The environmental monitoring and quantification of *M. tuberculosis* occupational exposure risk in various occupational settings in a platinum mine.

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Preface

For the aim of this project it was decided to use article format. For uniformity the whole dissertation is according to the guidelines of the chosen journal for potential publication which is the Annals of Occupational Hygiene. The journal requires that the references in the text should be in the form Jones (1995), or Jones and Brown (1995), or Jones *et al*. (1995) if there are more than two authors. References should be listed in alphabetical order by name of first author, using the Vancouver Style of abbreviation and punctuation.

Chapter 1 reflects a general introduction of TB aspects applicable to occupational settings. This chapter includes the problem statement and research question. Chapter 2 consists of an in-depth discussion of the bacterium responsible for tuberculosis, the manifestations of this disease and its common epidemiology in the mining trade, as well as the somewhat controversial UVGI System which is employed, among others, for tuberculosis control. Chapter 3 is written in article format. All tables and figures are included here, along with text, to present the findings of this study in a readable and understandable format. The article will be submitted to the Annals of Occupational Hygiene for peer reviewing and publication. Chapter 4 includes a final summary and conclusion, as well as recommendations for future studies. Chapter 5 consists of the appendices.

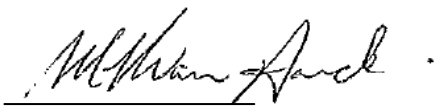
Author's Contribution

The study was planned and executed by a team of researchers. The contribution of each researcher is listed below.

Name	Contribution
Mr HL Badenhorst	• Designing and planning of the study; • Literature searches, interpretation of data and writing of article; • Execution of all monitoring processes.
Mr MN van Aarde	• Supervisor; • Assisted with approval of protocol, interpretation of results and documentation of the study; • Giving guidance with scientific aspects of the study.
Ms. A. Franken	• Co-Supervisor; • Assisted with designing and planning of the study, approval of protocol, interpretation of results and documentation of the study.

The following is a statement from the co-authors that confirms each individual's role in the study:

I declare that I have approved the above mentioned article and that my role in the study as indicated above is representative of my actual contribution and that I hereby give my consent that it may be published as part of HL Badenhorst's M.Sc (Occupational Hygiene) mini-dissertation.



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Abstract

Tuberculosis is a disease that has a detrimental effect on the economic growth of South Africa. The country's TB mortality rate is amongst the highest in the world, and the worst affected industry is mining. Effective environmental controls of tuberculosis in mining areas remain a challenge, mainly because there is a lack of quantitative data to guide the implementation of these controls. No occupational exposure limits exist for bio-aerosols, particularly *Mycobacterium tuberculosis*. This makes it difficult to distinguish between high- and low risk areas. It is believed that a single inhaled *M. tuberculosis* particle can cause the tuberculosis disease, and as this disease can deteriorate all major systems of the body, great care should be taken in the classification of an area.

Aim: This study aimed to quantify the environmental presence of the *M. tuberculosis* bacilli in various occupational settings of a platinum mine. **Method:** The monitored areas are all structures above ground, and include high TB risk areas, such as the hospital TB Ward, and low TB risk areas, such as an office area. Personal monitoring of the staff in high TB risk areas has also been conducted. Monitoring was done via the PTFE filter sampling method and the SKC Bio-Sampler® impinger method. The results of these two methods were compared to determine which method is more effective.

The environmental variables, such as carbon dioxide and –monoxide levels, temperature (both ambient and wet- bulb), and relative humidity, were also monitored in order to identify any possible correlations between these variables and the levels of ambient TB particles. The effectiveness of the Ultraviolet Germicidal Irradiation (UVGI) system, which is in place in some of the monitored areas, was also indirectly assessed, i.e. to see if there are any *M. tuberculosis* particles present in an area that makes use of an UVGI system. The PCR analytical method was used to quantify the number of *M. tuberculosis* bacilli sampled, and the results were statistically analysed.

Results: *M. tuberculosis* was found to be present in the office area, the laundry room, the hospital's waiting area, the training facility, the dining room, and the mobile clinic. No *M. tuberculosis* particles were found in the hospital's TB Ward and the change houses of the mine. The results showed that the PTFE filter method had a greater efficiency than the SKC Bio- Sampler® in monitoring environmental *M. tuberculosis* particles, as the PTFE filter method yielded positive samples where the SKC Bio-Sampler® did not. There is a practical significant difference between the two methods.

No viable correlations between the environmental variables and *M. tuberculosis* prevalence were established due to the low number of samples taken.

Conclusion: It seems that the effectiveness of a UVGI system is dependent on the number of people crowded into that specific area and the ventilation thereof. A UVGI system is only a precautionary measure and not a solution.

There are too many factors that still need better understanding before the risk of contracting environmental TB in high risk areas of a mine can be determined. The high risk areas seem to be occupational settings that have poor ventilation, but accommodate a large number of people. The highest risk of TB infection remains close contact with infected individuals, as the results of the employee monitoring testified.

Key Words:

tuberculosis, transmission, environment, mine setting, overcrowding, ventilation, multi-drug resistant tuberculosis.

Opsomming

Titel: *Die omgewingsmonitering en kwantifisering van M. tuberculosis blootstellings-risiko in verskeie beroepsomgewings in 'n platinum myn.*

Tuberkulose is 'n siekte wat 'n besonder nadelige effek op die ekonomiese groei van Suid Afrika het. Die land se sterftesyfer is een van die hoogste ter wêreld, en die mees geaffekteerde industrie is mynbou. Effektiewe omgewingsbeheer maatreëls teen tuberkulose in myn areas bly 'n uitdaging, hoofsaaklik omdat daar 'n tekort aan kwantitatiewe data is om die toepassing van beheer te lei. Geen beroepsblootstellings-drempels bestaan vir bio-aërosols nie, veral nie vir *Mycobacterium tuberculosis* nie. Dit bemoeilik dus die vermoë om te onderskei tussen hoë- en lae risiko areas. Daar word geglo dat 'n enkele ingeasemde *M. tuberculosis* deeltjie die siekte kan veroorsaak, en siende dat hierdie siekte al die hoofsisteme van die liggaam kan aftakel, moet die klassifikasie van 'n area met sekerheid gedoen kan word.

Die doel van hierdie studie is om die omgewingsteenwoordigheid van die *M. tuberculosis* basilie in verskeie werkareas van 'n platinum myn, sowel as sommige personeel wat in hierdie areas werk se persoonlike blootstelling, te kwantifiseer. Hierdie areas is bo-grondse strukture wat hoë risiko areas soos die hospitaal se TB eenheid, sowel as lae risiko areas, soos kantoor areas, insluit. Monitering is gedoen met behulp van die PTFE filtermetode en die SKC Bio-Sampler® metode. Die resultate van hierdie metodes is met mekaar vergelyk om te bepaal watter een van hierdie metodes die effektiefste is.

Omgewingsveranderlikes soos koolstofdioksied en -monoksied, temperatuur (beide omgewings en natbal), en relatiewe humiditeit is ook gemoniteer om enige korrelasies met die vlakke van omgewings TB te identifiseer. Die effektiwiteit van die UVGI sisteem, wat in sommige van die gemoniteerde areas teenwoordig is, is ook indirek geassesseer, d.w.s om te sien of daar enige *M. tuberculosis* deeltjies teenwoordig was in die areas wat van 'n UVGI sisteem gebruik maak. Die PCR analitiese metode is gebruik om die hoeveelheid *M. tuberculosis* basille te kwantifiseer. Die resultate is statisties uitgedruk.

Daar is gevind dat *M. tuberculosis* teenwoordig was in die kantoorarea, die wasgoed-kamer, die hospitaal se wagarea, die opleidingsfasiliteit, die eetlokaal, en die mobiele kliniek. Geen *M. tuberculosis* deeltjies is in die hospitaal se TB eenheid of in die myn se kleedkamers gevind nie. Hierdie resultate illustreer 'n statisties prakties-betekenisvolle verskil tussen die twee metodes. Die PTFE filtermetode het 'n groter

effektiwiteit as die SKC Bio-Sampler® ten opsigte van omgewings *M. tuberculosis* monitering, aangesien die PTFE filter metode positiewe monsters gelewer het waar SKC Bio-Sampler® niks gelewer het nie. Geen merkwaardige korrelasies tussen die omgewingsveranderlikes en die voorkoms van *M. tuberculosis* is gevind nie, omdat die getal monsters wat geneem is te min was. Dit blyk dat die effektiwiteit van ’n UVGI sisteem afhanklik is van die hoeveelheid mense in ’n spesifieke area en die ventilasie wat daar plaasvind. ’n UVGI sisteem is slegs ’n voorsorgmaatreël en nie ’n oplossing nie. Daar is nog te veel faktore wat verstaan moet word voordat ’n opmerklike TB aansteeklikheidsrisiko bepaal kan word. Die hoë risiko areas is daardie werkareas wat oor onvoldoende ventilasie beskik, maar tog ’n groot aantal mense akkommodeer. Die hoogste risiko vir TB infeksie is nog steeds die noue kontak met geïnfekteerde individue, soos deur die moniteringsresultate van die werknemers bevestig.

Sleutelwoorde:

tuberkulose, oordrag, omgewing, myn plasing, oor-bevolking, ventilasie, veelvuldige-medisinale weerstandbiedende tuberkulose.

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Symbols

%	Percentage
<	Smaller than
>	Larger than
CO	Carbon Monoxide
CO_2	Carbon Dioxide
L/min	Litres per minute
m	Meter
m^3	Cubic Meters
mg	Milligram
Min	Minutes
ml	Millilitre
mm	Millimetre
nm	Nanometres
ºC	Degrees Celsius
pH	Hydrogen ion concentration
PPM	Parts per Million
µM	Micrometer

Abbreviations

ABET	Adult Basic Education and Training Centre
AIDS	Acquired Immune Deficiency Syndrome
ASSU	Anglo Platinum Shared Service Unit
BBB	Blood Brain Barrier
CNS	Central Nervous System
CSF	Cerebrospinal Fluid
DNA	Deoxyribonucleic acid
GI	Gastrointestinal
HEPA	High Efficiency Particulate Air Filters
HIV	Human Immunodeficiency Virus
MDR-TB	Multi-drug-resistant Strain of Tuberculosis
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
PBS	Phosphate Buffered Saline

PCR	Polymerase Chain Reaction
PTFE	Polytetrafluoroethylene
SA	South Africa
STD	Sexually Transmitted Disease
TB	Tuberculosis
UVGI	Ultraviolet Germicidal Irradiation
WHO	World Health Organization
XDR-TB	Extreme Drug-resistant Tuberculosis

CHAPTER 1

INTRODUCTION

1.1 Overview

It is believed that a single *Mycobacterium tuberculosis* entity, when inhaled, can cause the disease known as tuberculosis (Prescott *et al*., 2005). This may be the reason why there are as yet no occupational exposure limits for *M. tuberculosis*, or for any other bio-aerosol (Van der Heever and Stanton, 2007). In light of this, the attitude should ideally be that exposure to a single *M. tuberculosis* entity should be considered as bio-aerosol exposure and should, therefore, be treated as a high exposure environment. Only if no *M. tuberculosis* entities are found in the air, should the environment ideally be considered as a low- exposure environment. Unfortunately, the average quantity of these micro-organisms that is present in the environment, especially in that of a South African mine occupational setting, is unknown for any given time. Therefore, the risk of contracting tuberculosis in these environments is yet to be determined.

The question could be asked whether the quantity of *M. tuberculosis* bacteria in the air, which is introduced by infected personnel, poses a significant contamination risk to non-infected personnel in the same environment. Furthermore, to what degree do the environmental factors like temperature and humidity, as well as the time spent in the proposed environment, enhance the chances of contracting tuberculosis.
Studies on tuberculosis in the mine setting, such as that of Corbett *et al*. (1999), Kleinschmidt and Churchyard (1997), and Rowe (2003), were done. These studies focussed on the aspects of the correlation between the disease and persons infected with the HIV virus, the identification of risk factors and groups, usually gold-miners, who have a high risk of contracting tuberculosis, and environmental factors, mainly exposure to silica, which can aggravate the lung damage caused by tuberculosis.
All these studies were therefore focused on the workers by methodology such as active personal sampling and questionnaires. There were no studies done on the active environmental sampling of tuberculosis in South Africa.

This environmental study was conducted at the Platinum Health Hospital of the Anglo Platinum Group in Rustenburg, but also included areas of mining operations and the ABET Training Centre, which are also located in Rustenburg. This study was restricted to workplaces where people are grouped closely together, i.e. the change houses, hospital waiting areas, classrooms, and dining areas, but also focused specifically on the Pulmonary Disease Ward, where tuberculosis is the main

combatant, and the laundry facility on the premises, where dirty (infected) linen is handled and treated. Area samples were also taken in the mobile clinic vehicle.
The research objectives are:

1) The qualitative detection of *M. tuberculosis* particles in the above mentioned workplaces.
2) Comparison between two different airborne measurement methods for *M. tuberculosis,* being NIOSH Method 0900, using PTFE filters as a collection medium and using a SKC Bio-Sampler® with PBS as a collection medium.
3) Assessment of environmental parameters, i.e. temperature (both ambient and wet-bulb, in degrees Celsius), humidity (relative percentage), CO_2 and CO concentration (in parts per million), in all workplaces where *M. tuberculosis* was monitored. This assessment is necessary to investigate any potential relationship between airborne levels of *M. tuberculosis* and indoor air conditions.
4) The evaluation of the effectiveness of the UVGI system in the control of exposure to *M. tuberculosis.*

Personal exposure monitoring was carried out, in addition to the area monitoring.
The personal exposure was monitored by using PTFE filters via a sample train. The personnel monitored consisted of 5 nurses, 5 members of the cleaning staff, and 5 laundry room workers. A total of 15 personal monitoring samples were taken.
The stationary samples consisted of 22 PTFE filter samples, and 19 bio-sampler samples. This brought the total number of samples to 56.
A questionnaire was also used to give guidance in identifying individuals who meet OSHA's definition of *suspected infectious tuberculosis* so that appropriate controls could be initiated. The questionnaire had two parts:
1) Reviewing the individual's TB history, and
2) Assessing current symptoms.

Indoor air quality measurements were also taken as part of the survey in order to expand on the relationship between temperature, humidity, carbon dioxide and -monoxide levels, and airborne TB (DNA copies per m^3), which were then statistically correlated on the amount of *M. tuberculosis* particles found.
This study reveals the quantities of airborne *M. tuberculosis* present in various mine environments, and in so-doing, aids in the understanding of the prevalence and behavioural properties of the disease so that it can be combated successfully in the near future.

1.2 Problem Statement

There are no occupational exposure limits for bio-aerosols, in particular *M. tuberculosis*. The average quantity of this micro-organism present in the environment of a mine occupational setting at any time is unknown. Therefore, the risk of contracting the tuberculosis disease in these environments is yet to be determined.

1.3 Research Question

Does the quantity of *M. tuberculosis* bacteria in the air, which is introduced by infected personnel, pose a significant contaminating risk to non-infected personnel in the same environment?

1.4 References

Corbett EL, Churchyard GJ, Clayton T, Herselman P, Williams B, Hayes R, *et al*. (1999) Risk Factors for Pulmonary Mycobacterial Disease in South African Goldminers. Am J Resp Crit Care Med; 159 94–99.

Kleinschmidt I, Churchyard GJ. (1997) Variations of Incidences of Tuberculosis in Subgroups of South African Goldminers. Occup Environ Med; 54 636-641.

Prescott LM, Harley JP, Klein DA. (2005) Microbiology. McGraw Hill. USA. p. 992. ISBN: 0072992913.

Rowe D. (2003) Occupational Hygiene Practices in the South African Mining Industry – Inspectorate Perspective. 30th International Conference of Safety in Mines Research Institutes, South African Institute of Mining and Metallurgy.

Van der Heever DJ, Stanton DW. (2007) Bioaerosols. In Stanton, DW, Kielblock J, Schoeman JJ, Johnston JR, editors. Handbook on Mine Occupational Hygiene Measurements. South Africa. The Mine Health and Safety Council (MHSC). p. 123-134. ISBN: 9781919853246

CHAPTER 2

LITERATURE STUDY

This chapter will discuss the bacterium responsible for tuberculosis, the manifestations of this disease and its common epidemiology in the mining trade, as well as the somewhat controversial UVGI System which is employed, among others, for tuberculosis control. Understanding the various aspects that surround this growing threat is the first step in developing effective strategies against it.

2.1 Tuberculosis Physical Properties

Tuberculosis (TB), the disease which has plagued mankind for centuries and the leading cause of adult death from any single infectious agent worldwide (Snashall and Patel, 2003), was often referred to as *The Consumption* due to the belief that it consumed people from within. Many superstitious beliefs and folklore surrounded the cause of this malady and the symptoms it manifested, but the scientist Robert Koch discovered in 1882 that the disease was caused by the bacterium *M. tuberculosis* (Prescott *et al*., 2005).

M. tuberculosis, a bacterium that can survive and grow in an oxygenated area (termed an aerobe), divides every 16 to 20 hours, which is an extremely slow division rate compared with other bacteria. It is a rod-like bacillus which is 2 to 4 micrometers (µm) in length and 0.2 – 0.5 µm in width. *M. tuberculosis* is also classified as a gram-positive bacterium and an acid-fast bacillus because it retains certain strains after treatment with an acidic solution. It possesses a cell wall with a high lipid and mycolic acid content, but lacks an outer phospholipids-composed membrane. The bacillus can withstand weak disinfectants and survive in a dry state for weeks. In nature, only the cells of a host organism can provide the optimal environment for sustainable growth (Prescott *et al*., 2005).

Three other TB- causing mycobacteria are also included in the *M. tuberculosis* complex, namely *M. bovis*, *M. africanum* and *M. microti*. *M. africanum* is a significant cause of tuberculosis in parts of Africa, but does not have a widespread prevalence. *M. bovis*, once a common cause of tuberculosis, has largely been eliminated as a public health threat by the introduction of pasteurized milk (in developed countries). *M. microti* usually exists in immuno-deficient people, however it is speculated that the prevalence of this pathogen may have been underestimated (Van Soolingen *et al.*, 1997).

2.2 Tuberculosis Physiology

Tuberculosis is known for attacking the lungs (as pulmonary TB), and is therefore called a pulmonary transmission disease. The infection in the lungs is also referred to as the primary infection. Transmission of *M. tuberculosis* occurs when infected individuals, who suffer from active (not latent/dormant) pulmonary TB, cough, sneeze, spit, shout or expel infectious aerosol droplets into the environment. Prescott *et al*. (2005) explains that these droplet nuclei are small particles, 0.5 - 5 µm in diameter, that result from the evaporation of larger particles called droplets. Droplet nuclei can remain airborne for hours or days and travel long distances. Up to 40,000 droplets can be released from a single sneeze, according to Cole and Cook (1998), and every single droplet, according to Nicas *et al*. (2005) and Behr *et al*. (1999) is capable of transmitting the disease as TB has a very low infectious dose. Inhaling less than 10 bacteria may cause tuberculosis, but many believe that that the inhalation of even a single *M. tuberculosis* bacterium is capable of causing the disease. The number of infectious droplets expelled by a carrier, the effectiveness of ventilation, the duration of exposure, and the virulence of the *M. tuberculosis* strain do, however, play a role in determining the probability of transmission from one person to the next. That is why isolation of persons with the active disease is so vital. If the infected persons are swiftly started on effective anti-tuberculosis therapy, they can cease to be contagious after 2 weeks of such treatment. If someone does become infected, it will take at least 21 days, or 3 to 4 weeks, before the newly-infected person can transmit the disease to others (Mayo Clinic, 2009).

Dust is also an important route of airborne transmission (Prescott *et al*., 2005). Dust that is re-suspended in the air can contribute greatly to the quantity of airborne pathogens as they are capable of adhering to dust particles. According to Prescott *et al*. (2005), meat that is infected with TB can also transmit the pathogen if it is consumed.

Once a tuberculin-free person acquires an infected droplet nucleus, the bacilli will multiply for 4 to 6 weeks., There is however a proposed incubation period of about 4 to 12 weeks. Tuberculosis is a disease that develops slowly (Prescott *et al*., 2005).
TB infection begins once the bacterium reaches the pulmonary alveoli (Kumar *et al.*, 2007). There the *M. tuberculosis* bacteria are phagocytosed by macrophages and a hypersensitivity response ensues which results in the formation of small, hard

nodules called tubercules, which are characteristic of tuberculosis and give the disease its name (Houben *et al.*, 2006).

Tuberculosis is classified as one of the granulomatous inflammatory conditions. Macrophages, T-lymphocytes, B-lymphocytes and fibroblasts are among the cells that aggregate to form a granuloma, with lymphocytes, that surrounds the infected macrophages. The granuloma prevents dissemination of the mycobacterium, and provides a local environment for communication of the immune system cells. T-lymphocytes (CD4+) secrete cytokines such as interferon gamma within this granuloma, which activate macrophages to destroy the bacterium that infects them. T-lymphocytes (CD8+) can also directly kill infected cells (Prescott *et al*., 2005).

The process of the disease will usually stop at this stage but the bacteria are not always eliminated within the granuloma. A few viable bacilli/spores often remain alive within the macrophage and become dormant, where they are capable of a prolonged latent (inactive) survival state if the person's immune system remains active and functions normally. The dormant bacillus will, under the condition of a healthy immune system, be of no bother to the infected person. Resistance to oxidative killing, inhibition of phagosome-lysosome fusion, and inhibition of diffusion of lysosome enzymes are some of the mechanisms that may explain the survival of *M. tuberculosis* inside the macrophages (Prescott *et al*., 2005).

Nevertheless, the bacilli start their invasion in the alveoli by replicating within the endosomes of the alveolar macrophages. The Ghon Focus, which is commonly located in either the lower part of the upper lung lobe or the upper part of the lower lung lobe, is the primary site of infection (Kumar *et al.*, 2007).

Another feature of the granulomas of human tuberculosis is the development of cell death, also called necrosis, in the centre of the tubercules. The infected person will usually heal after the initial infection and a scar will appear in the infected loci. In time the tubercule may change to a cheese- like consistency and is then called a caseous lesion. If such lesions calcify, they are termed Ghon complexes, which show up prominently in a chest x-ray. Sometimes the tubercule lesions liquefy and form air-filled tuberculous cavities. Some of these cavities are joined to the air passage bronchi during active cases of the disease, and the coughing up of this material, which contains living bacteria, can therefore be passed on and infection could follow (Prescott *et al*., 2005).

From these cavities the bacteria may also spread to new foci of infections throughout the body. Dendritic cells, which do not allow replication of the bacilli cells, pick them up and transport them to local (mediastinal) lymph nodes. The bacteria then spread via the bloodstream to other tissues and organs throughout the body, where they set up many foci of infection (Houben *et al.*, 2006).

The bacilli implant in areas of high partial pressure of oxygen: the lungs, renal cortex and reticuloendothelial system. This spreading is often called miliary tuberculosis due to the many tubercules the size of millet seeds (tiny and white) that are formed in the infected tissue. Miliary tuberculosis is a very severe form of tuberculosis. It may also be called reactivation tuberculosis because the bacteria have been reactivated in the initial site of infection (Prescott *et al*., 2005).

The prominent sites where secondary TB lesions can develop, are in the apex of the upper lung lobes (or other parts of the lung), in the peripheral lymph glands, the central nervous system, the genito-urinary system, the lining covering the outside of the gastrointestinal tract, the kidneys, the bones and joints, the circulatory system, and even the skin. Although extra pulmonary TB is not contagious, it may coexist with pulmonary TB, which is contagious (Prescott *et al*., 2005).

2.2.1 General Symptoms

Individuals with the TB disease start by manifesting the common symptoms which include fever, fatigue, loss of appetite and weight loss. A prolonged common cough lasting for at least 3 weeks with a progressive increase in production of mucus and coughing up blood is the classic symptom of tuberculosis infection. Other symptoms include night sweats, chest pains and often a tendency to fatigue very easily (Prescott *et al*., 2005).

The destructive action of *M. Tuberculosis* on the lungs and the manifestation of the symptoms have a detrimental effect on the worker's ability to perform various tasks, especially physically demanding jobs which are required from the general workers in a mine. A worker who suffers from TB causes a disruption in workflow and reduces productivity not only because of his high fatigued state, but also in the form of weeks or months of absenteeism. The direct cost of treatment is also a strong possible consequence. Obviously, the higher the number of infected workforce members, the higher the financial loss will be, especially for a mine (TWEF, 2002).

Infection of other organs causes a wide range of ailments and symptoms which also affects the above- mentioned situation. These secondary effects of tuberculosis will now be discussed.

2.2.2 Lymphatic Tuberculosis

When the tuberculosis bacilli escape the lung, the first route they travel is usually through the lymphatic system, where they will inevitably pass through the lymph nodes. The bacilli infect the nodes and cause a rapid inflammation response known as lymphadenitis, which is a specific chronic infection. This will lead to a disease known as scrofula, which is effectively tuberculosis of the neck, or, more precisely, a cervical tuberculous lymphadenopathy (Makoto and Masao, 2000).

The clinical manifestation is an enlargement of the cervical lymph nodes, usually under the lower jaw (Golden and Vikram, 2005). The swollen lymph nodes become hard, painless and moveable in the early stages of the disease, but inflammation soon causes adhesion of the lymph nodes to the surrounding skin. The lymph nodes may then merge together to form immovable clusters. Progression of the disease will cause caseous necrosis in the lymph nodes, which will lead to deliquesce of the tissue and the formation of a cold abscess, which refers to the appearance of a painless mass in the neck that is persistent and grows with time. This mass is referred to as a cold abscess, because there is no accompanying local colour or warmth (Makoto and Masao, 2000).

The skin around the ulcer's edge is dark red and slink, while the granulous tissues are pale (white) and edemous. These different stages of pathology may manifest simultaneously in each lymph node (Dandapat *et al*., 2005). Proper treatment and enhancement of the immune system will cause the pathological changes of the lymph nodes to stop and to undergo calcification. Other symptoms of scrofula are fever, chills, malaise, cachexia and other general intoxication symptoms (Golden and Vikram, 2005).

2.2.3 Tuberculosis of the Central Nervous System

CNS TB, according to Be *et al*. (2009), is very difficult to diagnose and treat. The treatment includes four drugs which were developed more than 30 years ago, and they only prevent death or disability in less than half the patients, and with the ever-increasing risk of TB strains that develop resistance, an era of even greater mortality looms.

The two major forms of CNS tuberculosis are meningitis, which accounts for 0.5–1% of tuberculosis disease and intra-cranial tuberculomas which, on a global level, account for up to 40% of brain tumours (Be *et al*., 2009).

The CNS is under threat as soon as the tuberculosis bacteria disseminate to the local lymph nodes and bloodstream, from where they then spread throughout the systemic circulatory system. Extensive bacteria that follow dissemination from the lungs increase the probability that a sub-cortical focus will be established in the CNS. Higher bacilli numbers in the circulatory system may therefore be associated with the increased likelihood that the CNS will be invaded and CNS TB develops (Donald *et al*., 2005).

It has to be remembered that the blood brain barrier (BBB) protects the CNS from the systemic circulatory system, and it is impermeable to many large hydrophilic molecules and circulating pathogens due to its various physiological properties. Also protecting the CNS is the blood-cerebrospinal fluid (CSF) barrier, which provides spatial separation of the circulatory system from the CSF at the choroids plexus. The integrity of this barrier can be breached, however, by a number of bacterial pathogens, including *M. tuberculosis*, and cause subsequent meningitis (Be *et al*., 2009).

It was found by Arnold Rich and Howard McCordock in 1933, that the majority of TB meningitis patients displayed a caseating focus in the brain parenchyma or the meninges. They postulated that these foci (termed Rich foci) develop around bacteria deposited in the meninges and brain parenchyma during the initial bacteraemia phase. These foci will eventually rupture and allow dissemination of the bacilli into the subarachnoid space, which would cause inflammatory meningitis (Be *et al*., 2009).

The exact mechanism by which the *M. tuberculosis* initially invades the BBB is still unclear, but various animal studies suggest that the bacilli can cross the BBB as a free (extra-cellular) organism (Wu *et al*., 2000). It is also still unclear whether *M. tuberculosis* resides primarily within the parenchyma of the brain, the vessel wall, or the endothelial cells lining the micro-vasculature after invading the CNS. It is proposed that *M. tuberculosis* resides, at least initially, in the endothelial cells lining the microvasculature. The spread of the bacilli into the subarachnoid space following rupture of a Rich focus triggers a robust inflammatory T-cell response. The

inflammation which develops in response to *M. tuberculosis* in the CNS is the cause for the clinical manifestation. The initial warning of CNS tuberculosis is a headache, stiff neck and a fever. Delirium, coma and death follow untreated TB meningitis. Hydrocephalus may develop if the CSF is obstructed by inflammatory infiltrate, and vasculitis contributes to infarction, which may cause irreparable neurological damage (Mastroianni *et al*., 1997).

2.2.4 Gastro-intestinal Tuberculosis

Marshall (1993) and Acharya *et al*. (2005) claim that Gastro-intestinal (GI) TB is the sixth commonest extra-pulmonary TB site to be affected, and accounts for 3%–5% of all extra-pulmonary TB involvement. Any part of the GI tract may be involved.

Hamer *et al*. (1998) divides GI TB manifestations into three categories: the ulcerative form (60%), hypertrophic form (10%) and mass-like lesions (ulcero-hypertrophic, 30%) that mimic malignancies. Again, the state of the infected person's immune system determines the manifestations. A reduced immune response delivers the ulcerative form, whereas an enhanced immune system manifests the hypertrophic form. The hypertrophic form comprises a thickening of the bowel wall with fibrosis, scarring, and a rigid mass-like appearance that mimics that of malignancies. The ulcero-hypertrophic form is a subtype with a combination of the features of the ulcerative and hypertrophic forms. Fever, weight loss, anorexia and night sweats are the usual symptoms of GI TB (Chong and Lim, 2009).

2.2.4.1 TB in the Oesophagus

Oesophageal TB is extremely rare and accounts for only 0.15% of all TB deaths. Dysphagia, coughing when swallowing, and haematemesis are symptoms that accompany this disease. Abid *et al*. (2005) suggest the middle third of the oesophagus as the usual site of attack. The main pathogenesis is believed to be the direct extension from adjacent mediastinal structures, rather than through swallowed contaminated sputum or haematogenous/lymphatic spread. A solitary ulcer with an excavating base and rolled-up nodular edges is the most common manifestation. The most serious manifestation is the aorto-oesophageal fistula, which is almost universally fatal if not treated (Chong and Lim, 2009).

2.2.4.2 TB in the Stomach and Duodenum

Yeomans *et al*. (1994) claims that the stomach and duodenum are rarely affected by GI TB due to a combination of an acidic environment, a scarcity of lymphoid tissue and the rapid passage of swallowed mycobacterium. The clinical manifestations

include non-specific symptoms, dyspepsia or abdominal pain, GI bleeding and obstructive symptoms such as nausea and vomiting. Gastric TB is more common in males (2–3 times), and in those aged 20–40 years, according to Chong and Lim (2009), and most patients have evidence of other organ involvement. The antral-pyloric complex is commonly affected, which then results in a gastric outlet obstruction, according to Amarapurkar *et al*. (2005).

The duodenum is the fourth most commonly affected site, according to Chong and Lim (2005), but over 90% of duodenal TB cases have other parts of the intestine involved. Manifestations include thickening of the diffuse mucosal fold, ulcers, which are usually transverse and circular, or an ulcerated mass, polyps, and fistulae formation. The largest series reported, which consisted of 28 cases, showed that the majority (82.2%) had obstructive symptoms secondary to luminal narrowing, of which 72% was due to external compression. The others had dyspepsia secondary to ulcerations (Chavahan and Ramakantan, 2003).

2.2.4.3 TB in the Jejunum

The jejunum is the third most commonly affected site, according to Chong and Lim (2009). The most common symptom is chronic abdominal pain, apart from other non-specific symptoms. A well-recognised complication is malabsorption, which most likely results from bacterial overgrowth. Up to 70% of patients in endemic areas may have jejunal structures, and the spectrum of lesions encountered is similar to those seen in the rest of the intestine.

2.2.4.4 TB in the Ileum

Chong and Lin (2009) proclaim the ileum as the most commonly affected site. The high density of lymphoid tissue, relatively longer faecal stasis, a neutral pH environment and absorptive transport mechanisms that allow swallowed mycobacterium to be absorbed, are the main reasons for the predilection, according to Sharma and Bhatia (2004). Findings may range from a normal appearance to small polyps or nodules to extensive ulcerations, hypertrophic, ulcero-hypertrophic and fibrotic lesions resulting in strictures, causing bowel obstructions and fistulae formations. Rapid emptying of contrast, known as the “Stierlin’s sign”, is commonly seen in terminal ileum involvement due to persistent irritability of the mucosa (Chong and Lim, 2009).

2.2.4.5 TB in the large Bowel

The colon is the second most commonly affected site, especially the caecum and the ascending colon, decreasing in frequency with increasing distance from the caecum. Signs of the disease include abdominal pain, a chronic abdominal mass and altered bowel habits. Intestinal obstruction (15%–60%), fistulae (25%), perforation (15%, with a mortality of 30%– 40%) and less frequently, massive haemorrhage, are just some of the serious complications (Mukewar *et al*., 2007).

2.2.4.6 TB in the Appendix

Appendicular TB is rare and accounts for only 2.9% of tuberculosis cases (Chong and Lim, 2009).

2.2.4.7 TB in the Caecum and the ascending Colon

The caecum is commonly involved along with the terminal ileum. In the early stages, the endoscopical appearances may be normal, resemble mild non-specific colitis or consist of small polyps. With progression, the caecal and ileal walls become thickened with enlargement of the draining lymph nodes. The caecum is typically involved, resulting in mass-like lesions. A thickened ileum with caecal and ascending colon involvement may manifest as the disease progresses. The ileocaecal valve usually becomes enlarged and patulous. A swollen gaping ileocaecal valve, a cone-shaped caecum and a narrowed adjacent terminal ileum give rise to the “inverted umbrella” defect, better known as the “Fleischner sign”. The ascending colon may be involved in isolation but usually occurs in association with caecal involvement. Severe nodular or constrictive involvement can lead to bowel obstruction (Chong and Lim, 2009).

2.2.4.8 TB in the transverse, descending, sigmoid Colon and Rectum

The involvement of these parts of the colon is more common than the stomach, duodenum and oesophagus. However, isolated involvement is rare. Findings are similar to those encountered in the proximal colon and resemble inflammatory bowel disease. In addition to the non-specific symptoms, manifestations of segmental colonic TB include chronic abdominal pain, altered bowel habits and rectal bleeding (Chong and Lim, 2009).

2.2.4.9 TB in the Chest and Liver (extra-enteric involvement)

Hepatic calcifications that range from a few specks to heavy calcification may be seen in other TB infected organs, especially the liver and the chest. Peritoneal and

omental involvement gives rise to large irregular masses (sometimes with central necrosis) and high density ascites. The mesentery and the peritoneum may be involved. Solid organ involvement, commonly the liver and the kidney, often manifest as calcified hypo-dense masses (Chong and Lim, 2009).

2.2.5 Urinary and Reproductive Tuberculosis

The genitourinary tract is the most common site after the lungs for tuberculosis infection. If the tuberculosis bacilli end up in and disperse via the circulatory system, the kidneys will be inevitably affected. Tuberculosis of the kidney is a disease that develops slowly though, and years (20 or more) can go by before any symptoms appear. Symptoms usually include pus and sometimes blood in the urine, an urge to urinate frequently, unexplained fever and perhaps weight loss. In fact it is proposed that by the time of diagnosis of renal tuberculosis, the primary source of pulmonary infection may already be inactive or calcified (Khan *et al*., 2004).

The initial renal focus point is usually a small tubercule in the glandular and cortical arterioles, but as time progresses, these lesions will grow into necrotizing lesions. The disease will then spread to the renal tubules and medulla, where further tubercules develop, usually at the turn of the loop of Henle, and combine to form large, necrotic, irregular cavities. These cavities will lead to the formation of fistulae and stricturing. Eventually, the kidney may become fibrotic and scarred (Khan *et al*., 2004).

Renal tuberculosis is bilateral, although 25% of patients do show asymmetric and unilateral infection. Ultimately, the kidney becomes atrophic, scarred, densely calcified, and non-functioning (autonephrectomy) if not appropriately treated.
Infection of the ureter occurs secondary to kidney infection. Eventually, the ureter will also become fibrotic. These pathologic processes can have an anatomical effect on the ureter by physically changing it to appear beaded, saw-toothed, corkscrew, or a pipe stem, depending on the stage of disease. This usually affects the upper and/or lower third part of the ureters (Khan *et al*., 2004).

The initial occurrence in bladder tuberculosis is interstitial cystitis, which will eventually cause bladder mucosal ulceration and thickening of the bladder wall. The diminished capacity of the urinary bladder is the result of scarring and bladder fibrosis (Khan *et al*., 2004).

Tuberculosis of the seminal vesicles yields the same pathologic processes as within the bladder (i.e. mucosal tuberculomas, ulceration, and fibrosis). Calcification of the seminal vesicles does occur in 10% of patients. Unlike seminal vesicle tuberculosis, tuberculosis of the prostate is usually secondary to descending infection from the kidney, and could cause an enlargement and calcification of the prostate. The tuberculous cavities or abscesses may discharge into the surrounding tissues, forming sinuses or fistulae to the perineum or rectum (eventually resulting in a watering-can perineum). The scrotum and urethra are rarely involved, and urethral involvement may be complicated by urethral strictures (Khan *et al*., 2004).

Chronic epididymitis and epididymo-orchitis may also develop due to tuberculosis infection. Tuberculous granulomas may develop within the testes and epididymis, the scrotal wall and tunica albuginea may thicken, and moderate accumulation of fluid may occasionally be observed. Female genital tuberculosis, which is invariably secondary to tuberculosis elsewhere, presents infertility, menstrual irregularity, and pain for the infected persons. Pregnancy is rare in the presence of genital tuberculosis and is often complicated by ectopic pregnancy or spontaneous abortion. Clinical features of female genital tuberculosis, if any, are non-specific. Obstruction is common in the fallopian tubes, as are hydrosalpinx and pyosalpinx. The tubes also become rigid and pipe-like because of fibrosis, and they lack peristalsis. A wet or dry peritonitis may accompany genital tuberculosis (Khan *et al*., 2004).

2.2.6 Tuberculosis in the Bones and Joints

Musculoskeletal tuberculosis arises mainly from haematogenous spreading of the bacilli soon after the initial pulmonary infection, according to Abdul and Mousa (2007). Osteo-articular tuberculosis usually starts as osteomyelitis in the growth plates of bones, where the blood supply is best, and then spreads locally into the joint spaces (Iseman, 2000), where joints can become infected by the activation of dormant lymphatic- or blood stream areas of morbidity (Abdul and Mousa, 2007). In the long bones TB originates in the epiphysis and causes tubercule formation in the marrow, with secondary infection of the trabeculae (Wright *et al*., 1996). The joint synovium then responds to the mycobacteria by developing an inflammatory reaction, followed by formation of granulation tissue. The pannus of formed granulation tissue then begins to erode and destroy cartilage and eventually bone, leading to demineralization, according to Abdul and Mousa (2007), who go on to explain that because TB is not a pyogenic infection, proteolytic enzymes, which destroy peripheral cartilage, are not produced. The joint space, therefore, is

preserved for a considerable time. If allowed to progress without treatment, however, abscesses may develop in the surrounding tissue.

Spinal TB, according to Rajasekaran *et al*. (1998), is the most common form of skeletal system TB and comprises 50% of all cases. Wherever the primary site of TB infection is, it travels by subligamentous spread in the spine, as well as into paravertebral spaces and adjacent soft tissues. It causes osteonecrosis characterized by loss of the extra cellular matrix of vertebral bone and collapse of the vertebrae (Meghji *et al*., 1997). The bone is devitalized by an exotoxin produced by the acid-fast bacilli. The anterior portions of two or more contiguous vertebrae are involved, owing to haematogenous spread through one arteria intervertebralis feeding two adjacent vertebrae (Shanley, 1995). The spinal cord may become involved either by compression by bony elements and/or an expanding abscess; or direct involvement of cord and leptomeninges by granulation tissue.

2.2.7 Tuberculosis in other Organs

About 15% of people may develop tuberculosis in an organ other than their lungs. The heart (pericardium), skeletal muscles and the thyroid are the parts of the body that are rarely infected by TB, and the only parts of the body that will not be affected by TB are the hair and nails (Atre, 2007).

2.3 The Progression of Tuberculosis

About 90% of people infected with *M. tuberculosis* have asymptomatic, latent TB infection, with only a 10% lifetime chance that a latent infection will progress to the tuberculosis disease. If it remains untreated however, the death rate for these active TB cases is more than 50%. Miliary tuberculosis occurs more commonly in immune-suppressed persons and young children (Onyebujoh and Rook, 2004).

Progression from TB infection to TB disease occurs when the TB bacilli overcome the immune system defences and begin to multiply. This secondary reactivation, which usually crops up in the lungs, occurs in 85 – 90% of cases, but only 1 – 5% of cases are affected by this reactivation soon after infection. These dormant bacilli can produce tuberculosis in 2 – 23% of these latent cases, often many years after infection (Onyebujoh and Rook, 2004).

There is therefore a significant distinction between latent TB infection and TB disease. In the first case the individual is still in a state of well- being, but does yield a positive skin test reaction to injected TB proteins (Prescott *et al*., 2005).

Recently, new multi-drug-resistant strains of tuberculosis (MDR-TB) have developed and are spreading. The multi-drug-resistant strain is defined as *M. tuberculosis* that is resistant to the treatment drugs isoniazid and rifampin, with or without resistance to other drugs. This has resulted in many cases of marginally treatable, often fatal, disease. Inadequate therapy is the most common means through which resistant bacteria are acquired, and patients who have previously undergone therapy should be presumed to harbour MDR-TB until proven otherwise (Prescott *et al*., 2005). The means by which MDR-TB occurs is now known. Tubercule bacilli have spontaneous, yet predictable rates of chromosomally-born mutations that grant resistance to drugs. These mutations are unlinked, and so there is no connection between the resistance to one drug and the resistance to an unrelated drug. The emergence of drug resistance represents the survival of random pre-existing mutations, and not a change caused by exposure to the drug. The fact that the mutations are not linked is the cardinal principle that forms the basis for TB chemotherapy. For example, the mutation that resists isoniazid or rifampin is expressed as roughly 1 in 108 replications of *M. tuberculosis*. The chance of spontaneous mutations causing resistance to both isoniazid and rifampin is the sum of these probabilities, or 1 in 1016. However, these biological mechanisms of resistance may break down when chemotherapy is inadequate. In circumstances of mono-therapy, erratic drug ingestion, omission of one or more drugs, sub-optimal dosage, poor drug absorption, or an insufficient number of active drugs in a regiment, a susceptible strain of *M. tuberculosis* may become resistant to multiple drugs within a matter of months (Prescott *et al*., 2005).

Multi-drug resistant tuberculosis is on the rise, and approximately 4.8% of new TB cases worldwide are due to MDR strains. These represent 489,139 patients annually. Treatment of MDR-TB, especially in the HIV co-infected individuals, is much more complex than in the case of fully drug- susceptible organisms, and is associated with higher treatment costs and longer treatment periods. In addition, such cases exhibit poorer patient outcome and higher mortality rates. MDR-TB meningitis is especially challenging to treat due to limited CNS penetration of several second line anti-TB drugs (Be *et al*., 2009).

When TB patients do not comply with treatment, or when they take their drugs irregularly, resistant bacteria survive while drug-susceptible strains die. Thus non-compliant patients diagnosed initially with drug-susceptible TB can "acquire" MDR-TB over time. MDR-TB now accounts for 1 out of every 20 new cases, making the global TB epidemic a far more urgent problem (Prescott *et al*., 2005). MDR-TB patients who remain non-compliant with treatment can acquire a still more worrisome form of TB dubbed extremely drug-resistant tuberculosis (XDR-TB), which resists practically every known drug at doctors' disposal. This lethal disease, which was discovered in 2005, is the downward spiral for those who suffer from TB. All but 1 of 53 HIV- infected individuals stricken with XDR-TB in KwaZulu-Natal in 2005 and 2006, died within several weeks of developing TB symptoms (Schmidt, 2008). It was previously thought that XDR-TB, once acquired, might not be infectious beyond hospitals and other clinical settings. The XDR-TB bacteria were believed to be too weak to be broadly transmissible, presumably because the bacteria are so mutated that they are generally unhealthy, but Cohen *et al*. (2003) believes some drug-resistant mutations might not exert the so-called fitness costs that would otherwise compromise XDR-TB bacteria and weaken them. The XDR-TB strains that harbour these rare mutations might survive preferentially and eventually predominate over time, especially if more effective drug treatments against these strains remain elusive. An aggressive and transmissible XDR-TB can spread relentlessly through human populations, if the fit strains prevail.

According to the platinum mine's Safety and Sustainable Development Report (2009), only one case of extremely resistant TB emerged in 2008 and one other case in 2007. The platinum mine actively screens for TB and provides comprehensive treatment to infected employees. During 2008, 734 (520 in 2007 and 891 in 2006) employees with new TB infection were treated. There were 91 deaths from TB, of which 81 were HIV-related (7 in 2007, of which 6 were positive for HIV; and 65 in 2006, when 72% of cases were positive for HIV). The rate of new TB cases increased with 1.2% between 2007 and 2008.

2.4 Epidemiology

Tuberculosis has plagued the human race since ancient times. Skeletal remains show that prehistoric humans (4000 BC) had TB, and tubercular decay has been found in the spines of mummies from 3000 – 2400 BC (Zink *et al*., 2003). Phthisis is a Greek term for tuberculosis. Around 460 BC, Hippocrates identified phthisis as the

most widespread disease of the times, involving coughing up of blood and fever, which was almost always fatal.

Today, tuberculosis is the most common cause of morbidity and death in adults living in developing countries, according to all sources. The World Health Organization (2009) claims that there were 9.27 million new cases of TB diagnosed in 2007, 55% of them in Asia and 31% in Africa. More than 80% of all TB patients live in sub-Saharan Africa and Asia (Tremblay, 2007). Demilew (2007) put this figure at 84% in 2007 for these two regions. According to Corbett *et al*. (2003), there were an estimated 8.3 million (7.3 - 9.2 million) new TB cases in 2000, or 137 (121 - 151) per 100 000 population; 3.7 million (3.1 - 4.0 million) were smear- positive, i.e., 61 (51 - 66) per 100 000 population. Most new cases were found in adults aged 15 to 49 years (5.4 million; 172/100 000). Among WHO regions, the African Region (essentially sub-Saharan Africa) had by far the highest annual incidence rate (290/100 000). Roughly 8.8 million new TB cases and 1.7 million TB- related deaths of people living in developing countries were reported by Corbett *et a*l. (2003). Tremblay (2007) estimated that 2 million people died of TB around the world in 2004. Demilew (2007) supports this number, and adds that in 2004, mortality and morbidity statistics included 14.6 million chronic active cases, 8.9 million new cases and 1.6 million deaths, mostly in developing countries. From 2000 to 2004, 20% of TB cases were resistant to standard treatments and 2% resistant to second- line drugs.

Over 2 billion people, one third of the world's population, have been exposed to the tuberculosis pathogen. All sources further claim that this number of people is infected with various strains of *M. tuberculosis*, and it is estimated that the lifetime risk of persons infected with TB to develop the disease, ranges between 10 – 20%. People with prolonged, frequent, or intense contact are at particularly high risk of becoming infected, with an estimated 22% infection rate. A person with active but untreated tuberculosis can infect 10–15 other people per year, and new infections occur at a rate of one per second (WHO, 2009).

Tuberculosis is therefore second only to HIV/AIDS in terms of the global burden of infectious disease. It is also the most common human immunodeficiency virus (HIV)-related opportunistic infection and the most important cause of morbidity and death in HIV- infected individuals in the developing world, according to Corless *et al*. (2009). Epidemic outbreaks of TB have been closely associated with HIV, and Corbett *et al*.

(2003) states that many of the reported outbreaks involved MDR-TB strains that respond poorly to standard therapy.

Dual infection with HIV and *M. tuberculosis* was responsible for 600,000 deaths in 2004. Of the 2 billion latently infected with *M. tuberculosis*, many develop reactivation disease years after the initial exposure. Co-infection with HIV increases the risk of development of reactivation tuberculosis disease from a lifetime risk of 5 - 10% to approximately 10% per year. Unfortunately, the number of dual infections with HIV and *M. tuberculosis* is increasing at an alarming rate with 2 million new double infections in 2004 alone (Corless *et al*., 2009).

HIV causes immuno-suppression and therefore increases the risk of infection and re-infection of tuberculosis. In fact, rectification of tuberculosis increases to 10% per year in patients that are co-infected, according to Hnizdo *et al*. (2000). Other immunosuppressive therapy, such as prolonged corticosteroid therapy, also increases the risk. The same goes for other diseases which put a lot of strain on the immune system, such as diabetes mellitus, silicosis, leukaemia and Hodgkin's disease, kidney disease, gastectomy and chronic malabsorption syndromes, as well as dietary diseases like anorexia and bulimia (CTCA, 2006).

Drug injection, a history of poor TB treatment or previous TB infection also contributes to the increased risk of a tuberculosis relapse. Some drugs that work by blocking tumour necrosis factor alpha, raise the risk of activating a latent infection due to the importance of this cytokine in the immune defence against TB. Smoking more than 20 cigarettes a day increases the risk of TB two to four times. Alcoholism also increases the risk of developing tuberculosis. TB has been termed a 'social disease' because it is linked to poverty, overcrowding and unsanitary conditions, and has been linked anecdotally with environmental risk factors that go hand-in-hand with poverty (Schmidt, 2008). Dimelew (2007) describes tuberculosis as one of the leading causes of death in the most economically- productive age group, which is 15 - 55 years; thereby causing enormous social- and economic disruption. This disruptive effect on national economics, according to Laxminarayan *et al*. (2007), is brought about through the direct loss of productivity among those of working age and by altering fertility, incentives for risk-taking behaviour, and investment in human- and physical capital. It is apparent that a high portion of productive and financial losses in the mining industry are a direct result of tuberculosis occurrence.

2.5 Epidemiology in South Africa

TB is growing globally at a rate of 0.4% per year, according to the WHO (2009). The African regions have an annual increase rate of 6.4% per year; with South Africa having one of the highest tuberculosis incidence rates in the world. Tuberculosis death rates in South Africa are estimated to be at 0.14% of the population per year. The country also harbours the largest number of co-infected adults, which is roughly 2 million. In 2005, the country with the highest estimated incidence of TB was Swaziland, with 1262 cases per 100 000 people, but Kleinschmidt and Churchyard (1997) claimed that South Africa faces possibly the world's worst epidemic of tuberculosis, with a national incidence of 3% increase in tuberculosis cases each year.

Active tuberculosis can occur from endogenous reactivation or exogenous re-infection in people who had a previous TB infection. Exogenous re-infection can play a dominant role in the pathogenesis of post-primary tuberculosis in an area with a high incidence of the disease. A different scenario could be evoked for a population with a low risk of infection, where the likelihood of pre-exposure is small and thus most cases of recurrence probably result from relapse phenomena, such as the emergence of HIV. Individuals living and working in high TB transmission settings have a particularly high risk of carrying latent TB, as is the case with South African miners. The prevalence of TB influences the extent to which exogenous re-infection occurs: the higher the prevalence, the greater the likelihood of exogenous re-infection (Bandera *et al*. 2001).

Silica dust, silicosis, HIV infection, socio-economic factors, and the high risk of tuberculosis in the South African mining population in general can greatly exacerbate platinum miners' risk of contracting TB. Exposure to silica dust, which is a recognized occupational hazard, can potentially lead to the development of silicosis and is believed to be the biggest contributing factor of pulmonary tuberculosis development risks (Hnizdo *et al*., 2000). Many miners do indeed develop several episodes of tuberculosis resulting from re-infection, which is probably due to the fact that miners are again exposed to silica dust after treatment for tuberculosis (platinum deposits are found in rock with high silica content). Prolonged exposure to silica dust in mine shafts is responsible for the high prevalence of silicosis, which in turn leads to high TB rates. The longer the duration of employment, the higher the susceptibility

of a South African miner becomes to develop silicosis, according to Corbett *et al*. (1999).

Dusty environments have also been shown to create similar detrimental lung function changes as those found in smokers, particularly the manifestation of chronic bronchitis symptoms. It is also proposed that miners may have a greater occupational exposure to potentially pathogenic environmental mycobacteria than workers in less dusty occupations. Kleinschmidt and Churchyard (1997) support the claim that silicosis is an important risk factor for tuberculosis. They conducted a study on mineworkers and found that workers who suffered from silicosis showed evidence of necropsy. Another more recent necropsy-based study has concluded that increasing average age and increased duration of service are contributing to a rise in the prevalence of TB in miners, but that there was nevertheless an underlying trend with time that could not be entirely explained by these factors. Their study also showed a significant association between the incidence of TB and occupation. This result remained unaltered whether exposure is aggregated separately for each occupation, taking into account any changes in occupation by individual men, or whether each man is assigned to an occupational group (main occupation) that he spent most of his previous service performing (Kleinschmidt and Churchyard, 1997). The low risk worker is a 20 year-old mineworker with less than two years service, working in a low dust job, and with no diagnosis of silicosis and no HIV infection. The low risk group had an annual tuberculosis incidence rate of <1/1000 in 1995. The high risk worker, by contrast, is a mineworker above the age of 55, with at least six years service, who has mostly worked in production jobs such as drilling, and who has been diagnosed with silicosis. He would have been subject to an annual TB incidence of 82.9/1000. The two extremes represent a rate ratio of nearly 85. Even without any radiological evidence of silicosis in the high risk worker, this rate ratio would still be about 50. If the additional risk of tuberculosis posed by HIV to the high-risk man is added, the annual incidence in such groups would be well above 10% even without any possible synergistic effect between HIV and silicosis on risk of TB (Kleinschmidt and Churchyard, 1997). These results were established more than 10 years ago and, as all sources agree that TB incidences increased annually, it is likely that these numbers increased profoundly to date.

A study done by Bandera *et al*. (2001) confirmed that re-infection in areas with a low incidence of tuberculosis is possible, although less common than in high-incidence geographical regions. This indicates that the major risks of tuberculosis re-infection

are represented by a high prevalence of *M. tuberculosis*. It was observed however, that there is a fourfold higher risk of re-infection in immigrant patients in comparison to local subjects. Cohesiveness within ethnic communities, overcrowding, and poor hygienic conditions, which are all too common in the mine setting, allow for an elevated frequency of close contact with a consequent high circulation of *M. tuberculosis* strains that could explain the increased risk of re-infection. This phenomenon also plays a major role for immigrants coming from areas with a high incidence of tuberculosis.

The majority of South African miners mainly consist of migrant workers from rural South Africa and neighbouring countries who work and live for the majority of the year in complexes based around mine shafts, returning to their home areas for 1-3 months each year. There are more than 50 000 migrant workers from Lesotho working in the South African mining industry. Lesotho has the fourth highest TB incidence rate in the world, and tuberculosis is responsible for 15% of all deaths in that country. The immigration of these workers contributes to the spreading of the disease. The relationship between the South African mining sector and the TB epidemic in Lesotho is unambiguous: a recent study showed that close to 40% of adult male TB patients in three of Maseru's main hospitals were working, or had formerly worked, in South African mines. Furthermore, at least 25% of the MDR-TB cases treated in Lesotho since August 2007 had a history of mining work or were referred directly from mines in South Africa (ARASA, 2008).

TB rates in the mines are up to 10 times that of the general population. Control of TB in the mining sector is therefore of tremendous significance and importance to national TB control. Immigration from high TB- incidence countries could modify the evolution of tuberculosis transmission in HIV-infected patients as the most important source of tuberculosis among the younger age groups, and could lead to alarming outbreaks of the disease caused by MDR organisms (ARASA, 2008). Other sources in the mining industry that could contribute greatly to the tuberculosis problem are cramped rooms with poor sanitation and unventilated housing structures. Poor socio-economic conditions and lack of awareness also aid in the prevalence of the disease. Suffocating heat, overcrowded working conditions, dust, noise, and work-time tensions due to supervisor/employee relationships and production pressures, are perceived to be the major reported complaints that lead to the causes of different forms of health problems. Workers most often hide their illness, due to fear of losing their job and fear of isolation from colleagues (Schmidt, 2008).

The increasing number of TB infection cases is also likely due to population growth and worsening poverty, but the WHO STOP TB Department has conducted population-level studies of risk factors. According to their analyses, malnutrition, indoor air pollution from solid fuel use, and active smoking constitute the three top factors posing a TB risk, followed by HIV infection, diabetes, and excessive drinking. For 40 years crowding has been cited as a crucial infection threat. However, this factor's unique contribution to TB risk is hard to quantify according to Lönnroth *et al*. (2010), who states that the relative risks from crowding vary with housing quality, TB prevalence in the community, and also with access to health care, which is associated with a chance of early cure of infectious cases. The WHO (2009) agrees that poverty and urbanization create the perfect conditions for TB transmission. Urbanization leads to higher population densities, crowded living conditions, and increased mobility among migrants seeking temporary work.

2.6 Risk Factors that can exacerbate Tuberculosis

The links between cigarette smoking and TB are well- documented. Approximately 1.1 billion people worldwide smoke cigarettes, including 930 million in developing- or middle- income countries, according to the WHO (2009). At the same time, half the world's population cooks on open fires or traditional stoves that are fuelled by coal or biomass (wood, animal dung, crop residues, or charcoal), often indoors in poorly ventilated spaces. These stoves produce smoke with chemical constituents similar to those in cigarette smoke, like carbon monoxide for example. Kolappan and Subramani (2009) point out that in the developing world most women do not smoke, and most men do not cook for their families. Therefore, in these settings smoking is one of the greatest TB risk factors for men, whereas indoor air pollution from solid fuel use is likely to be one of the greatest for women. Exposure to second-hand tobacco smoke also elevates the TB risk, making cigarette smoke exposure a risk factor for both sexes. The underlying mechanisms remain unclear, although some scientists speculate that cigarette smoke boosts TB infection risk by impairing the ability of lung cilia to clear bacteria from the respiratory tract (WHO, 2009).

Exposure might also raise progression risk by flooding the body with carbon monoxide. This gas, produced naturally by the body, helps regulate a type of programmed cell death called apoptosis. Evidence suggests apoptosis might account for TB latency, but under high carbon monoxide exposure conditions, such

as those induced by cigarette smoking and indoor burning of biomass, apoptosis dramatically declines and that might allow TB-infected cells to survive and flourish (Schmidt, 2008).

Excessive alcohol use, meanwhile, appears to raise progression and infection risks alike, the former by impairing immune responses, and the latter by inviting risky social interactions that foster transmission of the disease. Smoking and drinking tend to go hand-in-hand, which makes it hard to separate the effect of one from the other. TB risk is elevated among people who consume more than 40 ml of alcohol per day (Schmidt, 2008). On a population basis, malnutrition ranks as the risk factor most commonly linked with TB, according Tsiouris *et al*. (2007), who states that a wealth of ecological associations link TB with malnutrition in populations affected by famine, war, natural disasters, poverty, mass migration, and confinement in prisons or ghettos. Studies from animal models focus on the role of micronutrients, such as proteins and vitamins. The results of such studies, according to Cegielski and McMurray (2004), suggest that protein deficiency in particular impedes both innate and vaccine-induced resistance to TB, although precisely how it does so remains unclear. Nutritional support of undernourished populations at high risk of TB may reduce the incidence of TB in such groups. Malnutrition may result in poor collagen and immune protein production, which in turn leads to problems with lung parenchyma (i.e., the integrity of the lung tissue itself) and also with the immune function. It could be something as simple as vitamin D deficiency. Vitamin D helps with macrophage function, and macrophages help to clear TB bacteria.

Adding to a link with nutrition is growing evidence that diabetes exacerbates TB risk. Jeon and Murray (2008) concluded that diabetes is associated with TB risk regardless of study design and population. An increase in high-fat/low-nutrition diets with a lack of exercise, the combination of diabetes and smoking will probably cause more TB worldwide in the next 2 to 3 years than any other factor (Schmidt, 2008).
Additional factors that can contribute to TB prevalence include ignorance, different social customs and taboos, negligent treatment of females and children in a community, and lack of education. Use of commercial sex workers is common practice and the incidence of sexually transmitted diseases (STDs) in these men is extremely high. HIV prevalence in TB and STD patients has been increasing rapidly during the last few years (Schmidt, 2008).

Bandera *et al*. (2001) also showed that HIV-infected patients were more prone to recurrences than people without HIV infection. Others at risk include people who inject drugs using unsanitary needles, medically under-served and low-income populations, children exposed to adults in high-risk categories, patients who are immuno-compromised by conditions such as HIV/AIDS, people who take immunosuppressant drugs, and healthcare workers serving these high-risk clients. Tuberculosis incidences in healthcare workers parallels (but is higher than) that in the community, according to Snashall and Patel (2003), which allows TB to remain an occupational hazard in the healthcare setting. It is imperative that healthcare workers are protected against infection.

Tuberculosis places an astonishing burden on the afflicted persons, their families, the communities and on mining budgets. The greatest burden of TB falls on productive adults who, once infected, are weakened and often unable to work. The burden of taking care of sick individuals usually falls on other family members and, in addition to putting them at greater risk of infection, can lower their productivity. Besides loss of productivity, the cost of treating TB can also be significant. Mean household spending on TB can account for as much as 8 to 20 percent of annual household income, varying by region (Laxminarayan *et al*., 2007). However, the most devastating impact of TB is death: without treatment, two-thirds of smear-positive cases die within five to eight years, with most dying within 18 months of being infected. Impact of adult mortality on economic growth places an especially high economic burden on societies. The loss of working-age adults represents the loss of human capital and has a deep effect on household economic stability. The effect of adult mortality is greatest on households that were relatively poor to begin with, in part because they are less able to cope with unanticipated shocks. Adult mortality has a deterrent effect on the acquisition of human capital. Individuals may be less willing to get a higher education or make investments that pay off in the longer term, especially those that cannot be transferred to future generations in the same way as financial investments, if there is a greater risk that they may not be around to enjoy the returns of that investment. Greater adult mortality implies a lower rate of return to human capital investment, which in turn is a determinant of economic growth (Laxminarayan *et al*., (2007).

2.7 The UVGI System and Ventilation for Tuberculosis Control

2.7.1 UVGI Systems

The platinum mine makes use of UVGI systems for TB control in areas where there is a high density of people, especially the TB Wards. UVGI systems are implemented to kill or inactivate airborne micro-organisms, including *M. tuberculosis*. Duct irradiation systems and upper room air irradiation systems are the two types of systems which are generally utilized. UVGI systems make use of low-pressure mercury vapour lamps that emit radiant energy at a wavelength of 254 nanometres (nm). In duct irradiation systems, one or more UV tubes are positioned within a duct to irradiate air that leaves a room or facility. In upper room air irradiation systems, UV lamps are suspended from a ceiling or mounted on a wall. The lamps are positioned so that the air in the upper portion of the room is irradiated. The intent is to minimize the levels of UV radiation in the lower part of the room where the occupants are located. Both these systems rely on the mixing of air so that the air from the lower portion of the room is moved to the upper portion of the room where it can be irradiated (Coker *et al*., 2001).

UV radiation also has adverse health effects. At 254 nm, it is absorbed by the outer surfaces of the eyes and skin. Photokeratitis, which is inflammation of the cornea, and conjunctivitis, which is inflammation of the conjunctiva, can develop due to overexposure to UV radiation. These injuries may not be recognized as occupational injuries because there is a latency period before the adverse health effects are noticed. Symptoms may include a feeling of sand in the eyes, tearing, and sensitivity to light. Overexposure of the skin to UVGI also can result in erythema (reddening). It is yet unknown if UVGI exposure for humans is carcinogenic (Talbot *et al*., 2002).

2.7.2 Ventilation

Ventilation controls the prevalence of *M. tuberculosis* particles in the air via dilution and removal processes. Clean air that enters an area dilutes the concentration of airborne particles, which means that there is less chance that a TB droplet nucleus is inhaled. This clean air is either fresh air from outside of the area, or air that has been re-circulated through a high efficiency particulate air (HEPA) filter. The removal process entails the clearance of air from a room, or its purification with a HEPA filter before re-circulation (CNTC, 2004). An effective engineering control for TB occurs when the ventilation rate, i.e. the amount of air that is removed per unit time, is increased. If the ventilation rate is doubled for example, it will halve the time needed

to clear a room of airborne contaminants. Ventilation also causes the mixing of infectious particles in an area with the clean air that enters it, and this mixing enhances the dilution and removal of air in an area. Also, mixing prevents stagnation (CNTC, 2004).

Ventilation is a far better tuberculosis control measure because not only is it far cheaper to implement, but the potential adverse health effects of adequate ventilation are virtually zero.

2.8 Bio-aerosol Measurement Techniques

2.8.1 NIOSH Method 0900

This is a qualitative method that permits the detection of airborne *M. tuberculosis* particles. The sample train consist of a Polytetrafluoroethylene (PTFE) filter (37mm, 1.0µm pore size) connected to a personal pump, and sampling is done at a 4 L/min flow rate, and the recommended sampling duration is 8 hours. This method is used for personal sampling and not for area sampling.
If it detects approximately 20 or more *M. tuberculosis* particles, it means that there is an effective amount of *M. tuberculosis* particles present. If it detects below this number, it means that there is effectively no TB present. Principally, this method does not indicate exactly how many particles were detected, i.e. it is not a quantitative method (NIOSH, 1998).

2.8.2 The Impingement into a Liquid Method

The SKC Bio-Sampler® impinger (20 ml, nr. 225-9595) was used in this study. This impinger is designed to operate by drawing aerosols through an inlet tube that is curved to simulate the nasal passages (Van der Heever and Stanton, 2007). The air is then passed through a jet into a liquid medium, in this case phosphate-buffered saline (PBS). PBS is a water-based salt solution that contains sodium chloride and sodium phosphate. The buffer helps to maintain a constant pH, and the osmolarity and ion concentrations of the solution are isotonic and non-toxic to cells. The thin film of water that binds to the bacilli prevents denaturation or other conformational changes (Biological World, 2010).

The jet is positioned 30 mm above the bottom of the impinger. Aerosol particles enter the impinger and flow through a 1 mm diameter nozzle. When filled with 20 ml liquid, the nozzle outlet is 10 mm above the resting liquid surface. The sampler outlet

is above the nozzle outlet, leaving a sharp turn in the airflow streamlines at the nozzle outlet just above the liquid surface. Particles with high inertia cannot follow sharp turns in streamlines and will impact and penetrate the liquid surface after exiting the nozzle (Van der Heever and Stanton *et al*., 2007).

The SKC Bio-Sampler® contains inside it a specific design feature that may overcome some of the sampling problems encountered while using impingers for bio-aerosol collection. In many commercial impingers, sampling liquid loss through evaporation and the re-aerosolisation of collected particles greatly reduce the collection efficiency and viability of particles. The liquid in the Bio-Sampler swirls upward on the sampler's inner wall and removes collected particles. This gentle swirling motion generates very few bubbles and thus minimizes re-aerosolisation of collected particles. The Bio-Sampler's design also reduces particle bounce- off on the inner wall and so helps to ensure bio-aerosol viability (Van der Heever and Stanton *et al*., 2007). The SKC Bio-Sampler® is mounted securely on a tripod at a height of 1.5 – 1.6 m above the floor to approximate the breathing zone of a worker. The SKC Bio-Sampler® is connected to a VAC-U-GO Sampler pump, and sampling of TB is done at a flow rate of 12.5 L/min.

2.9 References

Abdul H, Mousa L. (2007) Bones and Joints Tuberculosis. Bahrain Medical Bulletin; 29 (1).

Abid S, Jafri W, Hamid S, Khan H, Hussain A. (2003) Endoscopic Features of Esophageal Tuberculosis. Gastrointest Endosc; 57 759-62.

Acharya SK, Tandon BN. (2005) Abdominal Tuberculosis. In Watters D, Kiire C, editores. Gastroenterology in the Tropics and Subtropics: A Practical Approach. London and Basingstoke: Macmillan Education. p. 85-102. ISBN 033359343X.

Aids and Rights Alliance for South Africa (ARASA) (2008) The Mining Sector, Tuberculosis and Migrant Labour in Southern Africa. Available from: URL:http://www.arasa.info

Amarapurkur DN, Patel ND, Amarapurkur AD. (2003) Primary Gastric Tuberculosis--Report of 5 Cases. BMC Gastroenterology. 3 6.

Anglo American. (2010) Safety and Sustainable Development Report. Available from: URL:http://www.angloplatinum.com/safety/caring/health.asp

Atre V. (2007) Tuberculosis: Myths and Facts. Available from: URL:http://www.scribd.com/doc/35034/SG-KE-TOI-Tuberculosis-Myths-and-facts

Bandera A, Gori A, Catozzi L, Esposti AD, Marchetti G, Molteni C, *et al*. (2001) Molecular Epidemiology Study of Exogenous Re-infection in an Area with a Low Incidence of Tuberculosis. J Clin Microboil; 39 2213–2218.

Be NA, Kim KS, Bishai WR, Jain, SK. (2009) Pathogenesis of Central Nervous System Tuberculosis. Curr Mol Med; 9(2) 94-99.

Behr MA, Warren SA, Salamon H. (1999) Transmission of Mycobacterium Tuberculosis from Patients smear-negative for acid-fast Bacilli. Lancet; 353(9151) 444–449.

BiologicaL World. (2010) Using phosphate-buffered Saline (PBS) in Biochemical and Cell Biology Research. Available from: URL:http://biologicalworld.com/pbs.htm

California Tuberculosis Controllers Association (CTCA) (2006) Targeted Testing and Treatment of latent Tuberculosis Infection in Adults and Children. Available from: URL:http://www.ctca.org/guidelines/IIA2targetedskintesting.pdf

Cegielski JP, McMurray DN. (2004) The Relationship between Malnutrition and Tuberculosis: Evidence from Studies in Humans and experimental Animals. Int J Tubercul Lung Dis; 8(3) 286-98.

Chavahan GE, Ramakantan R. (2003) Duodenal Tuberculosis: Radiological Features on Barium Studies and their clinical Correlation in 28 Cases. J Postgrad Med; 49 214-7.

Chong VH, Lim KS. (2009) Gastrointestinal Tuberculosis. Singapore Med J; 50(6) 638-646.

Cohen T, Sommers B, Murray M. (2003) The Effect of Drug Resistance on the Fitness of Mycobacterium Tuberculosis. Lancet Infect Dis; 3(1) 13-21.

Coker I, Nardell E, Fourie B, Brickner P, Parsons S, Bhagwandin N, *et al*. (2001) Guidelines for the Utilisation of Ultraviolet Germicidal Irradiation (UVGI) Technology in controlling Transmission of Tuberculosis in Healthcare Facilities in South Africa. Available from: URL:http://www.sahealthinfo.org/tb/guidelines.pdf

Cole E, Cook C. (1998) Characterization of infectious Aerosols in Healthcare Facilities: an Aid to effective engineering Controls and preventive Strategies. Am. J. Infect. Control; 26(4) 453–464.

Corbett EL, Churchyard GJ, Clayton T, Herselman P, Williams B, Hayes R, Mulder D, De Cock KM (1999) Risk factors for pulmonary Mycobacterial Disease in South African Goldminers. Am J Respir Crit Care Med; 159 94–99.

Corbett EL, Watt CJ, Walker N, Maher D, Williams BG, Raviglione MC, Dye C. (2003) The Growing Burden of Tuberculosis: Global Trends and Interactions with the HIV Epidemic. Arch Intern Med; 163 1009-1021.

Corless IB, Nicholas PK, Davis SM. (2009) HIV and tuberculosis in Durban, South Africa: Adherence to two medication regimens. AIDS Care. 21(9) 1106-1113.

Curry National Tuberculosis Centre (CNTC.) (2004) What does ventilation have to do with TB Control? Available from: URL:http://www.nationaltbcenter.edu/abouttb/tbcontrol_faqs/6_what_does_ventilation.pdf

Dandapat MC, Mishra BM, Kar PK. (2005) Peripheral Lymph Node Tuberculosis: A Review of 80 Cases. Brit J Surg; 77(8) 911.

Demilew AZ. (2007) Challenges and Opportunities in Tuberculosis Control at Workplace: BRAC TB Control Program in Garment Factories, Dhaka, Bangladesh. BRAC University.

Donald PR, Schaaf HS, Schoeman JF. (2005) Tuberculous Meningitis and Miliary Tuberculosis: the Rich Focus revisited J Infect; 50 193-195.

Golden MP, Vikram HR. (2005) Extra-pulmonary Tuberculosis: an Overview. Am Fam Phys; 72(9) 1761-1768.

Hamer DH, Gorbach SL. (1998) Tuberculosis of the intestinal Tract. In Feldman M, Scharschmidt BF, editors. Sleisenger and Fordtrans's Gastrointestinal and Liver Disease. Pathophysiology/Diagnosis/Management. Philadelphia: WB Saunders. p. 1622-1624. ISBN: 0721692842.

Hnizdo E, Singh T, Churchyard GJ. (2000) Chronic Pulmonary Function Impairment caused by initial and recurrent Pulmonary Tuberculosis following Treatment. Thorax 2000; 55 32–38.

Houben E, Nguyen L, Pieters J. (2006) Interaction of pathogenic Mycobacteria with the host Immune System. Curr Opin Microbiol; 9(1) 76–85.

Iseman MD. (2000) A Clinician's Guide to Tuberculosis. Philadelphia: Lippincott, Williams and Wilkins. p. 162-70. ISBN: 0781717493.

Jeon CY, Murray MB. (2008) Diabetes Mellitus increases the Risk of active Tuberculosis: A systemic Review of 13 observational Studies. Plos Med. 5(7) 152.

Khan AN, Chandramohan M, MacDonald S. (2004) Tuberculosis of the Genitourinary System. Am J Roentgenol Radium Ther Nucl Med; 121 487-499.

Kleinschmidt I, Churchyard GJ. (1997) Variations of Incidences of Tuberculosis in Subgroups of South African Goldminers. Occup Environ Med; 54 636-641.

Kolappan C, Subramani R. (2008) Association between Biomass Fuel and Pulmonary Tuberculosis: a nested case-control Study. Thorax: Int J Respir Med; 64 705-708.

Kumar V, Abbas, AK, Fausto N, Mitchell RN. (2007) Robbins Basic Pathology. Saunders Elsevier. p. 516–522. ISBN: 0808923668.

Laxminarayan R, Klein E, Dye C, Floyd K, Darley S, Adeyi O. (2007) Economic Benefit of Tuberculosis Control. The World Bank Human Development Network Health Nutrition and Population Team. Policy Research Working Paper 4295.

Lönnroth K, Castro KG, Chakaya JM, Chauhan LS, Floyed K, Glaziou P, Raviglione MC. (2010) Tuberculosis Control and Elimination 2010-50: Cure, Care, and Social Development. Lancet; 375(9728) 1814-1829.

Makoto T, Masao T. (2000) Pulmonary Tuberculosis. Lymphatic Tuberculosis J Curr Therapy; 18(8) 1521-1524.

Marshall JB. (1993) Tuberculosis of the Gastrointestinal Tract and Peritoneum. Am J Gastroentero; 88 989-999.

Mastroianni CM, Paoletti F, Lichtner M, D'Agostino C, Vullo V, Delia S. (1997) Cerebrospinal Fluid Cytokines in Patients with Tuberculous Meningitis. Clin Immunol Immunopathol; 84(2) 171-176.

Mayo Clinic. (2009) Tuberculosis. Available from:
URL:http://www.mayoclinic.com/health/tuberculosis/DS00372

Meghji S, White PA, Nair SP. (1997) Mycobacterium Tuberculosis Chaperonin 10 stimulates Bone Resorption: a potential contributory Factor in Pott's Disease. J Experiment Med; 186 1241-1246.

Mukewar S, Mukewar S, Dua KS. (2007) Tuberculosis of the Colon: endoscopic Features with prospective follow-up after anti-tuberculosis Treatment. Gastrointest. Endoscopy; 65 AB253.

National Institute for Occupational Safety and Health (NIOSH). Analytical Method No. 0900 Mycobacterium tuberculosis, airborne (1998). NIOSH, USA. Available from: http://www.cdc.gov/niosh/docs/2003-154/pdfs/0900.pdf

Nicas M, Nazaroff WW, Hubbard A. (2005) Toward understanding the Risk of secondary airborne Infection: Emission of respirable Pathogens. J Occup Environ Hyg; 2(3) 143-154.

Onyebujoh P, Rook GAW. (2004) Focus: Tuberculosis. Available from: URL:http://www.who.int/tdrold/dw/tb2004.htm

Prescott LM, Harley JP, Klein DA. (2005) Microbiology. McGraw Hill. USA. p. 992. ISBN: 0072992913.

Rajasekaran S, Shanmugasundaram TK, Parahakar R. (1998) Tuberculous Lesions of the lumbosacral Region. A 15-year follow-up Patient treated by ambulant Chemotherapy. Spine J; 23 1163-1167.

Rich AR, McCordock, H. (1933) The Pathogenesis of Tuberculosis Meningitis. Bulletins of the Johns Hopkins Hospital; 52 5-37.

Rowe D. (2003) Occupational Hygiene Practices in the South African Mining Industry – Inspectorate Perspective. 30th International Conference of Safety in Mines Research Institutes, South African Institute of Mining and Metallurgy.

Schmidt CW. (2008) Linking TB and the Environment. Environ Health Perspect; 116(11) 479–485.

Shanley DJ. (1995) Tuberculosis of the Spine: imaging Features. Am J Respir; 164 659-664.

Sharma MP, Bhatia V. (2004) Abdominal Tuberculosis. Indian J Med; 120 305-315.

Snashall D, Patel D. (2003) ABC of Occupational and Environmental Medicine. London. BMJ Publishing Group. p. 133. ISBN: 0585493391.

Van der Heever DJ, Stanton DW. (2007) Bioaerosols. In Stanton, DW, Kielblock J, Schoeman JJ, Johnston JR, editors. Handbook on Mine Occupational Hygiene Measurements. South Africa. The Mine Health and Safety Council (MHSC). p. 123-134. ISBN: 9781919853246

Talbot EA, Jensen P, Moffat JH, Wells CD. (2002) Occupational Risk from Ultraviolet Germicidal Irradiation (UVGI) Lamps. Int J Tubercul Lung Dis; 6(8) 738–741.

The World Economic Forum (TWEF). (2002) TB Management in the Workplace: an Introduction for African Business. World Health Organization. Available from: URL:https://members.weforum.org/pdf/Initiatives/GHI_Guidelines_WHO_TB_Africa.pdf

Tremblay GA, (2007) Historical Statistics Support a Hypothesis linking Tuberculosis and Air Pollution caused by Coal. Int J Tubercul Lung Dysfunc; 11(7) 722–732.

Tsiouris SJ, Gandhi NR, El-sadr WM, Friedland G. (2007) Tuberculosis and HIV: A new Paradigm for the Control and Management of linking Epidemics. Gen Med; 9(3) 62.

Van Soolingen D, Hoogenboezem T, De Haas PE. (1997) A Novel Pathogenic Taxon of the Mycobacterium Tuberculosis Complex, Canetti: characterization of an exceptional isolate from Africa. Int J Syst Bacteriol; 47(4) 1236–1245.

World Health Organization (WHO). A 2009. Global Tuberculosis Report: Country Profile South Africa. Available from: URL:http://apps.who.int/globalatlas/predefinedReports/TB/PDF_Files/zaf.pdf

World Health Organization (WHO). B 2009. WHO Report 2009 – Global Tuberculosis Control. Available from: URL:http://www.who.int/tb/publications/global_report/2009/key_points/en/index.html

Wright T, Sundaram M, McDonald D. (1996) Radiologic Case Study: Tuberculous Osteomyelitis and Arthritis. Orthopaedics; 19 699-702.

Wu HS, Kolonoski P, Chang YY, Bermudez LE. (2000) Invasion of the Brain and chronic Central Nervous System Infection after systemic Mycobacterium avium complex Infection in Mice. Am J Microbiol Immunol Infect; 68 2979-2984.

Yeomans ND, Lambert JR. (1994) Infections of the Stomach and Duodenum. In: Haubrich WS, Schaffner F, Berk JE, editors. Bockus Gastroenterology. Philadelphia. WB Saunders. p. 805-815. ISBN: 0721637256.

Zink A, Sola C, Reischl U, Grabner W, Rastogi N, Wolf H, Nerlich A. (2003) Characterization of Mycobacterium Tuberculosis Complex DNA's from Egyptian Mummies by Spoligotyping J Clin Microbiol; 41(1) 359–367.

CHAPTER 3

ARTICLE

This article will be submitted to the Annals of Occupational Hygiene. The author's instructions are as follows:

- *Conflict of interest.* The source of financial support for the work must be stated in the acknowledgements, unless it is clear from the author's affiliations. Other conflicts of interest must be declared to the Editor at the time of submission. These may include financial interest in products described, including stock- or share ownership, and payment for consultancy or legal testimony using the material in the paper. These conflicts will not necessarily prevent publication, but the Editor may decide that the declaration should be included in the paper.

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  Simpson AT, Groves JA, Unwin J, Piney M. (2000) Mineral Oil Metal Working Fluids (MWFs)—Development of practical Criteria for Mist Sampling. Ann Occup Hyg; 44 165–72.

  Vincent JH. (1989) Aerosol Sampling: Science and Practice. Chichester, UK: John Wiley. ISBN 0 471 92175 0.

  Swift DL, Cheng Y-S, Su Y-F, Yeh H-C. (1994) Ultrafine Aerosol Deposition in the Human Nasal and Oral Passages. In Dodgson J, McCallum RI, editors. Inhaled Particles VII. Oxford: Elsevier Science. p. 77–81. ISBN 0 08 040841 9 H.

  British Standards Institution. (1986). BS 6691: 1986. Fumes from Welding and allied Processes. Part 1. Guide to Methods for the Sampling and Analysis of Particulate Matter. London: British Standards Institution.

The Environmental Monitoring and Quantification of M. tuberculosis Occupational Exposure Risk in various Occupational Settings in a Platinum Mine.

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Word count: 7444
The aim of this study comprises four different elements of study. The high word count is due to the results and discussion of these four elements.

Abstract

Tuberculosis is a disease that has a detrimental effect on the economic growth of South Africa. The country's TB mortality rate is amongst the highest in the world, and the worst affected industry is mining. Effective environmental controls of tuberculosis in mining areas remain a challenge, mainly because there is a lack of quantitative data to guide the implementation of these controls. No occupational exposure limits exist for bio-aerosols, particularly *Mycobacterium tuberculosis*. This makes it difficult to distinguish between high- and low risk areas. It is believed that a single inhaled *M. tuberculosis* particle can cause the tuberculosis disease, and as this disease can deteriorate all major systems of the body, great care should be taken in the classification of an area.
Aim: This study aimed to quantify the environmental presence of the *M. tuberculosis* bacilli in various occupational settings of a platinum mine. **Method:** The monitored areas are all structures above ground, and include high TB risk areas, such as the hospital TB Ward, and low TB risk areas, such as an office area. Personal monitoring of the staff in high TB risk areas has also been conducted. Monitoring was done via the PTFE filter sampling method and the SKC Bio-Sampler® impinger method. The results of these two methods were compared to determine which method is more effective.
The environmental variables, such as carbon dioxide and –monoxide levels, temperature (both ambient and wet- bulb), and relative humidity, were also monitored in order to identify any possible correlations between these variables and the levels of ambient TB particles. The effectiveness of the Ultraviolet Germicidal Irradiation

(UVGI) system, which is in place in some of the monitored areas, was also indirectly assessed, i.e. to see if there are any *M. tuberculosis* particles present in an area that makes use of an UVGI system. The PCR analytical method was used to quantify the number of *M. tuberculosis* bacilli sampled, and the results were statistically analysed.

Results: *M. tuberculosis* was found to be present in the office area, the laundry room, the hospital's waiting area, the training facility, the dining room, and the mobile clinic. No *M. tuberculosis* particles were found in the hospital's TB Ward and the change houses of the mine. The results showed that the PTFE filter method had a greater efficiency than the SKC Bio- Sampler® in monitoring environmental *M. tuberculosis* particles, as the PTFE filter method yielded positive samples where the SKC Bio-Sampler® did not. There is a practical significant difference between the two methods.

No viable correlations between the environmental variables and *M. tuberculosis* prevalence were established due to the low number of samples taken.

Conclusion: It seems that the effectiveness of a UVGI system is dependent on the number of people crowded into that specific area and the ventilation thereof. A UVGI system is only a precautionary measure and not a solution.

There are too many factors that still need better understanding before the risk of contracting environmental TB in high risk areas of a mine can be determined. The high risk areas seem to be occupational settings that have poor ventilation, but accommodate a large number of people. The highest risk of TB infection remains close contact with infected individuals, as the results of the employee monitoring testified.

Key Words:

tuberculosis, transmission, environment, mine setting, overcrowding, ventilation, multi-drug resistant tuberculosis.

Introduction

South Africa has one of the highest tuberculosis incidence rates in the world (WHO, 2009). Tuberculosis death rates are estimated to be 139 per 100 000. The country also harbours the largest number of co-infected adults, which is roughly 2 million. Transmission of *M. tuberculosis* occurs when infected individuals, who suffer from active (not latent/dormant) pulmonary TB, cough, sneeze, spit, shout or expel infectious aerosol droplets into the environment (Prescott *et al*., 2005). These droplet nuclei are small particles, 0.5 - 5 µm in diameter, that result from the evaporation of larger particles called droplets. Droplet nuclei can remain airborne for hours or days

and travel long distances Cole and Cook (1998), and every single droplet, according to Nicas *et al*. (2005) and Behr *et al*. (1999), is capable of transmitting the disease, because TB has a very low infectious dose. Inhaling less than 10 bacteria may cause tuberculosis, but many believe that inhaling of even a single *M. tuberculosis* bacterium can cause the disease. The number of infectious droplets expelled by a carrier (which could be up to 40 000), the effectiveness of ventilation, the duration of exposure, and the virulence of the *M. tuberculosis* strain do however play a role in determining the probability of transmission from one person to the next. That is why isolation of persons with the active disease is so vital. If someone does become infected, it will take at least 21 days, or 3 to 4 weeks, before the newly- infected person can transmit the disease to others (Mayo Clinic, 2009).

Once a tuberculin-free person acquires an infected droplet nucleus, the bacilli will multiply for 4 to 6 weeks. However, there is a proposed incubation period of about 4 to 12 weeks (Prescott *et al*., 2005). TB infection begins once the bacterium reaches the pulmonary alveoli (Kumar *et al.*, 2007). A hypersensitivity response then ensues and the formation of small, hard nodules called tubercules result. These are characteristic of tuberculosis and give the disease its name (Houben *et al.*, 2006). About 90% of infected people have asymptomatic latent TB, with only a 10% lifetime chance that this latent infection will progress to the tuberculosis disease. If it remains untreated however, the death rate for these active TB cases is more than 50%. Progression from infection to disease occurs when the TB bacilli overcome the immune system and begin to multiply. This secondary reactivation, which usually crops up in the lungs, occurs in 85 – 90% of cases, but only 1 – 5% of cases are affected by this reactivation soon after infection. These dormant bacilli can produce tuberculosis in 2–23% of these latent cases, often many years after infection occurred (Onyebujoh and Rook, 2004). Miliary tuberculosis is also more prominent in immune-suppressed persons and young children (Onyebujoh and Rook, 2004).

Active tuberculosis can occur from endogenous reactivation or exogenous re-infection in people who had a previous TB infection, according to Bandera *et al*. (2001). They found evidence that exogenous re-infection can have a dominant role in the pathogenesis of post-primary tuberculosis in an area with a high incidence of the disease. A different scenario could be evoked for a population with a low risk of infection, where the likelihood of pre-exposure is small and thus most cases of recurrence probably result from relapse phenomena such as the emergence of human immunodeficiency virus (HIV). Individuals living and working in high TB

transmission settings have a particularly high risk of carrying latent TB, as is the case with South African miners. The prevalence of TB influences the extent to which exogenous re-infection occurs: the higher the prevalence, the greater the likelihood of exogenous re-infection. A study done by Bandera *et al*. (2001) confirmed that re-infection in areas with a low incidence of tuberculosis is possible, although less common than in high-incidence geographical regions. This indicates that the major risks of tuberculosis re-infection are represented by a high prevalence of *M. tuberculosis*. Cohesiveness within ethnic communities, overcrowding, poor hygienic conditions, and unventilated housing structures, which are all too common in the mine setting, allow for an elevated frequency of close contact, with a consequently high circulation of *M. tuberculosis* strains that could explain the increased risk of re-infection.

TB rates in the mines are up to 10 times that of the general population. Control of TB in the mining sector is therefore of tremendous significance and importance to national TB control (ARASA, 2008). Poor socio-economic conditions, lack of awareness, suffocating heat, dust, noise, and work time tensions due to supervisor/employee relationships and production pressures are the main additional factors in the mine setting that lead to the causes of different forms of health problems (Schmidt, 2008). The unique contribution of crowding in establishing TB risk is hard to quantify, according to Lönnroth *et al*. (2010). Crowding is an everyday occurrence in various areas of a mine, especially in change houses before and after a shift, dining rooms during lunchtimes, and the waiting areas of hospitals early in the morning, where the crowds can grow to staggering numbers. Necessity for space then causes the mineworkers to spend a fair amount of time in close proximity to each other. This crowding does not only enhance the inter-personal transmission of TB, but also adds to the environmental prevalence of TB particles in such an area, especially if the ventilation is inadequate. Such areas were, among others, the focus of this study. Mechanical ventilation control in the form of ceiling fans are employed in some areas, but most rely predominantly on natural ventilation for fresh air.

Other contaminants in the air, such as cigarette smoke and open fires or traditional stoves that are fuelled by coal or biomass (wood, animal dung, crop residues, or charcoal), especially if done indoors in poorly ventilated spaces, can greatly exacerbate TB (Schmidt, 2008). The reason for this may be due to chemical constituents, such as carbon monoxide, that impair the ability of lung cilia to clear bacteria from the respiratory tract (WHO, 2009).

Tuberculosis incidences in healthcare workers parallels (but is higher than) those in the community, according to Snashall and Patel (2003), which allows TB to remain an occupational hazard in the healthcare setting. It is imperative that healthcare workers are protected against infection.

Individuals with the TB disease start to manifest the common symptoms which include fever, fatigue, loss of appetite and weight loss. A prolonged common cough lasting for at least 3 weeks with a progressive increase in production of mucus and coughing up blood is the classic symptom of tuberculosis infection. Other symptoms include night sweats, chest pains and often a tendency to fatigue very easily (Prescott *et al*., 2005).

The destructive action of *M. tuberculosis* on the lungs, and the manifestation of the symptoms, have a detrimental effect on the worker's ability to perform various tasks, especially physically demanding jobs, which are required from the general workers in a mine. A worker who suffers from TB, according to TWEF (2002), causes a disruption in workflow and reduces productivity not only because of his high fatigued state, but also in the form of weeks or months of absenteeism. The direct cost of treatment is also a strong possible consequence. Obviously, the higher the number of infected workforce members, the higher the financial loss will be, especially for a mine. Laxminarayan *et al*. (2007) agrees that the loss of productivity and the cost of treating TB can be significant, but the most devastating impact of TB is, however, death: without treatment two-thirds of smear-positive cases die within five to eight years, with most dying within 18 months of being infected. Impact of adult mortality on economic growth places an especially high economic burden on mines. The loss of working-age adults represents the loss of human capital and has a deep effect on economic stability. Greater adult mortality implies a lower rate of returns on human capital investment, which in turn is a determinant of economic growth (Laxminarayan *et al*., (2007).

Recently, new multi-drug-resistant strains of tuberculosis (MDR-TB) have developed and are spreading. Multi-drug-resistant strain is defined as *M. tuberculosis* that is resistant to the treatment drugs isoniazid and rifampin, with or without resistance to other drugs. This has resulted in many cases of marginally treatable, often fatal, disease. MDR-TB now accounts for 1 of every 20 new cases, making the global TB epidemic a far more urgent problem (Prescott *et al*. 2005).

According to the platinum mine's Safety and Sustainable Development Report (2009), only one case of extremely resistant TB emerged in 2008 and one other case in 2007. The platinum mine actively screens for TB and provides comprehensive treatment to infected employees. During 2008, 734 (520 in 2007 and 891 in 2006) employees with new TB infection were treated. There were 91 deaths from TB, of which 81 were HIV-related (7 in 2007, of which 6 were positive for HIV; and 65 in 2006, when 72% of cases were positive for HIV). The rate of new TB cases increased with 1.2% between 2007 and 2008.

Various control measures exist to stem the devastating effect of tuberculosis. These include adequate ventilation and UVGI systems. The platinum mine makes use of UVGI systems for TB control in areas where there is a high density of people, especially the TB Wards. UVGI systems are employed to kill or inactivate airborne micro- organisms, including *M. tuberculosis*, but the effectiveness of a UVGI system is still a controversial debate. Tuberculosis measurement techniques are also vital to identify the potential threat of the M. tuberculosis bacilli.

This study therefore aims to qualitatively detect *M. tuberculosis* particles in the high risk workplaces in the mine setting, and in so doing, compare the two different measurement methods for airborne *M. tuberculosis*, i.e. NIOSH Method 0900 and the SKC Bio-Sampler®, as well as evaluate the effectiveness of the UVGI system. Environmental parameters are also assessed to determine if any potential relationship exists between airborne levels of *M. tuberculosis* and indoor air conditions.

Methodology

The NIOSH 0900 method and the impingement into a liquid method were the two sampling methods used in this study.

NIOSH Analytical Method No. 0900: *Mycobacterium tuberculosis*, airborne (1998).

Polytetrafluoroethylene (PTFE) filters (37mm, 1.0µm pore size) were enclosed in a cassette and connected to a Gillian 5000 personal pump. The PTFE filter sample train consisted of a filter cassette, flexible tubing and the Gillian 5000 sampling pump. Area- and personal sampling was done at a 4 L/min flow rate. The sampling was

scheduled for a 4 hour time period (area sampling) and an 8 hour time period (personal sampling). The pump was calibrated with a bubble flow meter and representative filter cassette train in line, before and after each sampling period. In the case of area sampling, the sampling train was mounted in an area according to the same specifications as the Bio-Sampler train (discussed below), then closed-face sampling at a flow rate of 4 L/min was carried out. The cassette plugs were reinserted after sampling, and each filter cassette was marked and stored in a fridge (temperature at -4 ºC).

The Impingement into a Liquid Method

The SKC Bio-Sampler® and the PTFE Filter train (with regards to area sampling) were mounted securely on a tripod at a height of 1.5 – 1.6 m above the floor to approximate the breathing zone of a worker. The SKC Bio-Sampler® was connected to a Liquid Trap (at its outlet) and from there to a VAC-U-GO Sampler pump, which was also calibrated a bubble flow meter, and area sampling of TB commenced at 12.5 L/min. The Liquid Trap prevents any liquid from the Bio-Sampler from reaching the sampling pump. Phosphate buffered saline (PBS) was the collection liquid used in the SKC Bio-Sampler®. The SKC Bio-Sampler® was cleaned after each sample period as follows: It was dissembled into its three separate components and washed in a distilled water/peracitic acid solution (10 mg peracitic acid per 250 ml distilled water). The components were then soaked in a 5% diluted Jik solution (active component in Jik is sodium hypochlorite), and then rinsed in clean distilled water, due to the corrosiveness of the disinfectant agents. Afterwards, they were wrapped in tissue paper and safely stored. No significant variation in the airflow rates of bothe methods were observed before or after the sampling periods

Alteration of Methods

Only one variation from the standard application of both methods has been incorporated in this study, and that is the time duration of the active area samples. Both methods had originally been developed for active personal sampling, and not for environmental (area) sampling, and therefore the recommendation is that an 8 hour sample time period is necessary. In this study the sample period has been halved to 4 hours for all active area sampling. The reason for this is twofold; firstly, none of the personnel at risk of contracting TB from the monitored workplaces remained in the area for the entire duration of the workday. Secondly, it is believed that a person whom is exposed to a tuberculosis environment for 4 hours has the exact same chance of contracting the disease as a person whom is exposed for eight

hours in the same environment. No deviation from the methods occurred for the active personal sampling process.

Preparation

Preparation of the filters, the impinger liquid, and the various cleaning agents for the instruments was done at the Microbiology Laboratory of the South African Institute for Occupational Health. Each PTFE filter was assembled with cellulose support pad in a plastic, three-piece filter cassette in a sterile environment wearing disposable powder-free gloves. The support pad and PTFE filter were inserted, with a forceps, into the lower section of the cassette. The middle and top cassette sections were then attached and the plugs inserted. A shrinkable sealing band was then placed around the cassette and air-dried. The filter cassettes were then placed into a sample bag for transport. All the necessary PPE, which included a N95 face mask and latex gloves, were worn during preparation of the filter cassettes. The impinger liquid (PBS) and the distilled water used for cleaning the Bio-Sampler device were autoclaved at 121℃ for 20 min for sterilization. Peracitic acid, used for cleaning the Bio-sampler after each sample, was also collected at the laboratory.

Workplaces and Workers measured

A combination of stationary area sampling and personal exposure sampling was done in this study. The floor plans of the rooms are detailed in Appendix A.

1) The Laundry Room

Ten active area samples were taken: 5 using the PTFE train and 5 using the Bio-Sampler, and 5 active personal samples using the PTFE sampling train, were taken of the laundry personnel. Active area sampling was done during the morning, when the laundry personnel spent the most time in the room.

2) The Hospital TB Ward

Ten active area samples were taken: 5 using the PTFE train and 5 using the Bio-Sampler, and 10 personal samples using the PTFE sampling train were taken: 5 nurses and 5 cleaning staff. Active area sampling was done during the afternoon, when the patients and staff spent the most time in the room. One PTFE and 1 bio-sample were taken in each of the following areas of the TB Ward: Room 2 (where patients are tested for TB), Room 4 (which housed patients with active pulmonary TB), Rooms 5 and 6 (MDR-TB patients), and the reception area of the ward.

3) The Hospital Waiting Area

Six Active area samples were taken: 3 using the PTFE train and 3 using the Bio-Sampler. Area sampling was done during the morning when the area was most crowded.

4) The Adult Basic Education and Training Centre

Four active area samples were taken: 2 using the PTFE train and 2 using the Bio-Sampler. One PTFE and one bio-sample each were taken for rooms 15 and 16, the rooms which accommodate the most students. The active area sampling was done during the morning when the teaching commenced and the classes were filled with students.

5) The Change House at a Mine Shaft

Three PTFE samples were taken in the morning after a shift.

6) The Dining Room at Employee Accommodation Area

Three PTFE samples were taken over the lunch period.

7) The Mobile Clinic

Two PTFE samples were taken inside the mobile clinic when out in the field (in the mornings).

8) The Shared Services Unit Offices (Controls)

Two PTFE and 2 Bio-Sampler samples were taken at the ASSU offices in their reception area. This area was considered a low exposure area.

The active area samples therefore, were 27 PTFE filter samples and 19 Bio-Samples. The number of personal samples taken was 15 PTFE filter samples. This brings the total number of samples taken in this study to 61.

A questionnaire was also used to give guidance in identifying individuals who meet OSHA's (1997) definition of "suspected infectious tuberculosis" so that appropriate controls could be initiated. The questionnaire had two parts: (1) reviewing the individual's TB history and (2) assessing current symptoms. All the workers who were used in this study completed the questionnaire. A sample of the questionnaire is included in Appendix B.

Indoor air quality measurements were also done as part of the survey in order to expand on the relationship between temperature, humidity, air ventilation (in m/s) and airborne TB, which was then statistically correlated with the amount of *M. tuberculosis* particles found. A TSI IAQ-CALC indoor air quality meter was used to determine the above- mentioned variables during each sample period in the various areas. Three reading measurements of 5 minutes each were taken during the area sampling times; 1 at the onset of the sampling, 1 after 2 hours and 1 at the concluding sampling time. The means of the obtained data, i.e. each of the different variables, were calculated and used in the results.

After the completion of each sample, the impingement liquid of the Bio-Sampler was poured into a plastic vial and stored, along with the PTFE filter cassette, in a fridge at -4℃. The samples were transported in a cooler bag .

Analysis of Results

The analysis of the samples was done in the National Institute of Occupational Health by trained technicians. Polymerase Chain Reaction (PCR)/ Microplate Reader, with *M. tuberculosis* as analyte, were used as the measurement technique. PCR permits the detection of target nucleic acid sequences of DNA, thereby eliminating the requirement for growth to detect and identify the *M. tuberculosis* organisms. The specificity, sensitivity, and reduced processing time of this technique are suitable for applications in aerobiological monitoring for the detection of small numbers of targeted micro-organisms.

Statistical Significance

Statistica 8 was incorporated to demonstrate the comparison between the two sampling methods' effectiveness, and any correlation between the various environmental factors and possible TB exposure in the various areas of this study.
The following statistical measures are reported:

- Descriptive statistics (e.g. means and standard deviations).
- Paired t-tests with p-values to indicate statistical significant differences and corresponding effect sizes (Cohen's d-values) to indicate practical significant differences.
- The Spearman's rank order correlation coefficient, and
- Graphical representations

Results

The Comparison between the PTFE Filter Method and the Impinger Method

Table 1: The DNA copies of *M. tuberculosis* bacilli per cubic meter as sampled per area by the impinger and PTFE filter method

Sample Area	Impinger Method	PTFE filter Method
	TB DNA copies/m^3	TB DNA copies/m^3
ASSU Offices		
Reception area	0	1377
Store room	0	0
TB Ward		
Room 2	0	0
Room 4	0	0
Room 5	0	0
Room 6	0	0
Reception area	0	0
Laundry Room		
Sample 1	416	3650
Sample 2	0	0
Sample 3	0	0
Sample 4	0	0
Sample 5	0	516
Hospital Waiting Area		
Sample 1	0	0
Sample 2	0	0
Sample 3	0	509
ABET Training Facility		
Room 15 (Sample 1)	0	452
Room 15 (Sample 2)	0	1027
Room 16 (Sample 1)	0	0
Room 16 (Sample 2)	0	0

The impinger method yielded only one positive result for tuberculosis: the laundry room (sample1). The rest of the impinger samples yielded not a single *M. tuberculosis* entity. The PTFE filter method found traces of tuberculosis in all areas, except in the TB Ward. No traces of *M. tuberculosis* were found in the TB ward by either method.

Table 2: The statistical results of the areas monitored by the PTFE filter method and the impinger methods

Unit: TB DNA copies/m^3

Area	Method	n	Mean	Std Dev	p	Effect size (d)
ASSU Area	Impinger	2	0.00	0.00	-	-
	PTFE	2	688.50	973.69	0.50	-0.71
TB Ward	Impinger	5	0.00	0.00	-	-
	PTFE	5	0.00	0.00	-	-
Laundry Room	Impinger	5	26.60	59.48	-	-
	PTFE	5	833.20	1590.41	0.30	-0.51
Hospital Waiting Area	Impinger	3	0.00	0.00	-	-
	PTFE	3	169.67	293.87	0.42	-0.58
ABET Training Area	Impinger	4	0.00	0.00	-	-
	PTFE	4	369.75	487.23	0.23	-0.76
All 5 Areas	Impinger	19	7.00	30.51	-	-
	PTFE	19	396.37	882.48	0.06	-0.44

Table 2 displays the statistical T-test results for the TB sampled in the areas where both the impinger method and PTFE filter method were used. The results portrayed here illustrate the comparison between these two methods per area, and the overall combination of all 5 areas. Included are the statistical means and standard deviations. The p value and the effect size (Cohen's d value) are the two values of focus. The negative sign (-) shows the direction of the difference.

The effect size has a scale that is ranked as follows (Ellis and Steyn, 2003):

If d = 0.2 there is a small effect and there is no practical significant difference.

If d = 0.5 there is a medium effect and therefore a practical visible difference.

If d = 0.8 there is a large effect and therefore a practical significance.

Practical significant difference is a difference that is large enough to have an effect in practice.

There was a practical significant difference between the two sampling methods in the ASSU area and the ABET Training Area, indicated by medium to large effect sizes. In the laundry room and Hospital waiting area there was a medium effect and therefore a practical visible difference between the two sampling methods. In the TB Ward both methods measured no TB DNA copies per cubic meter. No p-value and d-value could be calculated.

The combination of the 5 areas yielded a p-value that equals 0.06, which is not smaller than 0.05 and therefore not an indication of a statistical significant difference (although it leans towards it), and a d-value that equals (-) 0.44, which is an indication of a medium effect, and therefore an overall practical visible difference between the two methods.

Figure 1 and 2 below are Box Plot graphs that displays the basic statistical measures of the two sampling methods for the five areas. Both methods monitored an 'extreme' amount of TB in the laundry room (see also Table 1).

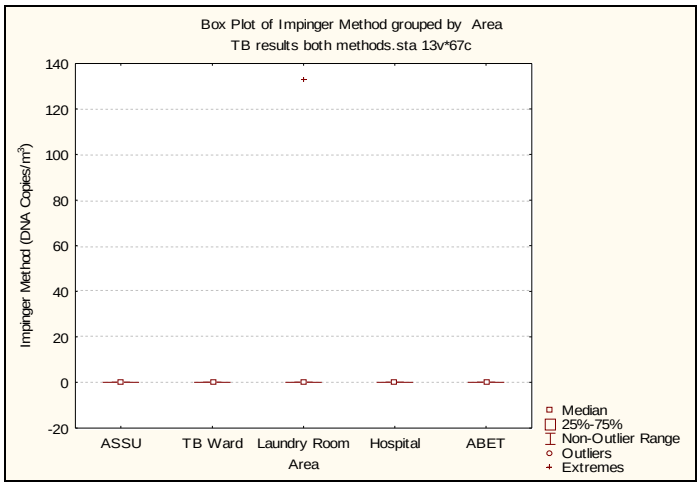


Figure 1: The Box Plot of the Impinger method (TB DNA copies/m^3) grouped by area

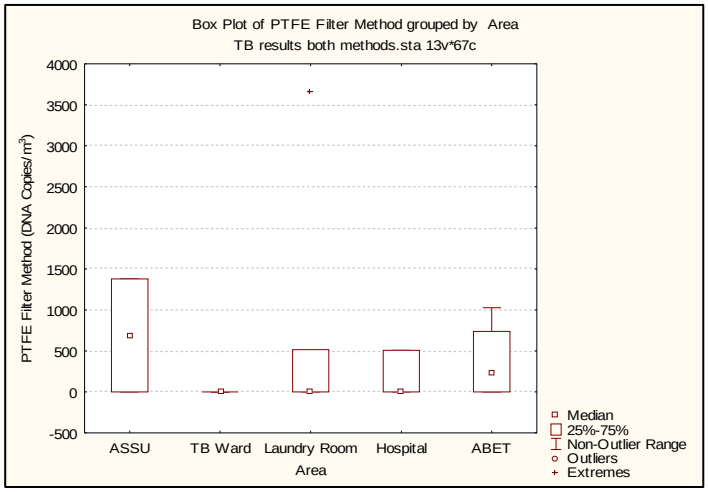


Figure 2: The Box Plot of the PTFE filter (TB DNA copies/m^3) method grouped by area

Areas measured exclusively with the PTFE Filter Method

Table 3: The DNA copies of *M. tuberculosis* bacilli per cubic meter as sampled per area exclusively with the PTFE filter method

Sample Area	PTFE Filter Method
	TB DNA copies/m^3
Change Houses	
Sample 1	0
Sample 2	0
Sample 3	0
Mobile Clinic	
Sample 1	0
Sample 2	3.42×10^{14}
Dining Room	
Sample 1	704
Sample 2	5788
Sample 3	0

The PTFE filter method yielded no positive results for tuberculosis in the change houses. In the mobile clinic it measured an exceptionally high number of TB DNA copies per cubic meter, although another measurement yielded nothing. There were two positive results for tuberculosis in the dining room.

The Environmental Variables

Table 4: The statistical results of the areas monitored by the PTFE filter and the environmental variables measured in each area

Variables	Area															
	ASSU		TB Ward		Laundry Room		Hospital waiting area		ABET Training Centre		Change Houses		Dining Room		Mobile Clinic	
	n	Mean (Std Dev)	n	Mean (Std Dev)	n	Mean (Std Dev)	n	Mean (Std Dev)	n	Mean (Std Dev)	n	Mean (Std Dev)	n	Mean (Std Dev)	n	Mean (Std Dev)
PTFE Method (TB DNA copies/m^3)	2	688.50 (973.69)	5	-	5	833.20 (1590.41)	3	169.67 (293.87)	4	369.75 (487.23)	3	-	3	2164.00 (3158.15)	2	$1.71x10^{14}$ ($2.42x10^{14}$)
CO_2 (ppm)	2	888.50 (9.19)	5	458.00 (36.08)	5	533.40 (97.36)	3	626.33 (119.22)	4	2947.25 (880.96)	3	583.33 (9.07)	3	546.67 (20.55)	2	501.00 (19.80)
CO (ppm)	2	1.25 (1.06)	5	0.26 (0.29)	5	0.20 (0.39)	3	0.17 (0.29)	4	0.33 (0.47)	3	-	3	-	2	0.15 (0.21)
Ambient Temp (℃)	2	23.10 (0.71)	5	26.32 (1.41)	5	25.86 (1.11)	3	26.37 (0.76)	4	29.23 (2.85)	3	28.13 (0.67)	3	24.37 (5.61)	2	23.60 (1.41)
Wet bulb Temp (℃)	2	13.70 (1.98)	5	17.36 (0.46)	5	18.04 (0.77)	3	18.43 (0.80)	4	22.10 (4.14)	3	18.73 (0.91)	3	18.70 (2.88)	2	17.40 (0.99)
RH (%)	2	37.35 (13.79)	5	43.50 (3.41)	5	49.28 (7.01)	3	48.07 (1.50)	4	56.15 (11.80)	3	40.90 (5.07)	3	55.73 (16.64)	2	58.75 (2.19)

Table 4 displays the means and standard deviations of the amount of *M. tuberculosis* particles measured with the PTFE filter method in the monitored areas, along with the data of the five environmental factors, i.e. CO_2, CO, temperature (both ambient and wet bulb), and the relative humidity per area monitored. The impinger method was excluded from this table because the data it yielded zero values for all measurements, except for one sample in the laundry room where a measurement of 416 TB DNA copies/m^3 was obtained.

Box Plot Graphs depicting each Environmental Variable against the Area monitored

Figures 3 - 7 below are Box Plot graphs that display basic statistical measures of the environmental variables for all the monitored areas.

The ABET training rooms have the highest CO_2 levels, as well as the highest temperatures, both ambient and wet bulb. The ASSU office area has the highest CO levels and the lowest wet bulb temperature readings. The dining room has the highest fluctuation in ambient temperature, and the highest relative humidity reading, although the median is below that of the ABET training rooms.

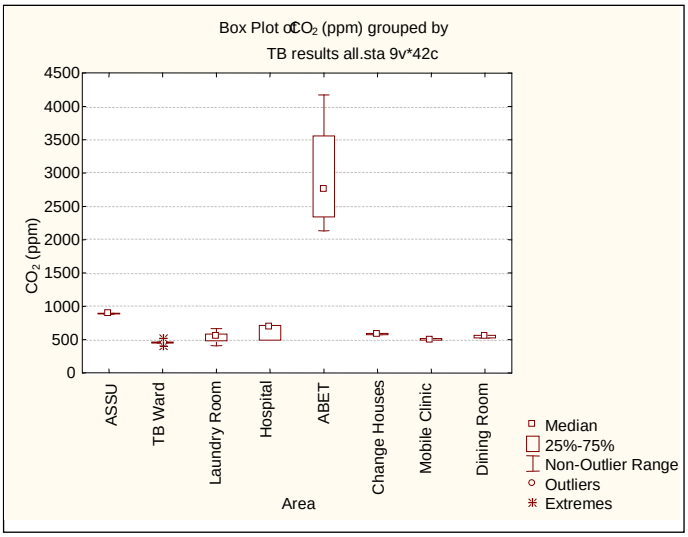


Figure 3: The Box Plot of CO_2 grouped by area

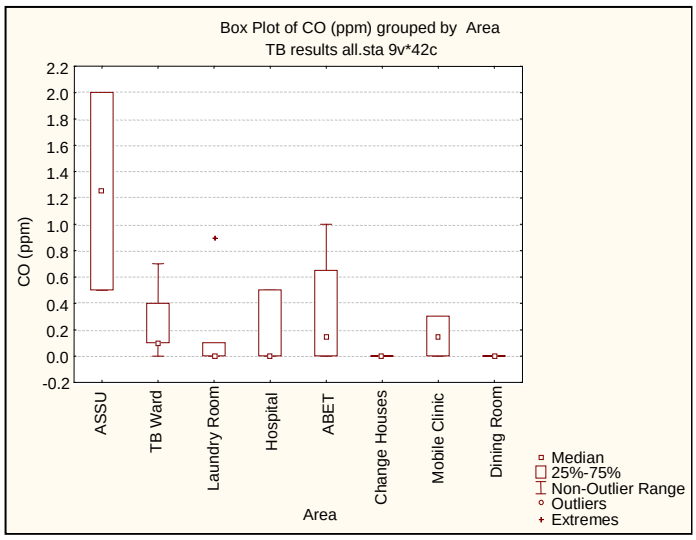


Figure 4: The Box Plot of CO grouped by area

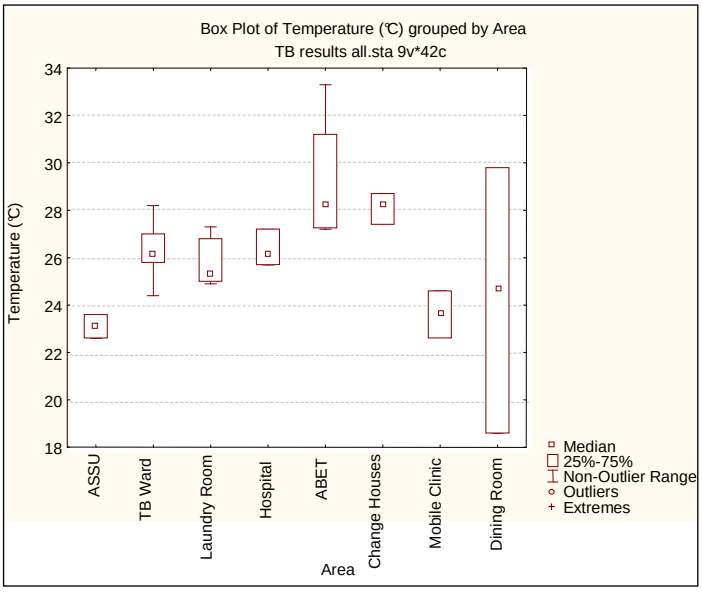


Figure 5: The Box Plot of ambient temperature grouped by area

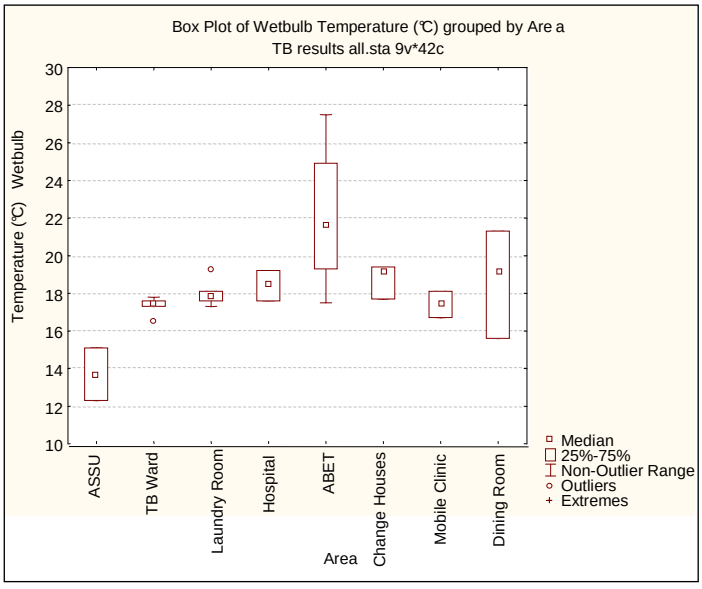


Figure 6: The Box Plot of wet bulb temperature grouped by area

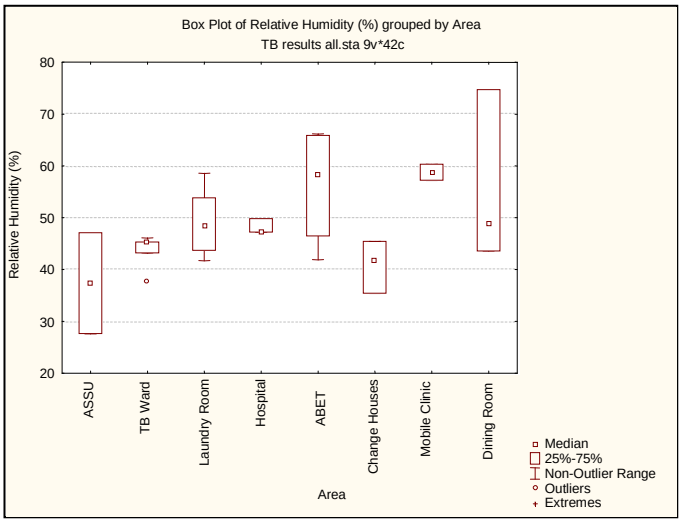


Figure 7: The Box Plot of relative humidity grouped by area

Correlations between the Environmental Variables and the two Sampling Methods

Table 5 depicts the numerical values of the Spearman's rank order correlations. Guidelines for interpreting the correlation as an effect size are as follows (Field, 2009):

0.1 = small effect – no practically significant correlation

0.3 = medium effect – practically visible correlation, and

0.5 = large effect – practically significant correlation.

Table 5: The Spearman's rank order correlations for environmental variables and the two sampling methods

The values in bold indicate significant correlations.

Variables	Marked correlations are significant at p< 0.05						
	Impinger Method	PTFE Method	CO_2 (ppm)	CO (ppm)	Ambient Temperature (℃)	Wet bulb Temperature (℃)	RH (%)
Impinger Method	1.00	**0.47**	-0.04	**-0.25**	0.04	0.09	**-0.17**
PTFE Method	**0.47**	1.00	**0.39**	**-0.34**	0.04	**0.14**	**-0.14**

According to Table 5, there is a practical significant correlation between the PTFE filter method and the impinger method. There is a positive medium correlation between CO_2 and TB DNA copies measured by the PTFE filter method, i.e. as the CO_2 level rises, so will the TB quantity. There is a small to medium negative correlation between both methods and CO, i.e. the lower the CO level, the higher both methods' TB quantity will be, and vice versa.

There is a small positive correlation between the wet bulb temperature and the PTFE filter method. There is a small negative correlation between the RH and both the methods, i.e. the lower the RH, the higher both methods' TB quantity will be, and vice versa.

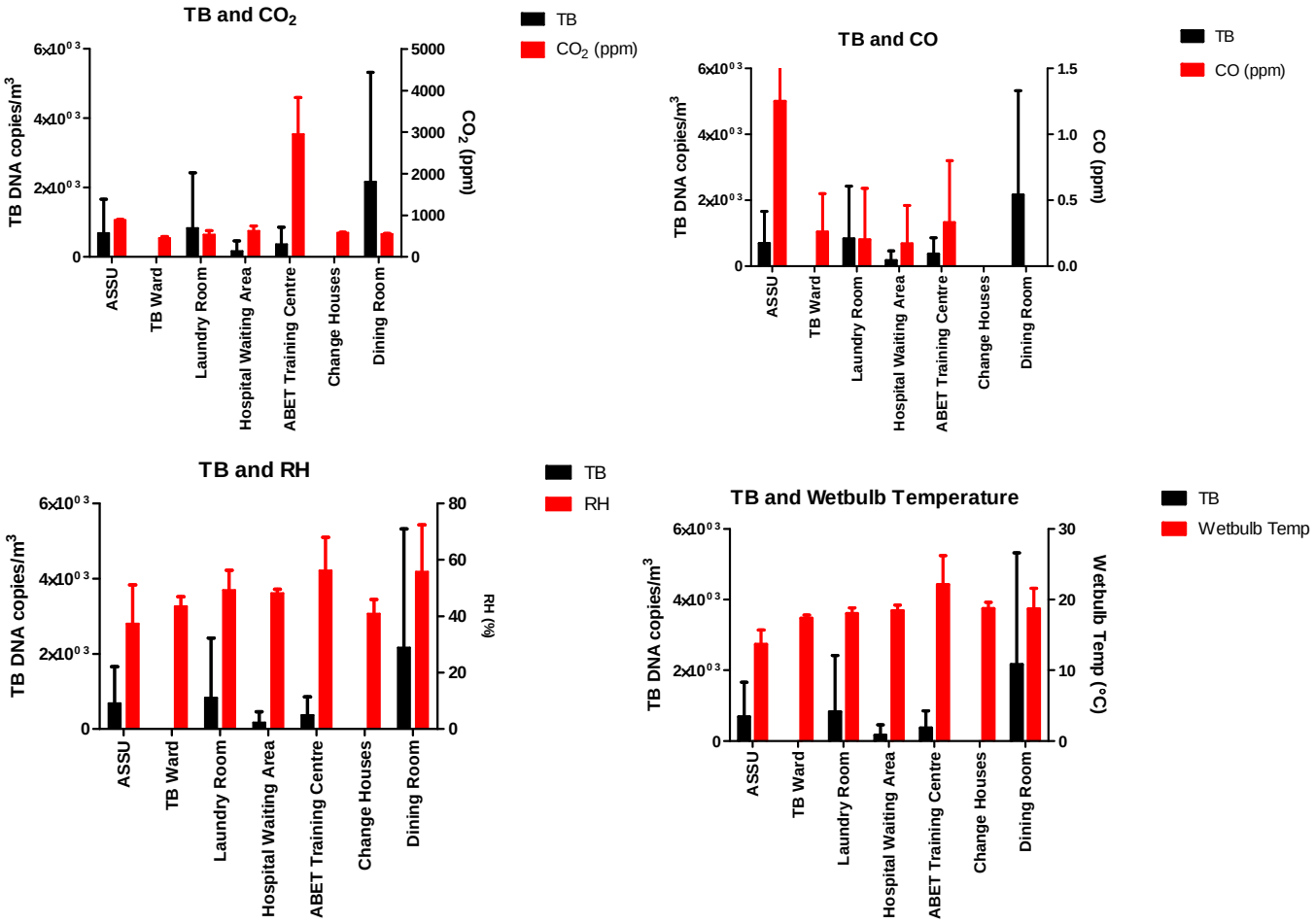


Figure 8: The relationship between PTFE filter method and the environmental variables (Mean ± Std Dev) in the combined monitored areas based on the Spearman's rank order correlation.

Figure 8 demonstrate the relationship between CO_2, CO, relative humidity and wet bulb temperature and the number of *M. tuberculosis* particles found by the PTFE filter method in all areas. The data of the mobile clinic was omitted because the extremely high TB particle count of this area caused the rest of the data portrayed in the graph to drop to zero, which means it rendered a false presentation of the correlations.

The degree of correlation between the PTFE filter method and the environmental variables that affect it is as follows:

CO_2 is 0.39, CO is -0.34, relative humidity is -0.14, and wet bulb temperature is 0.14.

Personal Sampling done with PTFE Filter Method

Table 6: Active personal sampling of personnel in the laundry area and TB Ward with the PTFE filter sampling method.

Personal Samples	TB DNA copies/m^3
TB Ward Nurses	
Sample 1	0
Sample 2	1498
Sample 3	0
Sample 4	$4.09x10^{22}$
Sample 5	0
TB Ward Cleaners	
Sample 1	0
Sample 2	0
Sample 3	513
Sample 4	0
Sample 5	442
Laundry Staff	
Sample 1	625
Sample 2	523
Sample 3	0
Sample 4	0
Sample 5	897

Of the 5 monitored nurses working in the TB Ward, only 2 had a positive TB exposure. One of these nurses had an exponentially high TB exposure (Sample 4). Similarly, 2 of the 5 cleaners who work predominantly in the TB Ward, yielded positive TB exposure. The extent of the cleaners' exposure is considerably less, compared to that of the exposed nurses. The personnel who work in the laundry room were also exposed to TB, to an extent similar to that of the TB Ward cleaners.

Table 7: Descriptive statistics of the personal samples of staff (TB DNA copies/m^3)

Personnel	N	Mean and Std Dev
TB Ward Nurses	5	$8.18x10^{21}$; $1.83x10^{22}$
TB Ward Cleaners	5	191.00 ; 262.74
Laundry Staff	5	409.00 ; 397.61

The mean of TB exposure for the three vocations place the TB Ward Nurses at the top, with an exposure that is exponentially higher than both cleaners and laundry staff. These statistics also suggest that staff working in the laundry room has a higher personal exposure to *M. tuberculosis* bacilli than the cleaners in the TB Ward. However, the large standard deviation shows that such ranking is not reliable at all.

Tuberculosis Questionnaires

Tuberculosis History

Of the 5 monitored TB Ward nurses, only 1 had a positive TB skin test, and only 1 other nurse had an abnormal chest x-ray. However, none of them ever had tuberculosis in the past. None of the laundry room staff ever had a positive TB test before and never had the disease. Of the 5 TB Ward cleaners, 2 had a positive TB skin test, and 1 other cleaner had an abnormal chest x-ray. Only one cleaner had the mucous she coughed up tested for TB, was not told if it was positive, but received medication. The cleaner finished the prescribed medicine and is not taking any at present.

Current Symptoms

None of the nurses have symptoms of tuberculosis. One of the laundry room staff has a loss of appetite and suffers from severe night sweats. One of the TB Ward cleaners also suffers from a loss of appetite, and another cleaner suffers from severe night sweats.

Discussion

The Comparison between the PTFE Filter Method and the Impinger Method:

The SKC Bio-Sampler® yielded only one positive result for the presence of *M. tuberculosis*, as illustrated in Table 1, in comparison to the PTFE filter method, which yielded positive results in all areas except the TB Ward. Just from studying Table 1, it is clear that there is an obvious difference between the efficiencies of the two sampling methods.

One of the reasons for the impinger's lack of data may be a consequence of its sampling flow rate. According to SKC Inc. (2010), any flow rate lower than 12.5 L/min will lead to a nozzle air velocity that is lower than the sonic velocity, i.e. the establishment of a downstream pressure of 0.5 of an atmosphere. As a result, collection efficiency of particles, especially smaller ones, will decrease. Schafer *et al*. (1999) found that the size distribution range of cultured single *M. tuberculosis* H37Ra particles is 3 – 11 µm, but the airborne particle size distribution range is 0.3 – 2.0 µm. They also clearly defined the smallest airborne mycobacteria particles to be around 0.3 µm, which is in contrast to the 1.0 µm reported in the literature. This could therefore imply that airborne *M. tuberculosis* particles are a little larger than viruses. Anwar *et al*. (2010) conducted a study to test the efficiency of the SKC Bio-

Sampler® for virus collection. They found that the SKC Bio-Sampler® showed a higher collection efficiency of viruses at a low flow rate, and the efficiency of the Bio-Sampler® severely dropped as the flow rate increased. This finding contradicts the manufacturer's suggested flow rate of 12.5 L/min. They also found that there is a higher evaporation loss at higher frequencies, which was also the case in this study. Anwar *et al*. (2010) recommends that sampling of viable virus particles for the Bio-Sampler® is better done under lower flow rates (< 6 L/min) for best collection efficiency. Arguably, this could also be applicable to *M. tuberculosis* particles.

According to Maier *et al*. (2009), impingers seem to be very efficient for particles in the range of 0.8 – 15 µm. Furthermore, the typical time duration for sampling is 20 minutes, which prevents evaporation loss during sampling. Anwar *et al*. (2010) also stated that the Bio-Sampler® showed higher collection efficiency at a lower time limit. Schafer *et al*. (1999) suggested that the aerodynamic behaviour of the *M. tuberculosis* H37Ra particle appears to be more similar to that of fibres than of spheres, and that aerosolized mycobacteria particles exhibit airborne behaviour similar to fibres. This may explain why the PTFE filter method has higher collection efficiency for *M. tuberculosis* than the impinger method. It could also be possible that the PBS in the impinger failed to hold, or preserve, the bacilli's integrity for the analysis. The Bio-Sampler® manufacturing company stated that the device's efficiency can only be assured if it is used in conjunction with ViaTrap™ liquid. PBS was used because it is a cheaper option than ViaTrap™ and it can be successfully analyzed with the PCR method; the SKC manufacturer (2010) states that ViaTrap™ may not be suitable for PCR analysis. Another factor that could have played a major role in contradicting these results is the workers. Most people who were present in the monitored areas, even after extensive explanation of the equipment's function, tended to avoid going near them, especially the impinger. In any event, the fact that the impinger monitored an amount of air that was three times that of the PTFE method, and yielded disappointing results in comparison, casts a dark light on the impinger's capability for effective *M. tuberculosis* sampling.

As one of the targets of this study is to compare the two methods in terms of data yield, their results have been expressed statistically. Statistical p-values are generally used to indicate statistically significant differences between two data sets. Table 2 displays both methods' p-values and it is noticed that they testify to no statistical significant difference between the two methods. However, statistically significant tests have a tendency to yield smaller p-values as the size of the data sets

increase. The data sets for each area are very small, and under circumstances where small data sets are used, the effect size is employed. The effect size is independent of the sample size and is a measure of practical significance. To determine if the difference between two groups is large enough to be significant in practice, Cohen's d-value is used as effect size. The scale of the effect size (d) implies that there is a practical significant difference between the two methods in the ASSU office and ABET training centre areas, and a practical visible difference in the hospital waiting area and the laundry room, but no practically significant difference in the TB Ward itself. The mean of the 5 areas (combined) show a medium effect size, indicating a practical visible difference between the data of the two sampling methods.

The TB Ward shows the same results for both methods: no environmental TB, which, according to the doctor and nursing staff, is normal. This may be due to the relatively few people who were present in a monitored area at any one time during the sampling period, which added up to no more than 10 people at a time. They include patients, nurses and cleaners. Adequate ventilation may also have a big effect on these results. Every room has a door which leads to the outside, along with two large windows approximately 2 m x 1 m in dimension. These were always left open because the medical authorities strictly forbid their closure, believing that it would be detrimental to the patients' health, even if they were only closed for the duration of the sampling period. Consequently, the 'worst case scenario' could not be created in the TB Ward area. Another factor could be that the UVGI lights, 1 in each room, successfully combated the environmental TB bacilli.

The results of hospital waiting room, however, suggest the contrary with regards to UV light effectiveness. The floor plan in Appendix A shows the lay-out of the room and the position of UVGI lights (8 in total) utilized in this area. Although there were no environmental tuberculosis levels according to the impinger method, the PTFE method has found a TB presence. However, the hospital waiting area is a much larger area than the rooms in the TB Ward, and plays host to a lot more people, as much as 120 at peak times. Again, people were hesitant to be anywhere near the sampling equipment, but as their numbers increased, lack of space drove them closer and so the TB particles may have been more concentrated in the ambient environment around the PTFE sampling equipment. Ventilation in this area may also have influenced the results. Although this area has been designed as a fairly open plan, with corridors at both ends, the doors and windows that lead to the outside

were closed during the sampling periods. This lack of adequate ventilation may have led to the positive TB samples.

The ASSU office area poses interesting results. This area was originally proposed to act as the control area, but it yielded an amount of *M. tuberculosis* particles that is reasonably high for a low risk area. Although this area hosts a maximum of 5 staff at any time (receptionist etc.) other people do enter the area from time to time as it is part of an office building. The main influence may again be ventilation, as it is extremely poor in this area. The windows and doors are always closed, due to the preference of the staff to always keep the air-conditioning unit on. The levels of carbon monoxide in the area may support this, as it is extremely high in comparison with other areas. No fresh air enters this area, and because of the number of *M. tuberculosis* particles found in the air, a person may have high probability of acquiring TB in this area.

The laundry room offers the best comparison between the two methods, as this was the only area where the impinger method captured *M. tuberculosis* particles. Access to the laundry area is fairly limited and only staff enters the area. There are no more than 5 people in the laundry room at any time. The windows and doors were kept shut for the duration of the sampling period, and only opened (door) for washing loads and when staff entered or left. TB can be found in linen (Walsh and Crumbie, 2007), and if handled roughly, can disperse the TB particles into the environment. That means that TB is not necessarily spread into this area by infected persons (staff or other), however, people who enter the area do have a high probability of acquiring the disease. The turbulence created by the handling of the laundry may also affected the monitoring efficiency of both methods; the air currents may have caused erratic drift patterns of the airborne *M. tuberculosis* particles and so propelled them away from the monitoring equipment.

M. tuberculosis particles were also found in the ABET training facility, but only in room 15. There are 40 - 50 people in each room and the door and windows were shut during monitoring. This area represents a situation where a large number of people are grouped together in a relatively small area (see floor plan, Appendix A) with little or no ventilation. These conditions are perfect for the presence and transmission of TB. However, both sampling methods revealed that room 16 was TB-free. The laboratory that prepared and analysed the samples declared that the PTFE filter of one of the samples was too thin/transparent, and therefore ineffective.

There was however no fault with the second sample, and there were no faults with the sampling train during the monitoring period. It can only be assumed that none of the persons in the room had TB, or that the TB levels were so low that the monitoring equipment could not capture them.

Areas measured exclusively with the PTFE Filter Method:

No *M. tuberculosis* particles were found in the change houses. This area is extremely large and very well naturally ventilated. A large number of workers, 60 on average, make use of this area at any one time. The workers are very active, and do not stay in the change houses for too long. The turbulence these workers create, when they pass close by the monitoring equipment for example, may have adversely affected the monitoring equipment's sampling efficiency. Most of the workers also avoided the stationary monitoring equipment and walked passed it in a rush.

High levels of TB were found in the dining room. A large amount of people made use of this area during the sample period, and there were on average 100 people present.

Only two samples were taken in the mobile clinic. One yielded an extremely high amount of tuberculosis, the other yielded nothing. The mobile area is a very small area that takes a maximum of 5 people at any one time (nurses and patients) however numerous people (patients) make use of the mobile clinic services on a daily basis. Ventilation is extremely poor. The fact that one sample yielded nothing may be because not a single person who went into the mobile clinic during the sampling period had TB, which is very doubtful, yet only 5 persons visited the mobile clinic on that specific day.

The environmental variables:

Table 4 displays the statistical means and standard deviations of the environmental variables compared to the PTFE filter method. The data of the impinger method has been omitted for these analyses as it yielded zero TB measurements for all samples except one. The ASSU office area had a high CO_2 value and a very high CO value in comparison to the other areas. This is most probably due to the lack of natural ventilation and possibly air-conditioning emissions. The rest of the areas are fairly normal, except for the high CO_2 value at the ABET training area. This is because of the large amount of people in the classroom, and the ventilation-free setting created for the monitoring duration. It is certainly clear that the amount of CO_2 is directly

proportional to the effectiveness of the ventilation and the number of people present. The temperatures, both ambient and wet bulb do not vary greatly and were normal. The average relative humidity in all the areas was also fairly normal, but there were peaks in both the dining area and the ABET training rooms. This is largely due to the number of people crowded in a space with little ventilation.

The Spearman's Rank order correlation coefficient is a non-parametric measure of statistical dependence between two variables. It assesses how well the relationship between two variables can be described by using a monotonic function. According to statistical analysers, the number of samples taken in this study for each area is too small to form a reliable conclusion regarding correlations of any type. Nevertheless, the correlations constructed in Table 5 reveal the following:
There is a small to medium negative correlation between the PTFE sampling method and CO, i.e. the lower CO, the higher the *M. tuberculosis* particles in the environment. Table 1, which clearly shows a high TB presence in an area (ASSU) with high CO levels, contradicts this, but again, not enough samples were taken to form a credible argument. There is also a small negative correlation between the relative humidity and the PTFE method, i.e. the higher the relative humidity, the lower the amount of *M. tuberculosis* particles in the air. Dunklin and Puck (1947) demonstrated that high relative humidity has a lethal effect on air-borne bacteria. Peccia *et al*. (2001) demonstrated that a high relative humidity suppresses the UVGI systems efficiency, so creating a high level of relative humidity is not feasible in order to control TB.

The Spearman's Rank also proposes that there is a small positive correlation between the wet bulb temperature and the sampling method, i.e. the higher the wet bulb temperature, the higher the amount of *M. tuberculosis* particles in the environment. There is no literature that explains any aspect of this possible relationship between *M. tuberculosis* particles and wet bulb temperature. There also seems to be a positive correlation between CO_2 and the PTFE sampling method. Exhaled air contributes greatly to higher CO_2 levels in the environment, especially in an area with no ventilation. Exhaled air could also contain and disperse TB particles. It can then be proposed that high CO_2 levels could act as an indicator of the potential presence of tuberculosis in an occupational environment.

The correlation between the two sampling methods and the environmental variables is depicted by Figure 8. These graphs do not portray the clear correlations which the

Spearman's Rank proposed. The reason for this is simply because the number of samples collected per area is too small to be statistically significant.

Personal Sampling:

The TB exposure of the nurses is mainly due to their close contact with infected patients during examinations and general care. The same can be said for the cleaners, who also pass in close proximity to the patients when they are busy with their tasks. The cleaners, however, do not spend the same amount of time in the high risk areas as the nurses do. The laundry workers are exposed to *M. tuberculosis*. It may be during their contact with other persons, but as they spend most of their time tending to the laundry, especially sorting the dirty laundry, it is safe to accept that this dirty laundry is the source. The fact that the personnel in the TB Ward is exposed to tuberculosis particles may question the effectiveness of the UVGI system, but close contact transmission of tuberculosis occurs much faster than the UVGI system's ability to kill it. None of the monitored personnel ever had TB according to their answers in the questionnaires, although some of them have had symptoms of the disease. The cleaners and laundry room staff were reluctant to complete the questionnaires and to discuss the disease. Their knowledge of the disease is very limited.

Conclusion

The PTFE filter method is more effective at *M. tuberculosis* sampling than the SKC Bio-Sampler® impinger method. The physical attributes and behaviour of airborne *M. tuberculosis* particles seem to be a significant factor that influences monitoring attempts. A more specific tuberculosis monitoring system, i.e. procedure, equipment and duration of sampling-time needs to be established, as it seems that generic micro-organism sampling methods tend to be unreliable.

The number of people in an area and the ventilation adequacy of that area seem to be the most important factors that influence the prevalence of tuberculosis. The UVGI system is effective in controlling airborne tuberculosis, but its effectiveness can easily be undermined if one of the above- mentioned factors are out of balance. It is most certainly possible that the environmental variables regarded in this study may have an effect on the environmental presence of *M. tuberculosis*, and may even form positive or negative correlations. However, more extensive studies which incorporate

a higher number of samples need to be done in the future before any safe conclusions can be made.

Some areas do pose a risk of contamination for non-infected personnel. The predominant areas seem to be the ASSU office area, the dining area, and the laundry room. The mobile clinic poses by far the biggest risk. It is therefore a high possibility that the quantity of *M. tuberculosis* bacteria in the air, which are introduced by infected personnel, can indeed pose a significant contaminating risk to non-infected personnel in the same environment, especially if there is a lack of effective tuberculosis control.

The average amount of *M. tuberculosis* particles present in an occupational setting has been quantified, and although it does not reflect extremely high amounts, these particles may still cause the disease if they are inhaled. More knowledge about the various aspects and influencing factors surrounding the *M. tuberculosis* bacilli still needs to be acquired before any significant calculations can be made regarding the occupational risk of contracting tuberculosis. The risk of non-infected personnel will always be high if they come into close contact with infected personnel. The reason for this is obviously because *M. tuberculosis* bacilli are grouped together, i.e. in a large concentration, as soon as they are expelled by the host, and then dispersed by air currents as they travel farther away. Logically, the further a non-infected individual is from an infected individual, the lower the risk of the non-infected individual to become infected.

References

Aids and Rights Alliance for South Africa (ARASA). (2008) The Mining Sector, Tuberculosis and Migrant Labour in Southern Africa. Available from: URL:http://www.arasa.info

Anglo American. (2010) Safety and Sustainable Development Report. Available from: URL:http://www.angloplatinum.com/safety/caring/health.asp

Anwar D, Oh S, Wu C. (2010) Virus collection Efficiency of Bio-sampler versus Impinger with variable Time and Flow Rate. University of Florida. Available from: URL: www.honors.ufl.edu/apps/Thesis.aspx/Download/312

Bandera A, Gori A, Catozzi L, Esposti AD, Marchetti G, Molteni C, *et al*. (2001) Molecular Epidemiology Study of Exogenous Re-infection in an Area with a Low Incidence of Tuberculosis. J Clin Microboil; 2213–2218.

Behr MA, Warren SA, Salamon H. (1999) Transmission of Mycobacterium Tuberculosis from Patients smear-negative for acid-fast Bacilli. Lancet; 353(9151) 444–449.

Cole E, Cook C. (1998) Characterization of Infectious Aerosols in Healthcare Facilities: an aid to effective engineering controls and preventive strategies. Am J Infect Control; 26(4) 453-464.

Dunklin EW, Puck TT. (1947) The Lethal Effect of Relative Humidity on Air-borne Bacteria. J Exp Med. 87(2) 87-101.

Ellis SM, Steyn HS. (2003) Practical significance (effect sizes) versus, or in combination with, statistical significance (p-values). Management Dynamics 12(4) 51-53.

Field, A. (2009) Discovering statistics using SPSS. London. Sage publications Ltd. 821. ISBN: 9781847879073.

Houben E, Nguyen L, Pieters J. (2006) Interaction of pathogenic Mycobacteria with the host Immune System. Curr Opin Microbiol; 9(1) 76–85.

Kumar V, Abbas, AK, Fausto N, Mitchell RN. (2007) Robbins Basic Pathology. Saunders Elsevier. p. 516–522. ISBN: 0808923668.

Laxminarayan R, Klein E, Dye C, Floyd K, Darley S, Adeyi O. (2007) Economic Benefit of Tuberculosis Control. The World Bank Human Development Network Health Nutrition and Population Team. Policy Research Working Paper 4295.

Lönnroth K, Castro KG, Chakaya JM, Chauhan LS, Floyed K, Glaziou P, Raviglione MC. (2010) Tuberculosis Control and Elimination 2010-50: cure, care, and social development. Lancet; 375(9728) 1814-1829.

Maier RM, Pepper IL, Gerba CP. (2009) Environmental Microbiology. London. Elsevier Ltd. p. 150. ISBN: 0124975704.

Mayo Clinic. (2009) Tuberculosis. Available from: URL:http://www.mayoclinic.com/health/tuberculosis/DS00372

National Institute for Occupational Safety and Health (NIOSH). Analytical Method No. 0900 Mycobacterium tuberculosis, airborne (1998). NIOSH, USA. Available from: http://www.cdc.gov/niosh/docs/2003-154/pdfs/0900.pdf

Occupational Safety and Health Administration (OSHA). (1997) Occupational Exposure to Tuberculosis; Proposed Rule - 62:54159-54309. Available from: URL:http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=FEDERAL_REGISTER&p_id=13717

Nicas M, Nazaroff WW, Hubbard A. (2005) Toward understanding the Risk of secondary airborne Infection: Emission of respirable Pathogens. J Occup Environ Hyg; 2(3) 143-154.

Onyebujoh P, Rook GAW. (2004) Focus: Tuberculosis. Available from: URL:http://www.who.int/tdrold/dw/tb2004.htm

Prescott LM, Harley JP, Klein DA. (2005) Microbiology. McGraw Hill. USA. p. 992. ISBN: 0072992913.

Peccia J, Werth HM, Miller S, Hernandez M. (2001) Effects of Relative Humidity on the Ultraviolet Induced Inactivation of Airborne Bacteria. Aerosol Sci Tech; 35 728–740.

Schafer MP, Fernback JE, Ernst MK. (1999) Detection and Characterization of Airborne *Mycobacterium tuberculosis* H37Ra Particles, A Surrogate for Airborne Pathogenic *M. tuberculosis*. American Association for Aerosol Research. Taylor and Francis. Aerosol Sci. Tech; 30 161–173.

Schmidt CW. (2008) Linking TB and the Environment. Environ Health Perspec; 116(11) 479–485.

SKC Inc. (2010) Bio-aerosol Sampling. Available from: URL:http://www.skcinc.com/

Snashall D, Patel D. (2003) ABC of Occupational and Environmental Medicine. London. BMJ Publishing Group. p. 133. ISBN: 0585493391.

Walsh M, Crumbie A. (2007) Watson's Clinic Nursing and Related Sciences. Elsevier Ltd. p. 983. ISBN: 9780702028250.

The World Economic Forum (TWEF). (2002) TB Management in the Workplace: an Introduction for African Business. World Health Organization. Available from: URL:https://members.weforum.org/pdf/Initiatives/GHI_Guidelines_WHO_TB_Africa.pdf

World Health Organization (WHO). (2009) WHO Report 2009 – Global Tuberculosis Control. Available from: URL:http://www.who.int/tb/publications/global_report/2009/key_points/en/index.html

CHAPTER 4

CONCLUDING CHAPTER

4.1 Further Discussion and Final Conclusion

This study succeeded in quantifying the ambient presence of *M. tuberculosis* in occupational settings that is often thought of as low risk areas. This pathogen can be present in any environment. Only if an environment is effectively and sufficiently controlled, can *M. tuberculosis* be suppressed and even eradicated. To determine the scale of control implementation, the level of *M. tuberculosis* presence should first be established, and this study found that the PTFE filter method is the best way to achieve this, as it better able to quantify ambient *M. tuberculosis* particles than the SKC Biosample® impinger method.

The highest risk of infection is due to close-contact personal transmission: it is after all in the human body where *M. tuberculosis* prospers, yet these bacilli still need to pass through the ambient environment before they can reach a suitable host. Although this study failed to provide quantitative evidence for correlations between environmental variables and the levels of *M. tuberculosis* entities found there, it must not be assumed that there is no relationship between them. Further studies that may succeed in quantitative evidence of correlations between these two aspects will be of great value in the struggle against TB. If a correlation exists, that specific environmental variable could be manipulated to suppress *M. tuberculosis* bacilli.

The two biggest factors affecting *M. tuberculosis* prevalence are people, i.e. the size of a crowd, gathered in an area and the adequacy of the ventilation in that area. Ventilation, whether mechanical or natural, should always be operational. These factors should always be taken into account whenever procedures and risk assessments are developed. Quantitative results that could indicate a proper ratio between these two aspects would be of great value. A third component, i.e. the UVGI system may be added into such a calculation. A proposed question could be for example: How many people can gather in a room with X ventilation (airflow/m^3) quality and X number of UVGI-lights? The efficiency of the UVGI system seems to depend on the relationship between crowding and ventilation, and should be considered as only an auxiliary control measure and not a principle control measure.

Even the specific areas that were monitored in this study (and others) can be studied in more depth to understand the degree of *M. tuberculosis* presence, as well as the conditions that may potentially aid and enhance its prevalence. The Mobile Clinic is a definite recommendation, not only because of the high amount of TB bacilli found in this area, but because *M. tuberculosis* is not the only pathogen that scours this

occupational setting. Potentially hundreds of people visit this setting every day, and therefore it is indeed a priority to stem the transmission of TB to the masses. The change houses also posed an interesting scenario. Many people would be of the opinion that the change house area is a high TB risk area, but it yielded no ambient *M. tuberculosis* particles, presumably because it was well ventilated. A scientific explanation may be of great value.

The quantity of *M. tuberculosis* bacteria in the air, which is introduced by infected personnel, may indeed pose a significant contaminating risk to non-infected personnel in the same environment. Calculating the exact risk require more scientific studies however. Knowledge is still the greatest power, and therefore it is important to educate and counsel potentially affected persons about the various characteristics, properties and harmful conditions in which TB thrives.

The biggest challenge in this study was to ensure the personal flow pumps achieved a flow rate of 4 L/min and maintained it for 4 hours. Flow pumps that claim to be able to reach a maximum flow rate of 4 L/min, could only reach a maximum flow rate of 3.5 – 3.8 L/min due to the resistance of the filter, and could not sustain this sampling capacity for the four hour sampling period: after about an hour the batteries died, even though they were fully charged for 24 hours prior to sampling. To solve this problem, a Gillian 5000 personal flow pump was used. This pump has a maximum flow rate of 5 L/min, and could therefore easily handle the 4L/min for 4 hours demand. The Gillian 5000 was also easier to calibrate and control than the other personal sampling pumps, and the personnel who wore it, agreed that it is more comfortable than the others and makes less noise. It is therefore strongly recommended that the Gillian 5000 personal sampling pump is used for further studies of biological air sampling.

Another aspect is the amount of samples needed for a study. The results of this study were limited by the small number of samples taken in each area, and so it is recommended that more samples are taken for further biological air sampling studies. The optimal placement of the sampling equipment may also merit further investigation, especially its positioning, so people cannot deliberately avoid it, but also not damage it.

4.2 Occupational Hygiene Recommendation

It is strongly recommended that ventilation control measures, such as creating negative pressure differences and installing HEPA filters, are incorporated in mobile clinics, as well as other high risk areas such as hospital waiting areas, the office area (ASSU), training facilities (ABET), dining rooms, laundry rooms, and TB Wards.

The most important control measure for environmental tuberculosis control is adequate ventilation. The mine has already incorporated some control measures, which include engineering-, administrative-, and personal protection controls, but these need to be enhanced.

4.2.1 Engineering Controls

OSHA (1997) states that it is important that a negative pressure is maintained in rooms and areas, especially where TB is isolated, to prevent the escape of aerosolized *M. tuberculosis* from such a room and into the corridors and other areas of the facility where unprotected employees may be exposed. In order for air to flow from one area to another, there must be a difference in the pressure between the two areas. Air will flow from the higher pressure to the lower pressure area. The lower pressure area is at "negative pressure" relative to the higher pressure area. The level of negative pressure achieved will depend on the physical configuration of the area, including the air flow path and flow openings. OSHA (1997) recommends a pressure differential of 0.003 centimetres of water and an inward air velocity of 0.5 meters per second as the minimum. The pressure difference necessary to achieve and maintain negative pressure in a room, is very small and may be difficult to measure accurately. Negative pressure can be achieved by balancing the room supply and exhaust flows to set the exhaust flow to a value of 10 % greater than the supply. Engineering controls creating negative pressure will prevent the escape of droplet nuclei from the room thus preventing dispersion of *M. tuberculosis* into the corridor and other areas of the facility where unprotected employees may be working (CNTC, 2004).

In addition, negative pressure also reduces the concentration of air contaminants. General ventilation preserves air quality by means of dilution and removal of airborne contaminants. Dilution diminishes the concentration of contaminants in a room by supplying clean air. The supply air mixes with and then displaces some of the contaminated room air, which is then removed from the room by the exhaust system. This process reduces the concentration of droplet nuclei in the room air and the risk of TB transmission (CNTC, 2004).

UVGI controls have been implemented in the rooms of the TB Ward and the hospital waiting area. Even though the active area sampling in the TB Ward revealed no *M. tuberculosis* presence, the personal monitoring of the nurses and cleaning staff clearly revealed a TB exposure.

OSHA (1997) does not recommend the use of UVGI in place of ventilation for controlling aerosolized *M. tuberculosis*. Although the germicidal properties of certain wavelengths of ultraviolet light are generally recognized, the Agency has not included UVGI as a primary engineering control in the proposed standard. Seeing that the clinical effectiveness of UV systems varies, and because of the risk for transmission of *M. tuberculosis* if a system malfunctions or is maintained improperly, UVGI is not recommended for the following specific applications:

1) Duct systems using UVGI are not recommended as a replacement for HEPA filters if air from isolation rooms must be re-circulated to other areas of a facility.
2) UVGI alone is not recommended as a substitute for HEPA filtration or local exhaust of air to the outside from booths, tents, or hoods used for cough-inducing procedures.
3) UVGI is not a substitute for negative pressure.

The NIOSH Respiratory Disease Research Program (RDPR) showed that UVGI is effective for inactivation of bacteria and bacterial spores. RDRP research has also demonstrated that, when used properly, portable air cleaners can help remove airborne infectious aerosols and provide better overall air mixing in rooms used to house infectious TB patients (NIOSH, 2007).

It may be suitable, however, if UVGI Systems are installed in reception areas, such as that of the ASSU, as well as the classrooms of the ABET training facility, to act as an auxiliary control method. The establishment of adequate ventilation is still a priority though.

High efficiency particulate air (HEPA) filters have very high removal efficiency: at least 99.97% of airborne particles (0.3 µm in diameter) are removed. Medically used HEPA filtration systems also incorporate high-energy ultra-violet light units to kill off the live bacteria and viruses trapped by the filter media (OSHA, 1997).

Engineering controls must be maintained, inspected and performance monitored for filter loading and leakage every six months, and whenever components are changed.

It is important to assure that engineering controls are maintained to such a degree that they continue to function effectively. It is the employer's responsibility to maintain engineering controls in proper working condition, and it is not appropriate to delay repairs until the six-month inspection. The maintenance plan may specify more frequent inspection, maintenance, and performance-monitoring based on conditions found in that particular work site (OSHA, 1997).

4.2.2 Administrative Controls

It is commonly accepted that the higher the number of people gathered, the higher the potential for tuberculosis prevalence. This might explain the lack of efficiency of the UVGI systems in the hospital's waiting area. It is advised to take the number of people present/allowed to gather in any location in any one time into consideration, and reduce this number to as low as possible. This may have time- and cost implications, but as this will reduce the chances of infection and transmission, costs will be saved with regards to company losses due to health reasons.

Regarding the prevalence of TB in the laundry room, it is recommended that all the different types of linen coming from high TB risk areas be separated at the source, and not mixed with the linen from other areas in the laundry room. The linen from high risk areas can then be placed directly into washing machines at the laundry room with the minimum exposure to the environment and personnel.

The Occupational Health and Safety Act (Act 85 of 1993): Regulations for Hazardous Biological Agents states that administrative controls include the development of a system that ensures that employees, patients, contractors and visitors are educated about the use of TB precautions, as well as their responsibility for adhering to the precautions, and periodic evaluations of adherence to these precautions. The findings of evaluations must then be used to implement improvements.

4.2.3 Approaches to reduce TB Transmission in the Occupational Setting

It is important to ensure that employees have early access to essential TB testing, and that treatment is provided as soon as possible where necessary. Education, counselling, and follow-up services need to be established and made available to the workforce. Practical guidelines for the prevention of TB transmission need to be compiled and implemented. Existing HIV/AIDS prevention initiatives need to be linked with new TB transmission strategies. The WHO (2009) DOTS program should be implemented, as it is an internationally-proven and effective TB treatment

regimen, and it is important to work in alliance with National TB Control Programs. Finally, it is important to respect confidentiality and ensure non-stigmatization and non-discrimination (OSHA, 1997).

4.2.4 Approaches to reduce TB Transmission in the Healthcare Setting

It is important to educate nurses on the etiology, transmission, prevention and treatment and the potential risk factors of environmental TB exposure in the workplace. Appropriate precautionary measures, including guidelines and standards of practice for nurses, should be implemented in all healthcare settings to prevent further spread of the infection. Following the recommendations of the ICN (2010) *Guidelines for Nurses in the Care and Control of Tuberculosis and Multi-Drug Resistant Tuberculosis*, the following should be assured:

- Nurses need to do continuous risk assessment that relates to workplace (environmental) risk factors that are known to increase the potential of TB transmission.
- Nurses need to ensure that protective equipment (e.g. high filtration masks) is worn when entering a risk area, and that the masks are adequate, i.e. properly fitted etc.
- Nurses need to understand and implement guidelines and standards for safe nursing practice.
- Nurses need to participate in the development of institutional/organizational strategies that support close monitoring of all TB infected persons as part of the routine health- and nursing care (ICN, 2010).

4.2.5 Training

Awareness and training that address TB control measures relevant to a variety of work settings and responsibilities are also of vital importance. A guide and manual for safe healthcare are also great assets.

Training that deals with occupational TB transmission should be based on a set of institutional policies and guidelines and provided on a regular basis depending on specific staff competencies and needs (ICN, 2010), and should include:

- Workplace environment guidelines and standards of practices orientation.
- Information on etiology, epidemiology, causes and types of TB infection;
- Explanation of causes and ways of TB transmission from patients to staff and visitors.

- Demonstration on how to use preventative measures (e.g., personal- and occupational hygiene).
- Information on testing, diagnosis and treatment protocols.
- Improving knowledge about counselling and support techniques.
- Developing awareness and skills to avoid stigmatization and discrimination of patients or staff infected by TB (ICN, 2010).

4.2.6 Respiratory Protection (PPE)

OSHA (1997) and NIOSH (2010) recommend the use of N95 and P100 respirators in case of *M. tuberculosis* exposure.

4.3 References

Francis J Curry National Tuberculosis Centre (CNTC). (2004) What does Ventilation have to do with TB Control? Available from: URL:http://www.nationaltbcenter.edu/abouttb/tbcontrol_faqs/6_what_does_ventilation.pdf

International Council of Nurses (ICN). (2010) Tuberculosis Exposure in the Healthcare Setting: Prevention of Occupational Transmissions. Available from: URL:http://www.icn.ch/publications/fact-sheets/

National Institute for Occupational Safety and Health (NIOSH). (2010) NIOSH Respiratory Diseases Research Program. Available from: URL:http://www.cdc.gov/niosh/nas/RDRP/ch6.1.htm

South Africa. (1995) Regulations for hazardous biological agents. Occupational health and safety act 85 of 1993. Pretoria: State printers.

United States Department of Labour (OSHA). (1997) Occupational Exposure to Tuberculosis; Proposed Rule - 62:54159-54309. Available from: URL:http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=FEDERAL_REGISTER&p_id=13717

CHAPTER 5

APPENDICES

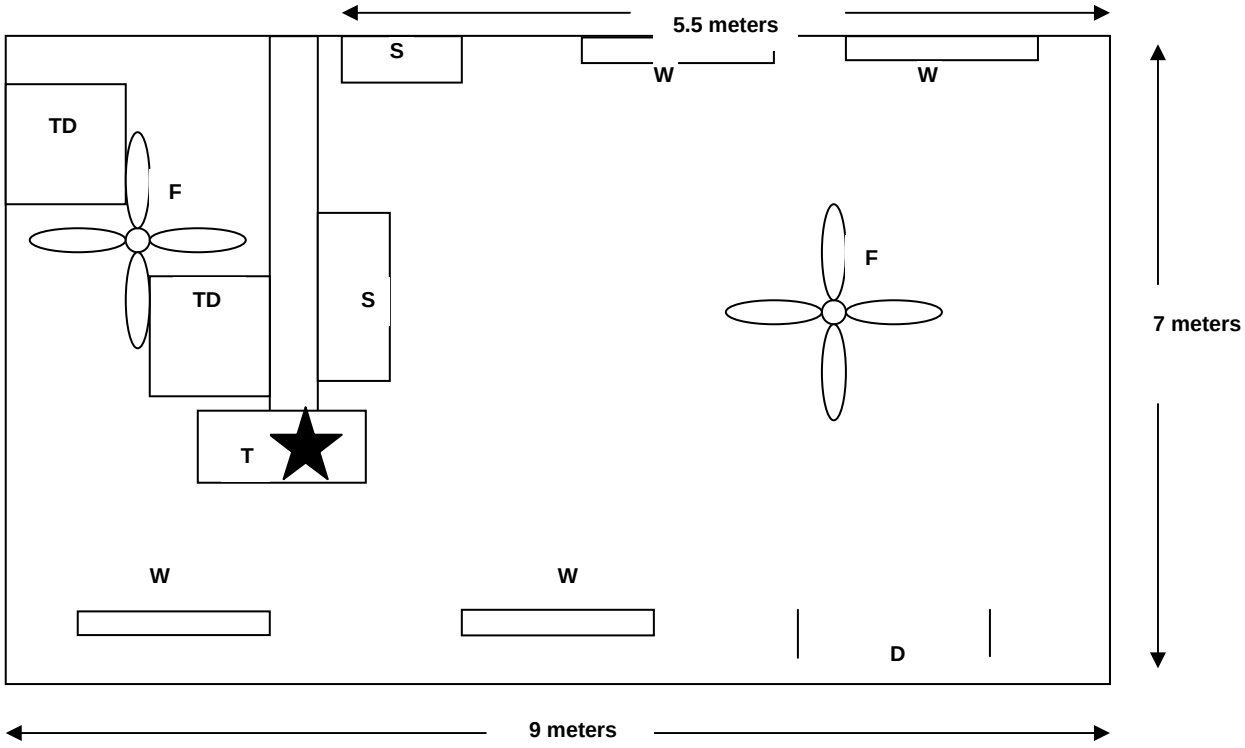
5.1 Appendix A: Floor plans of monitored areas

Key Index

★ Placement of monitoring devices

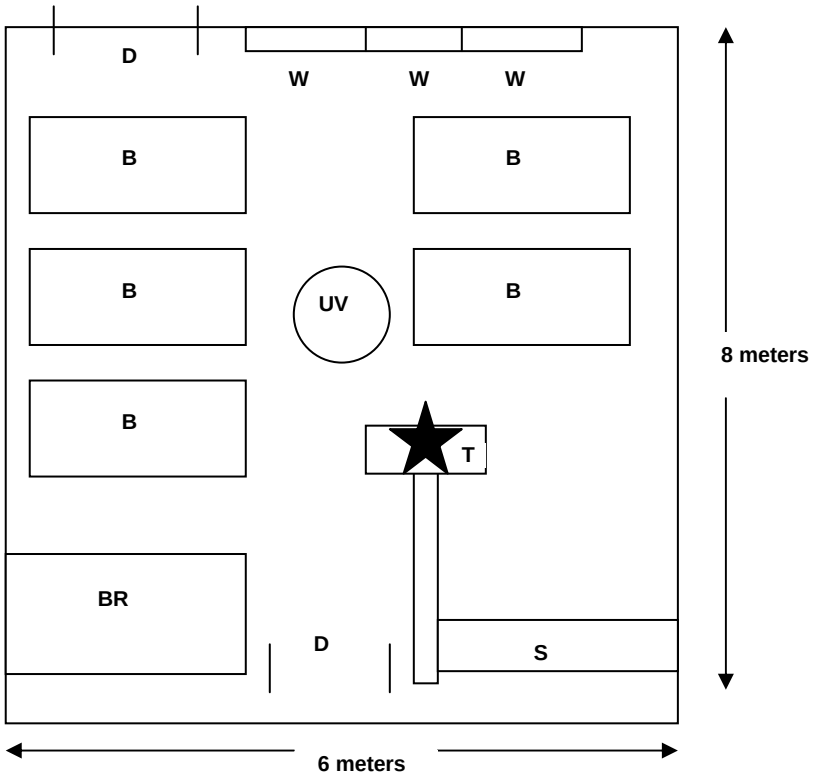
F	Fan
W	Window
T	Table
B	Bed
TD	Tumble drier
S	Sink
D	Door
BR	Bathroom
UV	Ultra Violet light
P	Passage way
C	Counter top
CH	Chairs
A/C	Air conditioner
L	Lockers
SH	Showers

Laundry Room

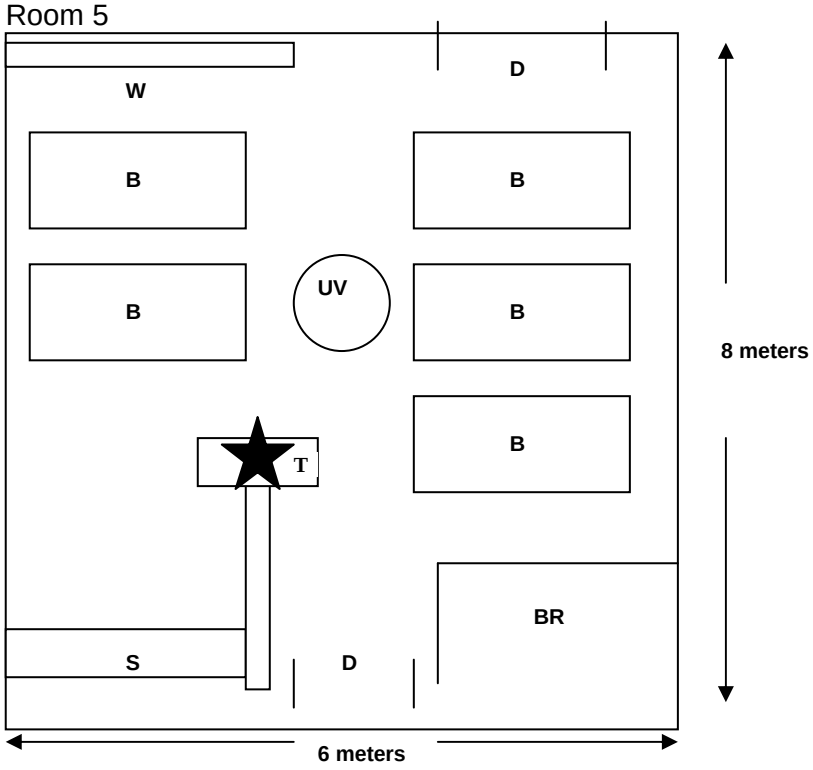


TB WARD

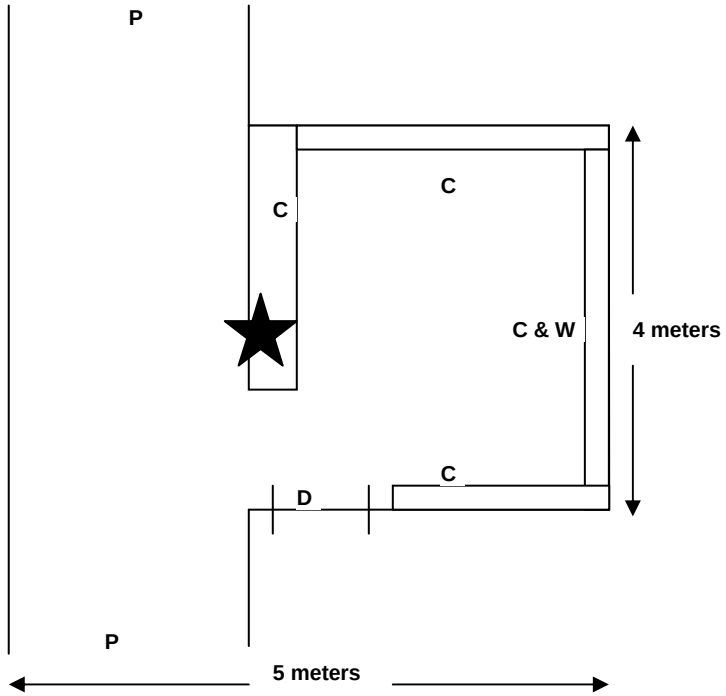
Room 2 and 4 and 6



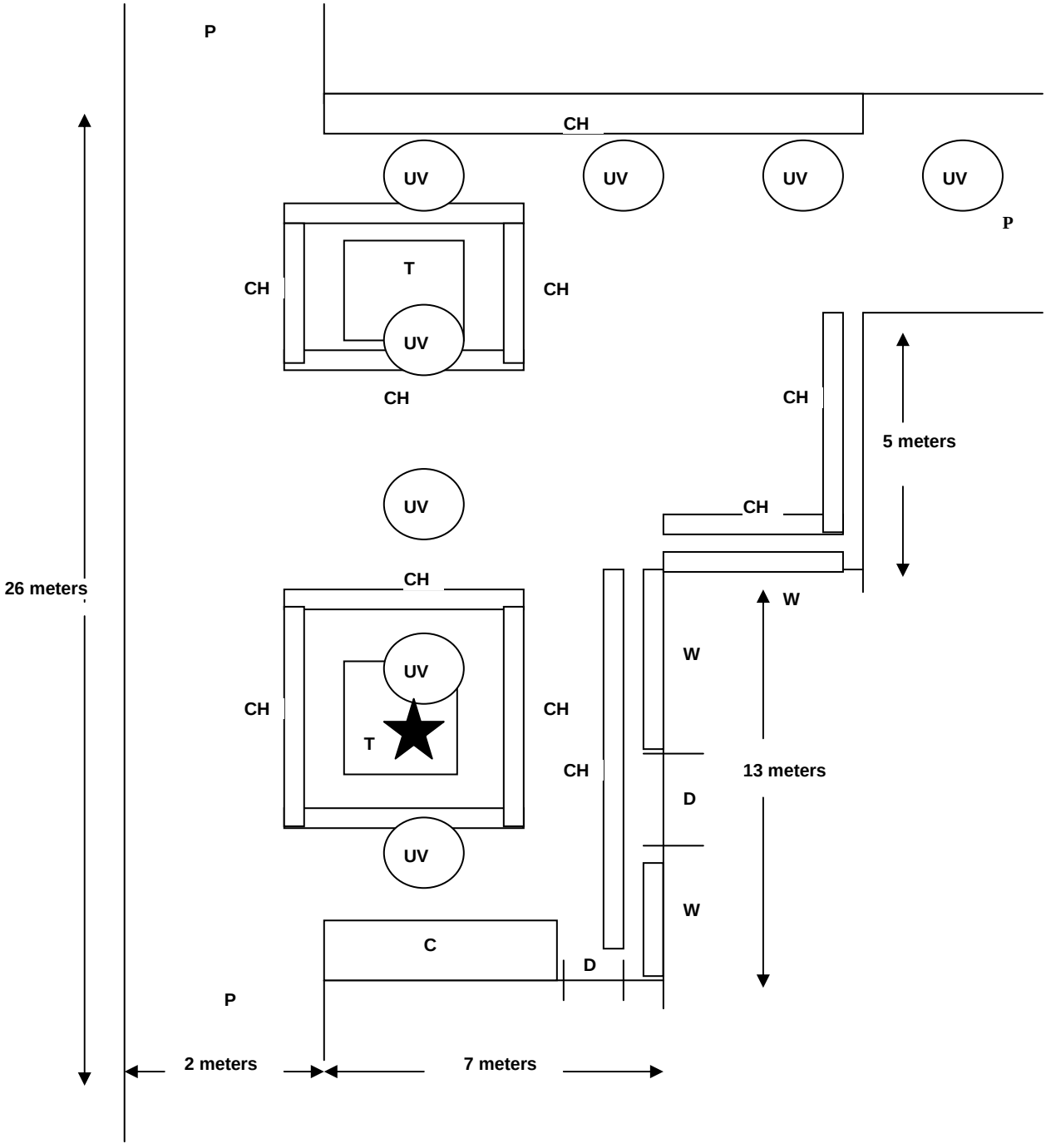
Room 5



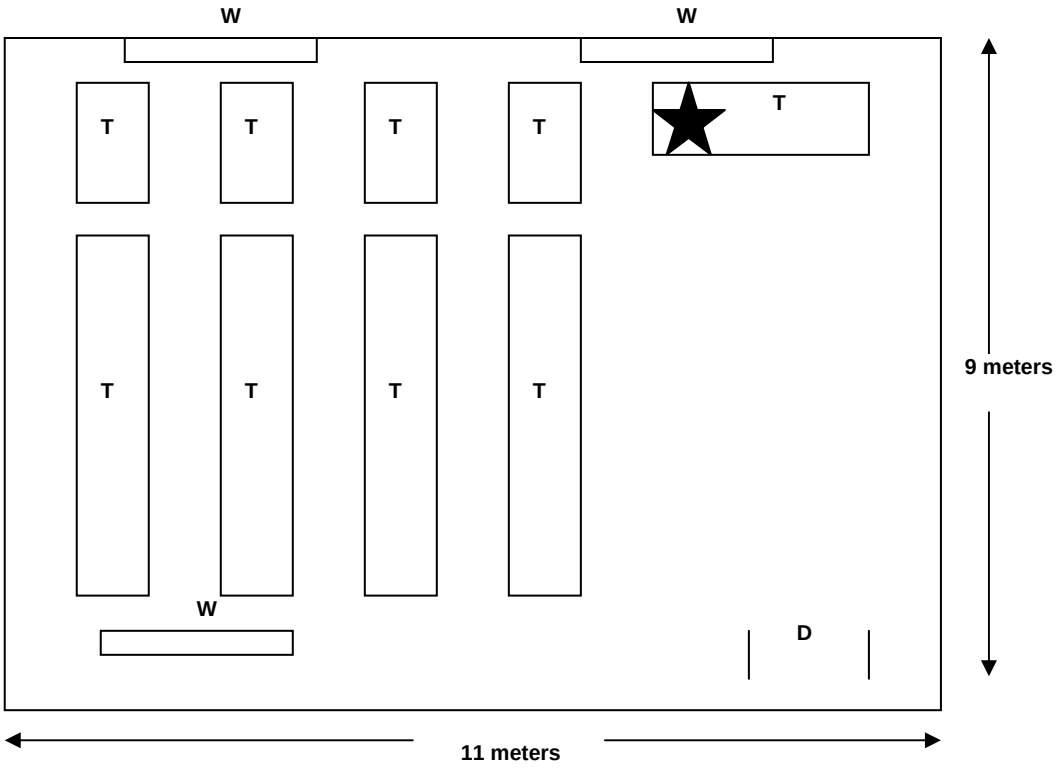
TB Ward Reception



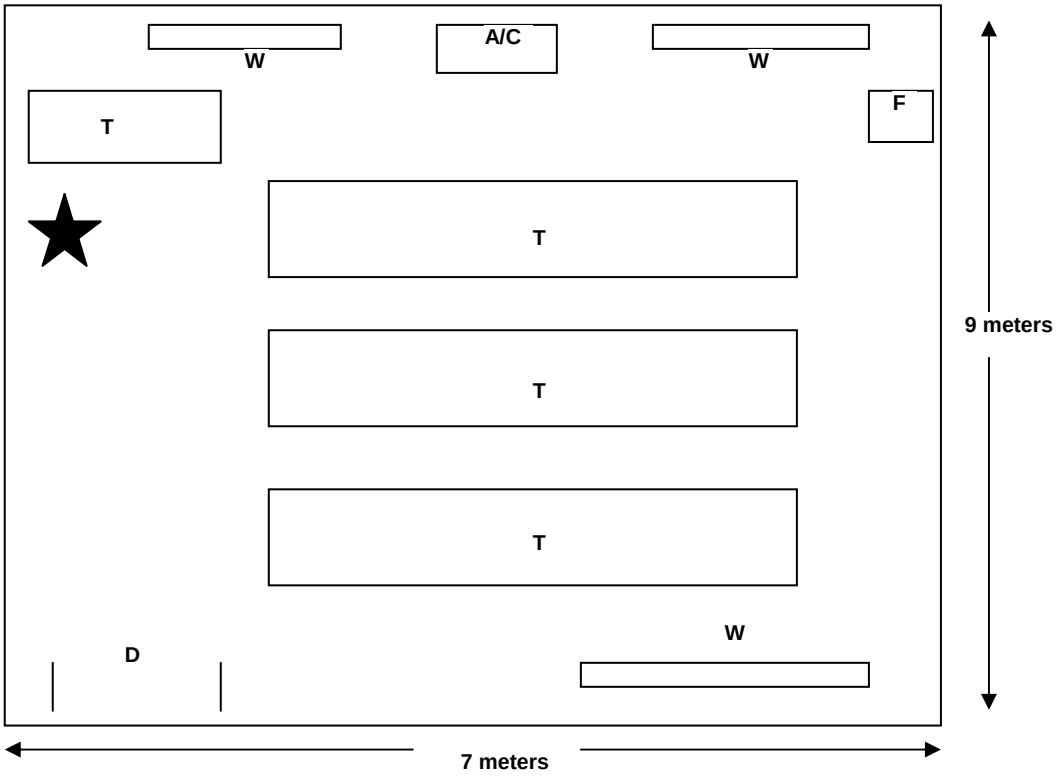
Waiting Room



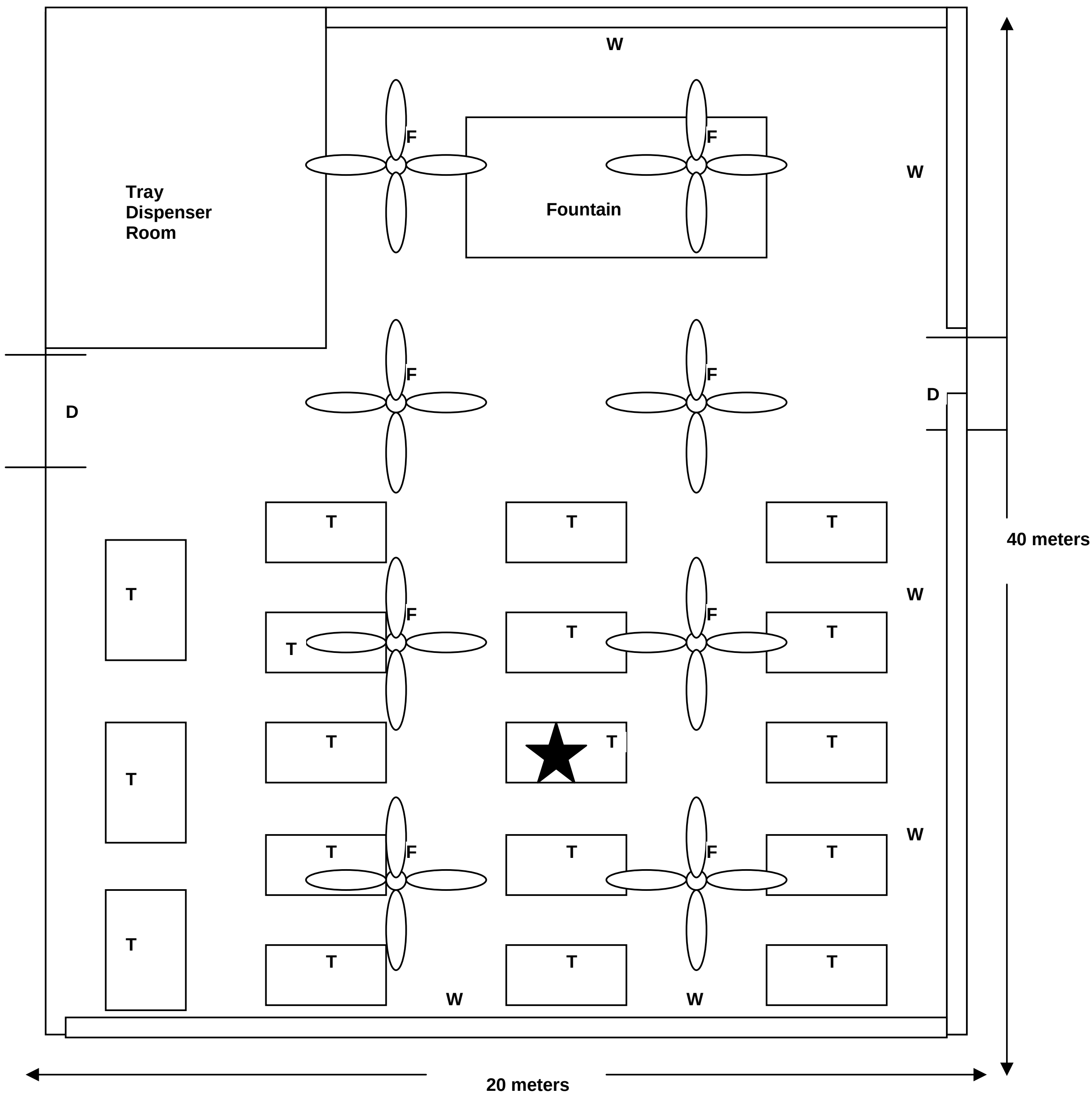
ABET Training room 15



ABET Training room 16



Dining Room



W
Tray
Dispenser
Room
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Fountain
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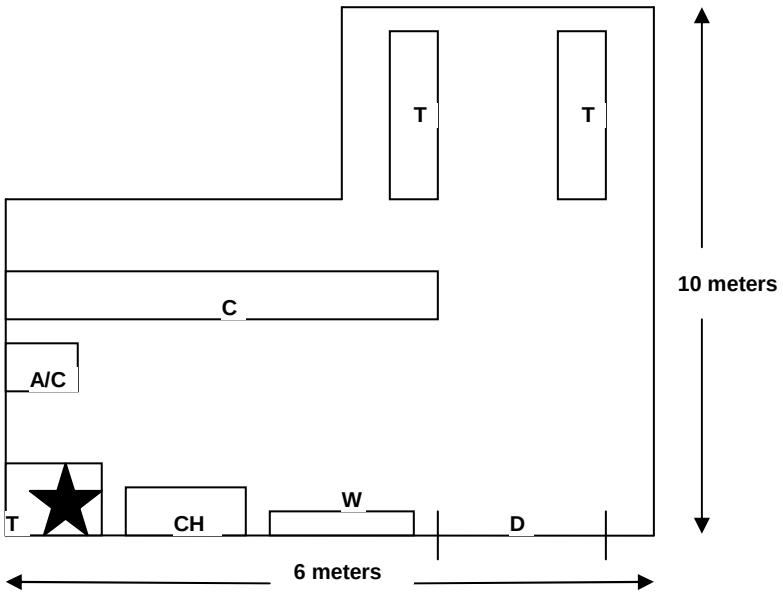
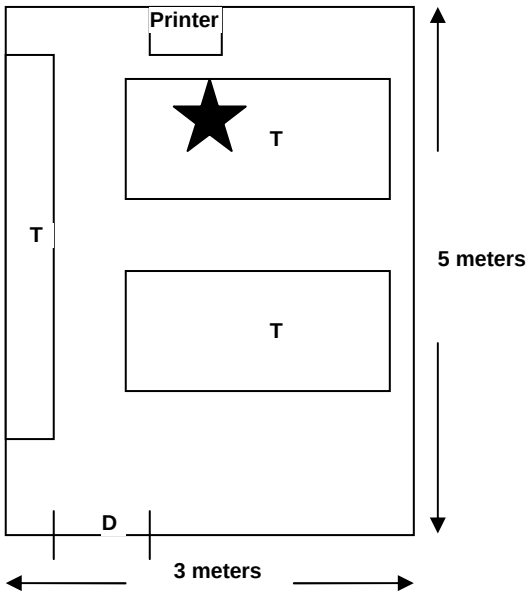
20 meters

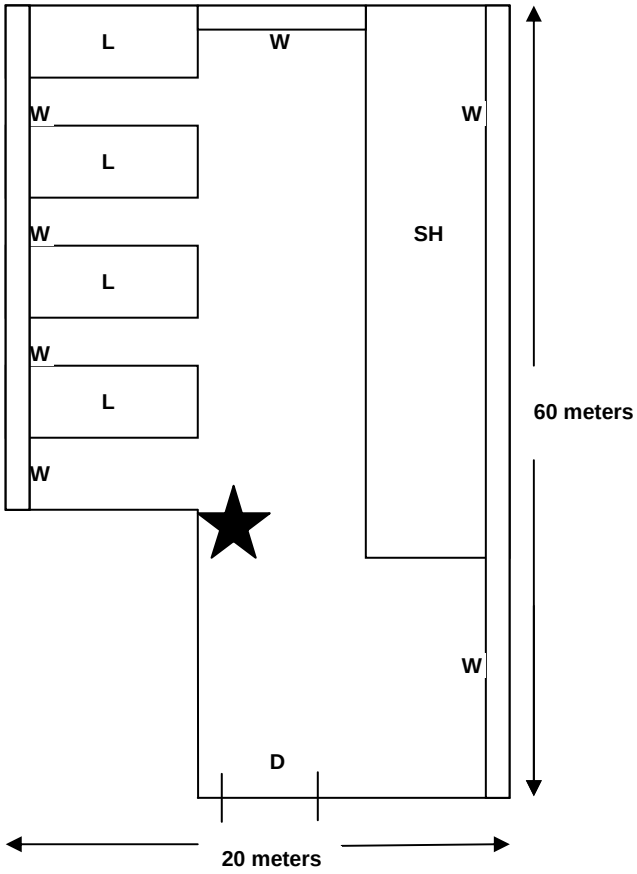
USSA Offices
Reception area



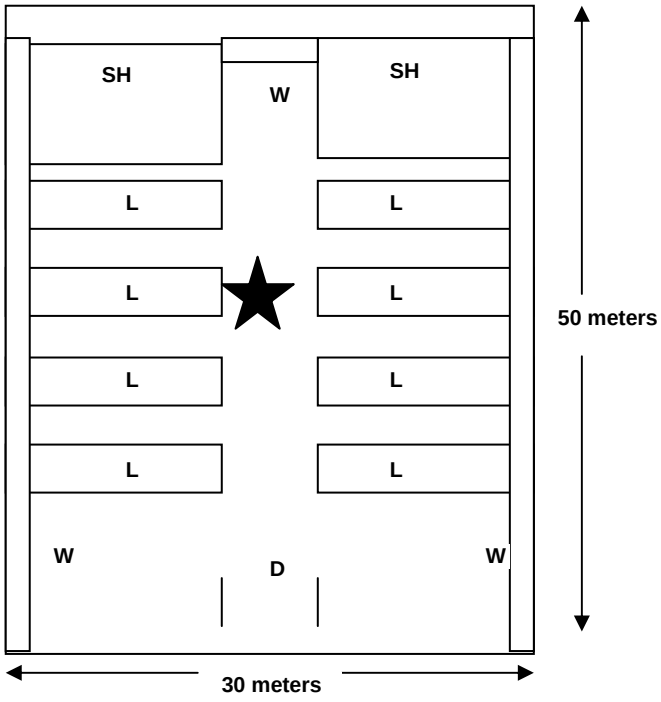
Store room



Change houses 3



Change house 2



5.2 Appendix B: Questionnaire

TB HISTORY **(Part One)**		
Have you ever had a positive TB skin test?		
Yes	No	Don't know
Have you ever had an abnormal chest x-ray?		
Yes	No	Don't know
If yes, how long ago?		
Have you recently had the mucous you cough up tested for TB?		
Yes	No	Don't know
If yes, were you told it was positive		
Yes	No	Don't know
Have you ever been told you have Infectious Tuberculosis?		
Yes	No	Don't know
If yes, how long ago?		
Have you ever been treated with medication for Infectious TB?		
Yes	No	Don't know
If yes, how many medications?		
One	Two	More than two
Are you still taking TB medicine?		
Yes	No	
Did you take all the TB medicine until the healthcare professional told you that you were finished?		
Yes	No	
Do you live with or have you been in close contact with someone who was recently diagnosed with TB? (e.g**.** shelter roommate, close friend, relative)		
Yes	No	Don't know
CURRENT SYMPTOMS **(Part Two)**		
Do you have a cough that has lasted longer than three weeks?		
Yes	No	
Do you cough up blood or mucous?		
Yes	No	
Have you lost your appetite? Aren't hungry?		
Yes	No	
Have you lost weight (more than 10 pounds) in the last two months without trying to?		
Yes	No	
Do you have night sweats (need to change the sheets or your clothes because they are wet)?		
Yes	No	