RESPIRATORY HEALTH STATUS IN RELATION TO OCCUPATIONAL EXPOSURE IN URANIUM MINING AND RECOVERY

BY

WOTAN REYNIER SIEGFRIED SWIEGERS

THESIS SUBMITTED AS PARTIAL FULFULLMENT OF THE REQUIREMENTS FOR THE PHILOSOPHIAE DOCTOR (Ph.D.) DEGREE IN COMMUNITY HEALTH

DEPARTMENT OF COMMUNITY HEALTH
FACULTY OF MEDICINE
UNIVERSITY OF PRETORIA
SOUTH AFRICA

SUPERVISOR: PROFESSOR CARL B. IJSSELMUIDEN
DEPARTMENT OF COMMUNITY HEALTH
UNIVERSITY OF PRETORIA
SOUTH AFRICA

OCTOBER 1999

Dedicated to my friend and mentor,

Professor M A (Attie) de Kock

Our real problem is in the hearts and minds of men.
It is not a problem of physics, but of ethics.
Man's skills have outstripped his morals.

His engineering - has leaped ahead of his wisdom.
We cannot cancel or call back his scientific advances,
but we can, and must, if the world is to survive,
help man to catch up.

In God's name, if we still believe in God.
Take him seriously, and somehow get control,
of what science has given to the world,
or else we shall likewise perish.

A. Einstein

ACKNOWLEDGMENTS

I am deeply grateful to many people who provided time, material and critique that assisted with the realisation of this thesis and would like to thank the following in particular:

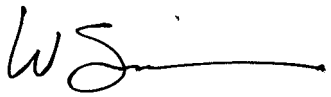
Prof M A de Kock, an outstanding clinical scientist and human being for support and encouragement through many years and for allowing me to use the opportunities that arose during the course of these projects. He taught me all I know about pulmonary medicine and research, and a great deal about life. None of this would have been possible without him.

Dr Robert Murray for broadening my horizons and for teaching me the value of past lessons learned and **Prof Margaret Becklake** for assisting with the initial research protocol. **Prof's Theunis V Z Kotze**, **D Kotze** and **Dr P Becker** for doing the statistical analysis. **Mr J H I Olivier**, **Prof J Klopper** and **Dr H J Wassermann**, (Tygerberg Hospital), for determining the uranium in the lung burden. **Dr Johan Deale**, (Tygerberg Hospital), for implementing the Sputum Cytology Programme. **Dr. H W Hitzeroth** of Genetic Services of the Department of National Health and Population Development for doing the (P_1 - typing) Alpha-1-Antitrypsin Study. **Erika Louwrens**, for typing and retyping this thesis.

Sister Rosa Thalwitzer and "the team", in particular, **Moira Ruziecki. Rössing Uranium Management** and employees for allowing me to use the occupational health data. I hope this thesis will enable them to explore new avenues for prevention. Last, but not least, **my family** for allowing me to spend so much of "their time" on reading and research. A special word of thanks to my son, **Wotan Swiegers (Jnr),** who assisted with the compiling of the references.

DECLARATION

I, the undersigned, declare that the work contained in this thesis (dissertation) is my own original work and it has not been submitted in any form for similar purposes to any University for a degree.

Signed: 

Date: 20 October 1995

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF GRAPHS

ABBREVIATIONS AND DEFINITIONS

AEC:	Atomic Energy Corporation (R.S.A.)
Alpha decay:	Radioactive disintegration resulting in emission of α-particle. Also alpha disintegration.
Alpha Particle:	Nucleus of helium atom of mass number four, consisting of two neutrons and two protons and so double positively charged. Emitted from natural or radioactive isotopes. Often written α-particle
ATC:	American Thoracic Society
Atomic number (Z):	Number of protons
BEIR IV	U.S. Academy of Science Committee on Biological Effects of Ionizing Radiation.
Best practical means	Term with statutory force since 1863, and the basis for control of atmospheric pollution in the UK. Defined as the best practicable means with regard to local conditions, financial implications and current technical knowledge, and includes the provision, maintenance and correct use of plant. Abbreviated BPM.
Beta decay:	Radioactive disintegration with the emission of an electron or positron accompanied by an uncharged antineutrino or neutrino. The mass number of the nucleus remains unchanged but the atomic number is increased by one or decreased by one depending on whether an electron or positron is emitted.
Beta particle:	An electron or positron emitted in beta decay from a radioactive isotope.
Bq:	Symbol for becquerel, the SI unit of radioactivity.
CNSLD	Chronic Non Specific Lung Disease
COPD	Chronic Obstructive Pulmonary Disease
Daughter Product	A nuclide that originates from the radioactive disintegration of a parent nuclide. Also decay product.
Decay:	The process of spontaneous transformation of a radionuclide. Radioactive Decay: Disintegration of the nucleus of an unstable nuclide by spontaneous emission of charged particle, photons, or both.
Dose equivalent:	The quantity obtained by multiplying the absorbed dose by a factor to allow for the different effectiveness of the various ionizing radiations in causing harm to tissues.
Dose:	General term for quantity of radiation.
ECCS	European Community for Coal and Steel
Element :	Material whose atoms all have the same number of protons.
EPA:	Environmental Protection Agency
ERS:	European Respiratory Society

Worker's Daily Exposure:	The average work shift concentration of radon progeny for each work area shall be used to calculate each miner's daily exposure. If no monitoring has been conducted in a work area on a particular day, the daily average work shift concentration for that area shall be determined by averaging the results obtained on the last day of the monitoring with the results from the next day that monitoring is conducted.
FEF_{25}	The forced expiratory flow after a quarter (25%) of the FVC has been exhaled.
FEF_{50}	The forced expiratory flow after half (50%) of the FVC has been exhaled.
FEF_{75}	The forced expiratory flow after three-quarters (75%) of the FVC has been exhaled.
FEV_1	The FEV_1 is the volume of air forcefully expired over the first 1 second of the FVC maneuver.
FEV_1%	The FEV_1% is the ratio of the FEV_1 and FVC expressed as a percent (i.e. FEV_1/FVC x 100)
FEV_1/FEVC%	The forced expiratory volume (over 1 second) divided by the forced inspiratory vital capacity expressed as a percentage.
FIVC	FIVC is the volume of gas that can be forcefully inspired from RV to TLC.
Follow-up Period	The length of time between a person entering an epidemiological study cohort and the present report (or the end of the study).
FRC	Functional residual capacity - the amount of air that remains in the lungs after a normal resting expiration.
FVC	The FVC is the volume of air that can be expired as forcefully and rapidly as possibly from TLC to RV.
FVC/FIVC	The forced vital capacity (FVC) divided by the forced inspiratory vital capacity (FIVC) expressed as a ratio.
Gamma Radiation	Electromagnetic radiation of high quantum energy emitted after nuclear reactions or by radioactive atoms when the nucleus is left in an excited state after emission of alpha or beta particles. Also gamma rays.
Half-Life:	The time required for a radioactive substance to decay to one half of its initial activity.
ICRP:	International Commission on Radiological Protection.
Ion:	Strictly, any atom or molecule that has resultant electric charge due to loss or gain of valency electrons. Free electrons are sometimes loosely classified as negative ions.
Ionisation:	Formation of ions by separating atoms, molecules or radicals, or by adding or subtracting electrons from atoms by strong electric fields in gas, or by weakening the electric attractions in a liquid, particularly water.

Ionising energy:	The energy required to produce an ion pair in a gas under specified conditions. Measured in eV. Air is about 32 eV.
Ionising radiation	Any electromagnetic or particulate radiation capable of producing ions, directly or indirectly, in its passage through matter
Isotope :	One of several nuclides with the same atomic number i.e. one of a set of chemically identical species of atoms which have the same atomic number but different mass numbers. A few elements have only one natural isotope.
Linear Hypothesis:	The hypothesis that excess risk is proportional to dose.
Mass number (A)	Number of protons plus neutrons.
MRC:	Medical Research Council.
MVV	The maximum volume that can be breathed per minute by voluntary effort.
NRPB	National Radiological Protection Board (U.K.)
Nuclear energy:	In principle, the binding energy of a system of particles forming an atomic nucleus. More usually, the energy released during nuclear reactions involving regrouping of such particles (e.g. fission or fusion processes). The term atomic energy is deprecated as it implies rearrangement of atoms rather than of nuclear particles.
Nuclide :	An atomic nucleus as characterized by its atomic number, its mass number and nuclear energy state.
PEFR	The maximum flow rate attained during an FVC maneuver recorded in litres per second.
Person Years (PY):	A standard technique for handling variable follow-up periods; multiply the number of persons by the number of years of follow-up. Person-years at Risk (PYR): In a life table analysis, the number of PY at risk of dying from disease, usually calculated from the time the miner enters the cohort until death or the end of follow-up. Some authors adjust the PYR for an assumed 10-year latent period for lung cancer by subtracting PYR accumulated during the first 10 years after a miner starts to work underground [see above, (Lagging)].
PIFR	The maximum inspiratory flow rate attained during an FIVC maneuver recorded in liters per second.
Radiation:	The dissemination of energy from a source. The energy falls off as the inverse square of the distance from the source in the absence of absorption. The term is applied to electromagnetic waves (radio waves, infrared, light, x-rays, ɣ-rays etc) and to acoustic waves. It is also applied to emitted particle (α, β, protons, neutrons etc)
Radon (Rn) or Radon and its progeny	Specifically refers to the "parent" noble gas (Rn-222), and its short-lived alpha radiation emitting radioactive decay products ("progeny" or "daughters"). Radon is a gas, the radon progeny are radioactive solids.

Rössing Worker	Rössing workers include all mine personnel who are employed by Rössing Uranium (eg drilling, blasting, haulage, maintenance, laboratories, administrative personnel etc)
RV	Residual volume - the amount of air that is left in the lung after a maximal inspiration.
Sievert (Sv):	The SI unit for dose equivalent, measured in grays times a quality factor for the type of radiation and a weighting factor for the tissue irradiated. Numerically equivalent to gray for electrons and X-rays irradiating the whole body. Symbol Sv. Sievert = grays of QF x modifying factors. The QF for alpha particles from inhaled radon progeny is generally considered to be in the range of 10 to 20.
Thoron	A metallic radioactive element, dark-gray in colour. Symbol Th, At. No. 90, r.a.m. 232.0381, mp 1845°C, rel.d. 11.2. Its abundance in the Earth's crust is 8.1ppm and there are few independent thorium minerals. It has six isotopes: Thoron progeny are the solid, short-lived, alpha radiation emitting decay products (progeny or daughters) of thoron gas.
TLC	Total lung capacity is the maximum amount of air that can be held in the lung after deep inspiration.
UNSCEAR	United Nations Scientific Committee of the effects of Atomic Radiation (U.S.)
Uranium	A hard grey metal. Symbol U, at no 92, r.a.m. 238.03, mp 1150°C, rel.d. 18.68. It has seven isotopes. Because the half life of uranium -235 is very much less than that of uranium -238 the relative abundance of these two isotopes has varied over time with uranium -235 being about 3% 2 x 10^9 years ago.
VC	Vital capacity - the volume of air from a maximal expiration to a maximum inspiration.
WHO	World Health Organisation
Worker's Daily Exposure	The average work shift concentration of radon progeny for each work area shall be used to calculate each miner's daily exposure. If no monitoring has been conducted in a work area on a particular day, the daily average work shift concentration for that area shall be determined by averaging the results obtained on the last day that monitoring is conducted.
Working Level (WL):	A standard measure of the alpha radiation in air. This energy can come from the radioactive decay of radon (Rn-222) and thoron (Rn-220) gases. The working level is defined as any combination of short-lived radon decay products per liter of air that will result in the emission of 1.3 x 10^5 million electron volts (MeV) of alpha energy during decay to lead-210.

Working Level Month (WLM):	A working level month (WLM) is the product of the radon progeny concentration in WL and the exposure duration in months. For example, if a miner is exposed at a concentration of 0.083 WL for 1 month (170 hours [hr]),* then the cumulative exposure for the month is 0.083 WLM. If the cumulative exposure of the same miner is 0.083 WLM for each of 12 consecutive months (2,040 hr), then the cumulative exposure for the year is 1 WLM.

SUMMARY

OBJECTIVE

The objective of this study is to examine the exposure- response relationship between prolonged exposure to low levels of silica, uranium, radon progeny and criteria pollutants and the respiratory health of uranium workers.

METHOD

Initially two pilot studies were done on selected groups of high-risk workers to determine the prevalence of alpha-1-antitrypsin deficiency and the retained burden of uranium in the lungs of exposed workers. The value of sputum cytology was also evaluated. A cross-sectional study was conducted in 1984 to determine the prevalence of spirometric abnormalities among uranium miners. The data from non-smokers without symptoms was used to develop lung function reference values relevant for the present population. Follow up analytical cross-sectional and case control studies were done in 1996 and 1999 to determine the mean independent effect of uranium on the respiratory health of miners and to detect abnormalities in both smokers and non-smokers. Data was collected on employment history, smoking habits, pulmonary function and chest radiographs. To determine the independent mean effect of uranium mining on the respiratory health of workers, only data of non-smokers in exposed cohorts were compared with unexposed control cohorts.

RESULTS

The prevalence of alpha-1-antitrypsin appeared to be high in workers with abnormal spirometric indices. The lung burden of retained uranium in workers in the final product recovery area was within normal limits. The sputum cytology was abandoned because it was found worldwide that cytological screening had no impact on population survival rates. Lung function prediction equations derived from multiple linear regressions were calculated

for the study population which differed from Schoenberg *et al* prediction equations. The data from the analytical cross-sectional study in1996 suggests that the level of exposure in this study group (without the confounding effect of cigarette smoking) is **not** associated with statistically significant impairment of lung function, increased prevalence of silicosis, tuberculosis and respiratory cancer. Only the FEF_{75} was found to be an indicator of early lung abnormality.

Data from the 1999 study supports the hypothesis that there is a small but significant exposure-response relationship between prolonged exposure to low levels of silica dust, and lung function abnormalities (in the absence of radiologically diagnosed silicosis). The prevalence of chronic obstructive pulmonary disease (COPD) and small airways disease (SAD) was small but significantly higher in exposed workers. The risk of developing COPD was 2.7 times higher for exposed workers. The risk for non-smokers was small but significant. The incidence of tuberculosis and lung cancer was not higher than expected (probably because ex-employees were not fully investigated).

CONCLUSION

Calculation of location specific prediction equations for different ethnic groups is advocated to enable the earliest detection of lung function abnormalities. FEF_{75} could be used as an early indicator of lung function impairment (provided strict quality control is maintained). Exposure to a combination of silica dust, radon progeny and smoking was associated with an increased risk of lung function abnormalities, but not with tuberculosis, silicosis and lung cancer. Conclusive assessment must await sufficient latency, and **ex-employees** must be investigated to establish the true magnitude and distribution of the effects of siliceous and uranium dust on the health of workers (which may continue after exposure cease).

OPSOMMING

DOELWIT

Die doelwit van hierdie studie was om die respiratoriese gesondheidstatus van uraanwerkers te bepaal wat langdurig blootgestel was aan lae vlakke van silika, uraanstof, omgewingsbesoedelingstowwe en radon.

METODE

Aanvanklik was twee loodsstudies van stapel gestuur om die voorkoms van alfa-1-antitrypsien te bepaal, en om die uraanlading in die longe van werkers vas te stel. Die waarde van sputum-sitologie was ook geevalueer. 'n Kruissnit-studie was in 1994 geloods om longfunksie abnormaliteite in werkers te identifiseer. Die inligting is gebruik om normale verwysingswaardes vir longfunksies in die studie populasie te bepaal. Opvolg analitiese studies was gedoen in 1996 en 1999 om die onafhanklike effek van uraan sowel as die invloed van lugbesoedeling op die respiratoriese sisteem te bepaal in rokers en nie-rokers. Inligting rakende werk en rooksgeskiedenes, longfunksie en borskas x-strale is ingewin. Om die onafhanklike invloed van lugbesoedeling op die respiratoriese status te bepaal, is slegs inligting van blootgestelde, nie-rokers gebruik en vergelyk met nie blootgestelde, nie-rokers.

RESULTATE

Die voorkomssyfer van alfa-1-antitripsien blyk hoog te wees in werkers met abnormale longfunksies. Die uraanlading in die longe was binne normale perke. Die sputum sitologie projek is laat vaar omdat wêreldwye resultate nie enige impak op die oorlewingsyfers van pasiënte met longkanker gehad het nie. Voorspelde normale waardes vir longfunksies was bereken vir dié studie populasie wat in sommige opsigte verskil het van die van Schoenberg *et al.* Inligting verkry tydens die 1996 kohort studie het geen onafhanklike effek van lugbesoedeling op die longfunksie van nie-rokers aangetoon nie. Die vloei by 75% van vitale kapasiteit (nie algemeen aanvaarde maatstaf) was egter statisties beduidend abnormaal.

Die inlingting verkry in die 1999 kohort studie, staaf die hipotese dat langdurende, laegraadse blootstelling wél geassosieer word met longfunksie abnormaliteite in beide rokers en nie-rokers (in die afwesigheid van radiologies bewese silikose). Die insidensie van kroniese obstruktiewe lugwegsiekte was statisties beduidend verhoog in blootgestelde werkers. Die risiko vir nie-rokers was klein, maar statistiese beduidend. Die voorkoms van tuberkulose en longkanker was nie hoër as verwag nie (waarskynlik omdat vorige werknemers nie volledig ondersoek is nie).

GEVOLGTREKKING

Om longfunksie abnormaliteite so vroeg as moontlik op te spoor, moet normale longfunksie verwysingswaardes vir verskillende etniese groepe bepaal word. Die vloei by 75% van vitale kapasiteit kan gebruik word as 'n indikator van vroëe longfunksie abnormaliteite (indien streng kwaliteitkontrole toegepas word). Blootstelling aan 'n kombinasie van lugbesoedelingstowwe en rook word geassosieer met 'n verhoogde voorkoms van longfunksie abnormaliteite en kroniese obstruktiewe lugweg siekte, maar nié met 'n verhoogde voorkoms van tuberkulose, silikose en longkanker nie. Finale gevolgtrekkings kan slegs gemaak word nadat voldoende voorsiening vir latentheid gemaak is. Vorige werknemers moet ondersoek word om die volledige impak en distribusie van abnormaliteite wat met uraanmynbou geassosieer word, te evalueer, (effekte wat vererger nadat blootstelling gestaak is).