings of a case-control study.

It is more likely that a case-control design nested in a prospective cohort will be successful. In this study design, employees should enter the study as cases when cancer is diagnosed during the period of occupation at the processing plant under study. Participants leaving the employment of the processing plant without a diagnosis of cancer, should be followed up until death occurs, or until cancer is diagnosed, whichever occurs first in time. Each identified case may be matched with a disease-free control at the time of diagnosis. Matching should be on the basis of age, gender and smoking status, but not on the basis of exposure. The advantage of this study design is that the occurrence of cancer, also as a cause of death, would be easy to clarify. The first disadvantage is the need for an extended follow-up period, since most participants would logically need to be followed up till the end of their lifetime. An extended follow-up time will also be necessary since the vanadium-processing industry supports a relatively small workforce, and it will probably require a long period of follow-up to obtain a sufficient sample size on which to base a study with significant statistical power. Secondly, a high rate of attrition is likely, since it would be difficult to motivate potential participants to adhere to follow-up over such an extended period of time. This could be handled by regularly scheduled contact with participants, through various methods of communication. Unfortunately, this will contribute to the increased costs (a third disadvantage) of such a study.

Chapter 5 - Conclusion

The aim of the study was to conduct a pilot retrospective case-control study to investigate the relationship between cumulative occupational exposure to V_2O_5 and the risk of developing cancer. The results of the study amongst employees from two representative vanadium processing plants, one in SA and one in the USA, fail to indicate a significant association between cancer and various indices of exposure to vanadium pentoxide. Failure to indicate a significant association might be due to the small number of cases identified in this study, that limited the statistical analyses options to the use of binary logistic regression procedures. The small number of cases thus limits the power of the study to show a significant association between vanadium pentoxide exposure and cancer.

However, it is also possible that an association does not exist, as indicated by the results of the statistical analyses. This conclusion is in need of confirmation and should be tested in a larger study group with more cancer cases, allowing more powerful statistical analyses, ideally multivariate logistic regression analysis. This would allow the testing of variables such as age, consumption of commercial spirits, smoking and exposure to V_2O_5 simultaneously in the same model, measuring the strength of association with cancer in the presence of all potentially predictive variables, giving results that are supported by powerful statistical methods.

The pilot study has confirmed that retrospective assessment of exposure to vanadium compounds in the vanadium processing industry is possible, but it is concluded that the following provisions apply:

- Only two categories of exposure classification should be used, namely exposed versus unexposed;
- A complete and dependable plant history must be available, covering detail of processing methodologies, physical structures, production volumes and work organisation, and all potential historical changes to these parameters;
- A detailed occupational history should be available for all potential participants, giving detail of the specific periods during which participants were involved in specific job descriptions in specific activity areas in and around the plant.

Experiences gained during the pilot study have led to the conclusion that confirmation of the cause of death and cancer status of previous employees was not practical in all cases, specifically not in the South African scenario. It is therefore concluded that a complete retrospective case-control study to assess the putative relationship between exposure to V_2O_5 and cancer in the South African scenario will not be practical due to difficulties in confirming the cause of death and cancer status of previous employees. In the USA scenario, however, tracing of previous employees, and access to cancer registries and death certificates should be more practical. A retrospective case-control study conducted in the USA should therefore be possible.

An open case-control design nested in a prospective cohort should be more successful in the South African scenario, but also more expensive and results will only be available after an extended follow-up period.

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Annexure 1: Ethics Approval

UNIVERSITEIT VAN PRETORIA
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University of Pretoria
Faculty of Health Sciences Research Ethics Committee
University of Pretoria
Tel: (012) 354 [illegible] Fax: [illegible]
E-Mail: [illegible]
[illegible] Private Bag X[illegible]
[illegible] Building Pretoria
Level 2, Room 2[illegible] [illegible]
Date: [illegible]/03/2004

Number	:	S34/2004
Title	:	Retrospective case control study of cancer incidence associated with vanadium pentoxide exposure in the mineral processing industry
Investigator	:	Dr M H Pourie, Dr WCA van Niekerk, School of Health Systems and Public Health, University of Pretoria
Sponsor	:	INFOTOX

This Student Protocol has been considered by the Faculty of Health Sciences Research Ethics Committee, University of Pretoria on 30/03/2004 and found to be acceptable

Prof P Carstens	BLC LLB LLD (Pret) Faculty of Law
Prof S.V. Gray	(female) BSc (Hons); MSc; DSc; Deputy Dean
Prof V.O.L. Karusseit	MBChB; MFGP (SA); M.Med (Chir); FCS (SA); Surgeon
Dr M E Kenosh	MBChB; DTM & H (Wits); C.E.O. of the Pretoria Academic Hospital
Prof M Kruger	(female) MB.ChB.(Pret); Mmed.Paed (Pret); PhD (Leuven)
Dr N K Likibi	MB.BCh.; Med.Adviser (Gauteng Dept. of Health)
Dr F M Mulaudzi	(female) Department of Nursing
Miss R Mullins	(female) BaHons; Teachers Diploma
Snr Sr J. Phatoli	(female) BCur (Et.Al) Senior Nursing-Sister
Prof H.W. Pretorius	MBChB; M.Med (Psych) MD; Psychiatrist
Reverend PDG Richards	[illegible]
Dr L Schoeman	(female) Bpharm, BA Hons (Psy), PhD
Dr C F Slabber	BSc (Med); MB BCh; FCP (SA); Acting Head, Dept Medical Oncology
Prof J.R. Snyman	MBChB; M.Pharm.Med; MD; Pharmacologist
Dr R Sommers	(female) MBChB; M.Med (Int); MPhar.Med
Dr T J P Swart	BChD, MSc (Odont), MChD (Oral Path) Senior Specialist; Oral Pathology
Prof C W van Staden	MBChB; Mmed (Psych); MD; FTCL; UPLM; Dept of Psychiatry

Student Ethics Sub-Committee

Mrs E Anrens	(female) B.Cur
Dr L Schoeman	(female) [illegible], BA Hons (Psy), PhD
Dr R Sommers	SECRETARIAT (female) MBChB; M.Med (Int); MPharMed
Dr S J C van der Walt	(female) [illegible], D.Cur (RAU)
Mrs N Lizamore	(female) [illegible]
Prof R S K Apatu	MBChB (Legon); PhD (Cambridge)
Advocate A G Nienaber	(female) [illegible] LLB; LLM (UP); [illegible] (UNISA)
Dr S I Cronje	[illegible] (UP) – [illegible] Theology
Dr M M Gesse	(female) BSc, MBChB, [illegible] (Pharm) [illegible]

PROF J R SNYMAN
[illegible]
[illegible] Faculty of Health Sciences Research
[illegible] University of Pretoria

DR L SCHOEMAN
[illegible]
[illegible] Faculty of Health Sciences Research
[illegible] Ethics Committee – University of Pretoria

Annexure 2: Information leaflet and informed consent

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Industrial Health Study

Participant information leaflet and informed consent

Leaflet and consent form for illiterate participants and participants with a basic education.

INSTRUCTIONS TO THE INTERVIEWER (Will appear in italic, you should read only the information in standard text to the participant)

You are using this form because the potential participant is not able to read or write or has only a basic education. Please read aloud in short sections, allowing sufficient time after each section for the participant to understand the content and to ask questions.
Please cover the entire leaflet and consent form in this way. If the potential participant should question you about the meaning of words or phrase, please explain.
If any technical or other questions about the study are raised, please say that you don't know but that you will find out or ask the scientist to explain. Please consult the scientists.

INTRODUCTION (*Start reading aloud from here*)

We are here because we want to make sure your working conditions are safe and healthy. We ask you to help us by giving us some information. We will tell you what we need, and then you can decide if you want to help us. If you agree to help us, you will also help other workers in other industries.

We will explain, and you must understand everything before you sign this paper. If there is something you don't understand, please ask and we will explain as best we can.

Do you understand?	Yes	No

WHAT DO SCIENTISTS WANT FROM YOU IN THIS STUDY?

If you agree to help us, we will ask you to fill in one form only. In the form, we will ask you personal information like your name, ID number, company number and if you are a pensioner. We will ask if you go to a medical doctor, clinic, sangoma or nyanga. We will also ask if you use snuff (sniff) and if you smoke, and about the smoke from making fire at home and if you drink alcohol. We will also ask you about all the places where you have worked before.

We will ask you to please tell us about your sicknesses. **We do not want to know if you have AIDS**, only the sicknesses like heart disease, high blood pressure (hypertension), sugar (diabetes), cancer and if you have shortness of breath. Please also give us permission to see the records or notes about your health that the doctor or the clinic keeps.

HOW MANY PEOPLE WILL TAKE PART IN THIS STUDY AND HOW LONG WILL IT TAKE?

If you decide to take part you will be one of about 500 people in the study. The study will last for up to 3 years.

IS IT A FAIR STUDY THAT RESPECTS YOUR HUMAN RIGHTS?

The government has very strict rules about a study like this. If people help us, their human rights must be respected. Nobody will know if you have decided to help us or not, not even you employer. That is your right. The Research Ethics Committee of the University of Pretoria has approved the way we are doing this study. That means the committee has agreed that the study is fair and that it respects your human rights.

Everything we see in the doctor’s records about your health or in your question form, will only be used for this study. At the end of the study, we will write a report or article, but your name or ID number will not be in these reports.

Governments have supervisors that make sure that we do our job well and that we respect your human rights. To do this, the supervisors might want to look at your question form and how we used the record from your doctor or clinic, which means they might also see your information.

You will not receive any money for answering the questions, but you will know that you have helped to protect the health of many other workers.

You may decide to stop helping us after you have answered the question form. If you want to stop, you have two weeks (14 days) to tell us. No one will ask you why you have decided to do this.

The reason for the two weeks is that, when the scientists start working, they will put together all the answers from everyone's question forms and all the facts from everyone's medical records. After this, they cannot say which answer came from which form, or which fact came from which medical record. After this, you cannot be taken out of the study.

After we have written a study report, you may ask about it, it will be finished in 2006.

Do you understand?	Yes	No

WHERE MAY YOU ASK QUESTIONS ABOUT THIS STUDY?

During the study, you may ask Dr. Marlene Fourie during workdays, from 08:00 to 15:00. The telephone number is (012) 460 0650 and the e-mail address is marlene@infotox.co.za

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WE ARE ASKING YOU TO HELP US WITH THE STUDY

We are asking you to answer the question form by your own free will and your answers may be used in the study. If you sign this paper, you also agree that we can see the records about your health from your doctor or clinic.

What do you answer to this? Are you willing to help us with the study?
Please allow the participant to answer the question. If the answer is "Yes", please complete the section below. If the answer is no, thank the person for his time and move on to the next potential participant.

I, the undersigned, ………………… (name of interviewer) have read aloud to the participant and have explained fully to the participant, named ………………………………, the participant information leaflet, which has indicated the nature and purpose of the study in which I have asked the participant to take part. The explanation I have given has mentioned both the possible risks and benefits of the study. The participant indicated that he/she understands that he/she will be free to withdraw from the study at any time prior to the processing of results, for any reason and without jeopardising his/her position with previous, current or future employers, to which he/she agrees.

I hereby certify that the participant has agreed to take part in this study.

Participant's name ______________________ (Please print)

Participant's Signature ___________________ Date ____________

Interviewer's Name ______________________ (Please print)

Interviewer's Signature ______________________ Date _____________

Witness's name* ______________________ (Please print)*
Consent procedure should be witnessed whenever possible.

Witness's Signature ______________________ Date _____________

Annexure 3: Questionnaire

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1. Personal Information

First names									
Last name									
ID number		Date of birth	D	D	M	M	Y	Y	
Company name		Date of interview	D	D	M	M	Y	Y	
Company number									
Are you a pensioner	Yes	No	Date of retirement	D	D	M	M	Y	Y
If yes, please give your pension number									

2. Smoking history

Are you currently a smoker	Yes	No

If No, go to question 3. If Yes, please ask for the numbers below. Do not accept answers like "many, little etc."

For how long have you smoked	

What do you smoke	(✓ one or more options)	How many per day
Cigarettes from a shop		
Cigars		
Pipe		
Handrolled (BB, Horseshoe, Zol)		
Dagga (Patjie)		

2.2. Coughing (Reactions to the smoke)

Do you cough from smoking	Yes	No
If yes, how often	Often	Seldom

2.3. If you are not currently a smoker:

Have you ever smoked before	Yes	No

If No, go to question 3. If Yes, please ask for the numbers below. Do not accept answers like "many, little etc."

For how long have you smoked		
When did you stop smoking (*approximate date*)		
What did you smoke	(✓ one or more options)	How many per day
Cigarettes from a shop		
Cigars		
Pipe		
Handrolled (BB, Horseshoe, Zol)		
Dagga (Patjie)		

While you were smoking, did you cough	Yes	No
If Yes, how often	Often	Seldom

3. Do you, or did you ever, use snuff ("snuif" or "sniff")

Yes	No	Powder	Liquid
How many times a day do you sniff			
For how long are you/ have you been sniffing			

4. Alcohol use

Do you drink any alcohol	Yes	No

4.1. What type of alcohol do you drink most often and how much do you drink per week (Please specify container e.g. bottle, dumpies or box)

	✓ one or more options	How much do you drink per week (specify container used)
Beer from a shop		
Homemade beer		
Wine: Bottle		
Box		
Homemade spirits		
Commercial spirits (whiskey, rum, etc.)		
When did you start drinking alcohol (age)		

✓ Yes or No	Yes	No
Do you ever feel you should cut down on your drinking		
Do you ever get annoyed by people criticizing your drinking		
Do you feel bad or guilty about your drinking		
Do you drink early in the morning to steady your nerves or to get rid of a hangover		

5. Medical history

These questions are related to your health, we want to see if your work place is healthy

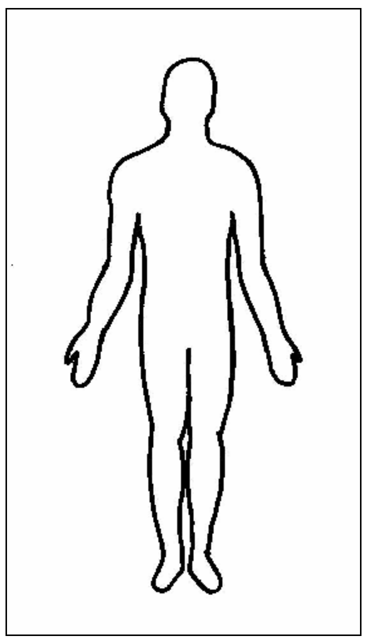
(✓ Yes or No)	Yes	No
1) Do you regularly see a medical doctor or a clinic		
2) Do you suffer, or have you ever suffered from any of the following conditions:		
a) Shortness of breath		
b) Heart disease		
c) High blood pressure (Hypertension)		
d) Lung cancer		
e) Diabetes (Sugar)		
f) Cancer		
If yes: Specify the type of cancer		
When did the doctor tell you about the cancer		

6. Family History

Is your own mother still alive	Yes	No
If no, what did she die from		
Is your own father still alive	Yes	No
If no, what did he die from		
Do you have sisters or brothers who have died	Yes	No
If yes, what did they die from		

- *If the answer is lung disease, please ask for specification*
- *If the participant indicates death by cancer, please ask:*

Can you show me where in the body was the cancer (use diagram below)



7. Details of your medical doctor/clinic you have visited most recently

Name of doctor/clinic	
Telephone number	
Address	
How long have you been seeing him/her	

7.1. Details of other medical doctors/clinics you used to visited

Name of doctor/clinic	
Telephone number	
Address	
How long have you been seeing him/her	

Name of doctor/clinic	
Telephone number	
Address	
How long have you been seeing him/her	

8. Fuel use in you family

8.1. Is your family using a coal or wood stove	Yes	No

If the family is using a coal or wood stove, please ask the following questions

Per month, how much coal did the family use in the stove during the past winter	________________Bags ________________20liter tins
Per month, how much coal did the family use in the stove during the past summer	________________Bags ________________20liter tins
Per month, how much firewood did the family use in the stove during the past winter (e.g. every day, once a week, etc.)	
Per month, how much firewood did the family use in the stove during the past summer (e.g. every day, once a week, etc.)	

8.2. Is your family using a brazier (imbawula)	Yes	No

If the family is using a brazier, please answer the following questions

Per month, how much coal did the family use in the brazier during the past winter	______________Bags ______________20liter tins
Per month, how much coal did the family use in the brazier during the past summer	______________Bags ______________20liter tins
Per month, how often did the family use firewood in the brazier during the past winter (e.g. every day, once a week, etc.)	
Per month, how often did the family use firewood in the brazier during the past summer (e.g. every day, once a week, etc.)	

8.3. Is your family using a paraffin stove	Yes	No

If the family is using a paraffin stove, please answer the following questions

Per month, how much paraffin did the family use in the stove during the past winter	______________ Liters
Per month, how much paraffin did the family use in the stove during the past summer	______________Liters

Please ask of all participants who had answered "yes" to any of questions 8.1 to 8.3:

(✓ Yes or No)	Yes	No	If yes, more than five years?
In the houses that you lived in, did the smoke from the cooking/heating fire ever make your eyes burn or cause you to cough			

12. Job history

Please handle this section as follows:

1. *For the first row: please ask "**What are you doing in the job you have now?"** and continue asking the questions at the top of the columns. Please fill out the answers in the correct columns.*
2. *At the completion of the first row, start the second row by asking "**What did you do in your job before this one?"** and continue asking the questions at the top of the columns. Please fill out the answers in the correct columns.*
3. *Please continue in this way to complete the job history, ending with the first job held by the participant.*

See *instructions above*								
What are you doing in the job you have now? (then the one before, and before that, up to the first job)	**With which company? (Employer)**	**What did they produce?**	**In which town or city?**	**When did you…**		**Was there vanadium pentoxide in this workplace? Please answer**		
				start in this job?	**stop doing this job?**	**Don't know**	**Yes**	**No**

Annexure 4: Tables for exposure assessment during years when occupational hygiene monitoring was not done

Table 3-1: Example of diagram with milestones for plant development, upgrade and emissions control.

Calendar year period	1964 - 1965	Milestone 1	1965 - 1967	Milestone 2	1968 - 1970	
Relevant information	Only metavanadate produced	Production of V_2O5 commences	Very little emission control. Several industrial incidents with shut-downs and start-ups	First phase emissions control implemented	Production of V_2O5 continues	Etc.…
Exposure intensity phase (Qualitative) Judged by panellist, using the information represented in the previous rows	None		Very high		Acceptable	

Row identification

Calendar year period

Relevant information that would influence estimation of the exposure intensity phase

Milestones are described in the yellow shaded area

The Exposure intensity phase: Panellist will choose from:

•Extreme •Very high •Not acceptable •Acceptable •Low •None

Table 3-2: Example of exposure matrix for the historical estimation of mg V_2O_5 per m^3 air.

Plant Number	Work area	Calendar year for estimation	Annual V_2O_5 production (tonnage) - examples, not real numbers	Exposure intensity phase (Qualitative)	Visibility of air contamination by dust	Quantitative range of estimated mg V_2O_5 per m^3 air
1 to n	Obtained from study participants	1976	2 000	Judged by panellist for each year, using the plant development, upgrade and emissions control milestones (Table 3-1).	Estimated by individuals that had been in service during the particular calendar year, for each year. Such individuals would include occupational health practitioners or other workers at the plant.	To be estimated by the panel and the panel a group, for ea[ch] year - example not real number[s]
		1977	1 900	Choose from: • Extreme • Very high • Not acceptable • Acceptable • Low • None	Choose from: • Extreme • Very bad • Not acceptable • Acceptable • Very light • None	1.25 – 1.75
		1978, etc…..	2 050			1.00 – 1.50
						1.50 – 2.00

Annexure 5: Results of personal dust monitoring at the South African Processing Plant

1990 - 1994

Table 4-1: Results of personal dust monitoring January to June 1990.

Occupations	Activity area	Estimated % reported V_2O_5 present as V_2O_5 compound	Time weighted average dust concentration (mg/m^3)	% V_2O_5 reported in sampled dust	Concentration of V_2O_5 in sampled dust (mg/m^3)
Fusion attendant	Fusion	80.00	0.18	10.00	0.014
Fusion attendant	Fusion	80.00	0.54	10.00	0.004
Fusion attendant	Fusion	80.00	1.40	10.00	0.011
Press attendant	Precipitation	0.00	Not used for calculations		0.000
Operator	Precipitation	80.00	0.36	10.00	0.029
Feed attendants	Nitrovan furnace	V_2O_5 not expected	Not used for calculations		0.000
Drum handler	MVO reactor	V_2O_5 not expected	Not used for calculations		0.000
Operator	MVO reactor and mix plant	V_2O_5 not expected	Not used for calculations		0.000
Reactor attendant	MVO reactor - cleaning	V_2O_5 not expected	Not used for calculations		0.000
Reactor attendant	MVO reactor	V_2O_5 not expected	Not used for calculations		0.000
Discharge attendant	Nitrovan furnace outlet	V_2O_5 not expected	Not used for calculations		0.000
Discharge attendant	Nitrovan furnace outlet	V_2O_5 not expected	Not used for calculations		0.000
Operator	Nitrovan furnace	V_2O_5 not expected	Not used for calculations		0.000
Operator	Nitrovan furnace	V_2O_5 not expected	Not used for calculations		0.000
Operator	Nitrovan furnace	V_2O_5 not expected	Not used for calculations		0.000
Feed attendants	Nitrovan furnace feeding	V_2O_5 not expected	Not used for calculations		0.000
Feed attendants	Nitrovan furnace feeding	V_2O_5 not expected	Not used for calculations		0.000
Feed attendants	Nitrovan furnace feeding	V_2O_5 not expected	Not used for calculations		0.000
Shipping	Shipping	1.00	0.74	6.25	0.000
Shipping	Shipping	1.00	0.06	6.25	0.000
Shipping	Shipping	1.00	0.92	6.25	0.001

Occupations	Activity area	Estimated % reported V_2O_5 present as V_2O_5 compound	Time weighted average dust concentration (mg/m^3)	% V_2O_5 reported in sampled dust	Concentration of V_2O_5 in sampled dust (mg/m^3)
Shipping	Shipping	1.00	0.71	6.25	0.000
Shipping	Shipping	1.00	0.92	6.25	0.001
Shipping	Shipping	1.00	0.24	6.25	0.000
Shipping	Shipping	1.00	0.39	6.25	0.000
Shipping	Shipping	1.00	0.46	6.25	0.000
Laboratory	Laboratory	4.00	0.21	4.34	0.000
Laboratory	Laboratory	4.00	0.18	4.34	0.000
Admin	Admin	V_2O_5 not expected	Not used for calculations		0.000
Artisan assistant	Roving	8.00	0.37	10.60	0.003
Artisan	Roving	8.00	0.32	4.34	0.001
Artisan	Roving	8.00	0.78	4.34	0.003
Artisan assistant	Roving	8.00	0.18	4.34	0.001
Artisan assistant	Roving	8.00	1.45	4.34	0.005
Artisan assistant	Roving	8.00	0.36	4.34	0.001
Artisan assistant	Roving	8.00	0.29	4.34	0.001
Artisan assistant	Roving	8.00	0.53	4.34	0.002
Security	Gate	V_2O_5 not expected	Not used for calculations		0.000
Production Manager	Roving	8.00	0.74	4.34	0.003
Stores	Stores	V_2O_5 not expected	Not used for calculations		0.000
Mean concentration of V_2O_5 in sampled dust (mg/m^3) applicable to rovers					0.002

Table 4-2: Results of personal dust monitoring July to December 1990.

Occupations	Activity area	Estimated % reported V_2O_5 present as V_2O_5 compound	Time weighted average dust concentration (mg/m^3)	% V_2O_5 reported in sampled dust	Concentration of V_2O_5 in sampled dust (mg/m^3)
Wheel barrow pushers	Mine/plant	V_2O_5 not expected	Not used for calculations		0.000
Silo attendant	Mine/plant	V_2O_5 not expected	Not used for calculations		0.000
H/Pack drivers	Mine/plant	V_2O_5 not expected	Not used for calculations		0.000
Wall packer	Mine/plant	V_2O_5 not expected	Not used for calculations		0.000
S/pile attendant	Mine/plant	V_2O_5 not expected	Not used for calculations		0.000
Assistant operator	Mine/plant	V_2O_5 not expected	Not used for calculations		0.000
Artisans	Mine/plant	V_2O_5 not expected	Not used for calculations		0.000
Miner	Mine	V_2O_5 not expected	Not used for calculations		0.000
Artisan assistants	Mine/plant	V_2O_5 not expected	Not used for calculations		0.000
Operators	Mine/plant	V_2O_5 not expected	Not used for calculations		0.000
Pug mill attendant	Mill	V_2O_5 not expected	Not used for calculations		0.000
Leach/mill attendant	Mill/leaching	V_2O_5 not expected	Not used for calculations		0.000
Tailings attendant	Tailings dump	V_2O_5 not expected	Not used for calculations		0.000
Front end loader driver	Mine/plant	V_2O_5 not expected	Not used for calculations		0.000
High Pressure cleaner	Precipitation	0.00	1.95	0.00	0.000
Operator	Precipitation	80.00	0.27	10.00	0.022
Operator	Precipitation	80.00	0.30	10.00	0.024
Operator	Precipitation	80.00	0.92	10.00	0.074

Occupations	**Activity area**	**Estimated % reported V_2O_5 present as V_2O_5 compound**	**Time weighted average dust concentration (mg/m^3)**	**% V_2O_5 reported in sampled dust**	**Concentration of V_2O_5 in sampled dust (mg/m^3)**
Fusion attendant	Fusion	80.00	0.98	10.00	0.08
Fusion attendant	Fusion	80.00	0.77	10.00	0.06
Fusion attendant	Fusion	80.00	0.33	10.00	0.03
Fusion attendant	Fusion	80.00	18.90	10.00	1.512
Operator	Nitrovan furnace	V_2O_5 not expected	Not used for calculations		0.000
Discharge attendant	Nitrovan furnace outlet	V_2O_5 not expected	Not used for calculations		0.000
Shipping	Shipping	1.00	0.39	6.25	0.00
Shipping	Shipping	1.00	0.68	6.25	0.00
Shipping	Shipping	1.00	0.74	6.25	0.00
Shipping	Shipping	1.00	0.74	6.25	0.00
Shipping	Shipping	1.00	0.74	6.25	0.00
Shipping	Shipping	1.00	0.74	6.25	0.00
Shipping	Shipping	1.00	0.74	6.25	0.00
Shipping	Shipping	1.00	0.74	6.25	0.00
Admin	Admin building	V_2O_5 not expected	Not used for calculations		0.000
Personnel	Admin building	V_2O_5 not expected	Not used for calculations		0.000
Lab	Lab	4.00	2.02	4.34	0.00
Lab	Lab	4.00	0.25	4.34	0.00
Security	Gate	V_2O_5 not expected	Not used for calculations		0.000
Mean **concentration of V_2O_5 in sampled dust (mg/m^3)** applicable to rovers					0.072

Table 4-3: Results of personal dust monitoring January 1991 to June 1992.

Occupations	Activity area	Estimated % reported V_2O_5 present as V_2O_5 compound	Time weighted average dust concentration (mg/m^3)	% V_2O_5 reported in sampled dust	Concentration of V_2O_5 in sampled dust (mg/m^3)
Admin	Admin building	V_2O_5 not expected	Not used for calculations		0.000
Admin	Admin	V_2O_5 not expected	Not used for calculations		0.000
Artisan	Roving	8.00	0.32	4.34	0.001
Artisan	Roving	8.00	0.78	4.34	0.003
Artisan assistant	Roving	8.00	0.37	10.60	0.003
Artisan assistant	Roving	8.00	0.18	4.34	0.001
Artisan assistant	Roving	8.00	1.45	4.34	0.005
Artisan assistant	Roving	8.00	0.36	4.34	0.001
Artisan assistant	Roving	8.00	0.29	4.34	0.001
Artisan assistant	Roving	8.00	0.53	4.34	0.002
Artisan assistants	Mine/plant	V_2O_5 not expected	Not used for calculations		0.000
Artisans	Mine/plant	V_2O_5 not expected	Not used for calculations		0.000
Assistant operator	Mine/plant	V_2O_5 not expected	Not used for calculations		0.000
Discharge attendant	Nitrovan furnace outlet	V_2O_5 not expected	Not used for calculations		0.000
Discharge attendant	Nitrovan furnace outlet	V_2O_5 not expected	Not used for calculations Not used for calculations		0.000
Discharge attendant	Nitrovan furnace outlet	V_2O_5 not expected	Not used for calculations		0.000
Drum handler	MVO reactor	V_2O_5 not expected	Not used for calculations		0.000
Feed attendants	Nitrovan furnace	V_2O_5 not expected	Not used for calculations		0.000
Feed attendants	Nitrovan furnace feeding	V_2O_5 not expected	Not used for calculations		0.000
Feed attendants	Nitrovan furnace feeding	V_2O_5 not expected	Not used for calculations		0.000

Occupations	Activity area	Estimated % reported V_2O_5 present as V_2O_5 compound	Time weighted average dust concentration (mg/m^3)	% V_2O_5 reported in sampled dust	Concentration of V_2O_5 in sampled dust (mg/m^3)
Feed attendants	Nitrovan furnace feeding	V_2O_5 not expected	Not used for calculations		0.000
Front end loader driver	**V_2O_5** not analysed	V_2O_5 not expected	Not used for calculations		0.000
Fusion attendants	Fusion	80.00	0.18	10.00	0.014
Fusion attendants	Fusion	80.00	0.54	10.00	0.043
Fusion attendants	Fusion	80.00	1.40	10.00	0.112
Fusion attendant	Fusion	80.00	0.98	10.00	0.078
Fusion attendant	Fusion	80.00	0.77	10.00	0.062
Fusion attendant	Fusion	80.00	0.33	10.00	0.026
Fusion attendant	Fusion	80.00	18.90	10.00	1.512
H/Pack drivers	Mine/plant	V_2O_5 not expected	Not used for calculations		0.000
High Pressure cleaner	Precipitation	0.00	1.95	0.00	0.000
Lab	Laboratory	4.00	2.02	4.34	0.004
Lab	Laboratory	4.00	0.25	4.34	0.000
Lab	Laboratory	4.00	0.21	4.34	0.000
Lab	Laboratory	4.00	0.18	4.34	0.000
Leach/mill attendant	Mill/leaching	V_2O_5 not expected	Not used for calculations		0.000
Miner	Mine	V_2O_5 not expected	Not used for calculations		0.000
Operator	Precipitation	80.00	0.27	10.00	0.022
Operator	Precipitation	80.00	0.30	10.00	0.024
Operator	Precipitation	80.00	0.92	10.00	0.074
Operator	Precipitation	80.00	0.36	10.00	0.029
Operator	Nitrovan furnace	V_2O_5 not expected	Not used for calculations		0.000
Operator	MVO reactor and mix plant	V_2O_5 not expected	Not used for calculations		0.000

Occupations	Activity area	Estimated % reported V_2O_5 present as V_2O_5 compound	Time weighted average dust concentration (mg/m^3)	% V_2O_5 reported in sampled dust	Concentration of V_2O_5 in sampled dust (mg/m^3)
Operator	Nitrovan furnace	V_2O_5 not expected	Not used for calculations		0.000
Operator	Nitrovan furnace	V_2O_5 not expected	Not used for calculations		0.000
Operator	Nitrovan furnace	V_2O_5 not expected	Not used for calculations		0.000
Operators	Mine/plant	V_2O_5 not expected	Not used for calculations		0.000
Personnel	Admin building	V_2O_5 not expected	Not used for calculations		0.000
Press attendant	Precipitation	0.00	Not used for calculations		0.000
Production Manager	Roving	8.00	0.74	4.34	0.003
Pug mill attendant	Mill	V_2O_5 not expected	Not used for calculations 0.00		0.000
Reactor attendant	MVO reactor - cleaning	V_2O_5 not expected	Not used for calculations		0.000
Reactor attendant	MVO reactor	V_2O_5 not expected	Not used for calculations		0.000
S/pile attendant	Mine/plant	V_2O_5 not expected	Not used for calculations		0.000
Security	Gate	V_2O_5 not expected	Not used for calculations		0.000
Security	Gate	V_2O_5 not expected	Not used for calculations		0.000
Shipping	Shipping	1.00	0.39	6.25	0.000
Shipping	Shipping	1.00	0.68	6.25	0.000
Shipping	Shipping	1.00	0.74	6.25	0.000
Shipping	Shipping	1.00	0.74	6.25	0.000
Shipping	Shipping	1.00	0.74	6.25	0.000
Shipping	Shipping	1.00	0.74	6.25	0.000
Shipping	Shipping	1.00	0.74	6.25	0.000
Shipping	Shipping	1.00	0.74	6.25	0.000
Shipping	Shipping	1.00	0.74	6.25	0.000

Occupations	**Activity area**	**Estimated % reported V_2O_5 present as V_2O_5 compound**	**Time weighted average dust concentration (mg/m^3)**	**% V_2O_5 reported in sampled dust**	**Concentration of V_2O_5 in sampled dust (mg/m^3)**
Shipping	Shipping	1.00	0.06	6.25	0.000
Shipping	Shipping	1.00	0.92	6.25	0.001
Shipping	Shipping	1.00	0.71	6.25	0.000
Shipping	Shipping	1.00	0.92	6.25	0.001
Shipping	Shipping	1.00	0.24	6.25	0.000
Shipping	Shipping	1.00	0.39	6.25	0.000
Shipping	Shipping	1.00	0.46	6.25	0.000
Silo attendants	Mine/plant	V_2O_5 not expected	Not used for calculations		0.000
Stores	Stores	V_2O_5 not expected	Not used for calculations		0.000
Tailings attendant	Tailings dump	V_2O_5 not expected	Not used for calculations		0.000
Wall packer	Mine/plant	V_2O_5 not expected	Not used for calculations		0.000
Wheel barrow pushers	Mine/plant	V_2O_5 not expected	Not used for calculations		0.000
Mean **concentration of V_2O_5 in sampled dust (mg/m^3)** applicable to rovers					0.039

Table 4-4: Results of personal dust monitoring July to December 1992.

Occupations	Activity area	Estimated % reported V_2O_5 present as V_2O_5 compound	Time weighted average dust concentration (mg/m^3)	% V_2O_5 reported in sampled dust	Concentration of V_2O_5 in sampled dust (mg/m^3)
Mine superintendent	Mine	V_2O_5 not expected	Not used for calculations		0.000
Beltsman	Mine	V_2O_5 not expected	Not used for calculations		0.000
Fitter assistant	Mine	V_2O_5 not expected	Not used for calculations		0.000
Wheelbarrow pusher	Mine	V_2O_5 not expected	Not used for calculations		0.000
Artisan assistants	Mine	V_2O_5 not expected	Not used for calculations		0.000
Boiler maker assistants	Mine	V_2O_5 not expected	Not used for calculations		0.000
Diesel mechanic assistant	Mine	V_2O_5 not expected	Not used for calculations		0.000
Artisan assistants	Plant/workshop	V_2O_5 not analysed	Not used for calculations		0.000
Artisan assistants	Plant/workshop	V_2O_5 not analysed	Not used for calculations		0.000
Artisan assistants	Plant/workshop	V_2O_5 not analysed	Not used for calculations		0.000
Artisan assistants	Plant/workshop	V_2O_5 not analysed	Not used for calculations		0.000
Fitter	Plant/workshop	V_2O_5 not analysed	Not used for calculations		0.000
Kiln Operator	Kiln	V_2O_5 not expected	Not used for calculations		0.000
Cooler attendant	Kiln	V_2O_5 not expected	Not used for calculations		0.000
Boiler maker assistants	Plant/workshop	V_2O_5 not expected	Not used for calculations		0.000
Discharge attendant	Nitrovan furnace outlet	V_2O_5 not expected	Not used for calculations		0.000
Front Loader driver	Kiln/ball mill	V_2O_5 not expected	Not used for calculations		0.000
Press cleaner	Precipitation	8.00	1.05	11.50	0.010
Reactor operator	MVO reactor	V_2O_5 not expected	Not used for calculations		0.000

Occupations	**Activity area**	**Estimated % reported V_2O_5 present as V_2O_5 compound**	**Time weighted average dust concentration (mg/m^3)**	**% V_2O_5 reported in sampled dust**	**Concentration of V_2O_5 in sampled dust (mg/m^3)**
Reactor	MVO reactor	V_2O_5 not expected	Not used for calculations		0.000
Development technical	Roving	8.00	0.29	12.00	0.003
Assistant engineer	Roving	8.00	0.42	12.00	0.004
Plant superintendent	Roving	8.00	0.21	12.00	0.002
Production manager	Roving	4.00	0.15	12.00	0.001
Chemical engineer	Roving	4.00	0.11	12.00	0.001
Stores/buyer	V_2O_5 not analysed	V_2O_5 not expected	Not used for calculations		0.000
Stores/receiver	V_2O_5 not analysed	V_2O_5 not expected	Not used for calculations		0.000
Security personnel	V_2O_5 not analysed	V_2O_5 not expected	Not used for calculations		0.000
Nurse	V_2O_5 not analysed	V_2O_5 not expected	Not used for calculations		0.000
Costing clerk	V_2O_5 not analysed	V_2O_5 not expected	Not used for calculations		0.000
Mean **concentration of V_2O_5 in sampled dust (mg/m^3)** applicable to rovers					0.002

Table 4-5: Results of personal dust monitoring January to June 1993.

Occupations	Activity area	Estimated % reported V_2O_5 present as V_2O_5 compound	Time weighted average dust concentration (mg/m^3)	% V_2O_5 reported in sampled dust	Concentration of V_2O_5 in sampled dust (mg/m^3)
Cleaner	Various Activity areas	V_2O_5 not expected	Not used for calculations		0.000
Surveyor	Mine	V_2O_5 not expected	Not used for calculations		0.000
Diesel mechanic	Mine	V_2O_5 not expected	Not used for calculations		0.000
Haulpack Driver	Mine	V_2O_5 not expected	Not used for calculations		0.000
Conveyor attendant	Mine	V_2O_5 not expected	Not used for calculations		0.000
Wall packers	Mine	V_2O_5 not expected	Not used for calculations		0.000
Tails attendant	Mine	V_2O_5 not expected	Not used for calculations		0.000
Front end loader drivers	Mine	V_2O_5 not expected	Not used for calculations		0.000
Artisan assistants	Various Activity areas	V_2O_5 not expected	Not used for calculations		0.000
Artisan assistants	Various Activity areas	V_2O_5 not expected	Not used for calculations		0.000
Fitter	Various Activity areas	V_2O_5 not expected	Not used for calculations		0.000
Boiler maker	Various Activity areas	V_2O_5 not expected	Not used for calculations		0.000
Leach Mill Attendants	Various Activity areas	V_2O_5 not expected	Not used for calculations		0.000
Assistant Operator	Nitrovan furnace	0.00	0.80	11.50	0.000
Operator	Nitrovan furnace	0.00	0.15	11.50	0.000
Operator	Nitrovan furnace	0.00	0.34	11.50	0.000
Fusion Attendant	Fusion Furnace	80.00	0.38	11.50	0.035
Raw material clerk	V_2O_5 not expected	V_2O_5 not expected	Not used for calculations		0.000
Team Leader Shipping	Shipping	1.00	0.36	11.50	0.000

Occupations	Activity area	Estimated % reported V_2O_5 present as V_2O_5 compound	Time weighted average dust concentration (mg/m^3)	% V_2O_5 reported in sampled dust	Concentration of V_2O_5 in sampled dust (mg/m^3)
Engineering manager	Roving	4.00	0.11	12.00	0.001
Section engineer	Roving	4.00	0.18	12.00	0.001
Chemical engineer	Roving	4.00	0.34	12.00	0.002
Production superintendent	Roving	8.00	0.14	12.00	0.001
Production superintendent	Roving	8.00	0.28	12.00	0.003
Financial/Admin manager	Administration	V_2O_5 not expected	Not used for calculations		0.000
Secretary	Administration	V_2O_5 not expected	Not used for calculations		0.000
Stores issuer	Supply store	V_2O_5 not expected	Not used for calculations		0.000
Sample preparers	Laboratory	V_2O_5 not expected	Not used for calculations		0.000
Store issuer	Supply store	V_2O_5 not expected	Not used for calculations		0.000
Assistant Loss Controller	Administration	V_2O_5 not expected	Not used for calculations		0.000
Mean **concentration of V_2O_5 in sampled dust (mg/m^3)** applicable to rovers					0.007

Table 6: Results of personal dust monitoring July 1993 to December 1993.

Occupations	Activity area	Estimated % reported V_2O_5 present as V_2O_5 compound	Time weighted average dust concentration (mg/m^3)	% V_2O_5 reported in sampled dust	Concentration of V_2O_5 in sampled dust (mg/m^3)
Cleaner	Mine, Mill, Crushers	V_2O_5 not expected	Not used for calculations		0.000
Silo attendant	Mine, Mill, Crushers	V_2O_5 not expected	Not used for calculations		0.000
Wheel Barrow Pusher	Mine, Mill, Crushers	V_2O_5 not expected	Not used for calculations		0.000
Haulpack Driver	Mine, Mill, Crushers	V_2O_5 not expected	Not used for calculations		0.000
Foreman (Mine workshop)	Mine, Mill, Crushers	V_2O_5 not expected	Not used for calculations		0.000
Dozer Driver	Mine, Mill, Crushers	V_2O_5 not expected	Not used for calculations		0.000
Labourer	Mine, Mill, Crushers	V_2O_5 not expected	Not used for calculations		0.000
Fitter	Mine, Mill, Crushers	V_2O_5 not expected	Not used for calculations		0.000
Boiler maker	Kiln, Filter Plant, Sulphate Recovery Plant, Main workshop and Electrical Department	V_2O_5 not expected	Not used for calculations		0.000
Boiler maker	Kiln, Filter Plant, Sulphate Recovery Plant, Main workshop and Electrical Department	V_2O_5 not expected	Not used for calculations		0.000
Artisan assistant	Kiln, Filter Plant, Sulphate Recovery Plant, Main workshop and Electrical Department	V_2O_5 not expected	Not used for calculations		0.000
Leach Mill Attendant	Kiln, Filter Plant, Sulphate Recovery Plant, Main workshop and Electrical Department	V_2O_5 not expected	Not used for calculations		0.000
Fitter	Kiln, Filter Plant, Sulphate Recovery Plant, Main workshop and Electrical Department	V_2O_5 not expected	Not used for calculations		0.000
Fitter	Kiln, Filter Plant, Sulphate Recovery Plant, Main workshop and Electrical Department	V_2O_5 not expected	Not used for calculations		0.000

Occupations	Activity area	Estimated % reported V_2O_5 present as V_2O_5 compound	Time weighted average dust concentration (mg/m^3)	% V_2O_5 reported in sampled dust	Concentration of V_2O_5 in sampled dust (mg/m^3)
Team Leader Shipping	Shipping	1.00	0.36	11.50	0.000
Assistant Operator - Kiln	Kiln, Filter Plant, Sulphate Recovery Plant, Main workshop and Electrical Department	V_2O_5 not expected	Not used for calculations		0.000
Assistant Operator - Reactor	MVO Reactor	0.00	0.98	11.50	0.000
Fusion Attendant	Fusion Furnace	80.00	0.61	11.50	0.056
Assistant operator - Mixplant	Mix plant	0.00	3.82	11.50	0.000
Dry Blender Attendant	Mix plant	0.00	0.47	11.50	0.000
Service operations Manager	Roving	4.00	0.27	12.00	0.001
Operations manager	Roving	4.00	0.16	12.00	0.001
Chemical engineer	Roving	4.00	0.23	12.00	0.001
Assistant engineer	Roving	4.00	0.45	12.00	0.002
Technical supervisor	Roving	4.00	0.24	12.00	0.001
Store issuer	Supply store	V_2O_5 not expected	Not used for calculations		0.000
Lab assistant	Laboratory	V_2O_5 not expected	Not used for calculations		0.000
Sample preparer	Laboratory	V_2O_5 not expected	Not used for calculations		0.000
Secretary	Administration	V_2O_5 not expected	Not used for calculations		0.000
Paymaster	Administration	V_2O_5 not expected	Not used for calculations		0.000
Mean concentration of V_2O_5 in sampled dust (mg/m^3) applicable to rovers					0.009

Table 7: Results of personal dust monitoring January to June 1994.

Occupations	Activity area	Estimated % reported V_2O_5 present as V_2O_5 compound	Time weighted average dust concentration (mg/m^3)	% V_2O_5 reported in sampled dust	Concentration of V_2O_5 in sampled dust (mg/m^3)
Foreman	Mine, Mill or crushers	V_2O_5 not expected	Not used for calculations		0.000
Mine surveyor assistant	Mine	V_2O_5 not expected	Not used for calculations		0.000
Assistant Mechanic	Mine, Mill or crushers	V_2O_5 not expected	Not used for calculations		0.000
Reading Taker	Mine, Mill or crushers	V_2O_5 not expected	Not used for calculations		0.000
Acting superintendent	Administration	V_2O_5 not expected	Not used for calculations		0.000
Artisan assistant	Workshop, Mine, Mill or crushers	V_2O_5 not expected	Not used for calculations		0.000
Artisan assistant	Workshop, Mine, Mill or crushers	V_2O_5 not expected	Not used for calculations		0.000
Artisan assistant	Workshop, Mine, Mill or crushers	V_2O_5 not expected	Not used for calculations		0.000
Artisan	Workshop, Mine, Mill or crushers	V_2O_5 not expected	Not used for calculations		0.000
Store Keeper	Store	V_2O_5 not expected	Not used for calculations		0.000
Boiler maker	Workshop, Mine, Mill or crushers	V_2O_5 not expected	Not used for calculations		0.000
Crusher Attendant	Crushers	V_2O_5 not expected	Not used for calculations		0.000
Reactor attendant	MVO reactor	V_2O_5 not expected	Not used for calculations		0.000
Drum attendant	MVO reactor	V_2O_5 not expected	Not used for calculations		0.000
Reagents attendant	Nitrovan, mix plant, precipitation	V_2O_5 not expected	Not used for calculations		0.000
Discharge attendant	Nitrovan furnace outlet	V_2O_5 not expected	Not used for calculations		0.000
Reactor drum attendant	MVO reactor	V_2O_5 not expected	Not used for calculations		0.000
Technical Super	Roving	4.00	0.11	12.00	0.001
Manager (Services)	Roving	4.00	0.14	12.00	0.001
Plant Technician	Roving	8.00	0.11	12.00	0.001
Plant Technician	Roving	8.00	0.22	12.00	0.002

Occupations	Activity area	Estimated % reported V_2O_5 present as V_2O_5 compound	Time weighted average dust concentration (mg/m^3)	% V_2O_5 reported in sampled dust	Concentration of V_2O_5 in sampled dust (mg/m^3)
Assistant Engineer	Roving	4.00	0.31	12.00	0.001
Security	Gate	V_2O_5 not expected	Not used for calculations		0.000
Lab assistant	Laboratory	V_2O_5 not expected	Not used for calculations		0.000
I.R. Officer	Administration	V_2O_5 not expected	Not used for calculations		0.000
Stores Receiver	Store	V_2O_5 not expected	Not used for calculations		0.000
Creditors Clerk	Administration	V_2O_5 not expected	Not used for calculations		0.000
Mean concentration of V_2O_5 in sampled dust (mg/m^3) applicable to rovers					0.000

Annexure 6: Results of personal dust monitoring at the USA processing plant

1988 - 2004

Abbreviations

CCD	Counter Current Decantation
HE	Heavy equipment
ISO	International Standards Organisation
MVO	Modified Vanadium Oxide (V_2O_3)
PAD	Feed
PFP	Feed
SX	Solvent extraction

Table 5-1: Results of personal dust monitoring 1988 to 1990.

Date	Occupation	Activity area	Estimated % reported V_2O_5 present as V_2O_5 compound	V_2O_5 concentration reported in inhalable dust (mg/m^3)	Reported V_2O_5 concentration adjusted for respirable dust (mg/m3)	Concentration V_2O_5 compound (mg/m^3)
Mar-88	Dozer operator - PAD	PAD - Feed	0.00	Not used for calculations		0.000
Mar-88	Labourer	PAD - Feed	0.00	Not used for calculations		0.000
Mar-88	MVO Operator	MVO Building	10.00	0.120	0.021	0.002
Mar-88	PFP Operator	PFP Building	0.00	Not used for calculations		0.000
Mar-88	PFP Operator	PFP Building	0.00	Not used for calculations		0.000
Mar-88	SX Operator	SX Building	10.00	0.050	0.009	0.001
Dec-88	Labourer	Leach Building	0.00	Not used for calculations		0.000
Dec-88	MVO Operator	MVO Building	10.00	2.690	0.460	0.046
Feb-89	Labourer	PFP Building	0.00	Not used for calculations		0.000
Feb-89	Maintenance	SX Building	10.00	0.020	0.003	0.000
Feb-89	Operator	MVO Building	10.00	2.100	0.359	0.210
Feb-89	Operator	SX Building	10.00	0.060	0.010	0.000
Mar-89	Labourer	flexicoke - feed	0.00	Not used for calculations		0.000
Mar-89	Labourer	MVO Building	10.00	0.480	0.082	0.048
Mar-89	Operator	MVO Building	10.00	0.390	0.067	0.039
Mar-89	Operator	flexicoke - feed	0.00	Not used for calculations		0.000
Mar-89	Operator	ore pad	0.00	Not used for calculations		0.000
Mar-89	Operator	PAD - Feed	0.00	Not used for calculations		0.000
Apr-89	Maintenance foreman	SX and MVO Building	10.00	1.140	0.195	0.114
Apr-89	Oiler	PFP, SX and MVO	6.67	0.350	0.060	0.023
Apr-89	Shift Foreman	General Plant	1.50	0.380	0.065	0.006
Apr-89	Sample preparer	Bucking room	0.00	Not used for calculations		0.000
May-89	Miscellaneous operator	General Plant	2.86	0.070	0.012	0.002

Date	Occupation	Activity area	Estimated % reported V_2O_5 present as V_2O_5 compound	V_2O_5 concentration reported in inhalable dust (mg/m^3)	Reported V_2O_5 concentration adjusted for respirable dust (mg/m3)	Concentration V_2O_5 compound (mg/m^3)
May-89	MVO Operator	MVO Building	10.00	0.720	0.123	0.072
May-89	Labourer	Product	10.00	0.120	0.021	0.012
May-89	SX Operator	SX Building	10.00	0.310	0.053	0.000
May-89	SX Maintenance	SX and MVO Building	10.00	1.370	0.234	0.137
May-88	labourer	dry grind	0.00	Not used for calculations		0.000
May-88	labourer	dry grind	0.00	Not used for calculations		0.000
May-88	Mechanic	PFP	0.00	Not used for calculations		0.000
May-88	Operator	Leach Building	0.00	Not used for calculations		0.000
May-88	Operator	Mine Truck	0.00	Not used for calculations		0.000
Sep-88	Miscellaneous operator	General Plant	2.86	0.080	0.014	0.001
Sep-88	MVO Operator	MVO Building	10.00	0.200	0.034	0.005
Jun-89	Labourer	MVO Building	10.00	0.330	0.056	0.009
Jun-89	Operator	MVO Building	10.00	0.610	0.104	0.016
Jun-89	Operator	flexicoke - feed	0.00	Not used for calculations		0.000
Jun-89	Operator	Leach Building	0.00	Not used for calculations		0.000
Aug-89	Labourer	SX Building	10.00	0.934		0.000
Aug-89	Maintenance	SX Building	10.00	0.049		0.000
Aug-89	Maintenance	General Plant	4.00	0.120	0.021	0.001
Aug-89	Operator	MVO Building	10.00	0.104	0.018	0.003
Aug-89	Operator	MVO Building	10.00	0.060	0.010	0.002
Aug-89	Operator	SX Building	10.00	0.081		0.000
Aug-89	Painter	General Plant	1.50	0.060		0.000
Aug-89	Warehouse Clerk	Warehouse	0.00	Not used for calculations		0.000
Jan-90	Foreman	Leach Building	0.00	Not used for calculations		0.000
Jan-90	Laborer	SX	10.00	0.100	0.017	0.003

Date	Occupation	Activity area	Estimated % reported V_2O_5 present as V_2O_5 compound	V_2O_5 concentration reported in inhalable dust (mg/m^3)	Reported V_2O_5 concentration adjusted for respirable dust (mg/m3)	Concentration V_2O_5 compound (mg/m^3)
Jan-90	Leach oper	Leach Building	0.00	Not used for calculations		0.000
Jan-90	Painter	Paint shop	0.00	Not used for calculations		0.000
Feb-90	Laborer	Dryer	10.00	0.120	0.021	0.003
Feb-90	Laborer	Kiln	0.00	Not used for calculations		0.000
Feb-90	Maintenance	SX	10.00	0.120	0.021	0.003
Feb-90	MVO Operator	MVO Building	10.00	0.120	0.021	0.003
Feb-90	SX Operator	SX	10.00	0.060	0.010	0.002
Mar-90	Laborer	Plant	4.75	0.110	0.019	0.001
Mar-90	HE oper	Yard	0.00	Not used for calculations		0.000
Mar-90	Operator	MVO Building	10.00	0.090	0.015	0.002
Apr-90	Clerk	Warehouse	0.00	0.010	0.002	0.000
Apr-90	Electrician	Fine ore bin	0.00	Not used for calculations		0.000
Apr-90	Foreman	Plant	1.50	0.060	0.010	0.000
Apr-90	Mechanic	Cooler	0.00	Not used for calculations		0.000
Apr-90	Operator	PAD	0.00	Not used for calculations		0.000
Apr-90	Sample preparer	Bucking room	0.00	Not used for calculations		0.000
May-90	Laborer	Bins	10.00	0.040		0.000
May-90	MVO Operator	MVO Building	10.00	0.060	0.010	0.002
May-90	Re feed operator	Kiln	0.00	Not used for calculations		0.000
May-90	SX Operator	SX	10.00	0.040	0.007	0.001
Jun-90	Maintenance	SX	10.00	0.040	0.007	0.001
Sep-90	Laborer	Plant	4.80	0.050	0.009	0.001
Sep-90	Maintenance	SX Building	10.00	0.080	0.014	0.002
Sep-90	MVO Operator	MVO Building	10.00	0.260	0.044	0.007
Sep-90	Operator	CCD	0.00	Not used for calculations		0.000

Date	Occupation	Activity area	Estimated % reported V_2O_5 present as V_2O_5 compound	V_2O_5 concentration reported in inhalable dust (mg/m^3)	Reported V_2O_5 concentration adjusted for respirable dust (mg/m3)	Concentration V_2O_5 compound (mg/m^3)
Sep-90	Painter	Paint shop	0.00	Not used for calculations		0.000

Table 5-2: Results of personal dust monitoring 1991 to 1997.

Date	Occupation	Activity area	Estimated % reported V_2O_5 present as V_2O_5 compound	V_2O_5 concentration reported in inhalable dust (mg/m^3)	Reported V_2O_5 concentration adjusted for respirable dust (mg/m3)	Concentration V_2O_5 compound (mg/m^3)
Mar-91	Leach/CCD operator	Leach CCD Building	0.00	Not used for calculations		0.000
Mar-91	MVO Operator	MVO Building	10.00	0.230	0.039	0.023
Mar-91	Operator	Dry grind	0.00	Not used for calculations		0.000
Mar-91	SX Operator	SX	10.00	0.250	0.043	0.025
Apr-91	MVO Operator	MVO Building	10.00	0.740	0.126	0.074
Jun-91	MVO Operator	MVO Building	10.00	0.040	0.007	0.004
Jun-91	SX Operator	SX	10.00	0.230	0.039	0.023
Aug-91	Electrician	Plant	4.00	0.060	0.010	0.002
Aug-91	Laborer	Product warehouse	0.00	Not used for calculations		0.000
Aug-91	Laborer	Leach Building	0.00	Not used for calculations		0.000
Aug-91	Leach operator	Leach Building	0.00	Not used for calculations		0.000
Aug-91	Master mechanic	Plant	4.00	0.020	0.003	0.001
Aug-91	MVO Operator	MVO Building	10.00	0.380	0.065	0.038
Aug-91	MVO Operator	MVO Building	10.00	0.680	0.116	0.068
Aug-91	Operator	Dry grind	0.00	Not used for calculations		0.000
Aug-91	SX Operator	SX Building	10.00	0.050	0.009	0.005
Sep-91	Electrician	Plant	4.00	0.050	0.009	0.002
Sep-91	Leach operator	Leach Building	0.00	Not used for calculations		0.000
Sep-91	MVO Operator	MVO Building	10.00	1.940	0.331	0.194
Sep-91	SX Operator	SX	10.00	0.170	0.029	0.017
Mar-92	Instrument tech	25% time in MVO	6.00	0.080	0.014	0.005
Mar-92	Leach operator	Leach Building	0.00	Not used for calculations		0.000
Mar-92	MVO Operator	MVO Building	24.00	0.360	0.062	0.086

Date	Occupation	Activity area	Estimated % reported V_2O_5 present as V_2O_5 compound	V_2O_5 concentration reported in inhalable dust (mg/m^3)	Reported V_2O_5 concentration adjusted for respirable dust (mg/m3)	Concentration V_2O_5 compound (mg/m^3)
Mar-92	SX Operator	SX	24.00	0.050	0.009	0.012
Apr-92	MVO Operator	MVO Building	24.00	0.070	0.012	0.017
May-92	Electrician	Plant	9.60	0.020	0.003	0.002
May-92	Loader operator	Feed bin and products	0.00	Not used for calculations		0.000
May-92	MVO Operator	MVO Building	24.00	2.160	0.369	0.518
May-92	Shift Foreman	Plant	3.60	0.020	0.003	0.001
May-92	SX Operator	SX	24.00	0.030	0.005	0.007
Jun-92	Employer relations	Admin	0.00	0.010	0.002	0.000
Jun-92	HE Tech	Workshop	0.00	Not used for calculations		0.000
Jun-92	Laborer	MVO Building	24.00	0.180	0.031	0.043
Jun-92	MVO Operator	MVO Building	24.00	0.100	0.017	0.024
Jun-92	Neutralization operator	Neutralization	0.00	Not used for calculations		0.000
Jul-92	Foreman	Mill	0.00	0.030	0.005	0.000
Jul-92	Laborer	Plant	11.52	0.020	0.003	0.002
Jul-92	Maintenance	Plant	9.60	0.020	0.003	0.002
Jul-92	Oiler	Plant	7.20	0.030	0.005	0.002
Jul-92	SX Operator	SX	24.00	0.050	0.009	0.012
Aug-92	Laborer	Plant	11.52	0.030	0.005	0.003
Aug-92	Maintenance	Plant	9.60	0.020	0.003	0.002
Aug-92	MVO Operator	MVO Building	24.00	0.260	0.044	0.062
Aug-92	Operator	Track	0.00	Not used for calculations		0.000
Sep-92	MVO Operator	MVO Building	24.00	0.070	0.012	0.017
Sep-92	Neutralization operator	Neutralization	0.00	Not used for calculations		0.000

Date	Occupation	Activity area	Estimated % reported V_2O_5 present as V_2O_5 compound	V_2O_5 concentration reported in inhalable dust (mg/m^3)	Reported V_2O_5 concentration adjusted for respirable dust (mg/m3)	Concentration V_2O_5 compound (mg/m^3)
Sep-92	Operator	Bucking room	0.00	Not used for calculations		0.000
Sep-92	SX Operator	SX	24.00	0.000	0.000	0.000
Oct-92	Laborer	Plant	11.52	0.120	0.021	0.014
Oct-92	Maintenance	Plant	9.60	0.020	0.003	0.002
Nov-92	Laborer	Plant	11.52	0.030	0.005	0.003
Nov-92	MVO Operator	MVO Building	24.00	0.090	0.015	0.022
Nov-92	Operator	Bucking room	0.00	Not used for calculations		0.000
Dec-92	Laborer	Plant	11.52	0.000	0.000	0.000
Dec-92	Maintenance	Plant	9.60	0.010	0.002	0.001
Dec-92	Supervisor	Warehouse	0.00	Not used for calculations		0.000
Jan-93	MVO Operator	MVO Building	39.00	0.180	0.031	0.070
Mar-93	MVO Operator	MVO Building	39.00	0.630	0.108	0.246
Apr-93	MVO Operator	MVO Building	39.00	0.420	0.072	0.164
May-93	Electrician	Plant	15.60	0.010	0.002	0.002
May-93	Laborer	Plant	11.52	0.310	0.053	0.036
May-93	Laborer	Plant	11.52	0.130	0.022	0.015
May-93	Loader operator	Loader operator	0.00	Not used for calculations		0.000
May-93	MVO Operator	MVO Building	39.00	0.200	0.034	0.078
May-93	SX Operator	SX	39.00	0.020	0.003	0.008
Jun-93	Engineer	Plant	15.60	0.010	0.002	0.002
Jun-93	Laborer	Plant	18.72	0.010	0.002	0.002
Jun-93	Leach operator	Leach	0.00	Not used for calculations		0.000
Jun-93	Maintenance	Plant	15.60	0.050	0.009	0.008
Jun-93	MVO Operator	MVO Building	39.00	2.280	0.390	0.889

Date	Occupation	Activity area	Estimated % reported V_2O_5 present as V_2O_5 compound	V_2O_5 concentration reported in inhalable dust (mg/m^3)	Reported V_2O_5 concentration adjusted for respirable dust (mg/m3)	Concentration V_2O_5 compound (mg/m^3)
Jun-93	Neutralization operator	Neutralization operator	0.00	Not used for calculations		0.000
Jun-93	Special projects coordinator	Office, sometimes plant	7.80	0.000	0.000	0.000
Jul-93	Group #1	Plant	9.36	0.020	0.003	0.002
Jul-93	Laborer	Plant	18.72	0.080	0.014	0.015
Jul-93	Maintenance	Plant	15.60	0.010	0.002	0.002
Jul-93	MVO Operator	MVO Building	39.00	0.190	0.032	0.074
Jul-93	Oiler	Plant	11.70	0.010	0.002	0.001
Jul-93	SX Operator	SX	39.00	0.000	0.000	0.000
Aug-93	Laborer	Plant	18.72	0.220	0.038	0.041
Aug-93	Maintenance	Plant	15.60	0.020	0.003	0.003
Aug-93	Operator	Track	0.00	Not used for calculations		0.000
Sep-93	MVO Operator	MVO Building	39.00	0.190	0.032	0.074
Sep-93	Neutralization operator	Neutralization operator	0.00	Not used for calculations		0.000
Sep-93	Operator	Bucking room	0.00	0.050	0.009	0.000
Sep-93	SX Operator	SX	39.00	0.040	0.007	0.016
Oct-93	Laborer	Plant	18.72	0.010	0.002	0.002
Oct-93	Maintenance	Plant	15.60	0.110	0.019	0.017
Nov-93	Laborer	Plant	18.72	0.020	0.003	0.004
Nov-93	Operator	Bucking room	0.00	Not used for calculations		0.000
Feb-94	Electrician	Plant	23.20	0.050	0.009	0.012
Feb-94	Operator	Leach operator	0.00	Not used for calculations		0.000
Feb-94	Product shipping	Product shipping	58.00	0.160	0.027	0.093

Date	Occupation	Activity area	Estimated % reported V_2O_5 present as V_2O_5 compound	V_2O_5 concentration reported in inhalable dust (mg/m^3)	Reported V_2O_5 concentration adjusted for respirable dust (mg/m3)	Concentration V_2O_5 compound (mg/m^3)
Feb-94	SX Operator	SX	58.00	0.040	0.007	0.023
Mar-94	Group #1 foreman	Mill	0.00	Not used for calculations		0.000
Mar-94	Laborer	Plant	27.84	0.120	0.021	0.033
Mar-94	Maintenance	Plant	23.20	0.050	0.009	0.012
Mar-94	MVO Operator	MVO Building	58.00	0.310	0.053	0.180
Mar-94	Operator	Product	58.00	0.290	0.050	0.168
Mar-94	Supervisor group#2	Warehouse	0.00	Not used for calculations		0.000
Apr-94	Group #1	Plant	13.92	0.070	0.012	0.010
Apr-94	Maintenance	Plant	23.20	4.480	0.765	1.039
Apr-94	MVO Operator	MVO Building	58.00	0.320	0.055	0.186
Apr-94	SX Operator	SX	58.00	0.090	0.015	0.052
May-94	Laborer	Plant	27.84	0.130	0.022	0.036
May-94	MVO Operator	MVO Building	58.00	0.290	0.050	0.168
May-94	Operator	Bucking room	0.00	Not used for calculations		0.000
May-94	Operator	Loader operator	0.00	Not used for calculations		0.000
May-94	Oiler	Plant	17.40	0.030	0.005	0.005
May-94	Operator	SX	58.00	0.030	0.005	0.017
Jun-94	Group#2	Warehouse	0.00	Not used for calculations		0.000
Jun-94	MVO Operator	MVO Building	58.00	0.090	0.015	0.052
Jun-94	Neutralization operator	Neutralization operator	0.00	Not used for calculations		0.000
Jun-94	Operator	Product	58.00	0.010	0.002	0.006
Jul-94	Electrician	Plant	23.20	0.080	0.014	0.019
Jul-94	Laborer	Plant	27.84	0.090	0.015	0.025
Jul-94	Master mechanic	Plant	23.20	0.020	0.003	0.005

Date	Occupation	Activity area	Estimated % reported V_2O_5 present as V_2O_5 compound	V_2O_5 concentration reported in inhalable dust (mg/m^3)	Reported V_2O_5 concentration adjusted for respirable dust (mg/m3)	Concentration V_2O_5 compound (mg/m^3)
Jul-94	MVO Operator	MVO Building	58.00	1.670	0.285	0.969
Jul-94	MVO Operator	MVO Building	58.00	3.380	0.578	1.960
Jul-94	SX Operator	SX	58.00	0.060	0.010	0.035
Aug-94	Maintenance	Plant	23.20	0.060	0.010	0.014
Aug-94	MVO Operator	MVO Building	58.00	0.110	0.019	0.064
Aug-94	Operator	Leach operator	0.00	Not used for calculations		0.000
Aug-94	Operator	Track	0.00	Not used for calculations		0.000
Sep-94	Laborer	Plant	27.84	0.180	0.031	0.050
Sep-94	Mechanic	Plant	23.20	0.020	0.003	0.005
Sep-94	MVO Operator	MVO Building	58.00	0.440	0.075	0.255
Sep-94	SX Operator	SX	58.00	0.030	0.005	0.017
Oct-94	Laborer	Product warehouse	0.00	Not used for calculations		0.000
Oct-94	Plant mechanic	MVO Building	58.00	0.250	0.043	0.145
Nov-94	Laborer	Plant	27.84	0.050	0.009	0.014
Nov-94	Operator	Track	0.00	Not used for calculations		0.000
Nov-94	Plant mechanic	Plant	23.20	0.050	0.009	0.012
Dec-94	Operator	Product operator	58.00	0.380	0.065	0.220
Feb-95	MVO Operator	MVO Building	54.00	0.170	0.029	0.092
Feb-95	Neutralization operator	Neutralization operator	0.00	Not used for calculations		0.000
Feb-95	Operator	Leach operator	0.00	Not used for calculations		0.000
Feb-95	Operator	Product operator	54.00	0.100	0.017	0.054
Mar-95	Group #1	Plant	32.40	0.040	0.007	0.013
Mar-95	Laborer	Plant	25.92	0.040	0.007	0.010
Mar-95	MVO Operator	MVO Building	54.00	0.110	0.019	0.059

Date	Occupation	Activity area	Estimated % reported V_2O_5 present as V_2O_5 compound	V_2O_5 concentration reported in inhalable dust (mg/m^3)	Reported V_2O_5 concentration adjusted for respirable dust (mg/m3)	Concentration V_2O_5 compound (mg/m^3)
Mar-95	SX Operator	SX	54.00	0.090	0.015	0.049
Apr-95	Maintenance	Plant	21.60	0.000	0.000	0.000
Apr-95	Master mechanic	Group#1	21.60	0.000	0.000	0.000
Apr-95	MVO Operator	MVO Building	54.00	0.070	0.012	0.038
May-95	Electrician	Plant	21.60	0.020	0.003	0.004
May-95	Laborer	Plant	25.92	0.010	0.002	0.003
May-95	MVO Operator	MVO Building	54.00	0.140	0.024	0.076
May-95	Operator	Bucking room	0.00	Not used for calculations		0.000
May-95	Operator	Loader operator	0.00	Not used for calculations		0.000
May-95	Operator	SX	54.00	0.030	0.005	0.016
Jun-95	Group#2	Office/Plant	5.40	0.040	0.007	0.002
Jun-95	MVO Operator	MVO Building	54.00	0.080	0.014	0.043
Jun-95	Neutralization operator	Neutralization operator	0.00	Not used for calculations		0.000
Jun-95	Operator	Bucking room	0.00	Not used for calculations		0.000
Jun-95	Operator	Product operator	54.00	0.080	0.014	0.043
Jul-95	Group#1	Plant	12.96	0.080	0.014	0.010
Jul-95	Laborer	Plant	25.92	0.090	0.015	0.023
Jul-95	MVO Operator	MVO Building	54.00	0.250	0.043	0.135
Jul-95	Oiler	Plant	16.20	0.120	0.021	0.019
Jul-95	Operator	SX	54.00	0.100	0.017	0.054
Aug-95	Maintenance	Plant	21.60	0.030	0.005	0.006
Aug-95	Operator	Leach operator	0.00	Not used for calculations		0.000
Aug-95	Operator	SX	54.00	0.050	0.009	0.027
Aug-95	Operator	Track	0.00	Not used for calculations		0.000

Date	Occupation	Activity area	Estimated % reported V_2O_5 present as V_2O_5 compound	V_2O_5 concentration reported in inhalable dust (mg/m^3)	Reported V_2O_5 concentration adjusted for respirable dust (mg/m3)	Concentration V_2O_5 compound (mg/m^3)
Sep-95	Laborer	Plant	25.92	0.040	0.007	0.010
Sep-95	Maintenance	Plant	21.60	0.040	0.007	0.009
Sep-95	MVO Operator	MVO Building	54.00	0.230	0.039	0.124
Oct-95	Maintenance	Plant	21.60	0.020	0.003	0.004
Oct-95	Operator	Product operator	16.20	0.040	0.007	0.006
Nov-95	MVO Operator	MVO Building	54.00	0.090	0.015	0.049
Dec-95	Group#2	Purchasing	0.00	Not used for calculations		0.000
Dec-95	Maintenance	Plant	21.60	0.050	0.009	0.011
Dec-95	Operator	RO Operator	21.60	0.020	0.003	0.011
Mar-96	MVO Operator	MVO Building	51.00	0.490	0.084	0.250
Mar-96	Neutralization operator	Neutralization operator	0.00	Not used for calculations		0.000
Mar-96	Operator	Bucking room	0.00	Not used for calculations		0.000
Mar-96	Operator	Leach operator	0.00	Not used for calculations		0.000
Mar-96	Operator	Product operator	15.30	0.030	0.005	0.005
Mar-96	SX Operator	SX	51.00	0.040	0.007	0.020
Apr-96	Electrician	Plant	20.40	0.060	0.010	0.012
Apr-96	Group#1	Instrument man	12.24	0.040	0.007	0.005
Apr-96	Group#1 Maintenance foreman	Plant	12.24	0.030	0.005	0.004
Apr-96	Laborer	Plant	24.48	0.090	0.015	0.022
Apr-96	Laborer	Plant	24.48	0.060	0.010	0.015
Apr-96	Laborer	Plant	24.48	0.120	0.021	0.029
Apr-96	Maintenance	Plant	20.40	2.670	0.456	0.545

Date	Occupation	Activity area	Estimated % reported V_2O_5 present as V_2O_5 compound	V_2O_5 concentration reported in inhalable dust (mg/m^3)	Reported V_2O_5 concentration adjusted for respirable dust (mg/m3)	Concentration V_2O_5 compound (mg/m^3)
Apr-96	Maintenance	Plant	20.40	0.460	0.079	0.094
Apr-96	Maintenance	Plant	20.40	0.050	0.009	0.010
Apr-96	MVO Operator	MVO Building	51.00	0.210	0.036	0.107
Apr-96	Neutralization operator	Neutralization operator	0.00	Not used for calculations		0.000
Apr-96	Operator	Bucking room	0.00	Not used for calculations		0.000
Apr-96	Operator	Loader operator	0.00	Not used for calculations		0.000
Apr-96	Operator	Product operator	15.30	0.350	0.060	0.054
Apr-96	Operator	Reverse Osmosis	20.40	0.070	0.012	0.036
Apr-96	SX Operator	SX	51.00	0.090	0.015	0.046
Jun-96	Group#1	Plant	30.60	0.000	0.000	0.000
Jun-96	MVO Operator	MVO Building	51.00	1.910	0.326	0.974
Jun-96	Oiler	Plant	15.30	0.040	0.007	0.006
Jun-96	Operator	SX	51.00	0.040	0.007	0.020
Sep-96	MVO Operator	MVO Building	51.00	0.330	0.056	0.168
Sep-96	Operator	Leach operator	0.00	Not used for calculations		0.000
Sep-96	Operator	Product operator	15.30	0.110	0.019	0.017
Sep-96	Operator	Reverse Osmosis	20.40	0.040	0.007	0.020
Sep-96	Operator	SX	51.00	0.020	0.003	0.010
Oct-96	Group#2	Warehouse	0.00	Not used for calculations		0.000
Oct-96	HE Mechanic	workshop	0.00	Not used for calculations		0.000
Oct-96	Laborer	Plant	24.48	0.050	0.009	0.012
Oct-96	Laborer	Plant	24.48	0.010	0.002	0.002
Oct-96	Laborer	Plant	24.48	0.020	0.003	0.005
Oct-96	Maintenance	Plant	20.40	0.000	0.000	0.000

Date	Occupation	Activity area	Estimated % reported V_2O_5 present as V_2O_5 compound	V_2O_5 concentration reported in inhalable dust (mg/m^3)	Reported V_2O_5 concentration adjusted for respirable dust (mg/m3)	Concentration V_2O_5 compound (mg/m^3)
Oct-96	Maintenance	Plant	20.40	0.020	0.003	0.004
Oct-96	MVO Operator	MVO Building	51.00	0.090	0.015	0.046
Oct-96	MVO Operator	MVO Building	51.00	0.360	0.062	0.184
Oct-96	Operator	Track	0.00	Not used for calculations		0.000
Nov-96	Maintenance	Plant	20.40	0.010	0.002	0.002
Nov-96	MVO Operator	MVO Building	51.00	0.060	0.010	0.031
Nov-96	MVO Operator	MVO Building	51.00	1.260	0.215	0.643
Dec-96	Laborer	Plant	24.48	0.010	0.002	0.002
Dec-96	Maintenance	Plant	20.40	0.020	0.003	0.004
Dec-96	MVO Operator	MVO Building	51.00	0.330	0.056	0.168
Mar-97	Laborer	Product shipping	54.00	0.080	0.014	0.043
Mar-97	MVO Operator	MVO Building	54.00	0.910	0.155	0.491
Mar-97	Operator	Product operator	54.00	0.500	0.085	0.270
Mar-97	Operator	RO Operator	21.60	0.050	0.009	0.027
Mar-97	Operator	SX	54.00	0.070	0.012	0.038
May-97	Group#1	Instrument man	12.96	0.010	0.002	0.001
May-97	Group#2	Warehouse	0.00	Not used for calculations		0.000
May-97	Laborer	Product shipping	54.00	0.560	0.096	0.302
May-97	MVO Operator	MVO Building	54.00	0.260	0.044	0.140
May-97	Neutralization operator	Neutralization operator	0.00	Not used for calculations		0.000
May-97	Operator	Bucking room	0.00	Not used for calculations		0.000
May-97	Operator	Leach operator	0.00	Not used for calculations		0.000
May-97	Operator	Loader operator	0.00	Not used for calculations		0.000
May-97	Operator	Product operator	54.00	0.070	0.012	0.038

Date	Occupation	Activity area	Estimated % reported V_2O_5 present as V_2O_5 compound	V_2O_5 concentration reported in inhalable dust (mg/m^3)	Reported V_2O_5 concentration adjusted for respirable dust (mg/m3)	Concentration V_2O_5 compound (mg/m^3)
May-97	Operator	SX	54.00	0.020	0.003	0.011
Jun-97	Maintenance	Plant	21.60	0.030	0.005	0.006
Jun-97	Oiler	Plant	16.20	0.050	0.009	0.008
Jun-97	Operator	Product shipping	54.00	0.020	0.003	0.011
Jun-97	Operator	Track	0.00	Not used for calculations		0.000
Aug-97	Group#1	Maintenance foreman	12.96	0.010	0.002	0.001
Aug-97	Maintenance	Plant	21.60	0.010	0.002	0.002
Aug-97	Maintenance	Plant	21.60	0.010	0.002	0.002
Aug-97	MVO Operator	MVO Building	54.00	0.040	0.007	0.022
Aug-97	Operator	SX	54.00	0.040	0.007	0.022
Sep-97	Laborer	Plant	25.92	0.010	0.002	0.003
Sep-97	Laborer	Product operator	54.00	0.090	0.015	0.049
Sep-97	MVO Operator	MVO Building	54.00	0.010	0.002	0.005
Sep-97	Operator	SX	54.00	0.020	0.003	0.011
Oct-97	Group#1	Process eng	12.96	0.020	0.003	0.003
Oct-97	Laborer	Plant	25.92	0.020	0.003	0.005
Oct-97	Laborer	Product laborer	54.00	0.100	0.017	0.054
Oct-97	Maintenance	Plant	21.60	0.020	0.003	0.004
Oct-97	Maintenance	Plant	21.60	0.040	0.007	0.009
Oct-97	MVO Operator	MVO Building	54.00	0.050	0.009	0.027
Oct-97	MVO Operator	MVO Building	54.00	0.040	0.007	0.022
Oct-97	Operator	SX	54.00	0.060	0.010	0.032
Nov-97	Laborer	Plant	25.92	0.030	0.005	0.008
Nov-97	Laborer	Plant	25.92	0.030	0.005	0.008
Nov-97	Laborer	Plant	25.92	0.030	0.005	0.008

Date	Occupation	Activity area	Estimated % reported V_2O_5 present as V_2O_5 compound	V_2O_5 concentration reported in inhalable dust (mg/m^3)	Reported V_2O_5 concentration adjusted for respirable dust (mg/m3)	Concentration V_2O_5 compound (mg/m^3)
Nov-97	Maintenance	Plant	21.60	0.030	0.005	0.006
Nov-97	MVO Operator	MVO Building	54.00	0.030	0.005	0.016
Nov-97	Operator	Leach operator	0.00	Not used for calculations		0.000
Dec-97	MVO Operator	MVO Building	54.00	0.060	0.010	0.032
Dec-97	Neutralization operator	Neutralization operator	0.00	Not used for calculations		0.000
Dec-97	Operator	Bucking Room	0.00	Not used for calculations		0.000

Table 5-3: Results of personal dust monitoring 1998 to 2004

Date	Occupation	Activity area	Estimated % reported V_2O_5 present as V_2O_5 compound	V_2O_5 concentration reported in respirable dust (mg/m^3)	Concentration V_2O_5 compound (mg/m^3)
Apr-98	Laborer	Product laborer	53.00	0.015	0.008
Apr-98	Laborer	Product laborer	53.00	0.011	0.006
Apr-98	Laborer	Product laborer	53.00	0.007	0.004
Apr-98	MVO Operator	MVO Building	53.00	0.051	0.027
Apr-98	Operator	SX	53.00	0.008	0.004
Apr-98	Operator	Reverse Osmosis	21.20	0.007	0.004
Apr-98	Operator	Bucking room	0.00	Not used for calculations	0.000
May-98	Electrician	Plant	21.20	0.011	0.002
May-98	Group#2	Office/Plant	5.30	0.006	0.000
May-98	MVO Operator	MVO Building	53.00	0.020	0.011
May-98	MVO Operator	MVO Building	53.00	0.029	0.015
May-98	Neutralization operator	Neutralization operator	0.00	Not used for calculations	0.000
May-98	Operator	Leach operator	0.00	Not used for calculations	0.000
May-98	Operator	Product operator	53.00	0.007	0.004
May-98	Operator	Track	0.00	Not used for calculations	0.000
Jun-98	Group#1	Process eng	12.72	0.012	0.002
Jun-98	Maintenance	Plant	21.20	0.018	0.004
Jun-98	Maintenance	Plant	21.20	0.011	0.002
Jun-98	Mechanic	HE	0.00	Not used for calculations	0.000
Jun-98	MVO Operator	MVO Building	53.00	0.059	0.031
Jun-98	Oiler	Plant	15.90	0.007	0.001
Jun-98	Operator	Loader operator	0.00	Not used for calculations	0.000
Jun-98	Operator	Product operator	53.00	0.083	0.044
Sep-98	Group#2	Office/Plant	5.30	0.015	0.001

Date	Occupation	Activity area	Estimated % reported V_2O_5 present as V_2O_5 compound	V_2O_5 concentration reported in respirable dust (mg/m^3)	Concentration V_2O_5 compound (mg/m^3)
Sep-98	Laborer	Product laborer	53.00	0.034	0.018
Sep-98	Laborer	Product laborer	53.00	0.009	0.005
Sep-98	Laborer	Plant	15.90	0.020	0.003
Sep-98	Laborer	Plant	25.44	0.006	0.002
Sep-98	Laborer	Product laborer	53.00	0.025	0.013
Sep-98	Laborer	Product laborer	53.00	0.017	0.009
Sep-98	MVO Operator	MVO Building	53.00	0.047	0.025
Sep-98	MVO Operator	MVO Building	53.00	0.022	0.012
Sep-98	MVO Operator	MVO Building	53.00	0.035	0.019
Sep-98	Neutralization operator	Neutralization operator	0.00	Not used for calculations	0.000
Sep-98	Operator	SX	53.00	0.003	0.002
Sep-98	Operator	Bucking room	0.00	Not used for calculations	0.000
Sep-98	Operator	Leach operator	0.00	Not used for calculations	0.000
Oct-98	Laborer	Plant	25.44	0.007	0.002
Nov-98	Laborer	Plant	25.44	0.064	0.016
Nov-98	Maintenance	Plant	21.20	0.005	0.001
Nov-98	MVO Operator	MVO Building	53.00	0.088	0.047
Nov-98	Operator	Product operator	53.00	0.040	0.021
Dec-98	Laborer	Plant	25.44	0.112	0.028
Dec-98	Laborer	Product laborer	53.00	0.062	0.033
Dec-98	Laborer	Product laborer	53.00	0.040	0.021
Dec-98	Laborer	Product laborer	53.00	0.030	0.016
Dec-98	Maintenance	Plant	21.20	0.064	0.014
Dec-98	MVO Operator	MVO Building	53.00	0.060	0.032
Dec-98	Operator	Leach operator	0.00	Not used for calculations	0.000
Mar-99	Operator	Bucking room	0.00	Not used for calculations	0.000

Date	Occupation	Activity area	Estimated % reported V_2O_5 present as V_2O_5 compound	V_2O_5 concentration reported in respirable dust (mg/m^3)	Concentration V_2O_5 compound (mg/m^3)
Mar-99	Operator	SX	59.00	0.010	0.006
Mar-99	MVO Operator	MVO Building	59.00	0.002	0.001
Mar-99	Operator	Reverse Osmosis	23.60	0.001	0.001
Apr-99	MVO Operator	MVO Building	59.00	0.002	0.001
Apr-99	Laborer	Product laborer	59.00	0.001	0.001
Apr-99	Laborer	Product laborer	59.00	0.003	0.002
Apr-99	Group#2	Warehouse	0.00	Not used for calculations	0.000
Apr-99	Operator	Leach operator	0.00	Not used for calculations	0.000
Apr-99	Group#1	Instrument man	14.16	0.001	0.000
Apr-99	MVO Operator	MVO Building	59.00	0.019	0.011
Apr-99	Group#1	Process eng	14.16	0.001	0.000
May-99	Neutralization operator	Neutralization operator	0.00	Not used for calculations	0.000
May-99	MVO Operator	MVO Building	59.00	0.006	0.004
May-99	Laborer	Plant	28.32	1.053	0.298
May-99	Operator	Track	0.00	Not used for calculations	0.000
May-99	Group#1	Plant	14.16	0.009	0.001
May-99	Electrician	Plant	23.60	0.001	0.000
May-99	Loader operator	Loader operator	0.00	Not used for calculations	0.000
May-99	Maintenance	Plant	23.60	0.001	0.000
Aug-99	Laborer	Plant	28.32	0.012	0.003
Aug-99	Loader operator	Loader operator	0.00	Not used for calculations	0.000
Aug-99	Maintenance	Plant	23.60	0.010	0.002
Aug-99	Operator	Leach operator	0.00	Not used for calculations	0.000
Aug-99	MVO Operator	MVO Building	59.00	0.018	0.011
Sep-99	Laborer	Product laborer	59.00	0.005	0.003
Sep-99	Laborer	Product laborer	59.00	0.002	0.001

Date	Occupation	Activity area	Estimated % reported V_2O_5 present as V_2O_5 compound	V_2O_5 concentration reported in respirable dust (mg/m^3)	Concentration V_2O_5 compound (mg/m^3)
Sep-99	MVO Operator	MVO Building	59.00	0.018	0.011
Sep-99	Operator	Reverse Osmosis	59.00	0.002	0.001
Sep-99	Operator	Bucking room	0.00	Not used for calculations	0.000
Oct-99	Laborer	Product laborer	59.00	0.016	0.009
Oct-99	Maintenance	Plant	23.60	0.003	0.001
Oct-99	Laborer	Plant	28.32	0.013	0.004
Oct-99	MVO Operator	MVO Building	59.00	0.006	0.004
Oct-99	Group#1	Plant	14.16	0.004	0.001
Nov-99	Operator	SX	59.00	0.005	0.003
Nov-99	MVO Operator	MVO Building	59.00	0.003	0.002
Nov-99	Operator	Bucking room	0.00	Not used for calculations	0.000
Nov-99	Maintenance	Plant	23.60	0.003	0.001
Nov-99	Electrician	Plant	23.60	0.003	0.001
Nov-99	MVO Operator	MVO Building	59.00	0.005	0.003
Nov-99	Laborer	Plant	28.32	0.003	0.001
Nov-99	Maintenance	Plant	23.60	0.019	0.004
Nov-99	Operator	Leach operator	0.00	Not used for calculations	0.000
Nov-99	Laborer	Product laborer	59.00	0.003	0.002
Dec-99	Laborer	Plant	28.32	0.005	0.001
Dec-99	Laborer	Plant	28.32	0.001	0.000
Dec-99	Laborer	Plant	28.32	0.001	0.000
Dec-99	Laborer	Plant	28.32	0.001	0.000
Dec-99	Maintenance	Plant	23.60	sample not correctly analysed	0.000
Mar-00	Operator	Reverse Osmosis	59.00	0.009	0.005
Mar-00	Laborer	Product laborer	59.00	0.015	0.009
Mar-00	Neutralization operator	Neutralization operator	0.00	Not used for calculations	0.000

Date	Occupation	Activity area	Estimated % reported V_2O_5 present as V_2O_5 compound	V_2O_5 concentration reported in respirable dust (mg/m^3)	Concentration V_2O_5 compound (mg/m^3)
Mar-00	MVO Operator	MVO Building	59.00	0.006	0.004
Mar-00	Laborer	Product laborer	59.00	0.001	0.001
Apr-00	Operator	Bucking room	0.00	Not used for calculations	0.000
Apr-00	Group#2	Warehouse	0.00	Not used for calculations	0.000
Apr-00	Operator	Leach operator	0.00	Not used for calculations	0.000
Apr-00	Laborer	Plant	28.32	0.005	0.001
Apr-00	Oiler	Plant	17.70	0.005	0.001
Jul-00	MVO Operator	MVO Building	59.00	0.023	0.014
Jul-00	Operator	SX	59.00	0.001	0.001
Jul-00	Laborer	Product laborer/shipping	59.00	0.001	0.001
Jul-00	Laborer	Product laborer/shipping	59.00	0.001	0.001
Jul-00	Laborer	Mill yard	0.00	Not used for calculations	0.000
Aug-00	Sample preparer	Bucking room	0.00	Not used for calculations	0.000
Aug-00	Laborer	Product laborer/shipping	59.00	0.001	0.001
Aug-00	Laborer	Product laborer/shipping	59.00	0.001	0.001
Aug-00	Supervisor	Plant	8.85	0.001	0.000
Aug-00	Mechanic	AMV thickener tank	0.00	Not used for calculations	0.000
Sep-00	MVO Operator	MVO Building	59.00	0.008	0.005
Sep-00	Supervisor	Plant / office	8.85	0.006	0.001
Sep-00	Supervisor	Plant / office	8.85	0.006	0.001
Sep-00	Supervisor	Plant / office	8.85	0.013	0.001
Sep-00	Supervisor	Product shipping	59.00	0.007	0.004
Oct-00	MVO Operator	MVO Building	59.00	0.013	0.008
Oct-00	Mechanic	HE Shop	0.00	Not used for calculations	0.000
Oct-00	Laborer	Product laborer/shipping	59.00	0.017	0.010
Oct-00	Laborer	Mill yard	0.00	Not used for calculations	0.000

Date	Occupation	Activity area	Estimated % reported V_2O_5 present as V_2O_5 compound	V_2O_5 concentration reported in respirable dust (mg/m^3)	Concentration V_2O_5 compound (mg/m^3)
Oct-00	Laborer	Product laborer/shipping	59.00	0.010	0.006
Nov-00	MVO Operator	MVO Building	59.00	0.027	0.016
Nov-00	Operator	Track	0.00	Not used for calculations	0.000
Nov-00	Neutralization operator	Neutralization operator	0.00	Not used for calculations	0.000
Nov-00	Laborer	Product laborer/shipping	59.00	0.022	0.013
Nov-00	Laborer	Product laborer/shipping	59.00	0.013	0.008
Dec-00	MVO Operator	MVO Building	59.00	0.014	0.008
Dec-00	Analyst	Laboratory	0.00	Not used for calculations	0.000
Dec-00	Mechanic	Plant	23.60	0.008	0.002
Dec-00	Laborer	Product laborer/shipping	59.00	0.013	0.008
Dec-00	Laborer	Product laborer/shipping	59.00	0.052	0.031
Feb-01	Operator	Leach operator	0.00	Not used for calculations	0.000
Feb-01	Laborer	Mill yard	0.00	Not used for calculations	0.000
Feb-01	Operator	Track/mill yard	0.00	Not used for calculations	0.000
Feb-01	Laborer	Product laborer/shipping	67.00	0.610	0.409
Feb-01	Sample preparer	Bucking room	0.00	Not used for calculations	0.000
Mar-01	MVO Operator	MVO Building	67.00	0.000	0.000
Mar-01	Operator	SX	67.00	0.058	0.039
Mar-01	Supervisor	SX	67.00	0.140	0.094
Mar-01	Laborer	Product laborer/shipping	67.00	0.097	0.065
Mar-01	Neutralization operator	Neutralization oper	0.00	Not used for calculations	0.000
Apr-01	MVO Operator	MVO Building	67.00	0.002	0.001
Apr-01	Feed operator	Plant	0.00	Not used for calculations	0.000
Apr-01	Operator	Reverse Osmosis	67.00	0.001	0.001
Apr-01	Operator	Product operator /shipping	67.00	0.096	0.064
Apr-01	Supervisor	Plant	10.05	0.001	0.000

Date	Occupation	Activity area	Estimated % reported V_2O_5 present as V_2O_5 compound	V_2O_5 concentration reported in respirable dust (mg/m^3)	Concentration V_2O_5 compound (mg/m^3)
May-01	Operator	SX	67.00	0.001	0.001
May-01	MVO Operator	MVO Building	67.00	0.002	0.001
May-01	Laborer	Plant	32.16	0.004	0.001
May-01	Maintenance	MVO/SX	67.00	0.001	0.001
May-01	Electrician	Plant	26.80	0.002	0.001
Jun-01	Sample preparer	Bucking room	0.00	Not used for calculations	0.000
Jun-01	Manager	Office/Plant	10.05	0.001	0.000
Jun-01	Laborer	Product laborer/shipping	67.00	0.001	0.001
Jun-01	MVO Operator	MVO Building	67.00	0.001	0.001
Jul-01	MVO Operator	MVO Building	67.00	0.016	0.011
Jul-01	Neutralization operator	Neutralization operator	0.00	Not used for calculations	0.000
Jul-01	Laborer	Plant	32.16	0.015	0.005
Jul-01	Oiler	Plant	20.10	0.005	0.001
Jul-01	Laborer	Product laborer/shipping	67.00	0.038	0.025
Aug-01	Operator	MVO SX	67.00	0.002	0.001
Aug-01	Operator	Leach operator	0.00	Not used for calculations	0.000
Aug-01	Maintenance	Plant	26.80	0.001	0.000
Aug-01	Safety manager	Plant	10.05	0.001	0.000
Oct-01	Maintenance	Plant	26.80	0.005	0.001
Oct-01	MVO Operator	MVO Building	67.00	0.017	0.011
Oct-01	Operator	Track plant	0.00	Not used for calculations	0.000
Oct-01	Laborer	Plant	32.16	0.001	0.000
Dec-01	MVO Operator	MVO Building	67.00	0.024	0.016
Dec-01	Operator	Leach operator	0.00	Not used for calculations	0.000
Dec-01	Laborer	Product laborer/shipping	67.00	0.004	0.003
Dec-01	Labourer/loader	Mill yard	0.00	Not used for calculations	0.000

Date	Occupation	Activity area	Estimated % reported V_2O_5 present as V_2O_5 compound	V_2O_5 concentration reported in respirable dust (mg/m^3)	Concentration V_2O_5 compound (mg/m^3)
Feb-02	Operator	MVO SX	66.00	0.013	0.009
Feb-02	Laborer	Product laborer/shipping	66.00	0.024	0.016
Feb-02	Laborer	Product laborer/shipping	66.00	0.258	0.170
Feb-02	Laborer	Mill yard	0.00	Not used for calculations	0.000
Feb-02	Electrician	Plant	26.40	0.001	0.000
Mar-02	MVO Operator	MVO Building	66.00	0.002	0.001
Mar-02	Laborer/loader	Loader	0.00	Not used for calculations	0.000
Mar-02	Operator	Track	0.00	Not used for calculations	0.000
Mar-02	Operator	Product operator	66.00	0.244	0.161
Mar-02	Laborer	Plant	31.68	0.001	0.000
Apr-02	Lab supervisor	lab/Technology	66.00	0.002	0.001
Apr-02	SX Supervisor	Plant	66.00	0.025	0.017
Apr-02	Leach supervisor	Plant	0.00	Not used for calculations	0.000
Apr-02	Instrument supervisor	Plant	26.40	0.006	0.002
May-02	Operator	MVO/SX	66.00	0.048	0.032
May-02	Operator	SX	66.00	0.004	0.003
May-02	Maintenance	MVO/SX	66.00	0.004	0.003
May-02	Maintenance	MVO/SX	66.00	0.006	0.004
May-02	Oiler	Plant	19.80	0.001	0.000
Jun-02	Sample prep	Bucking room	0.00	Not used for calculations	0.000
Jun-02	Laborer	Product shipping	66.00	0.011	0.007
Jun-02	Laborer	Plant	31.68	0.003	0.001
Jun-02	Laborer	Plant	31.68	0.003	0.001
Jun-02	Operator	Track	0.00	Not used for calculations	0.000
Jun-02	Operator	Product operator shipping	66.00	0.007	0.005
Jun-02	ISO Manager	Plant	9.90	0.001	0.000

Date	Occupation	Activity area	Estimated % reported V_2O_5 present as V_2O_5 compound	V_2O_5 concentration reported in respirable dust (mg/m^3)	Concentration V_2O_5 compound (mg/m^3)
Jun-02	MVO Operator	MVO/SX	66.00	7.919	5.227
Jun-02	Operator	Reverse Osmosis	66.00	0.006	0.004
Jun-02	Neutralization operator	Neutralization operator	0.00	Not used for calculations	0.000
Jun-02	Operator	Leach operator	0.00	Not used for calculations	0.000
Sep-02	Operator	MVO/SX	66.00	0.007	0.005
Sep-02	Operator	Product operator shipping	0.01	0.011	0.000
Sep-02	Loader/operator	Plant	9.90	0.004	0.000
Sep-02	Electrician	Plant	26.40	0.004	0.001
Sep-02	Laborer	Plant	31.68	0.000	0.000
Oct-02	MVO Operator	MVO/SX	66.00	0.003	0.002
Oct-02	Operator	RO Operator	66.00	0.002	0.001
Oct-02	Warehouse	Warehouse	0.00	Not used for calculations	0.000
Oct-02	Instrument tech	Plant	26.40	0.003	0.001
Nov-02	Operator	MVO/SX	66.00	0.012	0.008
Nov-02	Operator	Product operator shipping	66.00	0.003	0.002
Nov-02	Laborer	Mill yard	0.00	Not used for calculations	0.000
Nov-02	Laborer	Mill yard	0.00	Not used for calculations	0.000
Dec-02	MVO Operator	MVO Building	66.00	0.041	0.027
Dec-02	Bucking room	Bucking room	0.00	Not used for calculations	0.000
Dec-02	Laborer/loader	Loader	0.00	Not used for calculations	0.000
Feb-03	MVO Operator	MVO/SX	69.00	0.002	0.001
Feb-03	Laborer	Mill yard	0.00	Not used for calculations	0.000
Feb-03	Laborer	Product shipping	69.00	0.001	0.001
Feb-03	Laborer	Mill yard	0.00	Not used for calculations	0.000
Mar-03	Operator	MVO/SX	69.00	0.006	0.004
Mar-03	Operator	Leach operator	0.00	Not used for calculations	0.000

Date	Occupation	Activity area	Estimated % reported V_2O_5 present as V_2O_5 compound	V_2O_5 concentration reported in respirable dust (mg/m^3)	Concentration V_2O_5 compound (mg/m^3)
Mar-03	Operator	Product operator shipping	69.00	0.008	0.006
Mar-03	Electrician	Plant	27.60	0.002	0.001
Apr-03	Loader/operator	Plant	13.80	0.007	0.001
Apr-03	Laborer	Plant	17.25	0.013	0.002
Apr-03	Sample prep	Bucking room	0.00	Not used for calculations	0.000
May-03	Operator	MVO/SX	69.00	0.074	0.051
May-03	Operator	Leach operator	0.00	Not used for calculations	0.000
May-03	Operator	Product operator shipping	69.00	0.003	0.002
May-03	Oiler	Plant	20.70	0.007	0.001
Jun-03	MVO Operator	MVO Building	69.00	0.085	0.059
Jun-03	Maintenance	Plant	27.60	0.001	0.000
Jun-03	Operator	Product operator shipping	69.00	0.004	0.003
Jun-03	Operator	Product operator shipping	69.00	0.001	0.001
Aug-03	Supervisor	SX	69.00	0.006	0.004
Aug-03	Supervisor	Leach operator /plant	0.00	Not used for calculations	0.000
Aug-03	Lab manager	Plant/SX	34.50	0.001	0.000
Aug-03	Supervisor	Product shipping	69.00	0.003	0.002
Oct-03	MVO Operator	MVO/SX	69.00	0.004	0.003
Oct-03	Operator	Loader operator plant	0.00	Not used for calculations	0.000
Oct-03	Operator	Track plant	0.00	Not used for calculations	0.000
Oct-03	Neutralization operator	Neutralization operator	0.00	Not used for calculations	0.000
Oct-03	Operator	Product operator shipping	69.00	0.021	0.014
Oct-03	Maintenance	Plant	27.60	0.003	0.001
Oct-03	Maintenance	HE equipment	0.00	Not used for calculations	0.000
Oct-03	Maintenance	Metal shop	0.00	Not used for calculations	0.000
Dec-03	MVO Operator	MVO Building	69.00	0.028	0.019

Date	Occupation	Activity area	Estimated % reported V_2O_5 present as V_2O_5 compound	V_2O_5 concentration reported in respirable dust (mg/m^3)	Concentration V_2O_5 compound (mg/m^3)
Dec-03	Operator	Product operator shipping	69.00	0.010	0.007
Dec-03	Operator	Product operator shipping	69.00	0.001	0.001
Dec-03	Laborer	Plant	27.60	0.005	0.001
Mar-04	MVO Operator	MVO Building/SX	69.00	0.009	0.006
Mar-04	Operator	Product operator	69.00	0.004	0.003
Mar-04	Operator	Carvan	0.00	Not used for calculations	0.000
Apr-04	MVO Operator	MVO Building	69.00	0.004	0.003
Apr-04	Laborer	Plant	27.60	0.002	0.001
Apr-04	Laborer	Plant	27.60	0.005	0.001
Apr-04	Operator	Track plant	0.00	Not used for calculations	0.000
May-04	Operator	Loader operator plant	0.00	Not used for calculations	0.000
May-04	Operator	Product operator /shipping	69.00	0.001	0.001
May-04	Laborer	Loader operator	0.00	Not used for calculations	0.000
May-04	Laborer	Plant	27.60	0.001	0.000
Jun-04	Supervisor	SX	69.00	0.001	0.001
Jun-04	Supervisor	Leach operator /plant	10.35	0.001	0.000
Jun-04	Safety manager	Plant	10.35	0.001	0.000
Jun-04	Supervisor	Warehouse	0.00	Not used for calculations	0.000