PENINSULA TECHNIKON

WHOLEBODY AND HAND-ARM VIBRATION: Quantifying the risk of Exposure to Human Vibration at Rössing Uranium Ltd, Namibia

Thesis submitted in fulfilment of the requirements for the Degree of Masters of Technology in Environmental Health

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STATEMENT OF DECLARATION

WHOLEBODY AND HAND-ARM VIBRATION: Quantifying the Risk of Exposure to Human Vibration at Rössing Uranium Ltd, Namibia

With this statement, I, Fulencia Naomi Burns, affirm that the research upon which this thesis is supported, is my own (except where acknowledgements indicate otherwise), and that neither the entire research endeavor, nor any part of it has been, is being, or is to be submitted for another degree in this or any other educational institution.

Fulencia Naomi Burns **SEPTEMBER 2004**

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ABSTRACT

AIM & OBJECTIVES: *a)* To quantify human vibration exposures among the various similar occupational groups present on the mine, *b)* To determine the degree of vibration risk posed onto the mineworkers and *c)* To recommend and implement a sustainable human vibration management control programme.

METHODOLOGY: A cross-sectional descriptive study design was carried out on 135 mine workers employed in various similar occupational groups at Rössing Uranium mine, Namibia. Data acquisition originated from a multi-stage proportionally stratified random sampling technique. An approved Human Vibration measuring instrument was utilized to measure Hand-arm and Wholebody vibration exposure levels [A*eq* (m/s^2)] prevalent among the similar exposure groups. A structured questionnaire, developed specifically for the actual work environment enabled the collection of information such as work history, type of vibration exposure, exposure duration and vibration symptoms. Furthermore, group specific results [A*(8)*] were computed by means of the latest internationally accepted Health & Safety Executive Vibration calculators. In addition, statistical analyses were performed in order to establish the occupational groups that are at increased risk for the development of hand-arm and wholebody vibration induced health disorders.

RESULTS: Considerable higher levels of exposure in the Diesel/motor mechanics and the Fitters when compared to international hand-arm vibration exposure action value of 2.5m/s^2 [A *(8)* = 6.0 m/s^2 and 4.0 m/s^2 respectively] were noted. Similarly, with the estimation of a relationship between type of occupation and individual Aeq measured results, the significant p-values computed for the Bricklayer, Diesel/motor mechanics, the Plant electricians and the Panel beaters, demonstrated that these occupations are significant predictors of Aeq, and were subsequently identified as the occupations posing the highest vibration risks. In addition, of the 13 occupational exposure groups assessed for Hand-arm vibration, a higher proportion of 61.5% (8) groups exceeded the Hand-arm vibration daily exposure action value of 2.5 m/s^2. Subsequently, exceedences that were measured ranged from a minimum of 2.6 m/s^2 to a maximum of 11.40 m/s^2.

Out of the 16 occupational exposure groups that were assessed for wholebody vibration, 7(44%) exceeded the daily exposure action value [A*(8)* values > 0.5m/s^2]. Results obtained from the WB vibration calculator, showed that the occupations exhibiting the highest A*(8)* generated vibration levels in the study, were the Fine Crushing operators. Consequently the maintenance workers working on the Fine Crushing plant area when it is in operation will be exposed to similar levels [A*(8)* = 1.43 m/s^2]. The Pit equipment operators [A*(8)* = 1.39 m/s^2] showed the second highest A*(8)* exposures within their group followed by the MNO^2 plant equipment operators [A*(8)* = 1.22 m/s^2].The major wholebody vibration sources within these groups were a Track dozer (A*eq* = 2.03 m/s^2) used by the Open Pit equipment Operators and a Bell truck (A*eq* = 1.83 m/s^2) operated by the MNO^2 plant equipment operators. Similarly, the area at Fine Crushing posing the highest threat to whole body vibration was found to be at the Tertiary Crushers (A*eq* = 2.72 m/s^2). In overall, five (5) high risks, fourteen (14) moderate risks and four (4) low risk areas were identified mine wide.

CONCLUSIONS: This research study concluded that the vibration results measured in both the Wholebody and Hand-arm vibration exposure groups are sufficiently high within a number of occupations for the potential development of vibration-induced health disorders. In addition, the results confirmed the need to develop and implement a sustainable Human Vibration control program in identified high to medium risk areas, equipment and hand held power tools.

Key words: Wholebody vibration, Hand-arm vibration, Raynaud's Phenomenon, Low Back Pain, A(8) results, Aeq

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CHAPTER 1

1.1 INTRODUCTION

The monitoring and exposure of human vibration is fast becoming a major concern in many industrial workplace environments. This is largely due to an increase in occupational injuries caused by exposure to hazardous vibration levels. Many companies are also facing increased threats of compensation claims each year because of workers that were exposed to long, continuous vibration, without the availability of adequate protection or education. In the United States alone, it is reported that there are some 8-10 million people who are regularly exposed each day to occupational vibration and many more worldwide.[1]

Human vibration is a physical health hazard and is categorized according to the type of effect it has on specific human body parts which in turn depends on the type of job and equipment or tool being used during a work shift. Alternately, it is divided into Hand-arm vibration (HAV), affecting workers who use all manner of vibrating pneumatic, electrical, hydraulic and gasoline powered hand held tools and secondly, Whole-body vibration (WBV) which are associated with the use of industrial vehicles such as Forklifts, Haultrucks, Track dozers and also exposure to occupants/operators working on vibrating plant structures or inside buildings where a vibration source is present or located near to the building.

However, on rare occasions, "crossover exposures" between WBV and HAV do occur.[1] This alternately would depend on the type of job the worker is performing. An example of such a condition would be in the event of hand-tool usage such as a large size impact tool.

Due to the weight of the tool and awkward positions that a hand tool operator has to adapt to sometimes, he/she is forced to let the tool rest against his/her torso in an attempt to make the task more comfortable and also to damp the vibration. This results in vibration being transmitted to the hand-arm system as well as to the whole body. There are also instances where WBV and HAV exposures occur simultaneously, such as an equipment operator of an Industrial truck where vibration exposure is transmitted via the seating or floor and the steering wheel.

Continued, habitual use of vibrating hand tools and equipment are connected with various patterns of disease outcomes. These health effects vary considerably from situation to situation as other factors such as ergonomic design, damping and attenuation; resonance and many more have a great influence on the exposure characteristics and intensity levels of vibration exposure experienced by workers. Thus health related vibration disorders range from gastrointestinal disorders, vestibular disorders, back problems to visual disorders for workers exposed to whole body vibration and Raynaud's Phenomenon or cumulatively, Hand-arm Vibration Syndrome (HAVS) for exposure to hand-arm vibration. According to the level or intensity and duration of vibration, the effects on the worker will rank from simple perception to discomfort and severe pain.[2]

At present, several existing international standards impose limitations to human vibration exposure levels. These standards discuss the general aspects of vibration, the parameters that need to be measured, the measurement methodologies, and in particular, the vibration level thresholds to which companies/industries should conform.

However, due to the intricate nature of this type of health hazard, a number of different control measures are warranted in order to prevent, control and alternatively sustain vibration exposure levels on workers. Some of these measures will include a combination of engineering, administrative and medical surveillance practices for both types of vibration.

Human Vibration and its effect on the human body is still a relatively new type of occupational health hazard in Namibia and consequently receive very little attention. This dissertation will report on the findings of a research study performed on a mine located in Namibia, known as Rössing Uranium Limited. Alternately, this is the first attempt of its sort done in Namibia. The level of risk and the extent of whole body and hand-arm vibration exposure posed on the mineworkers with regard to daily vibrating tool and equipment usage is explored, interpreted and discussed.

Rössing Uranium Ltd is a huge international industrialist, which operates a grand open cast uranium mine and is located about 65 kilometres from the coastal town of Swakopmund, in the vast open plains of the Namib Desert. This region is characterised by sparse vegetation, rocky outcrops and gravel plains with an average rainfall of approximately 30mm per year and mild to very hot weather conditions throughout the year. This mine is one of the largest open cast uranium mines in the world and with solid reserves will continue to serve the world energy industry. It is also hoped that the monitoring strategies developed and followed during this vibration research study and the results that were obtained regarding the major risk areas within the various occupational exposure groups will aid similar industries in Namibia to identify potential human vibration risks and successfully develop and sustain an Occupational human vibration control program.

CHAPTER 2

2.1 THE PROBLEM AND ITS SETTING

In today's work environment, there are many potentially serious occupational health hazards that are detrimental to the health of workers. Some are well known, heavily explored and reported whereas others such as vibration is a type of health hazard that still needs a lot of future exploration and research in order to fully understand its effects. This hazard exists in a number of industries such as a power saw operator in the woodworking industry, a cutter in the stone cutting industry to a heavy equipment operator in the mining industry.

In this chapter, the main purpose of this study is documented together with its related sub-problems, hypotheses, delimitations, assumptions and deliminations. The relative importance for conducting this research endeavour is also emphasized.

2.2 **The Statement of the problem**

The purpose of this study was to evaluate the occurrence of Whole body and Hand- arm vibration at Rõssing Uranium Ltd with overall reference to job characteristics, administrative practices and technological practices in order to develop a sustainable Human Vibration management control programme.

2.3 The Statement of the sub-problems

2.3.1 Sub - problem one

The first sub problem was to evaluate job task exposure during uranium mining, processing and production in order to determine whether the execution of specific job tasks is associated with an increased risk to human vibration.

2.3.2 Sub - problem two

The second sub problem was to evaluate job characteristics in order to quantify the potential risk due to exposure within certain areas and the use of specific equipment and tools in the open cast-mining environment.

2.3.3 Sub - problem three

The third sub problem was to identify the key risk factors associated with human vibration exposure in order to develop a sustainable human vibration management control programme.

2.4 HYPOTHESES FORMULATION

Hypotheses are simply tentative predictions about the nature and direction of the relationship between two or more variables. Hence, the hypotheses for this research study were derived from the sub-problems as previously mentioned. In addition, the major predictor variables that led to the formulation of these hypotheses were type of job task, magnitude of vibration exposure, type of tools and equipment and exposure areas.

Therefore, the following three statements outlined the expected outcomes of this research study:

2.4.1 Hypothesis one

It is hypothesised that there is an association between the type of job task performed and the magnitude of vibration exposure posed onto the worker.

2.4.2 Hypothesis two

It is hypothesised that the extent of the vibration risk present within certain areas on the mine will vary according to the type of tools and equipment being used within these identified exposure areas.

2.4.3 Hypothesis three

It is hypothesised that the identified key risk factors will favour the formulation of a sustainable human vibration management control programme.

2.5 DELIMITATIONS

Since the research project intended to obtain base line measurements, it was attempted to include the majority of the workforce for participation in the study.

2.5.1 Inclusion Criteria

The sample population was limited to all fulltime-registered workers of Rössing Uranium mine who through qualitative assessment were identified as being at risk of potential exposure to vibration. This sample included workers whose overall work activities involved driving or operating any type of transportation equipment and whose work involves the operation of vibrating hand-held power tools.

2.5.2 Exclusion Criteria

Contractors or sub-contractors working at Rössing Uranium were excluded from the study. However, since quantitative baseline measurements were obtained through the measurements performed on the Rössing mine workers, this information might be used to qualitatively identify possible vibration risk areas among the contractor groups on the mine and consequently control the risks.

2.6 ASSUMPTIONS

2.6.1 First assumption

The first assumption was that workers would be willing to participate in the study and give honest responses.

2.6.2 Second assumption

The second assumption was that any level of vibration dose on the mine would contribute a risk to human health.

2.6.3 Third assumption

The third assumption was that exposure to one specific tool or equipment in one specific job category is perceived to be similar for all other workers inside that same job category.

2.6.4 Fourth assumption

The fourth assumption was that the Human Vibration calculators used during the generation of the final A(8) values, yielded valid and reliable results.

2.6.5 Fifth assumption

The fifth assumption was that the calibration procedure followed yielded valid measurement results.

2.6.6 Sixth assumption

The sixth assumption was that the time of day of sampling would not affect the outcome of the end vibration results.

2.7 DELIMINATIONS AND ABBREVIATIONS

A brief overview of the conceptualisation of the major terms and abbreviations used in the dissertation is presented in this section in order to enhance the understanding of the study under investigation.

Whole body vibration (WBV):	Whole body vibration refers to vibration transmitted to the entire body via the feet in standing work and the buttocks and back in seated work.[16]
Hand-arm vibration (HAV):	The mechanical vibration that, when transmitted to the human hand-arm system, entails risks to the health and safety of workers, in particular vascular, bone or joint, neurological, or muscular disorders.[16]
Similar Exposed Group (SEG):	Also referred to as Homogeneous exposure groups. In the context of this study, an SEG is a group of workers who are performing more or less the same tasks and who subsequently are exposed to similar health hazards.

Accelerometer:	It is a transducer that produces an output, which is proportional to the acceleration in some specified axis.[7]
Acceleration:	A vector quantity that specifies the rate of change of velocity (metre per second squared, m/s^2)[7]
Resonance:	Resonance, or natural frequency, can be described wherein the human body as well as other physical structures respond by acting as a sort of a vibration "tuner" rejecting certain impinging vibration frequencies and responding or "tuning" to other vibration frequencies by actually amplifying and exacerbating these impinging vibration frequencies.[4]
Exposure Action Value (EAV):	A sufficient level of daily worker exposure to vibration to warrant employers taking appropriate actions to control the exposure.[16]
Exposure Limit Value (ELV):	Daily level of worker exposure where the risk to health is estimated to be sufficiently high that further exposure must be prohibited.[16]
Machinery:	Machinery is an assembly of lined parts or components at least one of which moves.[17]

A (8) value:	Vibration in meters per second squared normalised to 8 hours. Consequently, a cumulative exposure using an average acceleration adjusted to represent an 8-hour working day is described.[7]
Building:	Is a static construction used for habitation or allocated to any other human activity, including offices, factories, hospitals, schools, and day-care centres.[19]
CE Marking:	This indicates that the manufacturer or importer claims compliance with the relevant requirements of all directives within the scope of which the product falls.[17]
Ergonomical seat:	Type of seat that can be adjusted automatically or manually according to the person's body weight, and that has settings to allow the operator to change the position of the seat according to his/her preference.
Raynaud's phenomenon:	A disorder of blood circulation in the fingers. This condition aggravate with cold exposure.
Taylor-Pelmear scale:	System used to classify vibration-induced Raynaud's phenomenon in four stages.

ISO:	International Organisation for Standardisation
TLV:	Threshold Limit Value
US ACGIH:	American Conference of Governmental Industrial Hygienists
SIMRAC:	Safety in Mines Research Advisory Committee
PPE:	Personal Protective Equipment
VDV:	Vibration Dose Value
RMS:	Root Mean Squared
Hz:	Hertz
Aeq:	Equivalent acceleration level
HAVS:	Hand-arm Vibration Syndrome
HSE:	Health and Safety Executive (in the United Kingdom)
x - axis:	Infinite straight line through the central point of an object running from back to front.[7]

y - axis:	Infinite straight line through the central point of an object running from left to right.[7]
z - axis:	Infinite straight line through the central point of an object running perpendicular to the x- and y- axis and from top to bottom.[7]

2.8 SIGNIFICANCE OF THE STUDY

The Namibian society lacks relevant information regarding any previous studies done pertaining to the risk of Human Vibration on the Namibian industrial workers. It is also noteworthy that no existing Namibian legislation relating to human vibration is available in Namibia. This consequently adversely influences the evaluation of any vibration related health effects on the human body. Hence, a need was identified to obtain more information on this ergonomical health risk factor to broaden knowledge and understanding in order to identify, prevent and sustainably control the effects of human vibration exposure.

The low-grade nature of the ore body of Rössing Uranium Ltd and the extremely competitive global markets require the industrialist to significantly and continuously improve on its operating efficiency. This in turn necessitates the continuous improvement of the health and comfort of the working environment to ensure a healthy and productive workforce. Since little information and inadequate statistical data relating to the risk of human vibration and its effects could be obtained, research in this area was seen to be inevitable. Prior to the commencement of this research endeavour, no base line data was available to estimate the current extent of human vibration exposure on the mine in question or in other related industries inside the Republic of Namibia.

With this report, the researcher intended to develop such base line data, which portrays the magnitude of the vibration-induced exposures on the mineworkers of Rössing Uranium Ltd. Consequently, this data identify the necessary actions to be taken to remedy the situation at the mine and reduce the reported levels in the identified risk areas to as low as reasonably achievable.

Hence, with this study, it would be rational to quantify the vibration exposure levels among the mineworkers to ascertain which areas or occupational exposure groups working with certain type of equipment and tools are exposed to significant risks of vibration.

(The reader is referred to Figure one, page 15 for a geographical map of Namibia representing the location of Rössing Uranium limited.)

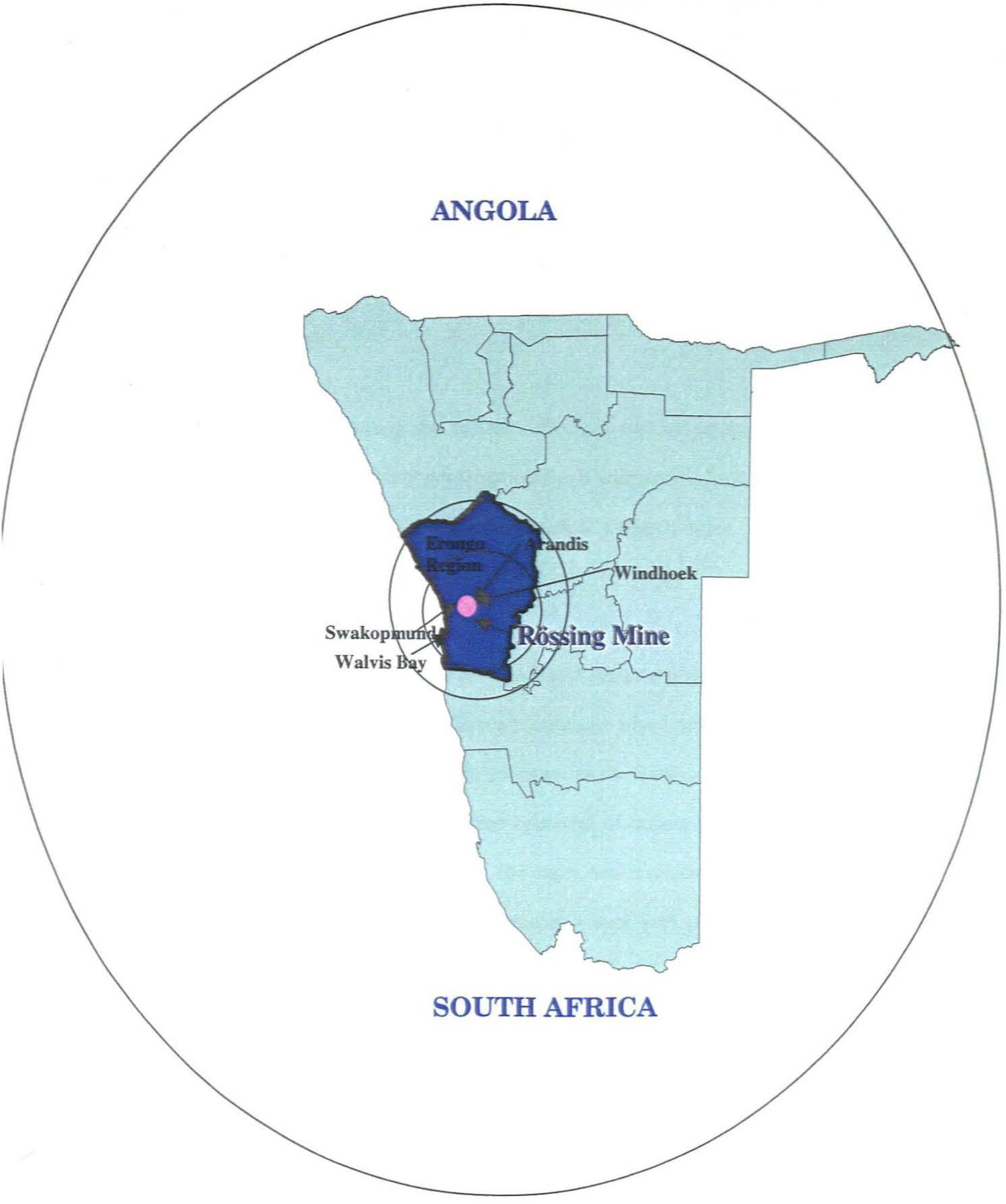


Figure 1: Map of the Republic of Namibia illustrating the geographical location of Rössing Uranium limited and the surrounding Namibian towns.

Source: Rössing Uranium website: http://www.rossing.com.na

CHAPTER 3

REVIEW OF THE RELATED LITERATURE

3.1 Introduction

Over the years, human vibration and its health effects on tool and equipment operators have achieved much publicised attention internationally. It was studied from as early as the 18th century and today it is still a very controversial research topic, largely due to its complexity.

Human exposure to vibration is normally evaluated separately in the form of Wholebody and Hand-arm vibration. However, there are instances where workers can be exposed to both simultaneously. Heavy equipment operators in the mining industry are most often exposed to whole body vibration whereas operators of impact tools, grinders and hand drills are exposed to hand-arm vibration. The major health effects are Hand-arm vibration syndrome (HAVS) for exposure to HAV and low back pain problems for exposure to WBV. Worldwide, several strategies are applied to minimize occupational vibration. Some of these measures include limiting exposure times, setting of control limits, applying purchasing criterions, the use of Personal Protective Equipment (PPE), avoiding constant vibration exposure, education and medical surveillance.

In this chapter, an overall picture is given pertaining to the origin and major characteristics of human vibration, together with the related standards, measurement principles and control measures.

3.2 The History of Hand-arm and Whole body vibration

Pneumatic hand tools were first used in the French mines at the start of 1839.[3] In 1862, Dr. Maurice Raynaud, a French physician, first described the paraesthesia followed by finger blanching attacks in females who were exposed to cold temperatures, but not vibration; this condition became known as Primary Raynaud's Disease. In 1911, Loriga in Italy first briefly described these symptoms in miners using vibrating pneumatic hand-tools. Nevertheless, it was not until the famous Hamilton study, conducted by Dr. Alice Hamilton, appeared in 1918 that the association between the use of vibrating tools and disease became more apparent.[4]

Awareness of Secondary Raynaud's phenomenon and its causes grew during the 1940s and 1950s. The Taylor-Pelmear scale published in 1975 allowed the condition to be assessed in a more consistent way. In 1987, the Stockholm workshop revised the aforementioned scale and divided the condition in 2 parts: vascular and neurological symptoms. The researchers looked at each hand separately and discounted seasonal variations in symptoms.[3]

In 1977, the International Labour Office (ILO) recognised vibration as an occupational disease and recommended that measures be taken to protect employees from the adverse health effects caused by this physical health hazard.[5] Locally, in Africa, a study conducted by *Franz, et al*[6], in 1987 concluded that workers in certain occupations in the South African gold mining industry might be at risk of exposure to human vibration. This hypothesis has been supported meaningfully when two Safeties in Mines Research Advisory Committee (SIMRAC) Projects, GEN 503 and HEALTH 703 confirmed this a few years later.[7,8]

Hence, in 1999, GEN 503 found that vibration levels in the South African mining industry were sufficiently high to increase the risk of vibration-induced disorders. This project was followed by HEALTH 703, which proved that HAVS (Hand-arm vibration syndrome) and WBV (Whole body vibration) occurred in the mining industry. Similarly, a pilot study done by *Joubert*[9], at the port of Durban, due to a result of complaints and an increase rate in sick leave amongst the forklift drivers showed that the majority of the vibration results exceeded the EEC machinery directive vibration exposure limit of 0.7 m/s^2 by up to four folds.

In 1998, *Bovenzi et.al*[10] conducted a review on past epidemiologic studies (1986-1997) on the relationship between exposure to whole-body vibration and low back pain. Their aim was to update the information on the epidemiologic evidence that existed on the adverse health effects of whole body vibration. They concluded that research design and the quality of exposure and health effect data in the field of WBV had improved over the past years. However the epidemiologic evidence found was not sufficient to outline a clear exposure response relationship between WBV and lower back disorders.

This was also the finding in a similar extensive review done on epidemiological literature on whole body vibration exposure and low back pain in 2000. This review included studies that were conducted from the middle of 1992 up to 1999. The study review concluded that whole-body vibrations might contribute to low back pains, however, the exposure – response relationship had not been clarified. Hence, they recommended that there was a need for good prospective studies with repeated measurements of exposure analyses of work postures and clear definitions and sub groupings of low back pain.[11]

Even though a lot of the work on human vibration is inconclusive, many studies do suggest that exposure to vibration is associated with musculoskeletal disorders. A review of the literature suggests that long-term exposure to whole-body vibration is related to degenerative changes of the spine and likely contribute to pathogenesis of disorders of female reproductive disorders.[12]

Subsequently, a justification for the relationship between dose and HAVS prevalence and symptom severity was provided by two studies done by *Bovenzi et al.* in 1988 and *Mirbod et al.* in 1992. Both studies found a statistically significant correlation between the severity of symptoms (graded according to the Taylor-Pelmear scale) and a dose measure based on total exposure time.[13]

3.2.1 HUMAN VIBRATION LEGISLATION

In Namibia, very little legislation and/or regulations exist on the risk of Human vibration onto the human body, but this is expected to change, as more industries will become aware of the long-term health effects of vibration induce exposure onto its workers. Internationally however, this type of health hazard is not unfamiliar and has earned much publicised attention over the years. Currently a number of standards exist, for example SABS ISO 2631-1, SABS ISO 8662, ISO 2631-2 to mention a few. These standards are used as guidance during the measurement, evaluation and assessment of human vibration. They also identifies legal vibration limits to which an industry or company must comply.

However, legal vibration levels vary between countries and jurisdictions. In the UK (United Kingdom), the HSE (Health and Safety Executive) recommends for hand-transmitted vibration a program of preventative measures and health surveillance at an action level equivalent to 2.8 m/s^2 for 8 hours. The US ACGIH (American Conference of Governmental Industrial Hygienists) recommends a daily exposure TLV (Threshold Limit Value) of $4m/s^2$.[14]

The EU (European Union) adopted a Human Vibration Direction on April 5, 2002 within which warning and action limit values were set. This directive established guidelines with respect to human exposure to hand-arm and whole-body vibration that would ultimately become law in the member nations of the EU. Subsequently, the main requirements of the new vibration directive are:

- Reduce vibration risk and exposure to a minimum,
- Assess risk and exposure levels,
- When the EAV is exceeded, plan and implement a programme of measures to reduce exposure,
- When the EAV is exceeded, provided appropriate health surveillance,
- Keep exposure below the ELV and
- Provide information and training for vibration-exposed employees.

The Directive also requires all European Union member states to introduce implementing legislation by 6th July 2005 on the control of risk from exposure to vibration at work.[15]

Rössing Uranium Limited has adapted and is making use of the requirements specified by the International Standard Organization (ISO) and the European Directive for Human Vibration. When setting control limits, it can be said that the mine is very "conservative" in comparison with other mines. The mine therefore strives to always maintain a standard, which is believed, exceeds the requirements of general international standards.

3.2.2 Human Vibration Exposure Action and Limit Values

The daily exposure action and limit values for both types of vibration stated in the European directive and ISO standards and which are applied at Rössing Uranium are:[16]

3.2.2.1 Hand-Arm Vibration

Daily Exposure Action and Limit values are set for a standardised reference period of 8 hours and are extensively used in industry in order to regulate vibration exposure.

- **EAV (Daily Exposure Action Value):** 2.5 m/s^2 standardised to an 8-hour reference period
- **EAL (Daily Exposure Limit Value):** 5.0 m/s^2 standardised to an 8-hour reference period

3.2.2.2 Whole Body Vibration

Standardised to a working day of 8 hours, an **Exposure Action Level** has been set at **0.5** $\mathbf{m/s^2}$ with an **Exposure Limit Value of 1.15** $\mathbf{m/s^2}$.

3.2.3 Legislative Requirements Pertaining to Machine Vibration

There is an overall duty to reduce vibration, so as far is reasonably practicable, in order to minimise the risk to human vibration exposure. Hence, the Council of the European Communities adopted a new Directive (89/392/EEC) requiring the approximation of the laws of the member states relating to machinery on the 14th of June 1989. This directive was last amended in 1998 and is now known as 98/37/EC.[17] The intention of this legislation is to assist industry by reducing barriers to trade within the Single Market by ensuring a common policy of safety and supply of machinery across the EEA (European Economic Area).[18] As a result, the Directive places certain requirements on manufacturers to declare information on the vibration levels generated by any equipment, whether for domestic, commercial or industrial applications that has parts actuated by a power source other than manual effort.

The principal aim for implementing such a directive is to reduce the level of vibration exposure generated from the source, before it comes into contact with the operator. In this sense, human vibration exposure is prevented from the start. In addition, the compliance to this directive is demonstrated through CE marking affixed to the equipment when complete and supported by a declaration of conformity signed by the manufacturer.

Machinery is split in two categories:[15]

1) Machinery of a particularly hazardous nature, which is listed in the Directive at Annex IV. These include chainsaws, woodworking machinery etc. These products must be submitted to an approved body, which will undertake full testing.

Then the manufacturer or importer must make a Declaration of Conformity and affix CE marking.

2) All other machines must also conform to the essential health and safety requirements listed in Annex 1 of the Directive. However, the manufacturer or importer may complete the assessment of conformity him/herself.

3.2.4 Legislation pertaining to Human Response to Building Vibration

Current Standards used in industry related to human response to building vibration are:

- **British Standard BS 6472: 1992** - Guide to the evaluation of human exposure to vibration in buildings (1 Hz to 80 Hz)
- **International Standard ISO 2631-2: 2003** - Mechanical vibration and shock, evaluation of human exposure to Wholebody vibration – Part 2 Vibrations in buildings (1 Hz to 80 Hz)

These standards are concerned about human exposure to whole body vibration and shock inside buildings with respect to the comfort and annoyance of the occupants. It characterises the measurement method for vibration in buildings. Hence the direction, location, duration and reporting of this type of human vibration is explained.

3.2.4.1 Action and Limit values for Human Vibration Inside Buildings

The threshold of perception for human beings typically falls at frequencies between 1 – 80 Hz. Vibrations above these levels can disturb, startle, cause annoyance or interfere with work activities. The acceptable limits for this type of vibration will be the same as that specified for Whole body vibration. Standardised to a working day of 8 hours, an **Exposure Action Level** has been set **at 0.5 m/s^2** with an **Exposure Limit Value of 1.15 m/s^2**. The highest vibration dose, measured in the three axes will be used to calculate the daily dose.[19]

3.3 HUMAN VIBRATION

The role of man as the operator of technical systems is ever increasing. However, the vibrations of machines, acting on man, can reduce the productivity of labour and its quality significantly.[20] This type of hazard and its effects have been recognised in various occupations worldwide for many years. These include the agricultural industry, aviation, motor mechanics and mining industry just to mention a few.

The rapid motion of an object such as a pneumatic drill, chainsaw, tractor seat or the seat of mining or earthmoving equipment causes vibration. Hence, vibration can cause permanent damage to the health of workers including bone damage, stomach and digestive problems, heart problems and varicose veins.[62] However, the health effects vary considerably from situation to situation as other factors such as ergonomic design, damping and attenuation, resonance and many more have a great influence on the exposure characteristics and intensity levels of vibration exposure experienced by employees.[21]

The difference in the exposures of HAV and WBV was described in a study conducted by *Issever et al.*[22] The purpose of the study was to assess the effects of machine-induced vibration on workers and to determine effective precautions for vibration-induced trauma. The study group consisted of 114 workers who were randomly selected: 50 rock drill workers and 64 heavy truck vehicle operators. Fifty-four office workers were selected as controls. The study and control groups were age-matched. The Medical Committee of Vibration Disease, Japanese Association of Industrial Health, interviewed all subjects to determine subjective symptoms using a 38-item questionnaire. Researchers found that complaints of pain in the fingers, sensitivity to cold, numbness and pain of fingers at night, weakness of static position, wrist-elbow pain, difficulty in bending and stretching elbow, pain in shoulder when holding up arms, lower back pain, sleeping disturbance and hearing difficulty were significantly higher in rock drillers than heavy vehicle operators and office workers ($p < 0.05$-0.01). They concluded that permanent vibration exposures could cause negative physical effects that may lead to the development of occupational diseases. In order to be protected against whole-body and hand-arm vibrations, technical and medical measures must be taken into account.

The medical effects of HAV and WBV are distinctly very different, as are their vibration exposure patterns and physical characteristics such as acceleration levels, vibration frequencies, and pathways into the human body. Therefore, HAV & WBV are normally discussed separately. Although they share a common physics, they do not share a common physiology nor do they share the same safety and health effects.[23]

3.4 OCCUPATIONAL EXPOSURE TO HAND-ARM VIBRATION

Millions of people in the workplace are exposed to potential injuries from vibrations caused by powered hand tools worldwide. Significant examples of such hand tools in specifically the mining industry are jackhammers, different size of impact tools, grinders, hand drills, needlescalers etc.

A postal survey conducted for the Health and Safety Executive (HSE) by the Medical Research Council by *Palmer et.al*[15] in 1999 estimated that about 4.8 million people in the United Kingdom alone are exposed regularly to HAV, including 1.2 million men and 44000 women above the HSE's recommended action level of 2.8m/s^2. Among men, the most common exposure sources were found in occupations such as maintenance fitters, carpenters, joiners, electricians, motor mechanics, plumbers, and builders. However, among the women, the most common exposure source was floor polishers and the most commonly exposed occupation was domestic worker or cleaner.[24]

Exposure to hand-transmitted vibration is difficult to quantify. Not only does the magnitude of the vibration vary with operating conditions, but also the size, strength and the manner of grip of the operators.[7] Depending on the type and place of work, vibration can enter one arm only or both arms simultaneously and may be transmitted through the hand and arm to the shoulder. Continued use of many vibrating power tools are find to be connected with various patterns of diseases affecting the blood vessels, nerves, bones, joints, muscles or connective tissues of the hand and forearm.[25]

However, the vibration exposure required to cause disorders depends on different parameters, the most important ones being the *vibration magnitude*, the *frequency spectrum* and the *daily and cumulative exposure duration*. Various studies have been conducted to assess the effect of hand-arm vibration onto women and men. *Bylund et.al*[26] conducted a study with the aim to determine whether there are gender differences as regards the quantity of absorbed power, i.e., vibration absorption per unit of time, during exposure to vibration from a specially constructed handle. The study was conducted on 24 subjects (12 female and 12 male). The experiments were performed with exposure in two vibration directions, X (h), and Z (h), and with two vibration levels, 3 and 6 m/s^2. Study results indicated that the male subjects had significantly higher power absorption during exposure to vibrations in the Z (h) direction at the vibration level of 6 m/s^2 than did the female subjects. However, when adjusted for anthropometrical measurements the difference did not remain significant. Higher vibration levels resulted in significantly higher absorption of power for both X(h) and Z(h) directions. The absorption was significantly higher in the Z(h) direction than in the X(h) direction. Hence, no gender difference in power absorption was shown.

Similarly, *Bylund et.al*[27]also conducted a descriptive study in Sweden to describe the symptoms and the prognosis of vibration injuries in women. The investigation was based on a study of 374 women who had reported an injury due to hand-arm vibration to the Social Insurance Office or had received financial compensation from the Swedish Labour Market Insurance scheme during 1988-1997. Information on, for example, self-rated health symptoms and vibration exposure was collected by means of a questionnaire. On average, the first symptoms started after 7 years of exposure and the first visit to a doctor took place after 11 years.

Neurological symptoms developed after a shorter period of exposure compared to vascular symptoms, 6.8 and 9.2 years, respectively. The prevalence of numbness at the time of reporting the injury was 91% and the prevalence of white fingers was reported by 54%. The occupational group with the highest prevalence of vibration injuries was dental technicians. Two thirds of the women had stopped using vibrating machines in their work. Among the women who suffered from white fingers when they reported the injury, 50% declared impairment or no improvement of the symptoms. One woman in five was retired and the same number of women had retrained due to the occupational injury.

The prevalence of HAVS so concerned the miners of a metal mine in the north of Ontario, that the mine's health and safety committee requested the Occupational Health Clinics for Ontario Workers (OHCOW), to investigate. Results concluded that of the 162 workers, who attended a medical examination, 50% were diagnosed with HAVS and 26% had other diagnoses, some both e.g. HAVS and Carpal Tunnel Syndrome.[28] A recent UK study assessing vibration exposure from the use of powered hand tools in mines found that impactive tools such as jigger picks and breakers can generate high levels of vibration, restricting recommended usage times to as little as 10 minutes. Tools with vibration reduction features showed varying degrees of reduction (up to 50%), but still need usage times restricted to as little as 30 minutes.[29]

Workers who use hand held vibrating tools are also exposed to diverse environmental and occupational factors accounting for the wide clinical spectra of the disease. Epidemiological studies have pointed out that the prevalence of vibration induced white finger is very wide, ranging from 0% - 5% in warm climates to 80% - 100% in northern climates.[30]

Similarly, leisure activities such as motorcycling or using domestic vibrating hand tools can occasionally expose the hands to vibration of high amplitude, but only long daily exposures may give rise to health problems.[31]

In an ergonomic review of repetitive strain injuries in the wood products industry, *BCRI* in 1994 found that one third of the workers experienced hand-arm vibration exposure from equipment or tools and that 25% of the workers experience symptoms of numbness and tingling when using such equipment or tools.[12] There is substantial evidence that as intensity and duration of exposure to vibrating tools increase, the risk of developing HAVS increases. There is also evidence that an increase in symptom severity is associated with increased exposure.[32] Therefore, a person found to have developed disorders induced by vibration in the work situation should not be returned to the same vibration exposure or work without any changes expected to lessen the risks.[33]

3.4.1 HUMAN RESPONSE TO HAND-ARM VIBRATION EXPOSURE

Many common tools and processes such as road drills, pedestal grinders, power hammers and chainsaws produce high levels of vibration which can cause permanent damage to the hands and arms. Workers exposed to high vibration levels at the hand on a regular basis may suffer from several kinds of injury to the hands and arm. Collectively, these injuries are known as HAVS.

This is a painful disease and is widespread in industries using powered vibratory hand tools and machines. The HSE has estimated that 1.2 million men and 44 000 women are exposed to significant level of HAV.[34]

However, the risk of permanent damage depends on factors such as how high the vibration levels are, frequency of use of the equipment for, awkwardness when using equipment and temperature.

Determining a relationship between occupational health exposure to hand-transmitted vibration and adverse health is not a simple task. The International Labour Office has compiled a list of important factors, which concur to cause injuries in the upper limbs of workers exposed to vibration.[35] Subsequently, all of these variables should be taken into consideration when determining the prevalence of HAVS in a study group.

These are characterised in table one below:

Table 1: **Factors potentially related to injurious effects during hand-transmitted vibration exposure**

Vibration Characteristics	Tools or Processes	Exposure Conditions	Environmental Conditions	Individual Characteristics
- Magnitude - Frequency - Direction	- Tool Design - Tool Type - Condition - Operation - Material being worked	- Duration - Pattern of exposure - Cumulative exposure duration	- Ambient temperature - Airflow - Noise - Dynamic response of the finger-hand-arm system - Mechanical impedance - Vibration transmissibility - Absorbed energy	- Method of working - Health - Training - Skill - Use of gloves - Individual susceptibility to injury

Source: ***Encyclopaedia of Occupational Health and Safety – 4th Edition, published by the International Labour Office, 1997***

3.4.2 Symptoms and Resultant Effects

a) Vibration white finger or Raynaud's phenomenon

Raynaud's phenomenon is simply a disorder of blood circulation in the fingers.[36] As cold helps trigger HAVS attacks, the simultaneous combination of vibration, cold, old age and nicotine from smoking is particularly deadly since all three tend to act as vasoconstrictors and thus help "close down" blood vessels.

Typical attacks occur with:

- Tingling and slight loss of feeling or numbness in the fingers,
- Whitening of the fingers, usually without affecting the thumb, and
- Pain, sometimes with redness, which accompanies the return of blood circulation generally after 30 minutes to two hours

In extreme conditions, the loss of blood supply to the fingers can lead to gangrene, which may require finger amputation. Thus, Raynaud's phenomenon can quickly become a serious occupational disease if not detected and treated in time. Figures 2 and 3 below illustrate examples of two stages of persons suffering from Raynaud's phenomenon:

Figure 2: Illustration of irreversible HAVS 1

Figure 3: Rare case of gangrene in HAVS 2

Source: Internet website - www.safetycenter.navy.mil

As with most occupational illnesses workers have different susceptibility to HAVS. In most cases the latency period for the development of the disease is at least several years. Hence, the shorter the latency period, the more susceptible the employee or the more serious the exposure to vibration is.[37] There are some tests available, which measure skin sensitivity or blood flow in the fingers, especially under cooling conditions. Together with careful analysis of an individual's work history and medical history, they are useful in judging if a person has Raynaud's phenomenon. For severe cases, prescribed drugs may reduce the attacks of white finger. However, the most effective therapy is to avoid further exposure to vibration.[36]

b) Sensory nerve damage

Damage to the nerves in the fingers will mean that the sense of touch and temperature are reduced. Permanent numbness or tingling in the fingers may also be experienced.

c) Damage to muscles, bones and joints

These will include loss of strength in the hands and pain in the wrists and arms.

The severity of hand-arm vibration syndrome is usually graded or assessed according to the Stockholm workshop scales. Although these scales are regarded the gold standard for assessing the severity of HAVS, they are based primarily on subjective symptoms. In overall, objective tests are desirable since most of the workers or patients are claiming workers compensation.

The aim of a very recent study was to explore the agreement between the Stockholm workshop scales and the outcome from ten (10) well-defined clinical tests commonly used in hand rehabilitation for assessment of hand function. A total of one hundred and eleven (111) vibration-exposed workers participated in the study. Ten objective tests of hand function and 4 questions on subjective hand symptoms were included. The results indicated that, out of these tests, perception of vibration, perception of touch/pressure and dexterity showed a moderate agreement with the Stockholm workshop scales. Among specific questions on hand symptoms, cold intolerance and pain showed a high agreement with Stockholm workshop scales. It was concluded that defined objective tests combined with directed questions on specific hand symptoms, together with the Stockholm workshop scales, might be helpful for diagnosing HAVS.[38]

Table 2: The Stockholm Workshop Scales [39]

STAGE	*GRADE*	*DESCRIPTION*
Vascular Component:		
0	-	Exposed to vibration: No symptoms
1	Mild	Occasional Blanching attacks affecting tips of 1 or more fingers
2	Moderate	Occasional attacks distal & middle phalanges of 1 or more fingers
3	Severe	Frequent attacks affecting all phalanges of most fingers
4	Very Severe	As in 3 with trophic skin changes
Neurological Component:		
0		Exposed to vibration: No symptoms
1		Intermittent or persistent numbness with or without tingling
2		As in 1 with reduced sensory perception
3		As in 2 with reduced tactile discrimination and manipulative dexterity

The HSE has recommended that it is not advisable for a worker to continue exposure to vibration if this is likely to result in the disease progressing to either stage 3 vascular or neurological. Up until stage 2, the symptoms are usually reversible if exposure to vibration is eliminated. Ultimately, some workers will have to change occupation. When stage 1 is reached, the affected worker should be counselled to consider another line of work. At stage 2 it should be strongly recommended and if stage 3 is reached, the worker should be removed from exposure to vibrating tools and equipment.[37] Hence, the before mentioned literature again clearly shows how imperative it is to implement and sustain a good health surveillance program for human vibration exposure within any workplace.

Griffin et al.[33] conducted a workshop in order to identify the current state of knowledge, uncertainties and future needs related to the diagnosis of disorders associated with the use of vibratory hand-held tools. Researchers found that for the most common vascular disorder (vibration-induced white finger), the principal symptom and sign involves attacks of well-demarcated finger blanching (Raynaud's phenomenon); low finger systolic blood pressure following cooling is indicative of vibration-induced white finger and zero fingers systolic blood pressure can confirm an attack of Raynaud's phenomenon. For neurological disorders, some symptoms can exist without detectable signs and some signs can exist without symptoms; numbness and tingling are commonly reported but neurological changes may be present without these symptoms.

Prevalence of HAVS in U.S (United States) tool users has been reported as high as 50%. Medical treatment is generally palliative and can include the use of certain blood pressure control medications to minimize the effects of the HAVS attacks.[1]

3.5 OCCUPATIONAL EXPOSURE TO WHOLEBODY VIBRATION

Exposure to whole-body vibration is a wide- spread occupational health risk factor that may cause adverse effects on the health in drivers of Lorries, fork-lifts, Haultrucks, tractors, cranes & loaders, and in helicopter pilots.

A major study conducted on open-cut mining equipment in the United States of America and also a recent survey on Australian open-cut and underground mining mobile equipment indicated unacceptable levels of exposure to whole body vibration in a large proportion of vehicles. Hence, up to 22% of vehicles surveyed showed whole body vibration levels that exceeded the Exposure limit and thus exposed operators to a significant risk of long-term health impairment.[40, 41]

Most of the studies that were done in the past concluded that the type of seating played an important role in the magnitude of vibration to which the human body might be exposed. Hence, occupational exposure to whole-body vibration has been reported to be associated with increased prevalence of back pain in the sense that the transmission of vibration to the body can be significantly influenced by the dynamic response of seating.[42] Consequently, Griffin et al conducted a whole-body vibration study to determine the benefits that might be obtained by changing seats in the vehicles. Whole-body vibration in 100 vehicles (with 67 conventional seats and 33 suspension seats) has been evaluated to determine the benefits that might be obtained by changing seats in the vehicles. Acceleration was measured on the floor and on the seat of 14 categories of vehicle (cars, vans, lift trucks, lorry, tractors, buses, dumpers, excavators, helicopters, armoured vehicles, mobile cranes, grass rollers, mowers and milk floats).

For each seat, the transmissibility and SEAT value (a measure of the overall isolation efficiency of a seat) were determined. Seat transfer functions measured in the vehicles were used to predict SEAT values if seats were interchanged between vehicles. The calculations suggested that 94% of the vehicles investigated would benefit from changing the current seat to a seat from one of the other vehicles investigated. The researchers found that the severity of whole-body vibration exposures in many work environments could be lessened through improvements to the seating dynamics.[43] In a French study, whole-body mechanical vibration transmission to operators was measured on approximately 75 industrial machines of fifteen different types. It was found that most of the machines studied needed anti-vibration treatment, by suspending the machine itself, by carefully uncoupling the work stations from the machines or by insulating the operator cabin against machine vibration, a solution which also helps to control other stresses, such as noise, temperature and dust.[44]

A study to estimate the vibration characteristics at the driving stand of compact construction machines and the compliance with the requirements of standards on seat and vehicle test codes showed that most of the compact machines tested were found to impart relatively severe fore-and-aft low-frequency vibration. However, the magnitude of this vibration depended on the type of work in progress and the operator's driving style. Only loaders and site dumpers seemed to be subject to strong vertical vibration. These machines are often equipped with compact vertical suspension seats, which are quite effective at reducing vertical vibration. The results suggest that seats that successfully pass the INRS class I test for seats of forklift trucks with a load capacity of less than 5 tonnes are suitable for reducing vertical vibration on compact construction machines. There are no compact seats with fore-and-aft suspension; however, more development work is required before any test codes are proposed.[45]

Another study indicated that industrial truck drivers might be exposed to high values of wholebody vibration with frequencies below 10 Hz due to surface irregularities and the lack of suspension systems on these vehicles.[46] Significant differences in resonance behaviours have been shown to occur between the vibration responses of females and males, particularly in females falling in the 5th percentile or less of the population for body weight. A five degree-of-freedom (5-DOF) lumped- parameter model was found to be effective in simulating the driving-point impedance and transmissibility responses of a female and male exposed to whole-body vibration. The model showed that there were differences in the distribution of the mass as well as the stiffness and damping characteristics of the major anatomical regions between the female and male. The ability to predict the effects of these differences is important for improving equipment concepts, which reduce vibration transmission.[47]

Whole body vibration is one of the most common occupational hazards in Britain. Recently is has been estimated that 8.5 million men and women are exposed on a weekly basis to occupational sources of WBV. In a recent study, Palmer et.al explored the impact of occupational exposure to whole body vibration on low back pain in the general population and estimated the burden of lower back pain attributable to WBV in comparison with occupational lifting. They found that the overall burden of lower back pain from occupational exposure to WBV was smaller than that attributable to lifting at work. However, the data on WBV do not provide a strong evidence to suggest a cause-effect relation.[48]

A few other population surveys provided estimates of risk from WBV. In one study, a crude Odds Ratio of 2.1 (95% CI 1.3 to 3.5) was observed for Lower Back Pain in 2872 Swedish men and women with exposure to WBV.[49, 48]

In a large Canadian study, Liira found that the Odds Ratio for long term back problems in blue-collar workers was 1.8 (95% CI 1.3 to 2.7) after adjustment for age, sex and smoking history, but not for physical job demands.[50, 48]

A Swedish cross-sectional case study with the general aim to investigate the association between musculoskeletal disorders and physical exposure based on WBV among drivers of all-terrain vehicles concluded that the risk for symptoms of musculoskeletal disorders in the neck, shoulders and upper back are about 2-3 times higher among all-terrain vehicle drivers compared to a control group from the general population.[51]

3.5.1 HUMAN RESPONSE TO WHOLE BODY VIBRATION EXPOSURE

Human Response to whole body vibration is a very complex phenomenon. Combinations of effects may occur simultaneously but also one effect may promote the onset of another.[52] Increased duration and increased vibration intensity mean increased vibration dose and are assumed to increase the risk, while periods of rest can reduce the risk. However, there are not sufficient data to show a quantitative relationship between whole body vibration exposure and the risk of health effects.[53]

The effects of Whole body vibration can be divided into acute and long-term effects. These are explored in the following few paragraphs.

3.5.1.1 Acute effects

The acute effects can be divided into three (3) categories:[54] a) discomfort, b) activity interference and c) changes in physiological function.

3.5.1.1.1 Discomfort

The discomfort produced by WBV depends on the vibration magnitude, vibration frequency, and direction of the vibration, position at which vibration contacts the body and the duration thereof. Hence, the most intense personal sensitivity to vibration lies in the frequency range of 4-8 Hz. However, some people will experience nausea, dizziness or vomiting at lower levels of vibration (less than 1 Hz), which is often referred to as motion sickness. The nature of the task being undertaken can affect the perception of vibration. For example, driving or riding in a recreational boat is usually perceived as a pleasant experience, whereas exposure to the same magnitude of vibration in an industrial environment would be perceived as uncomfortable and stressful.[55] Other stresses acting in combination with vibration also increase sensitivity, e.g. vibration in combination with noise produces a greater level of stress than vibration alone or noise alone.

3.5.1.1.2 Activity interference

These may be characterised as visual disorders occurring in the range of 20 – 90 Hz. The resonance frequency of the eyes is in the range 20-70 Hz. Hence, vibration in this range will decrease vision and as a result there may be a reduction in the person's performance.

Visual acuity is decreased and the image in the visual field (side vision) becomes blurred and unsteady. Adverse effect of vibration on eyesight is most important, as impaired vision may impair the efficiency of drivers of tractors, trucks, construction machinery or other vehicles and increase driver error and the risk of accidents.[55]

3.5.1.1.3 Changes in physiological function

These will include a slight degree of hyperventilation and increases in the heart rate. Vibration also causes increased muscle tension from voluntary and involuntary muscle contraction. Low-frequency vibrations of moderate intensity can induce sleep, whereas higher frequencies have the opposite effect. Blood pressure can also increase, particularly for vibration frequencies around 5Hz. People exposed to whole body vibration have complained of fatigue, headaches, weakness, reduced concentration and sleep problems. The effects are similar to the long-term effect of exposure to noise that is also present with vibration. Individual factors such as age, gender, weight and smoking have an affect on the body's response to vibration.[55]

3.5.2.1.2 Long- term effects

Spinal column effect

Lower back pain is the most common disease associated with long-term exposure to whole body vibration. The back is especially sensitive to vibration in the 4-12 Hz range.[55]

Other health effects that have been associated with whole-body vibration and especially the driving environment are kidney disorders, problems with balance, impotence and varicose (swollen) veins. Varicose veins of the scrotum (varicocele) and the anus (piles) are the most common.

The relationship between vibration exposure and fatigue has not been investigated to any great extent. In a study conducted by Wilson and Horn and 1979, over 50% of the drivers stated that fatigue was a major problem for them whilst driving. Seemingly conflicting findings of the effects of vibration have been reported. Some studies identified vibration as a stimulant and others as inducing drowsiness.[56]

3.6 HUMAN RESPONSE TO BUILDING VIBRATION

Because of the relatively rare occurrence of annoyance due to ground-borne vibration, especially within the mining industry, there has been limited research done on the topic of human response to building vibration.[57] Vibration in buildings can interfere with activities and affect human occupants in many ways. The quality of life and working efficiency may also be reduced as a result. However, human response to vibration in buildings is very complex. In many circumstances the degree of annoyance and complaint cannot be explained directly by the magnitude of monitored vibration alone.[58]

There are basically two kinds of vibration that can affect people in buildings:

a) Vibration transmitted to the human body as a whole through the supporting surface: through the feet when standing and buttocks when sitting, and

b) Vibrations of the building and the resulting reactions of the occupants. This kind of exposure results from the gross structure vibration, floor vibration and wall vibrations.[58]

The measurements used in this report applied mainly to the vibrations described in point **(b)** above and in particular to the vibration, rattling and annoyance effects produced when a building responds to a vibration source, whether the source is near or far from the receiver.

The effect of vibration on building occupants will depend upon the characteristics of the vibration and the context in which the person receive the vibration. The vibration is therefore defined in terms of its level and frequency content.[59]

Hence, based on the type of activity they are performing, humans have a certain threshold of tolerance to vibration. People in office settings will tolerate much lower vibration levels than those participating in an activity. Additionally, Hanes reported in 1970 that based on automobile and aircraft passenger comfort studies, the natural frequency of human internal organs is between 5-8 Hz. Therefore, inside buildings, floor systems with natural frequencies in that range will possibly cause human discomfort.[60] Hence, sensitivity to vibration is also known to be dependant on the direction of excitation and the human body responds differently when standing compared to lying.

3.7 OCCUPATIONAL HAND-ARM & WHOLE-BODY VIBRATION CONTROL

Human Vibration is a complex type of hazard that does not have one control measure that will solve all problems. Hence, it requires a holistic approach using sound occupational health and safety principles of control. These will largely include measures included under the areas of engineering and administrative control as well as personal protective equipment as the last resort.

3.7.1 Control of Hand-arm Vibration

Control measures will include following good work practices such as:[61]

- Limiting the duration of power tool usage
- Holding the tool away from the body using only hands and arms
- Not gripping the tool tightly when working.
- Awareness training
- Surveillance and job rotation where exposure to vibration is significant and
- Personal protective equipment such as anti-vibration gloves to reduce the transmission of vibration to the hand-arm system. These should be selected as a last resort with regard to the appropriate vibration exposure level, their comfort and their compatibility with other safety equipment.

3.7.2 Control of Whole body Vibration

Whole-Body Vibration control in vehicles such as trucks, buses, heavy equipment, etc. usually centres on the use of so-called "air-ride seats" which are designed primarily for maximum vertical vibration control in attenuating the particularly hazardous 4-8 Hz resonance frequencies. Some manufacturers also offer seats for not only vertical vibration control, but also front-to-back and side-to-side control too.[21]

Seats alone are not necessarily a remedy and should be supplemented where possible in vehicles with suspended cabs, properly inflated tires, and good shock absorbers.

Other control measures include:[62]

- Effective vehicle suspension,
- Regular vehicle maintenance,
- Fully adjustable controls and seating,
- Specific vehicle operator training,
- Job rotation,
- Adjusting seating for good seating and support,
- Keeping speed low when crossing uneven services and
- Taking of breaks when feeling tired, and do some stretching exercises.

3.8 VIBRATION MEASUREMENTS

The level of vibration of equipment and tools used in the work environment is measured or assessed at regular intervals and whenever there are changes in equipment and tool usage or production methods. The purpose of vibration measurements is to assess the vibration intensity hazard level(s) impinging on the hands and body of a worker operating a given tool and equipment; and subsequently comparing these measurements to existing HAV & WBV health and safety standards to determine exceedence and the implementation of control measures.[4]

The measure of vibration intensity is usually acceleration, more precisely a form of average acceleration known as "rms or root-mean-squared acceleration" as separately, and simultaneously, measured for each of the three mutually perpendicular axes.

Vibration at any given point is defined by six vectors; three mutually perpendicular "linear" motions which move in a line (i.e. front-to-back, up down, side-to-side) and three rotational vectors (i.e. pitch, yaw, roll). For occupational vibration, rotational motions are not measured, only the three (Triaxial) linear axes are simultaneously measured; for HAV, from tool handles, where the worker grasps the tool; for WBV, from the top of seat cushion where a vehicle driver sits.[1]

Human WBV resonance occurs in the vertical (up-down) direction from 4-8 Hertz. Whole body Vibration in the vertical position is of major concern in the case of a vehicle driver as spectral components of 4-8 Hz frequencies are contained in this position. These vibrations reach the operator's spine via the driver's seat and the spine will most likely involuntarily respond by actually amplifying and exacerbating the effects of the WBV exposure.

In other words, our body has the ability to select, accept, and amplify certain vibration frequencies over others in doing so it can worsen the effects of the vibration.[1] Hence, the human is least tolerant of vertical vibration in the before mentioned frequency range.[55]

3.9 SOURCES OF UNCERTAINTY IN VIBRATION MEASUREMENTS

The sources of uncertainty in assessing daily vibration exposure can be divided as follows:[63]

- **Instrumentation:** the influence of the instrumentation from mounting system to measurement,
- **Measurement process:** factors that will have an affect on the vibration magnitude such as the selection of measurement periods and the locations of transducers,
- **Exposure time assessment:** method of assessment of exposure-time can influence the estimate of daily vibration exposure,
- **Tool or Machine:** condition of tool/machine,
- **Operator**: factors relating to the operator of the tool such as their skill, technique, experience, training and motivation.
- **Task:** changes in the task being assessed – whether the sample measurement can be assumed to be representative of a whole day's work.

When discussing building and ground vibration attention must be given to the mounting techniques for vibration transducers and the instrumentation used if meaningful measurements are to be made. The vibration transducer mountings employed for the measurement of ground and building vibration depends on the nature of the problem and in particular whether it is one of possible damage or annoyance.

Investigations will often be concerned with annoyance, which will occur at much lower levels than damage to buildings, and hence measurements will usually be taken inside the building at the point of entry to the human body. Measurements should be made in three perpendicular directions on a building structure surface supporting the human body; where the worst-case result is then used. The vibration should be measured in terms of VDV or RMS acceleration levels with frequency-weighting curves for each of the three measurement directions.[58]

3.10 SUMMARY

The human body is a very complex, dynamic and intelligent structure, thus it is not an easy task to analyse the effect of vibration onto a human being. One of the many factors that render human vibration difficult to analyse and quantify extensively, is the fact that overall responses from person to person are very varied.[64] As far back as 1911, researchers associated vibration from hand-held power tools with the risk of pain, numbing, and blanching of the fingers, known today as vibration white finger or HAVS.[3]

Although a lot of progress has been made over the years in identifying and reducing the risk to hand-arm vibration exposure onto workers, many key aspects and uncertainties related to the overall measurement and the effective control of this type of occupational health risk are still not well understood. Similarly, several reviews have shown associations between exposure to seated WBV and low back pain. However, no dose-response relationship could be established. Therefore, the general opinion is now that occupations with exposure to WBV (job title) are *at risk* for development of low back pain, rather than pointing out WBV as the single causal factor.[51]

Another phenomenon that is not well documented or researched in the literature, are the degree of vibration and consequently the potential health effects a combination of WBV and HAV exposure could have on the human body during the execution of certain work activities where "crossover exposures" of vibration take place. This occurrence has been noted by some prominent specialists in the field of vibration, but has never been researched extensively.[1]

Consequently, it is evident that there is still a need for much more research work and exploration in the field of Occupational Human Vibration exposure, in order to fully understand this complex ergonomical health hazard and its ever-posing health threat onto the human body.

CHAPTER 4

THE DATA, THEIR TREATMENT AND THEIR INTERPRETATION

4.1 THE DATA

4.1.1 Data Management and Analysis

The data for this research project were grouped into Primary and Secondary data categories. The emphasis in this study was predominately on the primary data collected during the project, whereas specific references were also made to international freely available secondary data sources relevant to the study under investigation. For the purpose of adequate data management and analysis, all the primary data generated throughout the data collection phase were entered into a STATA data file and various Excel spreadsheets specifically designed for this reason (see appendix 6 & 7).

4.1.1.1 The primary data sources comprised of the following:

- The responses from the mineworkers to a structured questionnaire, which was specifically developed for this investigation,
- All the actual measurement results gathered from a Human Vibration monitoring survey on the mine including those generated by means of Excel computer software specifically designed and freely available on the internet,
- Measurements procedures on the three types of vibration assessed which were developed according to the relevant ISO standards,

- A summary table characterising the extent of the vibration exposure risks at Rōssing Uranium mine, (see appendix 8), and
- A geographical area map outlining the vibration areas on the mine, according to high, medium and low vibration risks (see appendix 9).

4.1.1.2 **The secondary data sources comprised of the following:**

- *Overall information on the types of Human Vibration:* This information was obtained from journal articles of similar completed international studies, ISO standards relating to both hand-arm and whole body vibration and specific books written by prominent writers in the field of vibration.

Reference was also made to similar studies such as the GEN 503 project conducted by SIMRAC on the measurement of vibration characteristics of mining equipment and impact percussive machines and tools on South African gold mines.[7]

- *Existing Site Personnel and Area information*: This data were obtained from the Human Resource department on the mine site and from the responsible First Line manager in each respective area during the start of the data acquisition process.

4.1.1.3 **Criteria Governing the Admissibility of Data**

- Only the measurement data obtained from the Human Vibration survey were regarded as admissible data into the study,
- Secondly, data obtained from the Human Resources department on the mine and also data requested from each section/area were acceptable and

- The latest relevant ISO standards and literature serving as guidance were also viewed as allowable data into the study.

4.2 METHODOLOGY

Data compilation comprised of both Hand-arm and Whole body vibration measurement data. The Whole body vibration measurements assessed the risk with seated such as driving of Haul trucks & Track dozers and standing tasks such as working on the Pre-screening plant, which is a vibrating structure and inside offices for the control group. Hand-arm vibration measurements assessed the vibration risk with the use of different types of vibrating hand held tools. All the measurements were taken of randomly selected members of the occupational similarly exposed groups identified on the mine.

4.2.1 The Research Design

A cross-sectional descriptive study design with some analytical features were employed in order to quantify the risk factors related to human vibration exposure at this Namibian open cast mining operation. The descriptive component of the research design enabled one to quantify the extent of the human vibration problem on the mine, whereas the analytic part allowed for comparison between different work groups. Identifying the main risk factors within similar occupational exposed groups was also rendered possible.

4.2.2 Sample Selection

The initial study population comprised of all registered full time workers employed at Rössing Uranium Ltd. A total population of 135 mineworkers were randomly selected for participation in the study.

A multi-stage proportionally stratified random sampling strategy was followed. First level stratification was based on department and the second level stratification on job title. Participants included in this study, were then randomly selected from each similarly exposed group. The control group were made up of office workers on the basis that they are the least exposed group to vibration on the mine. Hence, it is imperative to note that most of the workers on the mine are somehow exposed to minute vibration levels and the identification of members of controls was therefore rendered difficult.

Due to geographical differences within the control groups and to ensure that control samples taken are representative to the risk environment present, the controls were divided into two subgroups. Subgroup division was based on distances away from major vibration sources. I.e. **1** = Far away from vibration source, **2** = near vibration source. From the nature of this study and also due to pure logistical reasons it should be obvious that controls were not applicable to hand-arm vibration.

4.2.3 Sample Size Calculation

The respective estimated prevalence for whole-body vibration is internationally averaged around 25%, whereas hand-arm vibration is averaged at 20%.[4,65]

Therefore, given the structural layout, age of the mine and equipment and also the extent of the equipment and tools currently in use on the mine, whole body and hand-arm vibration exposure were sought of to be slightly higher in comparison to other similar mining operations in the world. Sample-size calculations were computed using, STATA version 7[66], which is an approved statistical data analyses package.

This was calculated with an alpha of 0.05 using the background prevalence of Hand-arm and Wholebody vibration as was previously reported. Statistical calculations concluded that a sample size of 157 for whole body vibration and a sample size of 71 for hand-arm vibration measurements would be necessary in order for the study to have a power of a minimum of 80%.

4.3 MEASUREMENT TOOLS

4.3.1 The Questionnaire

A structured study questionnaire (*see Appendix one*) was developed based on consultation with a vibration specialist and according to prevailing conditions on the mine. Provision was also made in the questionnaire for observations to be noted by the researcher during any Hand-arm and Whole Body vibration measurements. These observations covered type of seating, primary body orientation while performing work tasks, condition of the roads, grip of hand onto the tool and application of gloves to mention a few. Prior to the administering of the questionnaire, a pilot run was conducted in order to identify possible pit falls/improvements within the questionnaire, hence refining it. Accordingly, in the context of this report, the refined questionnaire contained items on type and duration of job tasks, type of equipment/tools used during a normal working day, smoking status, age, gender, exposure type and employment duration. Before a vibration measurement was taken, the questionnaire was first administered by the researcher to the randomly selected research participants within similarly occupational exposed groups on the mine.

4.3.2 ***The Human Vibration Instruments:*** *MAESTRO 01dB and Tri-axial Accelerometers*

An accredited Human Vibration measurement instrument was utilised for vibration measurement purposes. This is a Class 1 instrument and was designed according to the specifications required by international standard: ISO 8041 / A1: 1998. It is mainly dedicated for measuring vibrations transmitted to the whole body and hand-arm system.

The MAESTRO 01dB with its Tri-axial Accelerometers that was used for vibration measurements in this study are depicted in figures 4 and 5 below.

Figure 4: MAESTRO 01dB

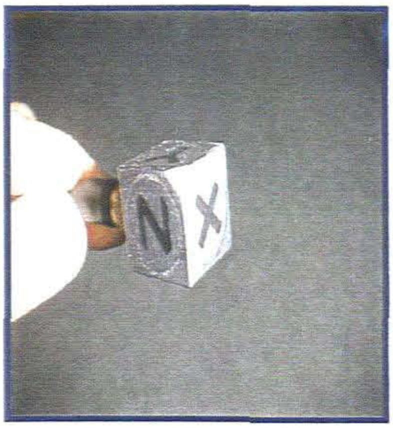


Figure 5: Tri-axial Accelerometers

4.3.3 *The Relevant ISO Standards*

Various International Standards were used as guidance tools during the entire data acquisition process and with the development of site derived vibration measurement procedures. These standards included the following for Wholebody and Hand-arm vibration respectively:

Whole Body Vibration

- **ISO 2631-1:1997** - Mechanical vibration and shock -- Evaluation of human exposure to whole-body vibration -- Part 1: General requirements
- **ISO 8727: 1997** - Mechanical vibration and shock -- Human exposure -- Biodynamic co-ordinate systems
- **Directive 2002/44/EC** – Journal of the European Directive for Human Vibration

Hand-Arm Vibration

- **ISO 5349-1:2001** - Mechanical vibration -- Measurement and evaluation of human exposure to hand-transmitted vibration -- Part 1: General requirements
- **ISO 5349-2:2001** - Mechanical vibration -- Measurement and evaluation of human exposure to hand-transmitted vibration -- Part 2: Practical guidance for measurement at the workplace
- **Directive 2002/44/EC** – Journal of the European Directive for Human Vibration
- **ISO 8727: 1997** - Mechanical vibration and shock -- Human exposure -- Biodynamic co-ordinate systems

Human Response to Building Vibration (Control Group)

- **ISO 2631-2:2003** - Mechanical vibration and shock -- Evaluation of human exposure to whole-body vibration -- Part 2: Vibration in buildings (1 Hz to 80 Hz)
- **ISO 2631-1:1997** - Mechanical vibration and shock -- Evaluation of human exposure to whole-body vibration -- Part 1: General requirements

4.3.4 The Measurement Procedures

All of the human vibration measurements were taken in the actual work environment wherever this was possible. However, in some cases, simulated workplace measurements were conducted in instances where this was rendered impossible. This was done mostly for hand-arm vibration and less often for whole body vibration.

The goal of the survey was first explained to the research participant before any measurements was taken. Afterwards when it was clear that the participant understood what was explained and expected, consent was asked for participation. The participant was then interviewed. In order to ensure the obtaining of reliable data, the participant's weight and height were obtained by means of a digital bathroom weighing scale and measuring tape respectively. The actual taking of the vibration measurement was consequently taken of the research participant in a situation, as the operator would have done during normal equipment or tool operation. In total, three (3) separate vibration measurement procedures were developed during the course of this research and alternately conducted in the field.

This was a procedure for the measurement of Whole body vibration, one for Hand-arm vibration and lastly a procedure for the measurement of Human Response to Building vibration. The reader is referred to *Appendix 2, 3 and 4* for copies of the detailed measurement procedures. For each one, different instrumentation settings and monitoring strategies were followed. However, one important characteristic that was imperative with all the vibration measurement procedures was the appropriate direction in which vibration measurements took place. Additional important components that were relevant and important during all three of the vibration measurement procedures are briefly discussed below:

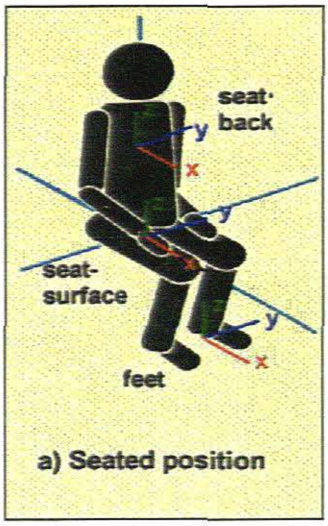
4.3.4.1 The Measurement of Whole Body Vibration

1. Direction of Measurement

Vibration was measured according to a co-ordinate system originating at a point from where vibration was considered to enter the human body. In the instance where vibration measurements were taken on earthmoving equipment, the primary entry point into the body was seen as the buttocks and in some instances the lower back area. On the other hand, measurements for vibration entering via the feet in standing positions were made near a point where feet are placed most of the time while working on a vibrating plant structure.

The vibration measurements were taken in all three axes (x, y, z) simultaneously and the Aeq value for the three directions noted as the individual sample result for that specific measurement period.

The two types of co-ordinate systems shown below in figure 6 and 7 were used.



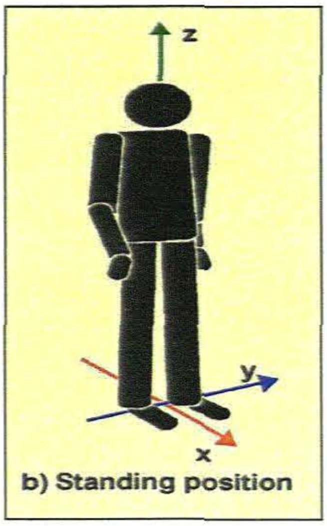


Figure 6: Co-ordinate system for sitting person

Figure 7: Co-ordinate system for standing person

Source of Pictures: Safety line Institute, Worksafe Australia – www.safeyline.wa.gov.au

2. Location of Measurement

The first step was to select the correct measurement locations. Alternatively, this was seen as the point of perceived application into the body and where the operator felt the vibration to be more dominant during normal equipment operation.

Hence, for a seated person, the point of entry was one of the following positions:

- The seat surface,
- The seat back-rest or
- The feet (floor)

For seated persons, the *seat transducer or seat pad (shown in figure 8 below) was placed on the seat with the driver sitting on top of it. This was true for any worker; operating any type of earth moving equipment such as Haul trucks, Track dozers and Forklifts.

Figure 8: Vibration Seat Pad Used During Whole Body Vibration Measurements

In the case of Wholebody vibration transmitted through the floor such as the measurements that were performed at the Fine Crushing plant the seat pad was placed on the floor surface with the person standing on top with his/her feet to ensure a good contact between the floor and the transducer. The actual measurements took place on a structural surface supporting the human body at the point of contact.

However, before taking a measurement, the research participant was first asked where in the cabin of the earth moving equipment he/she normally could feel the vibration the most; that is on the floor, backrest or the seat. The transducer was then placed onto the identified location. In most cases the identified area was on the seat, hence the transducer were placed in the centre of the seat and the participant was consequently requested to sit on it.

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* *A seat transducer comprises of a deformable pad that follows the seat contour and contains a triaxial accelerometer for*

3. Duration of Measurement

It was attempted to take measurements long enough in order to be representative in a statistical sense and to ensure that the vibration measured was typical for the exposure activity being assessed. In other words, the duration of the measurements was as long as the task being assessed at that moment would last. In the event that the operator would stop what he was doing or loose contact with the seat transducer, the measurement was stopped and the reading noted.

4.3.4.2 The Measurement of Hand-Arm Vibration

In cases where measurements were not possible or difficult to take during normal tool operation due to urgent breakdowns or unavailability of workers, simulated work procedures were conducted. This was mostly true for hand-arm vibration measurements that had to be taken in the actual plant environment. As an alternative, measurements were taken in the respective Workshop, on similar type of tools that the operator would have used when working in the actual plant environment on the plant equipment like using an impact tool when changing out pumps.

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simultaneous measurements in three axes of vibration.

1. Direction of Vibration Measurement

Figures 9 and 10 below characterises a schematic view of the co-ordinate systems used during most of the hand-arm vibration measurements.

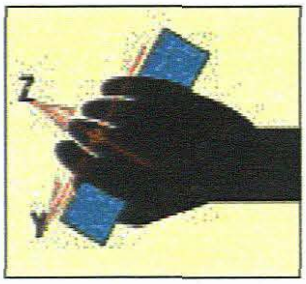


Figure 9

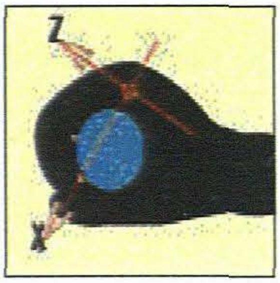


Figure 10

However, during one vibration measurement, the co-ordinate system characterised in figure 11 below was used.

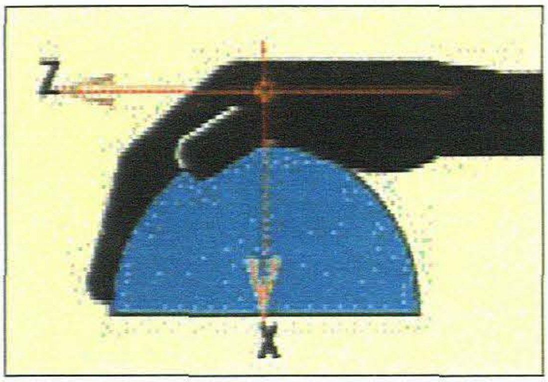


Figure 11: Co-ordinate system used during the measurement of vibration exerting from a sanding machine.
Source: Safety line Institute, Worksafe Australia – www.safeyline.wa.gov.au

2. Location of Vibration Measurement

When taking a measurement, it was attempted to align the accelerometer onto the tool in such a manner as to measure the vibration level at the point where it is perceived the vibration is entering the hand-arm system of the operator. Therefore, before attaching the accelerometer onto the handle of the tool, the operator was first asked where on the tool he normally feels the vibration to be more dominant. The researcher also asked the participant to hold the tool in the manner he will normally hold it when using it. This was done in order to obtain a visual idea of where to attach the accelerometer. The accelerometer was then attached tightly onto the identified location with cable ties.

An example of the type of research tools used and how the accelerometer was attached to the handle of a tool is shown in figure's 12 and 13 respectively.

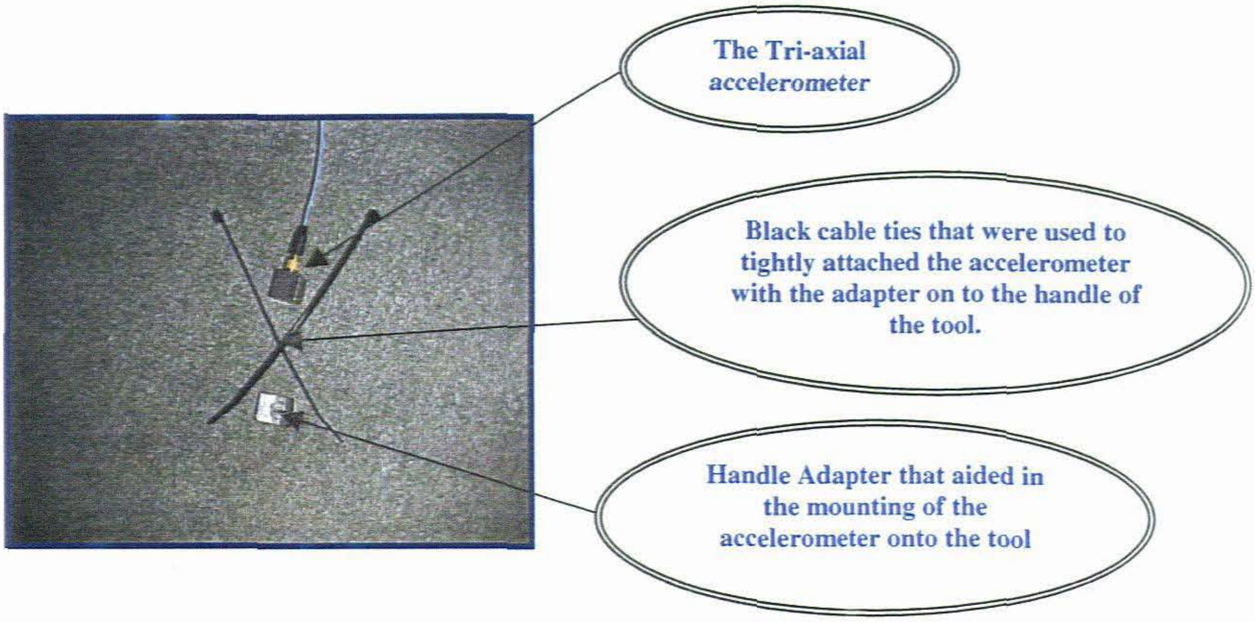


Figure 12: Research tools used during Hand-arm vibration measurements

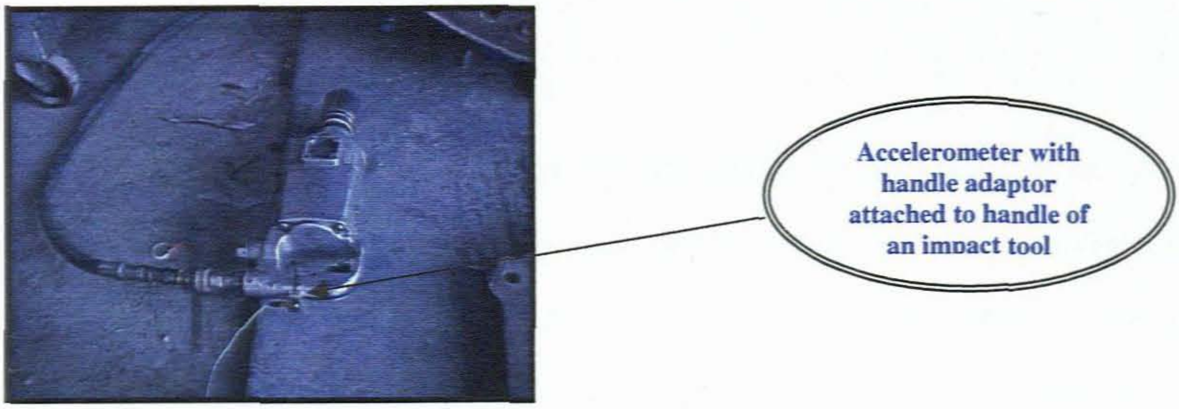


Figure 13: Example of how the accelerometer was attached to the handle of a tool

3. Duration of Measurement

For hand-arm vibration the duration of a majority of the measurements was taken for at least one to two minutes. However, it was noted that during some work activities, a tool such as an impact tool or hand drill was used for a very short time period. The durations were normally only a few seconds, for example with the tightening and loosening of nuts on a pump. In this case, measurements of such short durations were noted to be unreliable.

Therefore, for an operator who used a tool for short durations at a time (less then 1 minute), more than one measurement were taken in order to ensure that the total measurement time for that work activity were not less than 1 minute. In the end, the higher Aeq result for the two measurement periods were noted down as the raw result.

2. Location of Measurement

In general, the vibration evaluation was based on occupation, the tasks being performed by the occupants and the expected freedom from disturbance. The vibration was measured at that location in the room where the occupant spends most of his working day.

3. Duration of Measurement

It was attempted to conduct measurements long enough in order to be representative of the task being undertaken throughout a normal 8-hour working day.

4.4 PILOT RUN

As is the case with most scientific studies, it is imperative to perform a pilot run prior to the main investigation. The purpose of the pilot run was to investigate the feasibility of the proposed study and to detect possible flaws in the data collection instruments. Since there were no mines near with the similar characteristics as the one in question, the data collection tools were tested on equipment perceived to be emitting whole body vibration exposure and on tools perceived to be emitting hand-arm vibration exposure. Consequently, before the commencement of the main research study, all the vibration monitoring instruments, the questionnaire and the site developed measurement procedures for Whole Body, Hand-arm and Human Response to building vibration were tested on a small randomly selected group of workers on the mine. Following is the general protocol that was followed with the piloting of the measurement instruments and consequently during the entire research endeavour:

1) The instrument was calibrated according to the calibration procedure stipulated in the instrument manual.[67] This was done before and after a measurement period was completed,
2) General checks were performed to ascertain if the instrument was in a good working condition before a measurement period and if the vibration settings were correct,
3) In the case of whole body vibration measurements, the accelerometer was attached to the seat pad,
4) In the case of hand-arm vibration, the accelerometer was attached to the handle of the tool or area where vibration was perceived of entering the body via the hand and
5) The written measurement procedures were followed exactly in order to test the practicality of it and whether it works in the field.

To test for any instrument variation, repeated vibration measurements were taken on the same type of tools and research participant. This was done in order to ensure that the monitoring instrument is working effectively. Obtaining the same or more or less the same results each time indicated the reliability of the human vibration instrument. The ranges obtained between the results were small i.e. the instrument was therefore noted to be reliable.

4.5 CALIBRATION PROCEDURES

Calibration of the vibration instrument took place according to the specifications noted by the instrument supplier. This was by means of direct input of the sensitivity values of each accelerometer (x, y, z). The instrument was accompanied with three calibration data cards. These cards indicated the voltage sensitivity for each axis. *Hence, the sensitivity values used for each axis were as follows*:

- **10.25** mV/g for the y-axis
- **10.91** mV/g for the z-axis
- **9.09** mV/g for the x-axis

Consequently, before and after a measurement period, the correctness of the sensitivity values was checked.

4.6 DATA QUALITY ASSURANCE

The quality of collected measurement data was ascertained and confirmed at regular intervals. This was achieved through:

- Ensuring measuring equipment was calibrated and working properly before and after inspections and calibration,
- Ensuring that the instrument settings were correct i.e. for the determination of hand-arm vibration, the instrument should be set according to the requirements for hand-arm measurements, and
- Ensuring that regular battery checks are done.

4.7 ETHICAL AND LEGAL CONSIDERATIONS

4.7.1 Informed Consent

Prior to the commencement of the research study, written consent was first obtained from the main stakeholders of this study; the management of Rössing Uranium Limited, in the form of a letter. (*See Appendix 5*) Confidentiality of all results was also guaranteed and all research participants were protected by all means possible.

4.7.2 Safety

Although the measurement procedures employed in this study were not of an unsafe nature, safety was always put first in order to avoid any possible harm to all study participants.

4.7.3 General

Thorough interpretation of results was done before any information was released. Utmost care was also taken throughout this investigation and report to assure that all references were quoted correctly. No data was withheld, misrepresented or manipulated in order to advance any special interest of the research participants, principal investigator or the management of the Rössing Uranium mine.

4.8 THE RESEARCH STUDY VARIABLES

The research variables used during the statistical analyses of the data were both qualitative (categorical) and quantitative (numerical) in nature. A number of these research variables are summarized in table's 4.8.1 and 4.8.2 below.

4.8.1 The Independent Study Variables

Table 4.8.1: Nature of major independent study variables

CONCEPTIONAL DEFINITION OF VARIABLE	OPERATIONAL DEFINITION I.E. INDICATOR	SCALE OF MEASUREMENT	TYPE OF VARIABLE	DATA CODING
1. **Age**	Age at last birthday	Discrete	Numerical	-
2. **Exposure status**	Exposed to vibration or not	Nominal	Categorical	0 = yes 1 = no
3. **Occupation**	Type of job title on mine	Ordinal	Categorical	
4. **Smoking status**	Smoker, non-smoker or ex-smoker	Ordinal	Categorical	Smoker = 3, Ex-smoker = 2, Non-smoker = 1
5. **Vibration**	Perception of subject	Ordinal	Categorical	Not a problem = 1, OK = 2, A big problem = 3
6. **Exposure Time**	Length of exposure to vibration in a day (hours)	Continuous	Numerical	-
7. **Type of equipment being handled**	Hand tools or driving equipment.	Nominal	Categorical	Hand – arm = 1, Wholebody = 2
8. **Grip**	Grip of operators hand onto tool	Nominal	Categorical	Tight = 1, Loose= 2
9. **Controls**	Distance away from vibration source	Nominal	Categorical	1 = Far from vibration source, 2 = Near vibration source

4.8.2 The Dependent Study Variables

Table 4.8.2: Nature of the Dependent study variables

CONCEPTUAL DEFINITION OF VARIABLE	OPERATIONAL DEFINITION I.E. INDICATOR	SCALE OF MEASUREMENT	TYPE OF VARIABLE	DATA CODING
1. **Aeq (m/s^2)**	Magnitude of exposure from using different types of equipment and/or vibrating hand held tools.	Continuous	Numerical	-
2. **Human Vibration Symptoms**	*Hand-arm*: Tingling/needle pricks in fingers or hands, *Whole body*: Low back pain	Ordinal	Categorical	*Hand-arm symptoms*: Yes = 1, No = 2 *Whole Body symptoms*: Yes = 1, No = 2
3. **Level of Health risk: A (8)**	Level of risk amongst occupational SEG's	Ordinal	Categorical	**HAND-ARM** **High*: Greater than 2.5 m/s^2 **Moderate*: Greater than 2.5 but smaller than 5.0 m/s^2 **Low*: Smaller than 2.5 m/s^2 **WHOLEBODY** **High*: Greater than 1.15 m/s^2 **Moderate*: greater than 0.5 but smaller than 1.15 m/s^2 **Low*: Smaller than 0.5 m/s^2

***** ***Quantification of level of risk (A (8)) is as advised by the Rio Tinto Information Guideline on Human Vibration***

4.8.3 Confounding Variables

Intuitively, confounding can be thought of as a mixing of the effect of the exposure under study on the disease with that of a third factor. Confounding can therefore lead to an overestimate or even an underestimate of the true association between exposure and disease or it can even change the direction of the observed effect. During the course of the study, the following variables were sought of as possible confounders. Alternately, attempts were made where this was deemed necessary, in order to manage the effect during the statistical data analyses process.

- Previous occupational vibration exposure,
- ***Strength of grip*** of the operator onto the tool. Since people are different, they tend to do things differently. Therefore, some workers might have a tight grip on a tool when using it and some not. In the end, how hard a person gripped a tool affected the amount of vibrational energy entering the hands,
- ***Extramural activities*** relating to any activities whereby the possibility exists of lower back injury or even hand-arm vibration exposure e.g. mowing the lawn,
- ***Age:*** The older you are, the more prone your body is to the development of vibration-induced disorders since your immune system gets weaker,
- ***Weight:*** People who weigh more, are less prone to the development of vibration-induced disorders since their body does not vibrate that much in relation to a skinny person,
- ***Smoking habits***: Smoking is one of the risk factors causing vaso constriction. Hence, it may accelerate the development of Raynaud's phenomenon when this was associated with vibration exposure and

- ***Condition of road***: A dirt road was found to expose the driver more to vibration then a normal tar road. This was true due to the fact that a dirt road is more bumpy and rigid than a tar road.

4.9 DATA MANAGEMENT AND ANALYSES

Data management and analyses are simply the preparation for data entry, editing and analyses. Hence, data in this research study was managed by first coding the variables for computer entry. Each variable was given an exclusive abbreviated name for identification purposes into the data set. All categorical variables were coded appropriately. After the initial data capturing, the data were checked for any strange values or outliers and then analysed using an approved statistical data analyses computer package known as STATA, Intercooled version 7. The criterion for determining significance of relationships between the variables was $\alpha = 0.05$. The hypotheses that were formulated at the start of the study were also tested through the use of the appropriate statistical data analyses measures.

The nature of the analytical tests that were performed during the data analyses process is discussed below:

4.9.1 Descriptive Statistical Data Analyses

The overall reason for doing descriptive statistics was to characterize the study subjects and to make an informed choice on which type of inferential analytical statistics to employ on the dataset at a later stage. Exploratory data analyses were performed on all the data.

The numeric and categorical variables were constructed and summarized through univariate data analyses. To test the normality of the data, the Shapiro-Wilk test for normal data was performed on all numeric variables. Subsequently, the outcome of this analytical test indicated that the majority of the variables were significant (p-value of less than 0.05). This indicated that the data is skew and the median and interquartile range should be used as the measure of variability. Cumulative frequency histograms were developed in order to characterize what proportion of the sample populations were below or above the respective action limit values of both Wholebody and Hand-arm vibration.

4.9.2 Inferential Statistical Data Analyses

Bivariate, univariate and multivariate analyses were conducted in order to examine the pattern, the magnitude and the statistical significance of associations between variables. Alternately, the purpose was to estimate the pattern and strength of associations among variables and also to test the null hypotheses. Therefore, analyses of data inferentially were through computing odds ratios with Confidence intervals, showing clearly whether workers were exposed significantly or insignificantly to an increased or decreased health risk. Regression techniques were used to explore various explanatory models of exposure and confounding variables for both whole body and hand-arm vibration. Hence, simple and multiple linear regression statistical techniques were employed in order to establish the predictor variable for Aeq. Similarly, simple and multiple logistic regressions were employed to establish the best predictors for HA, WB vibration symptoms and the level of health risk.

4.9.3 Generation of the Aeq results into A(8) values

The calculation of the total eight-hour daily exposure of a SEG according to tool or equipment usage, vibration magnitude and the average exposure time in hours reported by the research participants, was achieved through the use of the latest Human Vibration Calculators for Hand-arm and Whole body vibration respectively. (*See appendix six and seven)*. The Health and Safety Executive (HSE) in London developed these two analyses tools that were freely available on their website.[3] Alternatively the following procedures were followed. In both cases, the vibration magnitude in m/s^2 (Aeq) and the reported daily vibration exposure durations in hours or minutes were entered in the white areas for up to six processes or less. However, since an overestimation of daily exposure durations were noted, each subject's self-reported time of use of any equipment or tool were normalised by the number of subjects in the group. In this instance, a maximum amount of 6 subjects were used. This gave a correct representation of an individual's average exposure, with the assumption that he/she spent that average time on each tool or equipment as reported in average by the group. Another measure that was implemented before the exposure times were recorded into the respective calculators was to remove the highest and lowest exposure times. In this manner, any strange or outlier values were removed from the group. Thereafter a partial vibration exposure value was automatically calculated for each data entry and this value appeared in the yellow areas. In conclusion, the overall daily vibration exposure result was displayed in the bottom right cell and this value was used as the final A (8) result for a specific similar exposed group.

CHAPTER 5

THE STUDY RESULTS

5.1 Introduction

Fine to hot weather conditions were experienced during most of the data collection period with temperatures ranging from a minimum of 6°C (mostly during night time and early morning) to a maximum of 36°C during the day. However, during the last month of data compilation, cool weather conditions were experienced with a minimum of 8.9°C and a maximum of 28.3°C.[•]

All the vibration measurement values within all of the three (3) measurement groups were measured and expressed in acceleration levels (m/s^2). In addition, the principal quantities used to represent the severity of exposures in both hand-arm and wholebody vibration was Aeq and A(8). Consequently, the MAESTRO human vibration instrument that was used provided a single Aeq value, which represented the equivalent acceleration level value according to the following formulas for the two types of vibration:

Whole Body Vibration: $Aeq = \sqrt{(1.4^2\, awx^2 + 1.4^2\, awy^2 + awz^2)}$

$Aeq = \max\,(1.4\, awx, 1.4\, any, awz)$

Hand-arm Vibration: $Aeq = \sqrt{(awx^2 + awy^2 + awz^2)}$

[•] *The weather data was extracted from Rössing Uranium month-end reports.*

Consequently, both the Hand-arm and Whole body vibration filters were automatically set according to the specifications required by the ISO 8041/A1: 1998 standard. Measurements were taken simultaneously in all three axes (x, y, z).

There are many complex factors involved in determining human exposure to vibration. Some are related to intrinsic factors and some to the vibration itself (extrinsic). The intrinsic variables are related to age, sex, weight and smoking whereas the extrinsic variables are related to the vibration level (acceleration, frequency, direction and duration). However, in view of the subjectivity of intrinsic factors, existing standards are restricted to extrinsic variables.[5]

In an attempt to prevent any selection bias that might have occurred during the data measurement process, an updated list of all the current registered mine workers was obtained. Since the commencement of the research study in the middle of 2003, various changes had taken place amongst the groups present on the mine in the form of people moving to different sections and people resigning. This resulted in changes in the number of workers present within each group. Alternatively, an updated list was obtained after the initial vibration measurements in a particular exposure group were completed. The current list was compared with the updated list and in this manner it was ascertained where measurements were still needed in order to be representative. Hence, in the following pages of this chapter, the quantitative measurement results, obtained by means of a human vibration survey, followed by the application of various applicable statistical investigations onto the study variables, are presented and interpreted in the form of tables and graphical depictions. Due to their differences, the detailed results of the two types of human vibration exposures are presented separately.

5.2 QUESTIONNAIRE RESULTS

5.2 Demographic Data

A structured questionnaire specifically designed for conditions at the mine, was administered successfully on 135 mineworkers representing the different similarly occupational groups at the mine. Statistical analyses revealed distributions such as the weight of the employees, frequency of smoking and length of smoking to be normally distributed (Shapiro-Wilk Tests, $p>0.05$). A mean of 80.4 kg (CI: 76.75 – 84.31) characterized the weight distribution of the hand-arm exposure group. The mean duration of employment at the mine amongst the hand-arm vibration research participants is less (10 years) compared to the Wholebody exposure group (16 years). In addition, the two vibration exposure groups differ by 6 years in age (47 & 41 years respectively).

(Table 5.2 & 5.2.1)

Table 5.2: Demographic characteristics of Hand-arm vibration exposure groups employed at Rössing Uranium Ltd, 2004

Variable	N	GM	95%CI	
Age (years)	61	41	37.93	43.45
Weight (kg)	67	80.4	76.75	84.31
Height (m)	67	1.7	1.72	1.76
Employment duration (years)	67	10.3	7.67	13.86
Exposure time (hours in 8-hour shift)	67	2.2	1.65	2.80
Aeq level per tool (m/s^2)	67	4.8	3.86	6.02
A(8) level per exposure group (m/s^2)	67	2.7	2.24	3.30

Table 5.2.1: Demographic characteristics of Wholebody vibration exposure groups employed at Rössing Uranium Ltd, 2004

Variable	N	GM	95%CI	
Age (years)	57	47	43.96	49.25
Weight (kg)	58	78.9	75.47	82.37
Height (m)	58	1.7	1.69	1.76
Employment duration (years)	58	16.3	13.12	20.18
Exposure time (hours in 8-hour shift)	58	5.2	4.34	6.11
Aeq level per equipment (m/s^2)	58	0.9	0.66	1.13
A(8) level per exposure group (m/s^2)	58	0.7	0.58	0.89

5.2.2 Hand-Arm and Whole Body Vibration Reported Symptoms

Table 5.2.2: Hand-arm and Whole body vibration related reported symptoms on the mine

Proportion with Human Vibration related symptoms	**(n = 50)**	
	Prevalence (%)	***p-value**
Hand-arm vibration symptoms reported	19(28%)	0.32
Symptoms experienced just after tool usage (n = 20)	13 (65%)	
Symptoms experienced few hours after tool usage (n = 20)	7 (35%)	
Wholebody vibration symptoms reported	11(19%)	0.12

*** Wilcoxon Ranksum test**

In the study, hand–arm vibration related symptoms were defined as the *occurrence of any unusual feelings such as tingling or needle pricks in the fingers or hands*. Univariate data analyses concluded that 19(28%) of the workers reported the presence of hand-arm vibration related symptoms. A larger proportion of the sample population 13(65%) experienced these symptoms just after tool usage, while 7(35%) reported that they normally experience these symptoms a few hours after they used a tool. (Table 5.2.2) During the interview process, it was also found that one (1) worker, who is a Welder by profession, had developed diagnosed Raynaud's phenomenon. His current and previous employment durations as a Welder added up to 47 years of exposure to Hand-arm Vibration.

In the case of Whole Body Vibration, *complaints of lower back pain* were regarded as an indicator resulting from whole body vibration exposure. A proportion of 11(19%) of the workers assessed, reported that they are experiencing low back pain problems. In addition, an insignificant difference (Wilcoxon Ranksum test, p=0.12) in the proportion of workers reporting the presence of hand-arm symptoms and those who do not were found.

Similar results were found for workers in the study population who reported whole body vibration symptoms and those who did not.

Table 5.2.3: Summary of observations noted during Wholebody vibration field measurements

OBSERVATIONS ($n = 52$)		**FREQUENCY**
Body posture while working*	**Sitting**	52(76%)
	Standing	16(24%)
Type of vibration seating present	**Ergonomical**	30(58%)
	Non-ergonomical	22(42%)
Condition of Road surface	**Bumpy**	44(84%)
	Smooth	8 (26%)

* *Values includes the measurements for controls and plant operators (n = 68)*

A section of the structured questionnaire administered to the workers comprised of observations, whereby specific annotations related to the worker's body posture, cab seating, and condition of the road to mention a few, were noted down by the researcher, while the study participant was performing his job as normal. These observations were seen as essential, since it provided a qualitative description of the work environment while an operator is performing his work tasks and it also aided in the identification of possible confounding variables, related to the measurement outcome. Analyses of the data univariately revealed that a higher proportion 30(58%) of the earthmoving equipment assessed, are equipped with ergonomically suited chairs compared to those equipment lacking ergonomical chairs 22(42%). In the study, an ergonomical chair was defined as *a type of chair that can be adjusted automatically or manually according to the person's body weight, and that has settings to allow the operator to change the position of the seat according to his/her preference.*

Hence, a possible relationship could be noted between the numbers of ergonomical seats present in vehicle cabins on the mine in relation to the low prevalence of reported WB vibration symptoms. Furthermore, while an operator is operating any type of earthmoving equipment, 84 %(44) of the time it's on a bumpy, uneven surface. (Table 5.2.3)

Table 5.2.4: Summary of observations noted during Hand-arm vibration field measurements

OBSERVATIONS (*n* = 67)		**FREQUENCY**
Wearing of gloves?	**Yes**	24(36%)
	No	43(64%)
Any bad body posture?	**Yes**	16(24%)
	No	51(76%)
Type of material under point of contact	**Steel**	42(63%)
	Rubber	3(5%)
	Plastic	19(28%)
	Wood	3(5%)
Grip onto the tool	**Tight**	64(95%)
	Loose	3(5%)

Univariate analyses for the hand-arm vibration observations showed that only 24(36%) of the 67 tool users assessed normally wear gloves when operating vibrating hand held tools, while a larger proportion of 43 (64%) do not normally wear gloves. The type of material, with which tool operators are predominantly in contact with while gripping the handle of a tool, is steel 42 (63%), followed by plastic 19 (28%). Bad body postures while performing work activities and consequently during the operation of tools were observed in 24% (16) of the hand-arm vibration study group. In addition, when operating a tool, 95% (64) of the time the handgrip onto the tool is tight (Table 5.2.4).

5.3 SYNOPSIS OF THE INDIVIDUAL Aeq RESULTS FOR BOTH HAND-ARM AND WHOLEBODY VIBRATION

As was reported earlier, the total sample population were divided into two main categories of vibration exposure: *1)* Whole body vibration exposure and *2)* Hand-arm vibration exposure. This division of exposure groups was predominantly based on similar job tasks and occupations present within the two groups. Subsequently, for Hand-arm vibration thirteen (13) different similarly exposed groups were identified whereas Whole body vibration initially comprised out of seventeen (17) occupational Similar Exposed Groups. However, the Open Pit training officer was removed due to possible unreliable results. These are characterised in table's 5.3.1 and 5.3.2 respectively.

Table 5.3.1: Hand-arm Vibration Exposure Groups

NO.	JOB TITLE
1	Assistant Fitters
2	Boilermaker
3	Rubberliners
4	Turners
5	Welders
6	Fitters
7	Bricklayer
8	Instrument Mechanics
9	Carpenter
10	Diesel/Motor Mechanics
11	Pit Electricians
12	Plant Electricians
13	Panel Beaters

Table 5.3.2: Whole Body Vibration Exposure Groups

NO.	JOB TITLE
1	GD-120 Operators
2	Wall control drillers
3	Mobile crane operators
4	Pit equipment operators
5	H&E Field support
6	Materials Operators
7	IVECO driver
8	Bus Driver
9	Tailings dam Equipment Operators
10	Hef truck Plant
11	Hiab operators
12	Open Pit Training officer
13	Rodmills Operators
14	Primary Crushers Operators
15	Pre-screening Maintenance
16	Fine crushing Operators
17	MNO^2 Operators

Bivariate summary statistics related to the type of vibration exposure (TOV) and Aeq results are characterised by table 5.3.3. Out of the total number of 135 vibration measurements reported, 58 comprised out of Whole body vibration measurements, 67 were Hand-arm vibration measurements and 10 research participants served as controls. The controls were defined as office workers performing mostly administrative tasks with the belief that they are the group exposed to the least levels of vibration on the mine. For that reason, it is imperative to note that all of the workers on the mine are somehow exposed to very insignificant levels of vibration. In addition, due to pure logistical reasons, the controls are only used for comparison against the Whole body vibration exposure group. The results show that the variability within the exposure groups is small. Hence, a median of 0.89 m/s^2 with an inter-quartile range (IQR) of 0.85 m/s^2 characterises the average Aeq results measured for Whole body vibration. In this same distribution, a median value of 5.31 m/s^2 with an IQR of 6.75 m/s^2 describes the Aeq results for Hand-arm vibration. The control group are characterised with a much lower and also expected Aeq level, (Median 0.09 m/s^2, IQR 0.07 m/s^2).

Table 5.3.3: Exposure group Characteristics based on Aeq measured results

EXPOSURE GROUP (*n* = 135)	**MEDIAN** (Aeq in m/s^2)	**INTERQUARTILE RANGE**
Controls **(n = 10)**	0.09	0.07
Whole Body Vibration **(n = 58)**	0.89	0.85
Hand-arm Vibration **(n = 67)**	5.31	6.75

5.4 THE WHOLE BODY VIBRATION EXPOSURE RESULTS

Forklifts, track dozers, haultrucks, front-end loaders, hiabs, light vehicles, busses, an Iveco combi, tyre dozers and graders were included in the types of earthmoving equipment that was assessed for whole body vibration across the mine. In total, twenty-two (22) different types of mobile equipment were measured (Table 5.4.1) and fifty-eight (58) operators were assessed for exposure to Whole body vibration.

Table 5.4.1: Characterization of the various types of Earthmoving equipment assessed for Whole body vibration on the mine

No.	Wholebody Vibration Equipment
1	Demag shovels
2	Track dozer
3	Rubber tyre dozer
4	Graders
5	Watercarts
6	Haultrucks
7	Light vehicles
8	Front end loaders
9	Hef-truck
10	METROE Bobcat
11	GD 120-drills
12	Halco Drills
13	Bus
14	Fork Lifts
15	Hiabs
16	Cranes .
17	Luggerbin Truck
18	Back Actor
19	Diesel Truck
20	IVECO
21	Bell Truck
22	Oshkosh truck

Table 5.4.2: Estimation of an association between type of occupation and Aeq result measured in m/s^2

Occupation	β-Coefficient	95% CI	p-value
GD-120 Operator	0.09	-6.55 – 6.75	0.97
Mobile Crane Operators	0.51	-5.84 – 6.87	0.87
Pit Equipment Operators	3.51	-1.94 – 8.96	0.20
H & E Field Support	0.74	-7.2 – 8.70	0.85
Materials Operator	0.34	-6.7 – 7.40	0.92
IVECO Driver	0.24	-9.8 – 10.30	0.96
Bus Driver	0.50	-9.5 – 10.56	0.92
Tailings Dam Equipment Operator	0.61	-5.54 – 6.77	0.84
Hef truck Controller + Operator	1.23	-5.87 – 8.34	0.72
Hiab Operator	0.81	-7.13 – 8.77	0.83
Rodmills Operator	0.45	-7.49 – 8.40	0.90
Primary Crushers Operator	-1.14	-8.09 – 7.80	0.97
Fine Crushing Operators	1.31	-5.34 – 7.96	0.69
MNO^2 Operators	1.42	-6.52 – 9.38	0.71
Base (Wall Control Drillers)	0.20	-4.82 – 5.23	0.93

In the above analysis, it was attempted to determine which predictor variables are the best predictors of Aeq ($p>0.05$). However, according to the results it appears that all the variables are poor predictors of Aeq. Conversely, the above information was used in order to establish those groups, which are posing the highest vibration exposure based on the Beta estimate result. Positive, but insignificant slopes is demonstrated by the high beta estimates for Open Pit Operators ($\beta = 3.51$; $p = 0.20$), Heftruck controller & operators ($\beta = 1.23$; $p = 0.72$), Fine Crushing Operators ($\beta = 1.31$; $p = 0.69$) and the MNO^2 Operators ($\beta = 1.42$; $p = 0.71$) Hence, all of the before mentioned occupations are exhibiting a potential increased risk for the development of WB symptoms, but this is not of a significant nature. The rest of the results demonstrate a downward slope in general (Table 5.4.2).

Results in table 5.4.3 surprisingly show that none of the variables are significant predictors for the development of WB vibration symptoms. Nevertheless, the variable age, demonstrates a 9% borderline insignificant increased risk (OR = 1.09; CI: 0.99 – 1.20). Similarly, being a smoker exhibits an almost 5 fold borderline insignificant increased risk of developing wholebody vibration symptoms (OR = 4.62; CI: 0.82 – 26.02). An insignificant 4% increased risk is also associated with employment duration and the onset of disease (OR = 1.04; CI: 0.95 – 1.13).

Table 5.4.3: Determining an association between various risk factors and developing WB symptoms

Risk Factors	*Odds Ratio*	*95% CI*	*p-value*
Unadjusted bivariate results			
Aeq	0.62	0.20 – 1.91	0.40
Employee Duration	1.04	0.95 – 1.13	0.36
Exposure Time	1.00	0.76 – 1.32	0.96
Extramural Activities	0.82	0.15 - 4.42	0.82
Age	1.09	0.99 – 1.20	0.05
Weight	0.97	0.91 – 1.02	0.28
Previous Exposure	2.91	0.73 – 11.58	0.12
Ex-Smokers	2.05	0.33 – 12.66	0.43
Smokers	4.62	0.82 – 26.02	0.08
Road	0.66	0.11 – 3.93	0.65
Adjusted for age & smoke			
Aeq	0.67	0.22 – 2.04	0.48
Employee Duration	1.02	0.88 – 1.18	0.77
Exposure Time	0.90	0.65 – 1.23	0.52

5.4.4 The A (8) Equivalent Whole Body Vibration Measurement Results Based on Occupational Similar Exposed Groups

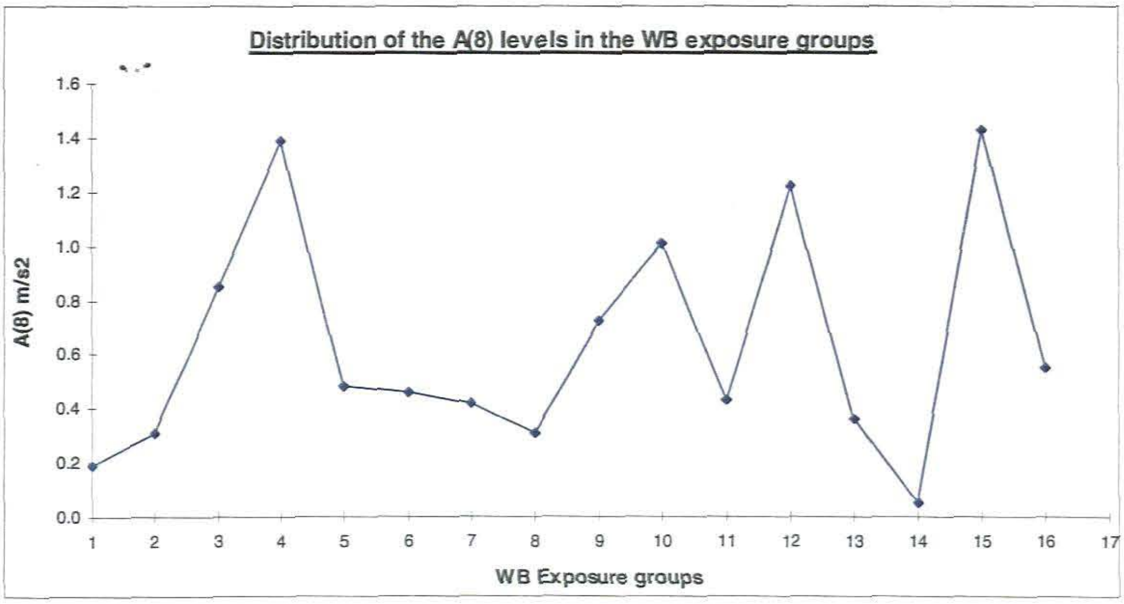
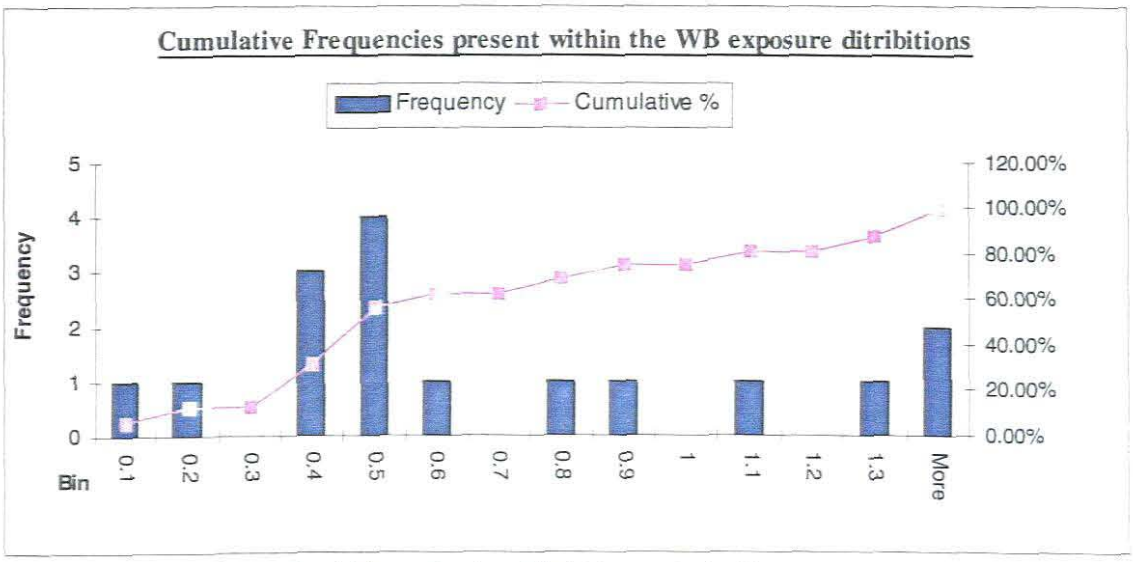


Figure15: Distribution of the A(8) Wholebody (WB) levels within the exposure groups

In figure 15, the local variations of individual A(8) vibration data is characterised. In terms of visual observation, it is evident from the above graph, that the exposures within the distribution are very variable as can also be denoted from the zigzag pattern of the graph.



Bin = A bin is the numeric range for which any given bar of the histogram chart adds up.

Figure 16: Representation of the cumulative frequencies amongst the WB exposure groups

The Histogram in figure 16 provides a deeper insight into the exposure distributions of the Wholebody vibration sample population. Hence, the cumulative frequency distributions are showing what proportion of the workers within the occupations is below or above the ISO action value of $0.5 m/s^2$. Consequently, 56% of the sample population are equal to or less than $0.5 m/s^2$, whereas a lesser proportion (44%) was above 0.6.

Results obtained from the WB vibration calculator, showed that amongst the exposures for Wholebody vibration, the occupations exhibiting the highest A(8) generated vibration levels in the study, were the Fine Crushing operators. Consequently the maintenance workers working on the Fine Crushing plant area when it is in operation will be exposed to similar levels (A(8) = $1.43 m/s^2$). In addition, the Pit equipment operators (A(8) = $1.39 m/s^2$) showed the second highest A(8) exposures within their group followed by the MNO^2 plant equipment operators (A(8) = $1.22 m/s^2$)(Table 5.4.4). The earthmoving equipments generating the highest WBV Aeq exposures in all three measured axes were a Track dozer (Aeq = $2.03 m/s^2$) used by the Open Pit equipment Operators and a Bell truck (Aeq = $1.83 m/s^2$) operated by the MNO^2 plant equipment operators. Similarly, the area at Fine Crushing posing the highest threat to wholebody vibration is at the Tertiary Crushers (Aeq = $2.72 m/s^2$). Moreover, within the occupations that exceeded the wholebody vibration exposure standard of $0.5 m/s^2$, but to a lesser extent, the major vibration sources measured in equivalent acceleration levels were an Oshkosh truck (Aeq = $1.12 m/s^2$) operated by the Mobile equipment operators, a Hyster Forklift (Aeq = $0.59 m/s^2$) used by the Materials operators at Central stores, and a CAT Back actor which is operated by the Tailings dam equipment operators (Aeq = $1.15 m/s^2$) (Table 5.4.4).

Table 5.4.4: Characterization of the magnitude of vibration exposures amongst the different occupational SEG's, with the tools in each group that exceeded the EAV

No.	Occupation	Wholebody Vibration Sources	A (8) m/s^2	Sources within SEG that exceeded the *EAV
1	Wall control driller	Halco Drill 1, Halco Drill 2	0.19	NONE
2	GD-120 Operator	GD- 120 Drill	0.31	NONE
3	Mobile crane operator	110 ton DEMAG crane, 75 ton P&H crane, Oshkosh, Luggerbin truck, 35 ton GROVE crane	0.85	All – Oshkosh truck measured the highest Aeq
4	Pit equipment operator	Shovel, Haultruck, Rubber Tyre dozer, Track dozer, Grader, Front-end Loader, Water truck	1.39	All – Track dozer (76) measured the highest Aeq
5	H&E Field support	Light Vehicle Bakkie	0.48	Both
6	Materials Operator	Forklift	0.46	Hyster Forklift measured highest Aeq
7	IVECO driver	IVECO combi	0.42	NONE
8	Bus Driver	Bus	0.31	NONE
9	Equipment operator Tailings dam	(CAT) Back Actors, (CAT) Front End Loaders, (CAT) Grader, (CAT) Track dozer, (CAT) Diesel Truck	0.72	All - Back Actor measured the highest Aeq
10	Hef truck Controller & Operator	Hef Truck, Forklift, Bobcat	1.01	All - Bobcat measured the highest Aeq
11	Hiab operators (Also fitters)	Hiab	0.43	HINO (7 ton) Hiab measured highest Aeq
12	MNO^2 Plant Equipment Operators	Front-end Loader, Bell truck	1.22	All – Bell truck measured highest Aeq
13	Rodmills Operator	Forklift, Plant structure	0.36	Hyster Forklift measured highest Aeq
14	Primary Crushers Operators	Plant Vibration	0.05	NONE
15	Fine Crushers Operators	Luggerbin truck, Plant structures	1.43	All – The Tertiary crushers measured the highest Aeq
16	Pre-screening	Plant structures	0.55	All – Pre-screening plant structures

AV = $0.5 m/s^2$ for an eight hour working period

A schematic presentation of the Wholebody vibration A(8) exposure results for 2004 together with the EAV for Wholebody vibration as was presented in table 5.4.4 previously, is depicted in figure 17. It is also evident from this graph that the maximum A(8) exposure level amongst the similarly exposed groups that was assessed, was recorded at Fine Crushing, specifically at the Tertiary crushers (1.43m/s^2) whereas the minimum A(8) vibration levels was surprisingly recorded at the Primary Crushers area (0.05 m/s^2).

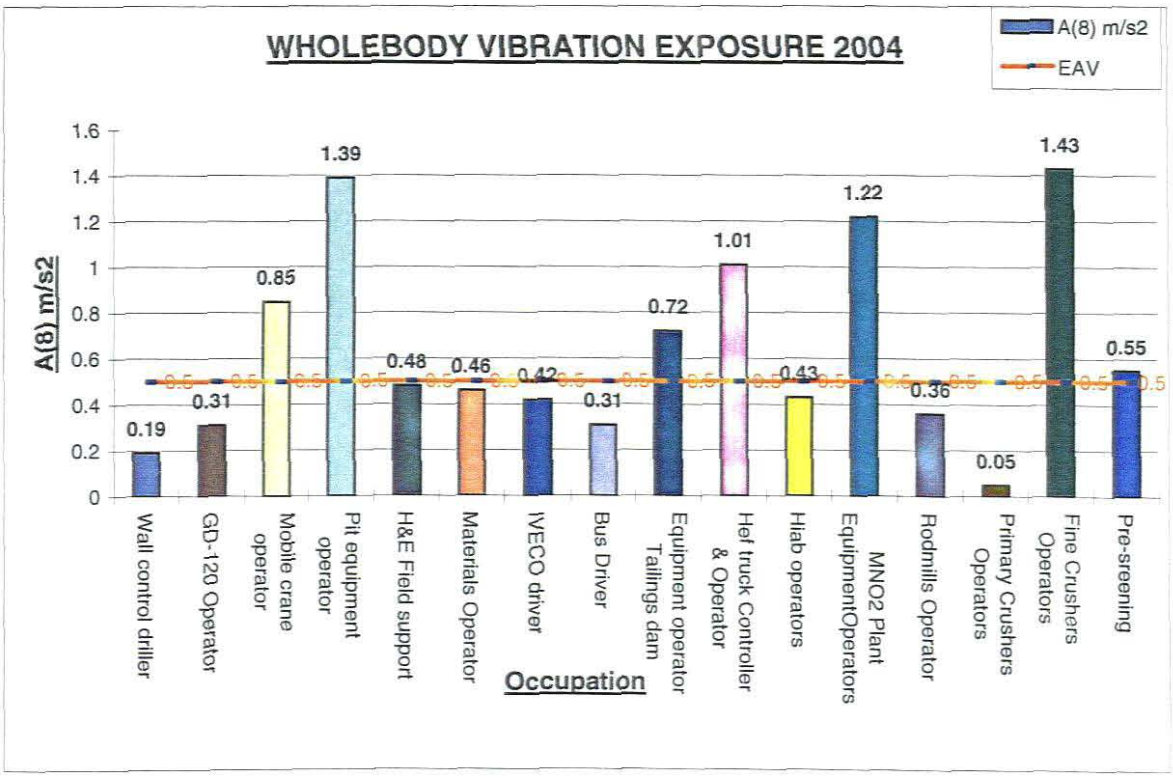


Figure 17: Schematic Presentation of the Magnitude of Wholebody Vibration Exposure at Rössing Uranium, 2004

Table 5.4.5: The vibration levels of occupational similar exposed groups present on the mine exceeding the ISO: 2631/1 vibration exposure action value of 0.5 m/s^2

OCCUPATION	A (8) level m/s^2 (x, y, z axis)
Mobile Crane Operators	0.85
Pit Equipment Operators	**1.39**
Tailings dam Equipment Operators	0.72
Hef truck Controller & Operator	1.01
MNO^2 Plant equipment Operators	**1.22**
Fine Crushing Operators	**1.43**
Pre-screening Area	0.55

The major occupational groups that exceeded the ISO vibration standards are presented in table 5.4.5. Out of the 16 occupational exposure groups that were assessed for wholebody vibration, 7(44%) exceeded the daily exposure action value (A(8) values > 0.5m/s^2). This exceedence ranged from a minimum of 0.55m/s^2 to a maximum of 1.43m/s^2. In addition, out of these 7 groups, 3(19%) of the groups, which are highlighted in the above table, exceeded the exposure limit value (A(8) values > 1.15 m/s^2); ranging from a minimum of 1.22 m/s^2 to a maximum of 1.43 m/s^2.

5.5 THE HAND-ARM VIBRATION EXPOSURE RESULTS

A total of sixty-seven (67) hand-arm vibration measurements were conducted amongst thirteen (13) different similar exposed groups working with approximate seventeen (17) different types of vibrating hand held tools across the mine. Jackhammers, different size air operated impact tools, different size electrical and air operated grinders, needlescalers, and nibblers to mention a few were hand held tools that were assessed in this study. This research project found that different size air and electrical impact tools and grinders are the type of vibrating hand held tools to be more predominantly used across all the thirteen (13) occupations. Fitters, boilermakers, bricklayers, diesel/motor mechanics, panel beaters and electricians were amongst the occupational groups making predominantly use of these tools and were consequently assessed in this study. The work activity that is normally performed on a daily basis within the occupations includes grinding, fitting, sweising, gouching, and welding.

Similarly to the analyses performed on the Wholebody vibration data, linear regression analyses were also conducted on the dependent variable and the independent variables; in order to predict which of the occupations poses the highest hand-arm vibration risk. The occupation exhibiting the lowest vibration exposure, the Turners, ($\beta = 0.41$; $p = 0.89$) was used as the base group. The significant p-values together with the positive beta coefficients demonstrated by the Bricklayer ($\beta = 12.76$; $p = 0.03$), Diesel/motor mechanics ($\beta = 9.46$; $p = 0.008$), the Plant electricians ($\beta = 8.05$; $p = 0.03$) and the Panel beaters ($\beta = 9.57$; $p = 0.04$), indicates that these occupations are significant predictors of Aeq, and are subsequently posing the highest vibration risk.

Results also showed that a fitter (β = 6.92; p = 0.05) and an assistant fitter (β = 7.47; p = 0.05) are significant borderline increased predictors for the development of any hand-arm vibration related symptoms. In most cases however, a positive relationship between the independent and dependent variables existed (Table 5.5.1).

Table 5.5.1: Estimation of the relationship between type of occupation and Aeq result measured in m/s^2

Occupation	β- Coefficient	95% CI	p-value
Assistant Fitters	7.47	-0.14 – 15.09	0.05
Boilermakers	5.12	-1.76 – 12.00	0.14
Rubberliners	2.52	-5.10 – 10.14	0.51
Welders	6.83	-1.48 – 15.15	0.10
Fitters	6.92	-0.13 – 13.97	0.05
Bricklayer	12.76	1.60 – 23.92	0.03
Instrument Mechanics	1.15	-7.16 – 9.47	0.78
Carpenter	0.57	-10.58 – 11.73	0.91
Diesel/Motor Mechanic	9.46	2.54 – 16.38	0.008
Pit Electricians	1.39	-7.71 – 10.50	0.76
Plant Electricians	8.05	0.61 – 15.48	0.03
Panel Beaters	9.57	0.46 – 18.68	0.04
Base (Turners)	0.41	-6.02 – 6.85	0.89

Table 5.5.2: Determining an association between various risk factors and developing Hand-arm vibration related symptoms

Risk Factor	*Odds Ratio*	*95%CI*	*p-value*
Aeq	1.13	1.01 – 1.26	0.02
Employee Duration	1.02	0.97 – 1.08	0.31
Exposure Time	0.77	0.59 – 1.01	0.06
Extramural Activities	0.92	0.29 – 2.88	0.89
The wearing of gloves	0.76	0.24 – 2.38	0.64
Type of grip onto tool	0.78	0.06 – 9.17	0.84
Age	0.99	0.94 – 1.05	0.96
Previous Employment	0.83 (1)	0.21 – 3.20	0.79
(1=Yes, 2 = No)	0.48 (2)	0.11 – 2.01	0.31
Weight	0.99	0.96 – 1.03	0.79
Ex-Smoker	2.85	0.69 – 11.76	0.15
Smoker	2.15	0.62 – 7.42	0.22

A significant increased association are exhibited between Aeq and the odds for developing hand-arm vibration symptoms (OR = 1.13; CI: 1.01 – 1.26). Hence, there is a 13% significant increased risk associated with Aeq as a predictor for the development of Hand-arm vibration related symptoms. In addition, a 2% insignificant increased odd is associated with the length of employment on the mine and the onset of vibration disease or symptoms (OR = 1.02; CI: 0.97 – 1.08) (Table 5.5.2).

5.5.3 The A (8) Equivalent Hand-Arm Vibration Measurement Results Based on Occupational Similar Exposed Groups

Table 5.5.3: Characterization of the Magnitude of Vibration Exposures amongst the Different Occupational SEG's

No.	Occupations	Hand-arm vibration sources	A(8) m/s^2	Sources within SEG that exceeded EAV
1	Boilermakers	Large & small electric grinders, Pipe grinder, Welding machine, ½ inch impact tool, large and small nibblers, gouching tool, 1 inch air impact tool, gouching tool	3.0	Electrical Large Grinder measured the highest Aeq
2	Fitters	Pneumatic air operated 1inch impact tool, air operated 1 ½ inch impact tool, Air Grinder	4.0	All – Air operated 1 ½ inch impact tool measured highest Aeq
3	Asst. Fitters	1 ½ inch impact tool, Air operated half inch. Impact tool	3.0	Air operated 1 ½ inch impact tool measured highest Aeq
4	Turners	Pedestal drill, Turning Machine	0.3	NONE
5	Rubberliners	Different size Grinders, Sticher	1.9	Small air operated Grinder measured the highest Aeq
6	Welders	Electrical grinder, Needle scaler, ¾ Impact tool, 1 inch Impact tool	3.0	Needle scaler measured the highest Aeq
7	Bricklayer	Jackhammer	11.4	Jackhammer
8	Instrument Mechanics	Hand drill, Air angle Grinder, Electrical baby grinder	0.3	Angle Grinder measured the highest Aeq
9	Carpenter	Sanding machine	0.9	NONE
10	Diesel/Motor Mechanics	Small air operated impact, break shoe tool, air drill, 285A Impact wrench, 1 inch air impact tool, Grinder, Air Torque tool, 750 inch impact tool, ½ impact tool	6.0	The 1 inch air operated impact tool measured the highest Aeq
11	Mine Electricians	Air operated hand drill, different size Impact Tools	1.0	½ inch impact tool measured the highest Aeq
12	Plant Electricians	Hand drill, Large electrical Bosch grinder, Impact tool	2.6	Large Bosch Electrical Grinder measured the highest Aeq
13	Panel Beaters	Needle Scaler, Grinder, Sanding machine	3.2	Needle Scaler measured the highest Aeq

*** EAV – 2.5m/s^2 for eight hours**

The variability in vibration exposures based on the A(8) results as was described in table 5.5.3 is graphically depicted in figure 18 below.

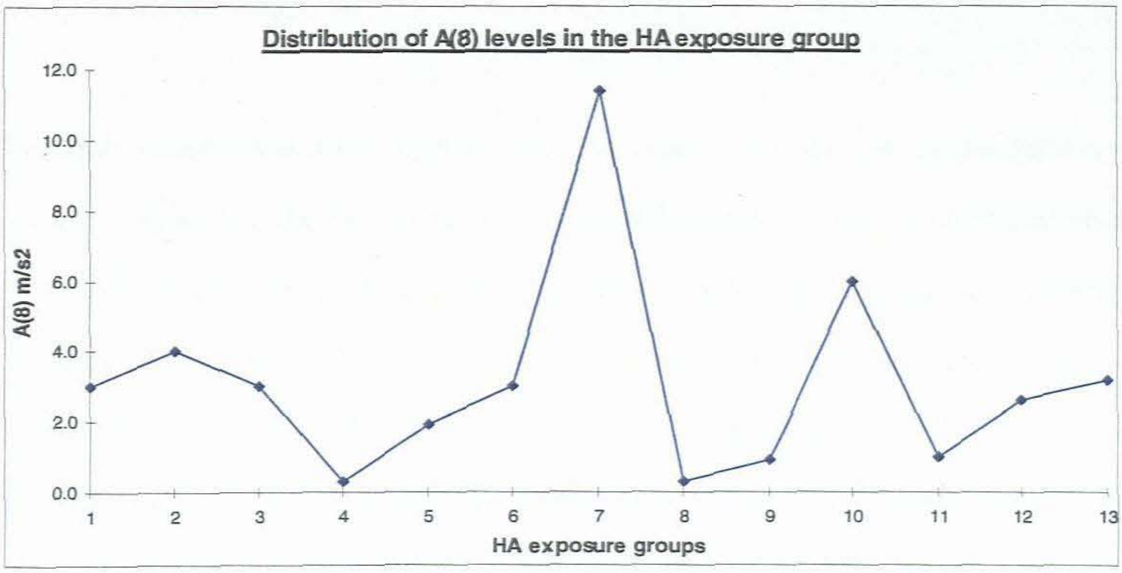
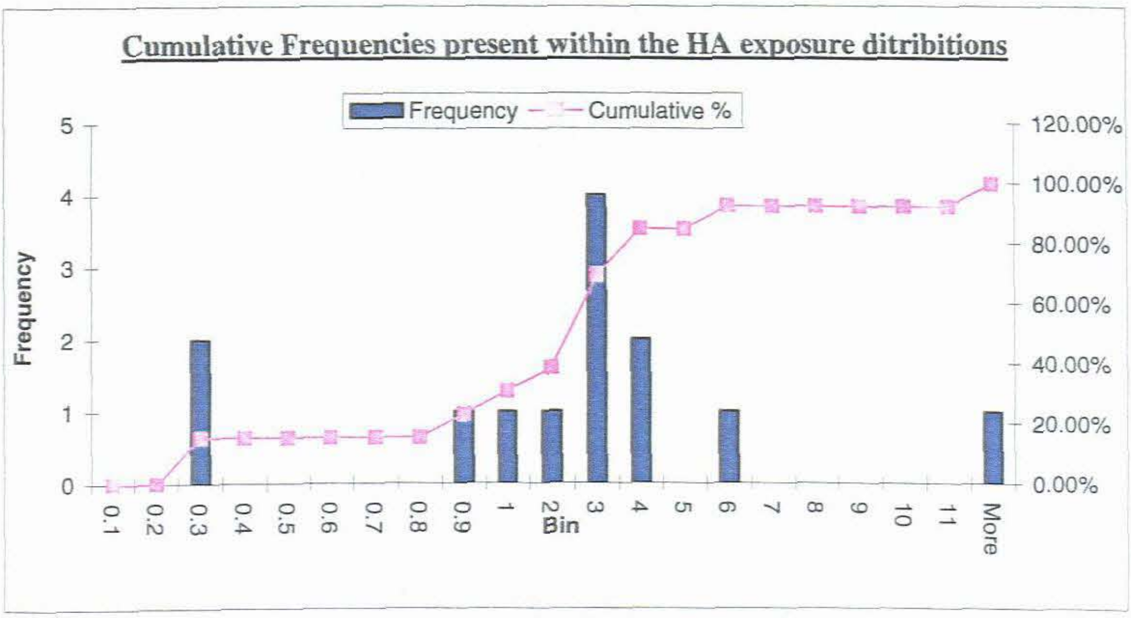


Figure 18: Distribution of the A(8) Hand-arm (HA) levels within the exposure groups

Through visual observation, figure 18 clearly demonstrates that there are a lot of variability pertaining to levels of A(8) results between the different occupations within the sample population.



Bin = A bin is the numeric range for which any given bar of the histogram chart adds up.

Figure 19: Representation of the cumulative frequencies amongst the HA exposure groups

Similar to what was discussed in figure 16 previously, it is evident from the cumulative frequency distribution described in figure 19 above that 61% of the sample population lies above the action value of 2.5m/s^2 compared to a lesser proportion of the workers falling below the action value(49%).

The study revealed that the occupations with the highest A(8) vibration risk for Hand-arm vibration exposure is the Bricklayer (11.4 m/s^2), followed by the Diesel/motor mechanics (6.0 m/s^2) and the Fitters (4.0 m/s^2). The occupations exerting the least hand-arm vibration exposure levels were the Turners and the Instrumentation mechanics, exhibiting both an A(8) level of 0.3 m/s^2 (Table 5.5.3). The major vibrating hand held sources that exceeded the ISO EAV standard of 2.5m/s^2 are characterised in table 5.5.4. Please note that the vibration measurements on the tools were taken in all three of the vibration axis simultaneously (x, y, z) and hence are reported as such. The highest acceleration results measured in m/s^2 between each tool are presented. Consequently, these tools were identified as large electrical grinders (Aeq = 9.37m/s^2), 1-½ inch air operated impact tools (Aeq = 12.47m/s^2), a Jackhammer (Aeq = 13.18 m/s^2) and Needle scalers (11.72 m/s^2).

Table 5.5.4: The table characterises the major vibrating Hand held tools exceeding ISO standard

Major tools exceeding standard	Aeq (m/s^2)
Jackhammer	13.18
1 1/2 inch Impact tools	12.47
1 inch Impact tools	9.34
Large Electrical grinders	9.37
Needle scalers	11.72
Break shoe Tool	10.93
Air Sanding machine	8.26

The A (8) vibration exposure results presented in table 5.5.3 are summarised in the following graph with the principal aim to give a schematic view on the differences in vibration exposure amongst the hand - arm vibration exposure groups, highlighting the most significant exposure groups.

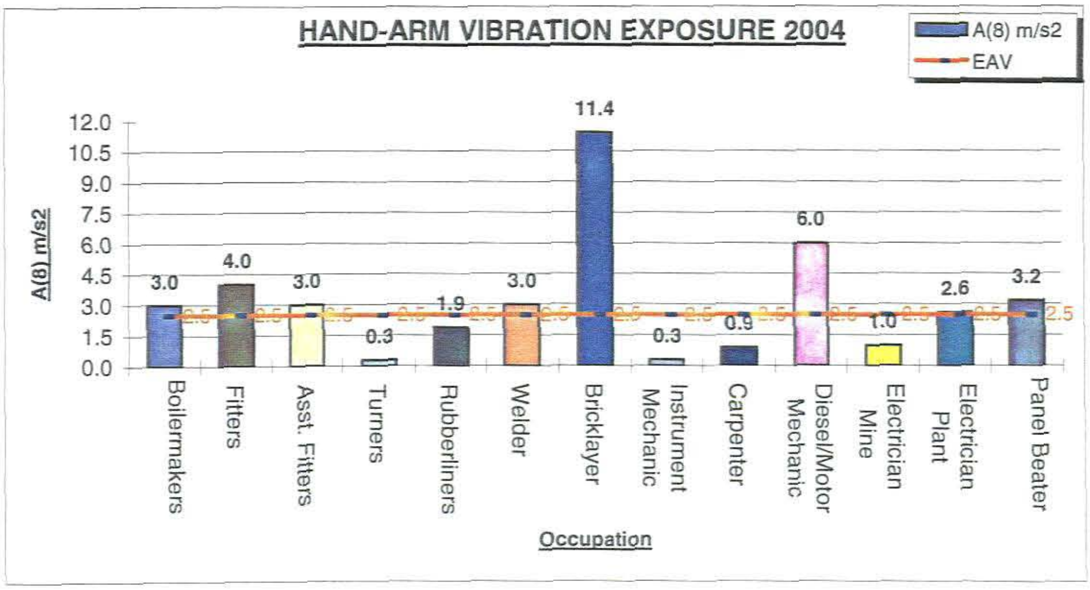


Figure 20: Schematic Presentation of the Magnitude of Hand-Arm Vibration Exposure at Rössing Uranium Mine, 2004

Table 5.5.5: Vibration levels of occupational similar exposed groups present on the mine exceeding the ISO 5349 1/2 vibration action level of 2.5 m/s^2

OCCUPATION	A (8) level m/s^2 (x, y, z axis)
Boilermakers	3.0
Fitters	4.0
Assistant Fitters	3.0
Welders	3.0
Bricklayer	**11.4**
Diesel/Motor Mechanics	**6.0**
Plant Electricians	2.6
Panel Beaters	3.2

Of the 13 occupational exposure groups assessed for Hand-arm vibration, a higher proportion of 61.5% (8) groups exceeded the Hand-arm vibration daily exposure action value of 2.5m/s^2. Subsequently, exceedences that were measured ranged from a minimum of 2.6m/s^2 to a maximum of 11.40 m/s^2. In addition, from these 8 groups, two (2) groups, which are highlighted in the table 5.5.5 above, exceeded the Exposure Limit Value of 5.0 m/s^2, with a range of 6.0m/s^2 to 11.4m/s^2.

The final analyses of the primary A(8) vibration results included the division of all the similarly occupational groups assessed for Hand-arm and Wholebody vibration exposure into risk ratings of high, medium and low vibration exposure based on the computed A(8) vibration results. This risk rating was conducted in conjunction to the standards advised by the Rio Tinto Occupational Health information guideline on human vibration.[68] Subsequently, the identified vibration risk areas on the mine were constructed based on the criterion presented in table 5.5.6 below:

Table 5.5.6: Exposure risk rating of vibration exposure groups at Rössing Uranium

LEVEL	EXPOSURE RATING	COLOUR
HAND-ARM VIBRATION		
High	> 5.0 m/s^2	**Red**
Moderate	> 2.5 but < 5.0 m/s^2	Green
Low	< 2.5 m/s^2	Yellow
WHOLEBODY VIBRATION		
High	> 1.15 m/s^2	**Red**
Moderate	> 0.5 but < 1.15 m/s^2	Green
Low	< 0.5 m/s^2	Yellow

Thus, the application of this criterion on the computed A(8) results, revealed the presence of five (5) high risk, fourteen (14) moderate risk and four (4) low risk vibration exposure areas mine wide. Furthermore, the assessment of the risk, which is associated with the use of various types of tools and equipment in the different areas mine wide is characterised and summarized in appendix 8. From the table in Appendix 8 it is evident that the hand-arm vibration workers are at a higher risk than wholebody vibration workers.

Moreover, in relation to appendix 8, the reader is also referred to appendix 9, to find a geographical area map of Rössing Uranium mine, indicating the dispersion of the identified high, medium and low vibration risk areas present across the mine as was reported earlier.

CHAPTER 6

6. DISCUSSION

6.1 Introduction

Results of this study revealed the presence of five individual high risk and fourteen moderate risk vibration exposure areas on the mine (Appendix 9). As was expected, the overall magnitude of the vibration risks differed between the various similarly occupational groups (figure's 17 & 20) and consequently with the use of certain types of tools and equipment. The type of occupations contributing most to the exposure risks together with the type of tools and equipment posing the highest individual vibration risk have been identified; providing a basis for targeting future control activities. Additionally, the study revealed that the Hand-arm vibration exposure groups are posing a higher vibration risk compared to the measured Wholebody vibration exposures.

However, one of the most pertinent limitations of this study was the occurrence of recall or report bias. There were instances in the study where workers tended to overestimate their daily exposure times to vibrating tools and equipment as ascertained by their responses to the question: "*Approximately how many hours in a work day do you use this equipment or tool?*" compared to their known job descriptions and responsibilities. This type of bias has been reported in a number of similar vibration assessments. A study by Tominaga in 1982 showed that tool operators generally overestimate their exposures by a factor of two. Similarly, in a more recent study conducted by Palmer et.al, in 2000, the researchers found that workers overestimated their exposure times by a median factor of 2.5 (IQR: 1.6-5.9).[63]

One of the measures that are usually implemented by researchers in an attempt to obtain a more accurate daily exposure time is through observing a representative number of workers from each occupational exposure group for a minimum of one hour. This measure, however, is very difficult to accurately quantify, since the amount of time whereby operators make use of the reported vibrating tools and equipment varies greatly from day to day. Alternatively, in the present study, the reported exposure times were normalised with the number of people in a particular occupational group, with the underlying assumption that the worker is having continuous contact with that tool or equipment during the identified time period. This was done before the individual Aeq and exposure time results were incorporated into each respective human vibration calculator for the determination of the daily A(8) exposure level per group.

6.2 Wholebody vibration exposure

The presence of wholebody vibration related symptoms, which were defined as the presence of lower back problems, were reported by 19% of the 68 workers assessed for wholebody vibration, which is less than the approximate international prevalence of 25%. The lower prevalence of symptoms could possibly be explained by the fact that a higher proportion of the earthmoving equipments that was assessed on the mine, were found to be equipped with suitable ergonomical seating. The type and condition of seats do play an important role in controlling the risk to vibration. The seats can be designed to attenuate vibration that is normally present at high frequencies. In use, the resonance frequencies of common seats are in the region of 4 Hz. The amplification at resonance is partially determined by the damping in the seat.

An increase in the damping of the seat cushioning tends to reduce the amplification at resonance but increase the transmissibility at high frequencies. The large variations in transmissibility between seats result in significant differences in the vibration experienced by people in the end.[69]

Generally, no significant associations were exhibited between type of occupation and the related vibration measured result (Table 5.4.2). However, the positive, but insignificant slopes that were demonstrated by the results obtained for the Open Pit equipment operators, Heftruck controller & operators, Fine Crushing Operators and the MNO^2 plant equipment operators suggested that these four types of occupations are exhibiting a potential increased risk for the development of WB symptoms, but which is not of a significant nature. One of the possible reasons for this drawback of occupation as insignificant predictors for Aeq in this distribution and the weak associations that were shown in general could perhaps be related to the small sample size of the exposure group, which were found to be another limitation of this study.

From the computed A(8) results it was however evident, that the execution of specific job tasks, which in turn will depend on the type of occupation, can be related with an increased risk to wholebody vibration (Table 5.4.4). This was mostly evident from the results obtained for the Open Pit equipment operators ($A(8) = 1.39\ m/s^2$), Fine Crushing operators ($A(8) = 1.43\ m/s^2$) and MNO^2 plant equipment operators ($A(8) = 1.22\ m/s^2$). Hence, these occupations are of great concern, since the nature of the job tasks causes the workers to be exposed to the reported levels of vibration for most of their working day; since the type of work that they perform warrants them to operate the equipment for at least five to seven hours in a day.

It is also imperative to note, that the Open pit equipment operators in particular, also take their lunch breaks inside the equipment cabins while it is operating, hence their vibration exposure is of a continuous nature, which in turn increases their risk for the potential future development of wholebody vibration symptoms. Additional factors that might explain the high results in these occupations are the fact that most of the equipment within these occupations is old. Secondly, the surface area where operators drive, especially the Open Pit equipment operators are very bumpy and uneven.

Within the wholebody vibration occupations that exceeded the ISO 2631/1 vibration exposure action limit of 0.5 m/s^2, some of the major vibration sources measured in equivalent acceleration levels (Aeq) were Track dozers, a Bell truck, an Oshkosh truck and Forklifts, all who's measured levels exceeded this limit. When comparing the vibration levels measured for specific types of equipment, against the consequent A(8) exposure levels reported in the respective occupation, it is evident that the level of health risk to which an operator would be exposed to in the end, might depend on the equipment type and the frequency of use. However, there were several additional factors that might have had an effect on the vibration results, but which was not assessed in this study. Some of these factors include the condition of present tires and the vehicle itself, the age of the mobile equipment and plant structures, availability and quality of suspension in the vehicles and frequency of maintenance. Additionally, all of the mobile equipment was measured under normal working conditions, which involved different driving areas and surfaces. Hence, some areas had fewer potholes or hobbles than others, creating less vibration.

6.3 Hand-arm vibration exposure

The presence of hand-arm vibration related symptoms which were defined in the study questionnaire as any unusual feeling or needle pricks in the fingers or hands just after the use of a vibrating hand tool, a few hours after the use of a vibrating tool or all the time, were reported at 28%, which is higher than estimated international prevalence (20%). During the interview process, it was also found that one (1) worker, who is a Welder by profession, had developed diagnosed Raynaud's phenomenon. This high prevalence of reported symptoms might be related to several practices that are being applied by the workers whilst working. Subsequently, this includes the fact that only 36% of the 67 tool users assessed normally wear gloves when operating vibrating hand held tools. This however, might be explained by the fact that workers do find it sometimes uncomfortable to operate vibrating hand tools while wearing gloves. The importance of wearing gloves while operating power tools were illustrated in a study performed by *Chang et al.*[70] Study results indicated that the wearing of gloves, in particular Nylon gloves, reduced 16% and 15% of hand-arm vibration in the z-axis and the sum of three axes as compared with barehanded conditions.

Secondly, this study found that when operating a hand tool, 95% of the time the handgrip onto the tool is tight. All of this can be linked back to a lack of awareness on pertinent issues relating to human vibration control. Consequently, during the project, it was also noted that for most of the employees assessed, the term human vibration, Raynaud's phenomena or hand-arm vibration syndrome was very new and they consequently did not understand it.

This alternately once again demonstrated that there is a need to increase awareness in the workplace on what vibration are, the major vibration sources, best practice methods to apply and the effects of vibration and related disorders. This finding was expected, since it was the first time that an assessment of this nature was conducted at the mine.

Strong associations were detected between the type of occupation and Aeq (measured vibration level) as the predictor variable. Hence the results showed that the Bricklayer, Diesel/motor mechanics, the Plant electricians and the Panel beaters are significant predictors of Aeq, and are subsequently posing the highest individual vibration threat compared to rest of the occupations assessed. Similarly, further computation of the A*(8)* results per occupational group, confirmed that the Bricklayer, Diesel/motor mechanics (A*(8)* = 6.0 m/s^2) and in addition, the Fitters (A*(8)* = 4.0 m/s^2) are posing the highest vibration risks. However, at present, only one person is employed as a Bricklayer on the mine, hence the magnitude of the number of workers exposed to vibration levels this high is minute. Therefore, the occupations, which are currently of a greater concern, are the Diesel/motor mechanics ($n = 34$) and the Fitters ($n = 33$). Evidently, the type of tools that they come into contact with in a normal work day are different size grinders, impact tools, to needlescalers and break shoe tools, all of which exceeded the ISO limit, based on their individual Aeq measured results. It is also noteworthy that a Swedish study conducted on car mechanics in 2003, found that about 15% of the sample population had VWF, although their effective daily length of exposure was only 14 minutes a day.[71] In addition, according to ISO 5349-1:2001, the average hand-arm vibration A*(8)* values that was computed in the current study can be expected to cause vascular symptoms within approximately 4-8 years in 10% of the exposed workers employed as diesel mechanics and fitters respectively, with the assumption that they are exposed on a daily basis to one type or similar type of tools.

A similar type of exposure assessment was done on Forestry workers. Hence the researchers found that according to the measured results, vascular symptoms can be expected to occur within 6 years in 10% of the workers. This estimate is a little less than what was found in this study.[72] However, the probability of an individual developing any symptoms related to hand-arm vibration will ultimately depend on his/her susceptibility to disease, presence of any pre-existing diseases and also work related, personal and environmental factors.

More relevant to this study, the prevalence of symptoms in a group situation, each of whom who performs equivalent work involving a similar tool or tools, is additionally dependent on the range of individual and exposure factors in the group.[25]

A strong increased association were exhibited between the level of vibration exposure and the odds for developing hand-arm vibration symptoms (OR = 1.13; CI: 1.01 - 1.26). Subsequently, a range of past epidemiological studies had shown similar strong evidence of positive associations between high-level exposure to hand-arm vibration and the risk of developing vascular symptoms of hand-arm vibration syndrome. Hence, in a study conducted by Bovenzi et al. vibration-exposed stone drillers and stone cutters/chippers showed a 6.06-fold (95% CI 2.0–19.6) increase in risk of developing VWF in comparison to unexposed quarry and mill workers. Similar results were observed in another study of stone workers conducted by Bovenzi in 1994. Quarry drillers and stone carvers exposed to vibration showed an OR for VWF of 9.33 (95% CI 4.9–17.8) when compared to a reference group of polishers and machine operators.[13]

It is vital to mention that there are several factors that might have played a roll in the resultant vibration magnitudes produced by each different type of tool in this study. Subsequently, the age of the tool, the make and frequency of maintenance are some pertinent factors worthy of mention. Hence, during some qualitative assessments conducted whilst measurements were performed on research participants, it became apparent that the majority of the tools in use at the mine are old and some are not so frequently maintained. This in turn could also increase the risk for the potential development of Raynaud's phenomenon in the future.

As was previously mentioned, amongst the risk factors noted as predictors for the development of HA vibration symptoms was the measured vibration level (Aeq) and to a lesser extent, the length of employment on the mine (Table 5.5.2). Surprisingly, additional risk factors such as the grip onto the tool (CI: 0.06 – 9.17) and exposure time (CI: 0.59 – 1.01) did not demonstrate a strong significant associated risk, as would have been expected. This could be linked to the small sample size and the variability noted in the large 95% confidence intervals. Similar studies found that old age and smoking are significantly linked to the onset of vibration induced white finger; however this finding was not demonstrated in this study.[68]

Many international surveys have provided evidence of increased vibration risks posed onto a number of exposed occupations such as tractor drivers, dentists and forestry workers to name a few. However, there are few related studies done in the mining sector, on the specific type of earthmoving equipment, tools or occupations as were assessed in the current study.

One of the few studies that conducted a vibration survey within the mining sector was the assessment performed by SIMRAC in 1999 (GEN 503).[7] The researchers took vibration measurements on all the mining equipment of South African gold mines. The study concluded that the measured vibration levels generated by mining tools and equipment are sufficiently high to create an enhanced level of risk of vibration-induced disorders in a significant group of operators; which is a similar conclusive finding to this study.

The study of human vibration and its effects are an ever-evolving science. There is still uncertainty about the exposure-response relation between hand-arm vibration and HAVS. *Griffin et.al*[73] suggested in a study that improvements are still possible to both the frequency weighting and the time dependency used to predict the development of vibration-induced white finger in current ISO standards.

6.4 POSSIBLE BENEFITS TO RÖSSING URANIUM MINE AS A RESULT FROM THE RESEARCH SURVEY

- ✓ **Rössing Uranium Ltd workforce**: They benefit from an improved working environment, which is consequently a reduced risk from developing human vibration induced related health disorders, which consequently leads to increased productivity,
- ✓ **Rössing Uranium Ltd.:** The knowledge that was obtained from the study helped the mine to define the impact of the vibration risk present and to identify develop sustainable control measures in order to reduce the reported vibration levels to as low as reasonably achievable. This in turn may reduce the risk of compensation threats in the future,

- ✓ The research findings may also assist Rõssing Uranium to work towards compliance to the Occupational Health standards as specified by the Rio Tinto Group and
- ✓ Labor and resources are appropriately directed in areas, which were identified by the study as high to medium risk, and where corrective measures need to be taken.

6.5 THE LIMITATIONS OF THE STUDY

There were several limitations pertaining to this study that are worthy of mention:

- ✓ Recall or report bias was noted in the form of overestimation of daily exposure times to tool and equipment usage. Hence, there were instances in the study where workers tended to overestimate their daily exposure times to vibrating tools and equipment as ascertained by their responses to the question: "*Approximately how many hours in a work day do you use this equipment or tool?*" compared to their known job descriptions and responsibilities.
- ✓ There were no control group against which the hand-arm exposure results could be compared against on mine. The actual control group should have been in areas out side the mine. However, due to time constraints, assessment of this was not possible,
- ✓ *Exclusion of contractor workers:* Qualitative observations concluded that there are some contractors on the mine that are exposed to high risks of hand-arm vibration. For instance during the use of vibrating hand tools such as jackhammers. However, the inclusion criteria upon which this study was based, did not allow for this group to be assessed,

- ✓ It was found that another area where a worker can come into contact with Hand-arm Vibration is via the steering wheel during normal equipment operation. This study did not assess this vibration risk area,
- ✓ The small sample size of the study, and
- ✓ During the vibration survey, a lot of crossover exposures or instances where workers are exposed to both types of human vibration simultaneously were noticed. However, the magnitude of the effect of this phenomenon onto the workers was not assessed. Hence, this is a possible research question that could be explored by future researchers.

CHAPTER 7

7. CONCLUSION & RECOMMENDATIONS

7.1 CONCLUSION

This research study concluded that the vibration results measured in both the Wholebody and Hand-arm vibration exposure groups are sufficiently high within a number of occupations for the potential future development of vibration-induced health disorders. In addition, the results confirmed the need to develop and implement a sustainable Human Vibration control program in identified high to medium risk areas.

This conclusion is indicative of the following noticeable results:

a) A considerable higher level of exposure was confirmed in the Diesel/motor mechanics and the Fitters when compared to the international hand-arm vibration EAV of 2.5m/s^2 [A *(8)* = 6.0 m/s^2 and 4.0 m/s^2 respectively],

b) The estimation of the relationship between type of occupation and individual Aeq results concluded that the Bricklayer, Diesel/motor mechanics, the Plant electricians and the Panel beaters, are significant predictors of Aeq, and are subsequently posing high vibration risks,

c) A significant increased association were exhibited between Aeq and the odds for developing hand-arm vibration symptoms (OR = 1.13; CI: 1.01 – 1.26),

d) Out of the 16 occupational exposure groups that were assessed for wholebody vibration, 7(44%) exceeded the daily exposure action value [A*(8)* values > 0.5m/s^2] and

e) The occupations found to be at risk for the development of low-back pain or other related wholebody vibration symptoms were the Open pit equipment operators ($1.39 m/s^2$), MNO^2 plant equipment operators ($1.22\ m/s^2$) and the Fine crushing plant operators ($1.43 m/s^2$).

It is however, imperative to note that this research endeavor was performed under normal operating conditions on the mine, which in turn, presented several limitations to the study. Nevertheless, regardless of the limitations which were reported earlier, the research project managed to identify and also quantify the major vibration risk areas on the mine. In addition, the base line results gave an indication on the occupations and vibration sources which should be the priorities for corrective action and it also highlighted some common exposures at the mine that warrant further investigation by future researchers.

7.2 RECOMMENDATIONS

This study has illustrated that the current vibration exposure levels on the mine are high enough in some occupational groups, for the potential development of vibration induced health disorders. Hence, the management of Rössing mine should consider the following recommendations in order to reduce the reported vibration exposure levels in the identified risk areas to as low as reasonably achievable. More importantly, the extent of the type of remedial actions to be enforced in an area will ultimately depend on the overall level and type of vibration risk that was found to be present in that respective area as is characterised in appendix 8 of this research report. In addition, it is also imperative to note that to allow for the effective management of the identified vibration risks, continuous monitoring on the identified high to medium risk areas and sources should be conducted, in order to ensure that the original risks have been controlled and no new risks have been introduced.

The first remedial action that will be applicable to all the areas on the mine is the implementation of a Low Vibration Purchasing Criterion. The general purpose for such a criterion would be to strive to prevent vibration exposure at the start of the purchasing process, instead of having to manage the vibration risks caused by equipment/tools exerting hazardous vibration levels in the end, when workers are already using them or when machinery are already installed in plant areas or workshops. This activity has also the potential of saving the company a lot of money and valuable time in the long run. The criterion will apply to any type of vibrating hand held power tool and earthmoving equipment identified by this study to pose a hazardous vibration health risk.

The following information needs to be obtained from potential suppliers during the tendering process:

1. Do the equipment / tool meets the exposure guidelines in the referenced standards?
2. What is the frequency-weighted acceleration of the equipment?
3. Under what operating conditions were the measurements made?
4. Which published standard was used when conducting the evaluation?
5. A declaration of Conformity to show that it meets essential health and safety requirements and
6. Instructions for safe installation, use and maintenance

The second form of remedial action to be introduced on the mine is the development and implementation of an extensive Human Vibration Control Programme. It should be noted that human vibration is a complex type of health hazard that does not have one control measure that will solve all problems. For this reason it will require a holistic approach using sound occupational health principles of control. This will warrant the implementation of control measures incorporated under the areas of engineering, administrative, medical surveillance and PPE control.

Subsequently, for Hand-arm vibration exposure, some of the Engineering control strategies to be implemented and which is applicable to work environments on the mine includes:

- **Appropriate tool selection:** Making use of Anti-Vibration tools,
- **Eliminating the use of vibrating tools if possible through measures such as automation:** Choose the lowest vibration equipment and tool accessories suitable for the job,

- Ensure that **job design** where possible is such that poor body posture, which can cause strain on hands and arms, is prevented and
- The recommended regular **daily times for using specific tools** should be strictly observed and enforced as described in table 7.2.1 below:

The American Conference of Governmental Industrial Hygienists (ACGIH) has developed Threshold Limit Values (TLVs) for vibration exposure from hand-held tools. These exposure limits are given as frequency-weighted acceleration, which represents a single number of the vibration exposure level. Consequently, Table 7.2.1 list allowable acceleration levels and exposure durations to which most workers may be exposed without severe damage to fingers. The ACGIH advises that these guidelines be applied in conjunction with other protective measures including vibration control.

Table 7.2.1: ACGIH Threshold Limit Values for exposure of the hand to vibration in X, Y, or Z direction

The ACGIH Threshold Limit Values (TLVs) for exposure of the hand to vibration in X, Y, or Z direction*	
Total Daily Exposure Duration (hours)	**Maximum value of frequency weighted acceleration (m/s^2) in any direction***
4 to less than 8 hours	4
2 to less than 4 hours	6
1 to less than 2 hours	8
Less than 1hour	12

*** Directions of axes in the three-dimensional system**

__Source:__ OSH Answers: Vibration measurement, control and standards – www.ccohs.ca

Along with the application of engineering control measures, workers can also reduce the risk of hand-arm vibration syndrome through the following examples of administrative best practices:

- Employ a minimum handgrip consistent with safe operation of the tool or process,
- Try to avoid continuous exposure by taking rest periods,
- Rest the tool on the work piece whenever practical and hold it away from body,
- Refrain from using faulty tools,
- Do regular maintenance on all vibrating hand tools according to the manufactures specifications and
- Consult a doctor at the first sign of vibration disease and ask about the possibility of changing to a job with less exposure if this deems necessary and
- *Awareness training*: As it was noted in the discussion, a definite need for awareness training on Human vibration was identified. Hence, the development and administering of training programs to the workers would be an effective means of heightening the awareness of HAVS in the workplace.

An additional recommendation of attaching pictograms to the tools identified as high to moderate risk vibration sources is also advised. By doing this, the operator is warned of the potential health risks when using the tool, hence enforcing the execution of best practice methods.

Personal Protective Equipment (PPE) should be selected as a last resort with regard to the appropriate vibration exposure level, their comfort and their compatibility with other safety equipment. PPE, such as anti-vibration gloves that meet the requirements of ISO: 10819 may be used in conjunction with the other control measures as described previously in order to reduce vibration directed onto the hand-arm system.[16]

Figure 21 below illustrate an example of anti-vibration gloves that is used in some industries worldwide.

Figure 21: Full-finger protected Anti-vibration gloves

Engineering control methods for Wholebody vibration would include the application and presence of the following:[5]

- Effective vehicle suspension,
- Regular vehicle maintenance, especially the suspension component of the vehicle,
- Fully adjustable controls and ergonomical seating,
- Job rotation,
- Adjusting seating for good seating and support,
- Keeping speed low when crossing uneven services and
- Taking of breaks and doing some stretching exercises on a regular basis.

Administrative control measures:

- *Awareness training:* Operators should be informed about what wholebody vibration are, major sources of exposure, the action & limit values, associated health and other effects of exposure to whole-body vibration, and different methods of prevention. Training should also cover the proper use and adjustment of seats. A poor body posture is often regarded as partially responsible for back problems associated with exposure to vibration. Operators need to be trained on how to adopt a posture, which minimises the transmission of vibration to the body.

- *Regular maintenance* of seats and vehicles is also essential.

The third remedial action to be introduced is the development and incorporation of a human vibration medical surveillance programme into the existing health surveillance programme. Hence, with the incorporation of human vibration programme, the site physician will be able to identify any vibration related health symptoms, assess it, determine their relationship with the type of work performed and give the appropriate advice and/or medical treatment to the worker.[74] Therefore, the main purpose of the programme will be to prevent and to a lesser extent control any significant vibration induced injuries in the identified exposed groups.

As a minimum requirement, the actual health surveillance will need to be performed by means of a questionnaire administered by a competent person at an interview with the individual. At the discretion of the site medical physician, a clinical examination with the option of a number of objective tests may be included.[75] It is however recommended that the help of a specialised person be obtained to do the baseline objective tests onto the workers.

Additional requirements to the programme include:

- Workers identified based on occupation and related work tasks as being regularly exposed to hand-arm or whole body vibration should medically be screened: **a)** Prior to employment and **b)** At regular intervals as long as exposure continues,
- A record should be made and kept of all reports and symptoms pertaining to finger blanching, back disorders and other related vibration health disorders,
- It is also recommended to introduce an initial examination to identify any existing disorders of the spinal column, spinal disc, any illnesses of the gastrointestinal tract or any cardiovascular problems, any HAV disorders etc. that could be exacerbated by wholebody or hand-arm vibration,
- Follow-up examinations during employment will identify if any of the existing problems are exacerbated or if any new ones have developed and
- The results of the medical surveillance programme should be fed back to the line management through either written or verbal communication.

7.3 Areas identified for possible further exploration

One area of interest and importance, which was not assessed in this study, was the crossover of hand-arm vibration and wholebody vibration exposure and the potential effect this might have onto the workers. An example observed in the study was when a fitter worked with a large size impact tool. Due to the weight of the tool and awkward positions that the fitter in specific has to adapt to sometimes, he is forced to let the tool rest against his torso in an attempt to make the task more comfortable and also to damp the vibration. This consequently results in vibration being transmitted to the hand-arm system as well as to the whole body. No literature or past studies, to ascertain the possible extent of the health effects this type of phenomenon might have on the human body, could be found.

Similarly, another type of exposure situation observed in the study was when the operator is exposed to both types of vibration simultaneously. Examples of such situations were noticed during the operation of heavy earthmoving equipment where the operator is exposed to vibration coming from the steering wheel and controls and the seat at the same time. Additionally, another limitation of this study is that no vibration assessments were made on the controls of the heavy earthmoving equipment. One study of HAV exposure from motorcycle controls in 119 Japanese police officers found vibration levels of 2.2 – 4.9 m/s^2, and significantly higher rates of adverse health effects when compared with a control group.[76] These findings might suggest that the equipment controls in the current study are sources of potentially hazardous levels of vibration; hence, further evaluation in this field would be beneficial.

More importantly, there are occupations on the mine where a worker such as a Boilermaker, are exposed to both hand-arm vibration when (s)he operates tools such as Grinders and to wholebody vibration where (s)he for instances operates a Hiab. Hence, in the study the average *A(8)* exposure of a Boilermaker was measured at $3.0m/s^2$, and for operating a Hiab the exposure was measured at $0.43m/s^2$ for eight hours. In the end the Boilermaker might be exposed to two relative moderate vibration exposures risks within a work shift.

Another research area worthy of exploration would be to determine the prevalence and severity of HAVS on the mine. This current study has indicated that there are areas present on the mine where workers are regularly exposed to hand-arm vibration levels exceeding the EAV of 2.5 m/s2. Hence, it would be reasonable to quantify the actual extent of HAVS among these workers through the application of various medical tests and work histories.

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APPENDIX 1

PENINSULA TECHNIKON

Research Project:

OLE-BODY AND HAND-ARM VIBRATION STUDY AT RöSSING URANIUM LTD, NAMIBIA 2003/4

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stionnaire Instructions

›ur answers to the questions in this questionnaire will be regarded as strictly idential and will be used for research purposes only.
se answer the questions as objectively and honest as possible.

ake sure that you answer all the questions and do not skip any accidentally.

ase read every question carefully before you answer it.

swer all the questions by ticking the appropriate box, unless prompted otherwise.

Gender ☐ M ☒ F

k you for the courtesy of your assistance.

ncia Burns
ers in Technology: Environmental Health
nsula Technikon

PENINSULA TECHNIKON
Department of Health Sciences

Research Project:

WHOLE-BODY & HAND-ARM VIBRATION: Quantifying the Risk of Human Vibration at RöSSING URANIUM LTD, NAMIBIA.

OFFICIAL USE

Survey Number ☐☐☐ 1

Principal Researcher: *FULENCIA BURNS*

Interviewer: ____________________

Date of Interview: ☐☐☐☐☐☐
Day Month Year

A. Demographic Data

1. Employment number ☐☐☐☐☐☐☐☐☐☐☐☐ 2

2. Are you a casual or permanent worker ?
Casual ☐ 1
Permanent ☐ 2
☐ 3

3. Age (Years) ☐☐ ☐☐ 4

4. Gender
Male M 1
Female F 2
☐ 5

5. Weight in Kilograms (Kgs) ☐☐☐☐ ☐☐☐☐ 6

Height in Centimeters (Cms) ☐☐☐ ☐☐☐ 7

6. In which area/section on the mine are you working?
____
____
☐ 8

7. What is your job title in this area?

☐ 9

8. Give a short description of your daily tasks.

☐ 10

B. WORK HISTORY

1. How long are you working for the mine?
(years) ☐☐

☐☐ 11

2. In which sections have you been working up to now?

☐ 12

3. Where did you work before you joined the mine?

☐ 13

4. What was your job description there?

☐ 14

5. How long did you work there?
(years) ☐☐

☐☐ 15

C. SMOKING HISTORY

1. What is your smoking status?

Smoker ☐1
Ex-smoker ☐2
Non-smoker ☐3

☐ 16

2. What do you smoke in particular?

Cigarettes ☐1
Pipe ☐2
Cigar ☐3
Marijuana ☐4

☐ 17

3. How much do you smoke on average? E.g. number of cigarettes per day etc. ________________________		☐☐ 18
4. How long have you been smoking (years)?	☐☐ years	☐☐ 19
5. Have you ever stopped smoking for a period?	Y 1 N 2	☐ 20
6. If yes, how long ago (years) was this?	☐☐ years	☐☐☐ 21

D. WORK ENVIRONMENT

1. How bad are the following factors in your place of work?
Is it 1. Not a problem, 2. Acceptable/okay, 3. A big problem

1.1 Heat	Heat is how warm it is. If it is very hot you will; sweat a lot	☐☐☐ 1 2 3	☐ 22
1.2 Noise	Noise is what you hear and hurts your ears.	☐☐☐ 1 2 3	☐ 23
1.3 Vibration	Its the shaking what you feel when you touch the tool/equipment or sit on it.	☐☐☐ 1 2 3	☐ 24

2. Which equipment/tool do you use most of the time? ________________________		☐ 25
3. Approximately how many hours in a normal work day do you use this equipment or tool?	☐☐	☐☐ 26
4. Do you have any unusual feelings such as tingling or needle pricks in your fingers at times?	Y 1 N 2	☐ 27
5. If yes, when does this usually occur?		
All the time	☐ 1	
Just after using an equipment/tool	☐ 2	
Few hours after using equipment/tool	☐ 3	☐ 28
6. Do you have any lower-back pain problems?	Y 1 N 2	☐ 29

E. EXTRAMURAL ACTIVITIES

1. Do you have any hobbies?

☐ Y 1
☐ N 2

☐ 30

2. What is it?

☐ 31

3. Do you partake in any kind of sport activities?

☐ Y 1
☐ N 2

☐ 32

4. Indicate whether you partake in the following sporting activities:

Golf	☐ Y 1	☐ N 2	☐ 33
Soccer	☐ Y 1	☐ N 2	☐ 34
Rugby	☐ Y 1	☐ N 2	☐ 35
Volleyball	☐ Y 1	☐ N 2	☐ 36
Motorbike racing	☐ Y 1	☐ N 2	☐ 37
Any other sports	☐ Y 1	☐ N 2	☐ 38

Please specify type of sport.

☐ 39

OBSERVATIONS

- * Whole Body vibration ☐ 1
- * Hand-arm vibration ☐ 2
- * Whole Body & Hand Arm Vibration ☐ 3

☐ 40

a) WHOLE BODY VIBRATION

1. What is the primary body orientation?
   (Sitting, standing, lying etc.)

☐ 41

2. What material is under the point of contact?
   (Steel, Foam, etc.)

☐ 42

3. What type of seat is used? (if applicable) ____________________________		☐ 43
4. Can the seat be adjusted according to body weight (automatically or otherwise)?	☐ Y 1 ☐ N 2	☐ 44
5. If yes, was the seat adjusted to the operator's weight?	☐ Y 1 ☐ N 2	☐ 45
6. Condition of the road. ____________________________		☐ 46
b) HAND-ARM VIBRATION		
6. What type of material is the handle made of? (steel, rubber, plastic etc.) ____________________________		☐ 47
7. Is the operator wearing gloves?	☐ Y 1 ☐ N 2	☐ 48
8. If yes, of what material is the glove made of?		
Rubber	☐ 1	
Leather	☐ 2	
Cloth	☐ 3	☐ 49
9. Is there any obvious bad posture involved? (unnatural angles of the hand or the arm)	☐ Y 1 ☐ N 2	☐ 50
10. How is the grip of the hand onto the tool? ____________________________		☐ 51

THANK YOU VERY MUCH FOR YOUR KIND CO-OPERATION

RÖSSING

OH & E MANAGEMENT PROCEDURES		**Reference:** ENV/OHS/028	**Revision:** 0.0
		Page: 1 of 9	**Date:** January 2004
Compiled: F.Burns	**Reviewed:** J. Hassall	**Approved:** A. Abrahams	**Authorised:** W. Van Rooyen
SUBJECT: The Measurement of Whole body Vibration			

APPENDIX 2

CONTENTS

1.0 BACKGROUND

Whole body vibration refers to the mechanical vibration that, when transmitted to the whole body, entails risks to the health and safety of workers, in particular lower-back morbidity and trauma of the spine.

European Directive for Human Vibration 2002/44/EC

In other words, it is vibration transmitted to the entire body via the feet in standing work and the buttocks and back in seated work. A person driving a vehicle, for example, is subjected to whole-body vibration through the buttocks, and if there is back support, through the back as well. The pathological effects associated with exposure to whole-body vibration include lower back problems, gastrointestinal problems, vestibular disorders (problems with balance) and also visual disorders.

Increased duration and increased vibration intensity means an increased vibration dose and are assumed to increase the risk, while periods of rest can reduce the risk.

The primary quantity of vibration magnitude is **acceleration**.

2.0 OBJECTIVE

The objective of this procedure is to set down a set protocol as to how the measurement of whole-body vibration must take place in the field.

3.0 SCOPE

This procedure characterises the measurement method for Whole Body vibration. Hence the direction, location, duration and reporting of this type of human vibration is discussed.

4.0 GLOSSARY OF TERMS

a) **Acceleration** – A vector quantity that specifies the rate of change of velocity (metre per second squared, m/s^2)
b) **Accelerometer** – A transducer that produces an output, which is proportional to the acceleration in some, specified axis.
c) **Exposure Action Value (EAV)** – This is a sufficient level of daily worker exposure to vibration to warrant employers taking appropriate actions to control the exposure.
d) **Exposure Limit Value (ELV)** - This is a daily level of worker exposure where the risk to health is estimated to be sufficiently high that further exposure must be prohibited. If effective action is taken at the EAV level. The ELV should rarely be exceeded.
e) **Root Mean square (RMS) or A8** – Vibration in meters per second squared normalised to 8 hours [m/s^2 A (8)] or A (8) shortened. Consequently a cumulative exposure using an average acceleration adjusted to represent an 8-hour working day is described.

5.0 INSTRUMENTATION

The instrumentation needed for the measurement of Whole body vibration will comprise the following:

- MAESTRO 01dB –Stell human vibration monitoring instrument
- Seat Pad
- Triaxial Shear accelerometer with cable
- Monitoring sheet to record results
- Small flat screwdriver

- Digital camera (Optional)
- Area Risk Assessment Card

Prepare the human vibration instrument according to the specifications described in the supplier's manual provided.
NOTE: When calibrating the instrument by means of voltage sensitivity input values, use the following: (page 25-26).

- Y axis – 10.25 mV/g
- X axis – 9.09 mV/g
- Z axis – 10.91 mV/g

To be able to obtain the sensitivity option, first select Tri: 10mV/g, than press the right arrow and than the arrow pointing downwards. Press OK and use the up and down arrows to change values.

6.0 RESPONSIBILITIES

a) H&E MANAGEMENT FIELD SUPPORT SHALL:

- Operate the MAESTRO human vibration measuring instrument exactly as specified in the instrument manual provided.
- Report any deviations regarding the instrument to the H&E co-ordinator.
- Perform a human vibration survey as specified in 12.0.
- Update the human vibration monitoring map.
- Perform regular checks of functionality with a vibration calibrator before and after a sequence of measurement. Use the steps in the instrument manual as a guideline.

b) H&E MANAGEMENT CO-ORDINATOR SHALL:

- Inspect the MAESTRO on a regular basis to ascertain operating condition.
- Ensure that vibration checks are performed before and after measurements.

c) OH&E TECHNICAL SUPPORT SHALL:

- Assist when any problems are being experienced with the system.

7.0 FACTORS THAT WILL HAVE AN EFFECT ON THE WORKING OF THE ACCELEROMETER

- Humidity in the cabling system
- Very loud noise
- Corrosive materials
- Highly magnetic areas
- Radiation

NB: Always handle the accelerometer with great care. It has a limit of shock it can take, thus if dropped it may be damaged, resulting in unreliable results.

8.0 DAILY EXPOSURE ACTION AND LIMIT VALUES

Standardised to a working day of 8 hours, an **Exposure Action Level** has been set **at 0.5 m/s^2** with an **Exposure Limit Value of 1.15 m/s^2**. The highest vibration dose, measured in the three axes will be used to calculate the daily dose.

European Directive for Human Vibration 2002/44/EC

9.0 WHOLE BODY VIBRATION MEASUREMENT

The procedure for the measurement of whole body vibration was set up according to the specifications laid down in the ISO Standard 2631-1: Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration, Part 1: General Requirements

a) Direction of measurement

The vibration must be measured according to a co-ordinate system originating at the point at which vibration is considered to enter the human body. Examples are shown in figures one two and three:

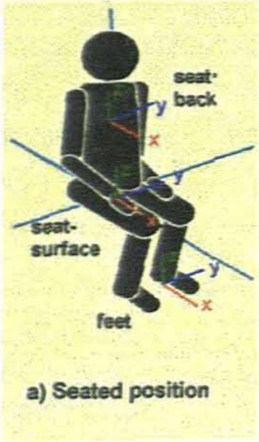


Figure 1

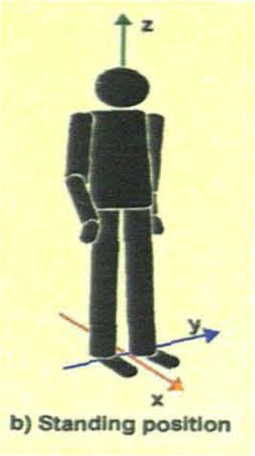


Figure 2

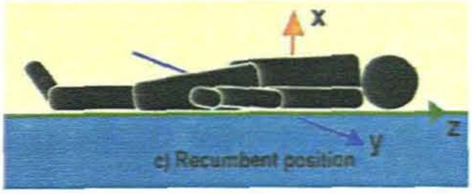


Figure 3

The direction in which vibration is measured takes place on three different axes. They are:

- **Z-axis** – This is your most important direction and it measures vibration up and down i.e. vertical vibration, aligned primarily along the axis of the spine.
- **Y-axis** – Measures vibration in the horizontal lateral direction, from left to right.
- **X-axis** – Measures vibration in the horizontal direction, back to front.

(ISO 2631-1:1997, ISO)

Hence, using the above figures as guidance, the direction in which to place the seat pad according to the co-ordinate system and position of the body is clarified.

b) Location of measurement

The first step is the selection of the measurement locations. It is very important to remember that vibration transmitted to the body should be measured at the point of application to the body.

For a seated person, the point of entry would be:

- the seat surface;
- the seat back-rest; and
- the feet

NB: *The weight of a person also plays a role on the outcome and consequently the quality of a result. Normally industrial vehicles have adjustments at the back of the seat or in front whereby the seat is adjusted according to the weight of a person. Before taking a measurement, ascertain whether the seat is adjusted accordingly.*

The measurements of the vibration entering via the feet should be made near a point where feet are placed most of the time.

For a horizontal position (person lying) the points of contact are beneath:

- the pelvis;
- the back; and the head

The *seat transducer is placed on the seat with a driver sitting on it or is strapped either to the driver' s back or the seat backrest. To measure whole-body vibration transmitted through the floor, the seat transducer is placed on the floor with a small weight or the person itself, on top to ensure a good contact between the floor and the transducer. **(Also refer to the three figures above.)**

NOTE:

In the case when vibration is transferred to the body by a rigid surface e.g. bumpy road, the measurement can be taken on the supporting surfaces adjacent to the points of contact.

Each time the location of measurements should be clearly identified in the assessment reports. Another important point to remember when locating vibration transducers is to align them with the axes of the co-ordinate system at the point where vibration enters the body.
In some cases it can be difficult to obtain a proper alignment, consequently the ISO standard: **ISO 2631-1:1997** allows a deviation of up to 15 degrees from the nominal directions.

c) Duration of measurement

The duration of measurements should be long enough to be representative in a statistical sense and to ensure that the vibration measured is typical for the exposures, which are being assessed.

For instance, take a measurement for one complete cycle of work operation for a Haultruck in the Mining area:

A Haultruck has five stages:
1. Loading of ore
2. Transport of ore to Primary Crushers (Full truck)
3. Scan
4. Tipping at Primary Crushers
5. Return to shovel for next loading (Empty truck)

When deciding on the duration of measurements, it is important to analyse all the tasks that are being undertaken and any additional conditions that may affect the duration. Very often a complete exposure consists of various periods with different characteristics. Consequently, to fully assess the exposure, separate analyses of those periods may be required.

---

* *A seat transducer forms part of the vibration measurement instrument. It consists of a deformable pad that follows the seat contour and contains a triaxial accelerometer for simultaneous measurements in three axes of vibration.*

Each time the duration of measurements should be recorded in the final assessment report. In this case the **Start-Stop** mode may be used as described in the instrument manual – Chapter three pages 20-21.

10.0 GENERAL PROCEDURE WHEN TAKING MEASUREMENTS

- Calibrate the instrument to be used according to the calibration procedure in the instrument manual. This needs to be done before and after a measurement period.
- Perform general checks to ascertain if the instrument is in good working condition. Also ascertain whether the correct type of human vibration (in this case 'Whole-Body') is selected on the instrument.
- Attach the accelerometer to the seat pad – note the direction of the three axes when taking a measurement in the following figure:

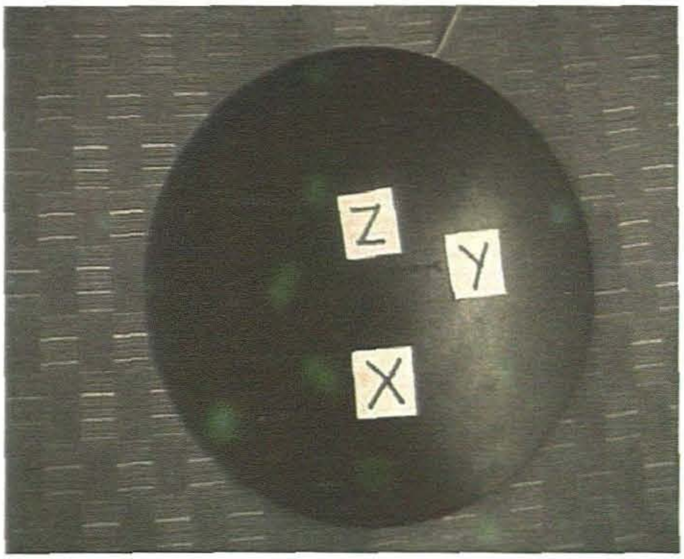


Figure 4: Seat pad with tri-axial accelerometer for Whole body vibration measurements.

- Ensure that you have all the necessary PPE required for the particular area that you selected, including a completed risk assessment card.
- Proceed to the area selected for measurement.
- Notify the responsible person of your intentions.
- Before commencing with any measurement, explain the procedure and purpose to the operator.
- Identify the direction of measurement.
- Take your measurement while person is operating equipment e.g. Haultruck, Crane etc.

10.1 Taking of measurements in the Open Pit

- The Open Pit is a restricted area and a valid open pit licence is necessary to enter the area.
- On entering the boomgate at the Pit Offices report to pit control and get permission to enter the area.
- Identify the type of equipment to be sampled.
- Contact Pit Control with the radio and ask them to inform the operator of your intentions or do it yourself.
- Remember not to interfere with production.
- Get the attention of operator before embarking any type of Open Pit equipment.
- Record the duration of the measurement, equipment number & type etc.
- REMEMBER TO ALWAYS CONDUCT WORK IN A SAFE AND SENSIBLE MANNER!

After the taking of a measurement the results will be displayed in the Result Menu on the instrument. Follow the steps set out on Page 23 in the instrument manual to retrieve the measurement results. Record results on the table provided and than onto the OH & E Management database. Remember to update the area map accordingly.

11.0 FINAL ASSESSMENT REPORT

Summarize your findings in a report that will be submitted to the H & E Management Co-ordinator.

Your report should include the following:

- Date of assessment
- Description of areas/ equipment covered
- Clear purpose of the assessment
- Methodology followed to obtain data
- Results in table format
- Discussion
- Recommendations
- References

12.0 RE-ASSESSMENT

12.1 Re-assessment of the levels of vibration of vehicles and equipment should be performed at least every two years,

12.2 When there are changes or replacements in equipment and vehicles, or in the production process,

12.3 With the introduction of new types of equipment and vehicles

With the re-assessment, the whole-body vibration map should also be updated accordingly.

13.0 REFERENCES

13.1 **SABS ISO 2631-1:1997**, Mechanical vibration and shock: Evaluation of human exposure to whole-body vibration, **Part one**: General Requirements

13.2 MVI Technologies, INRS, **MAESTRO** 4 channel vibration measurements user manual, 2000

13.3 **European Directive** for Human Vibration, 2002/44/EC

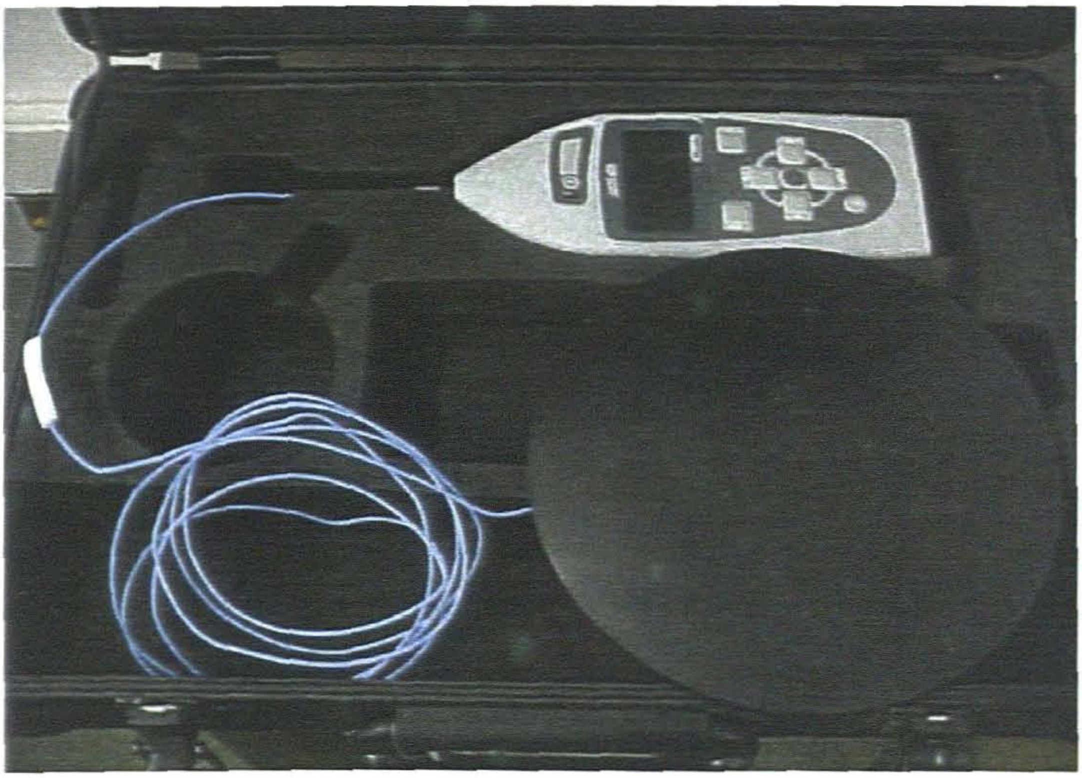
APPENDIX ONE

THE RECORDING OF WHOLE BODY VIBRATION MEASUREMENTS

ATE	EQUIPMENT TYPE	DURATION OF MEASUREMENT	POSITION OF SEAT PAD e.g. floor, back or seat	DIRECTION OF MEASUREMENT + RESULT	Aeq
				X:	
				Y:	
				Z:	

APPENDIX TWO

MEASURING EQUIPMENT FOR WHOLE BODY VIBRATION



RÖSSING

OH&E MANAGEMENT PROCEDURES		**Reference:** ENV/OHS/ 027	**Revision:** 0.0
		Page: 1 of 9	**Date:** Nov. 2003
Compiled: F.Burns	**Reviewed:** J. Hassall	**Approved:** A. Abrahams	**Authorised:** W. Van Rooyen
SUBJECT: The Measurement of Hand-arm Vibration			

APPENDIX 3

CONTENTS

1.0 BACKGROUND

Hand-arm vibration is defined by the European Union Directive for Human Vibration as:

The mechanical vibration that, when transmitted to the human hand-arm system, entails risks to the health and safety of workers, in particular vascular, bone or joint, neurological, or muscular disorders.

Intensive vibration can be transmitted to the hands and arms of operators from vibrating tools, vibrating machinery or vibrating work pieces. Depending on the type and place of work, vibration can enter one arm only or both arms simultaneously and may be transmitted through the hand and arm to the shoulder.

2.0 OBJECTIVE

The objective of this procedure is to set down a set protocol as to how the measurement of hand-arm vibration will take place in the field.

3.0 SCOPE

This procedure characterises the measurement method for Hand-arm vibration. Hence the direction, location, duration and reporting of this type of human vibration is explained.

After obtaining the baseline information for vibration, monitoring will take place each time new tools are introduced or when there are any physical structural changes in plant and workshop areas.

4.0 INSTRUMENTATION

The instrumentation needed for the measurement of Hand-arm vibration will comprise out of the following:

- MAESTRO 01dB –Stell human vibration monitoring instrument
- Shear accelerometer with cable
- Hand-arm adapter to screw transducer onto instrument
- Cable ties for adapter
- Monitoring data capturing sheet to record results
- Digital Camera (Optional)
- Area Risk Assessment Card

Prepare the human vibration instrument according to the specifications described in the supplier's manual provided. **Note:** Equipment must be checked for correct operation before & after use. The calibration must be traceable to a recognised standard maintained by an accredited laboratory.

<u>NOTE</u>: When calibrating the instrument by means of voltage sensitivity input values, use the following: (page 25-26).

- Y axis – 10.25 mV/g
- X axis – 9.09 mV/g
- Z axis – 10.91 mV/g

To be able to obtain the sensitivity option, first select Tri: 10mV/g, than press the right arrow and then the arrow pointing downwards. Press OK and use the up and down arrows to change values.

5.0 GLOSSARY OF TERMS

a) **Acceleration**
A vector quantity that specifies the rate of change of velocity (metre per second squared, m/s^2)

b) **Accelerometer**
It is a transducer, which produces an output that is proportional to the acceleration in some specified axis.

c) **Exposure Action Value (EAV)**
This is a sufficient level of daily worker exposure to vibration to warrant employers taking appropriate actions to control the exposure.

d) **Exposure Limit Value (ELV)**
This is a daily level of worker exposure where the risk to health is estimated to be sufficiently high that further exposure must be prohibited. If effective action is taken at the EAV level, the ELV should rarely be exceeded.

e) **Daily Exposure Value or A (8)**
The A (8) value is the daily vibration exposure of the operator measured in m/s^2. Consequently it is made up of the vibration total value and the exposure time to that source.

6.0 FACTORS THAT WILL EFFECT ON THE EFFECTIVITY OF THE TRANSDUCER/ACCELEROMETER

- Humidity in the cabling system
- Very loud noise
- Corrosive materials
- Highly magnetic areas
- Radiation – high levels

NB: Always handle the accelerometer with great care. It has a limit of shock it can take, thus if dropped it may be damaged and this can lead to unreliable results.

7.0 RESPONSIBILITIES

a) <u>THE H&E MANAGEMENT FIELD SUPPORT SHALL:</u>

- Operate the MAESTRO human vibration monitoring instrument exactly as specified in the instrument manual provided.
- Report any deviations of instrument to the relevant H&E Co-ordinator.
- Update the Human Vibration area map, characterising the tools in different areas on the mine with the different levels of vibration exposure.
- Perform regular checks of functionality with a vibration calibrator or alternative calibration system before and after a sequence of measurements.

b) <u>THE H&E MANAGEMENT CO-ORDINATOR SHALL:</u>

- Inspect the MAESTRO on a regular basis to ascertain operating condition.
- Ensure that vibration checks are performed before and after measurements.
- Ensure validity of results
- Ensure that the instrument is send away for annual calibration.
- Ensure that the relevant line management received a report of their area surveyed.
- Ensure that the document controller receive a hard and soft copy of the report to be filed.

c) THE OH&E TECHNICAL SUPPORT SHALL:

- Assist when any problems are being experienced within the system.

8.0 DAILY EXPOSURE ACTION AND LIMIT VALUES

Daily Exposure Action and Limit values are set for a standardised reference period of 8 hours and are extensively used in industry in order to regulate vibration exposure.

- **Daily Exposure Action Value:** 2.5 m/s^2 standardised to an 8-hour reference period
- **Daily Exposure Limit Value:** 5.0 m/s^2 standardised to an 8-hour reference period

European Directive 2002/44/EC

9.0 MEASUREMENT OF HAND-ARM VIBRATION

The procedure for the measurement of hand-arm vibration was set up according to the specifications laid down in the two ISO Standards 5349: First Edition 2001-05-01 Mechanical vibration – Measurement and evaluation of human exposure to hand-transmitted vibration, Parts one and two. Reference Numbers ISO 5349-1:2001(E) and ISO 5349-2:2001(E)

a) Direction of vibration measurement

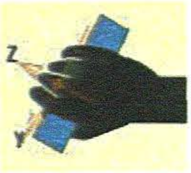
When the hand grasps a handle, a basic central co-ordinate system is used where the front of the handgrip is used as the origin of the system in which the plane x, z lies vertical to the palm of the hand. The plane y, z passes horizontally through the longitudinal axis of the third mid-hand bone.

The direction in which vibration is measured takes place on three different axes. (Refer to figures a, b & c.)

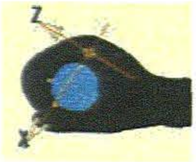
The nature of each is:

- **Z-axis** – This is your most important direction and it measures vibration **up** and **down** i.e. vertical vibration, aligned primarily along the axis of the forearm.
- **Y-axis** – Measures vibration in a horizontal direction, from **left** to **right**.
- **X-axis** – Measures vibration in a lateral direction, **back** to **front**.

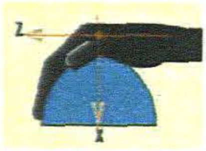
The exposure of the human body to vibration is assessed by means of measuring the vibration entering the body. Vibration is normally measured along three (3) perpendicular directions. If there is more than one point at which vibration enters the body, there will be more than one co-ordinate system for obtaining measurements.



a)



b)



c)

b) Location of measurement

The measurement in the three axes must be made on the surface of the hands in the areas, or in clearly related areas, where the energy enters the body. If the operator's hand is in direct contact with the vibrating surface of the handgrip, the transducer should be fastened to the vibrating structure. Best practice would be to first ask the operator the area on the tool where he/she normally feels vibration is more dominant onto the hand-arm system.

If the magnitude of vibration varies significantly over different parts of the handle, then the maximum value at a point in contact with the hand should be recorded at the end of a measurement.

Fixing the accelerometer onto a tool or piece of equipment

- After determining the correct location to fix the transducer, take the hand-arm adapter provided and place the accelerometer into it. **Note:** the "correct location" is the area where the accelerometer will make best contact with the vibrating surface.
- Fix this onto the determined location with cable wire and ensure that it is tight enough to avoid any movement.
- Take your measurement

c) Duration of measurement

A measurement period must be an average over a period, which is representative of the typical use of a power tool, machine or process. However the total measuring time should be **at least** one minute. Measurements of very short duration are unlikely to be reliable. In cases where an operator uses a tool for short durations at a time (less then 1 minute), at least 3 measurements should be taken; and the total measurement time should be **not less** than 1 minute.

10.0 GENERAL PROCEDURE TO FOLLOW WHEN TAKING MEASUREMENTS

- Calibrate the instrument to be used according to calibration procedure and perform general checks to ascertain if instrument is in good working condition.
- Ensure to check whether the instrument is set according to the type of vibration monitoring you will be performing.
- Select exposure group to be sampled
- Ensure that you have the necessary PPE for the selected area including a risk assessment card.
- Proceed to the area selected for measurement.
- Notify the responsible person of your intentions.
- Before commencing with any measurement, explain the procedure and what you want to do to the operator.
- Ascertain the type of equipment/tool person works with mostly in the day.
- Identify the correct direction/location of measurement.
- Take a measurement while person is operating the tool.
- Take 1minute measurements on each tool the person comes in contact with and calculate the A (8) value.
- In case of devices, which need to be held with both hands, measurements must be made on each hand. The exposure is determined by reference to the higher value of the two.
- Record this eight hour daily exposure value as your final result

After the taking of a measurement the results will be displayed in the Result menu. Follow the steps set out on Page 23 in the instrument manual to retrieve the measurement results. Record results on the table provided and than onto the ENV database.

11.0 CALCULATION OF THE A (8) VALUE

The A(8) can be calculated by means of the following equation:

$$A(8) = a_{hv} \sqrt{T/T_0}$$

Where:

T is the total daily duration of exposure to the vibration $a_{hv;}$
T_0 is the reference duration of 8 hours or 28800 seconds

However, in cases where the total daily vibration exposure consists of several operations with different vibration magnitudes, then the daily vibration exposure, shall be obtained by using the following equation:

$$A(8) = a_{hv}\sqrt{T/T_0 \sum_{i=1}^{n} a_{hv} i\, T_i}$$

Where:

$a_{hv}i$ is the vibration total value for the i th operation,
n is the number of individual vibration exposures,
Ti is the duration of the ith operation

OR

It can be easily calculated automatically by making use of a **Hand- arm Vibration Calculator.**

<u>How to use the Human Vibration Calculator</u>

a) Enter the vibration magnitude in m/s^2 and the daily exposure duration in hours or minutes in the white areas for up to six processes or tools,
b) A partial vibration exposure will appear for each entry in the yellow area,
c) The overall daily vibration exposure A (8) will be displayed in the bottom right cell.
d) The human vibration calculator is located on the K-drive, - *K: Env/Control/Occhyg/ Human Vibration*

12.0 FINAL ASSESSMENT REPORT

Summarize your findings in a report that will be submitted to the H&E Management Co-ordinator.

Your report should include the following:

- Date of assessment
- Description of areas/ equipment covered
- Clear purpose of the assessment
- Methodology followed to obtain data
- Photo's showing the type of tool and the location where accelerometer were placed.
- Calculation of A (8)
- Results in table format clearly indicating the location of measurements
- Discussion
- Recommendations
- References

13.0 RE-ASSESSMENT

13.1 Re-assessment of the levels of vibration of equipment's and tools should be performed at least every two years,

13.2 When there are changes or replacements in equipment and tools, or in the production process,

13.3 With the introduction of new equipment and tools

With the re-assessment, the hand-arm vibration map should also be updated accordingly.

14.0 REFERENCES

14.1 MVI Technologies, INRS, **MAESTRO** 4 channel vibration measurements user manual, 2000

14.2 **European Directive** for Human Vibration, 2002/44/EC

14.3 ISO 5349-1 – Mechanical vibration – Measurement and evaluation of human exposure to hand-transmitted vibration – **Part one**: General Requirements

14.4 ISO 5349-2 – Mechanical vibration – Measurement and evaluation of human exposure to hand-transmitted vibration – **Part two**: Practical guidance for measurement at the workplace.

14.5 HSE website: www.hse.org

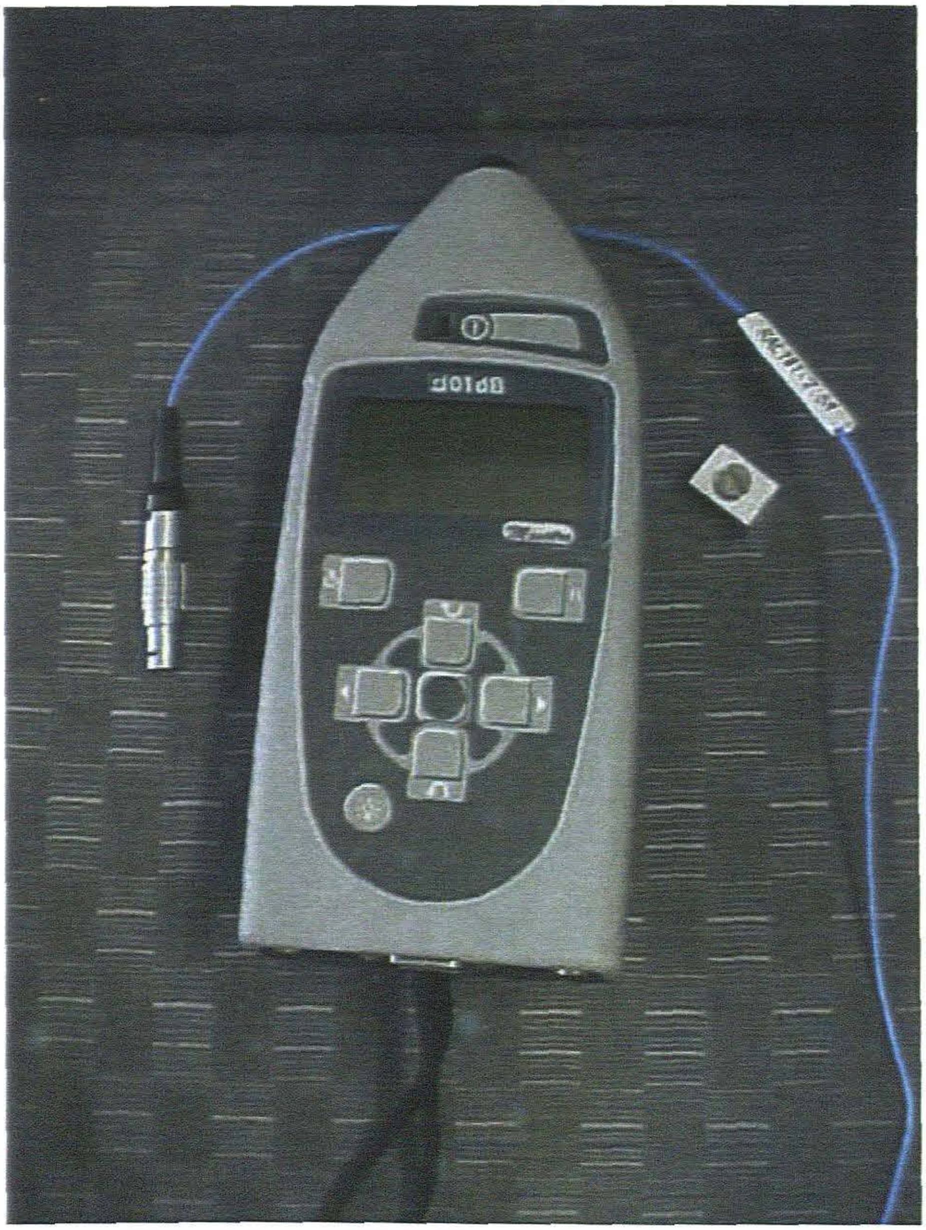
ANNEXURE ONE

MEASUREMENT DATA SHEET FOR HAND-ARM VIBRATION

TE	AREA	TYPE OF TOOL	DURATION OF MEASUREMENT	POSITION OF TRANSDUCER	DIRECTION OF MEASUREMENT + RESULT m/s^2	Aeq m/s^2
					X:	
					Y:	
					Z:	

ANNEXURE TWO

SCHEMATIC REPRESENTATION OF HAND-ARM VIBRATION INSTRUMENTATION



RÖSSING

OH & E MANAGEMENT PROCEDURES		**Reference:** ENV/OHS/029	**Revision:** 0.0
		Page: 1 of 9	**Date:** June 2004
Compiled: F. Burns	**Reviewed:** J. Hassall	**Approved:** A. Abrahams	**Authorised:** W. Van Rooyen
SUBJECT: The Measurement of Whole body Vibration in Buildings			

APPENDIX 4

CONTENTS

1.0 BACKGROUND

Vibration in buildings can interfere with activities and affect human occupants in many ways. The quality of life and working efficiency may also be reduced as a result. However, human response to vibration in buildings is very complex. In many circumstances the degree of annoyance and complaint cannot be explained directly by the magnitude of monitored vibration alone.

There are basically two kinds of vibration that can affect people in buildings:

a) Vibration transmitted to the human body as a whole through the supporting surface: through the feet when standing, buttocks when sitting etc. and
b) Vibrations of the building and the resulting reactions of the occupants. This kind of exposure results from the gross structure vibration, floor vibration and wall vibrations.

This procedure applies mainly to the vibrations described in point **(b)** above and in particular to the vibration, rattling and annoyance effects produced when a building responds to a vibration source.

(American National Standard)

2.0 OBJECTIVE

The objective of this procedure is to set down a protocol as how the measurement of whole-body vibration inside buildings and on plant areas should take place.

3.0 SCOPE

This procedure characterises the measurement method for vibration in buildings and on plant areas. Hence the direction, location, duration and reporting of this type of human vibration is explained.

4.0 GLOSSARY OF TERMS

a) **Acceleration** – A vector quantity that specifies the rate of change of velocity (metre per second squared, ms^2)
b) **Accelerometer** – A transducer that produces an output, which is proportional to the acceleration in some, specified axis.
c) **Root Mean square (RMS) or A8** – Comprises out of meters per second squared normalised to 8 hours [m/s^2 A (8)] or A (8) shortened. Consequently a cumulative exposure using an average acceleration adjusted to represent an 8-hour working day is described.
d) **Building** - static construction used for habitation or allocated to any other human activity, including offices, factories, hospitals, schools, and day-care centres.
e) **Exposure Action Value (EAV)** - This is a sufficient level of daily worker exposure to vibration to warrant employers taking appropriate actions to control the exposure.
f) **Exposure Limit Value (ELV)** - This is a daily level of worker exposure where the risk to health is estimated to be sufficiently high that further exposure must be prohibited. If effective action is taken at the EAV level, the ELV should rarely be exceeded.

5.0 INSTRUMENTATION

The instrumentation needed for the measurement of Whole body vibration in a building and on a plant will comprise out of the following:

- MAESTRO 01dB –Stell human vibration monitoring instrument
- Seat Pad
- Shear accelerometer with cable
- Monitoring sheet to record results
- Small flat screwdriver
- Digital camera (Optional)

Prepare the human vibration instrument according to the specifications described in the supplier's manual provided.

NOTE: When calibrating the instrument by means of voltage sensitivity input values, use the following: (page 25-26).

- Y axis – 10.25 mV/g
- X axis – 9.09 mV/g
- Z axis – 10.91 mV/g

To be able to obtain the sensitivity option, first select **Tri: 10mV/g**, than press the **right** arrow and than the arrow pointing **downwards**. Press **OK** and use the up and down arrows to change values.

6.0 RESPONSIBILITIES

a) THE H&E MANAGEMENT FIELD SUPPORT SHALL:

- Operate the MAESTRO human vibration monitoring instrument exactly as specified in the instrument manual provided.
- Report any deviations regarding the instrument to the H&E co-ordinator.
- Perform a human vibration survey at least every second year.
- Update the human vibration map when needed.
- Perform regular checks of functionality before and after a sequence of measurements. Use the steps in the instrument manual as a guideline.
- On completion of surveyed area, write up a detailed report and forward it to the H&E management Co-ordinator

b) THE H&E MANAGEMENT CO-ORDINATOR SHALL:

- Inspect the MAESTRO on a regular basis to ascertain operating condition.
- Ensure that vibration checks are performed before and after measurements.
- Ensure that the MAESTRO are send away for annual calibration
- Ensure that the relevant line management receives a report of their area surveyed.
- Ensure that the document controller receives a hard and electronic copy of the report to be filed.

c) THE OH TECHNICAL SUPPORT SHALL:

- Assist when any problems are being experienced with the Human Vibration system.

7.0 FACTORS THAT WILL INFLUENCE THE WORKING OF THE ACCELEROMETER

- Humidity in the cabling system
- Very loud noise
- Corrosion materials
- Highly magnetic areas
- Radiation

NB: Always handle the accelerometer with great care. It has a limit of shock it can take, thus if dropped it may be damaged, resulting in unreliable results.

8.0 ACCEPTABLE LIMITS OF HUMAN VIBRATION INSIDE BUILDINGS

The threshold of perception for human beings typically falls at frequencies between 1 – 80 Hz. Vibrations above these levels can disturb, startle, cause annoyance or interfere with work activities. Hence, the acceptable limits for this type of vibration will be the same as that specified for Whole body vibration on earth moving equipment. This is characterised as:

Standardised to a working day of 8 hours, an **Exposure Action Level** has been set **at 0.5 m/s^2** with an **Exposure Limit Value of 1.15 m/s^2**. The highest vibration dose, measured in the three axes will be used to calculate the daily dose.

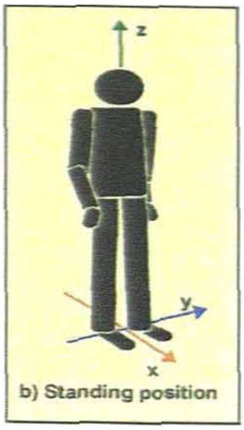
9.0 WHOLE BODY VIBRATION MEASUREMENTS INSIDE BUILDINGS AND ON PLANT STRUCTURES

The procedure for the measurement of whole body vibration was set up according to the specifications laid down in the ISO Standards ***2631-2:*** *Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration, Part 2: Vibration in buildings (1 Hz to 80 Hz) and ISO* ***2631-1****: Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration: General Requirements*

a) Direction of measurement

The vibration must be measured in all three orthogonal directions simultaneously. The orientations of the structure-related x, y and z shall be those for a standing person as given below in figure 1

Figure 1: Co-ordinate system used during the measurement of Whole body vibration inside offices.



The direction in which vibration is measured takes place on three different axes.

They are:

- **Z-axis** – This is your most important direction and it measures vibration up and down i.e. vertical vibration, aligned primarily along the axis of the forearm.
- **Y-axis** – Measures vibration in a horizontal direction, from left to right.
- **X-axis** – Measures vibration in a lateral direction, back to front.

(ISO 2631-1:1997, ISO)

b) Location of measurement

The evaluation shall be based solely on the expected occupation, the tasks performed by the occupants and the expected freedom from disturbance. Each **relevant** place or room shall be inspected according to this criterion. The vibration shall be measured at that location in the room where the highest magnitude of the frequency-weighted vibration occurs, or as specifically directed on a suitable surface of the building structure. Hence, the actual measurement should take place on a structural surface supporting the human body at the point of contact.

Each time the location of measurements should be clearly identified in the assessment reports. Another important point to remember when locating vibration transducers is to align them with the axes of the co-ordinate system at the point where it is evident that vibration enters the body. In some cases it can be difficult to obtain a proper alignment, consequently the ISO standard: **ISO 2631-1:1997** allows a deviation of up to 15 degrees.

c) Duration of Measurement

The duration of measurements should be long enough to be representative in a statistical sense and to ensure that the vibration measured is typical for the exposures, which are being assessed.

10.0 GENERAL PROCEDURE WHEN TAKING MEASUREMENTS

- Calibrate the instrument to be used according to the calibration procedure in the instrument manual. This needs to be done before and after a measurement period.
- Perform general checks to ascertain if instrument is in good working condition. Also ascertain whether the correct type of human vibration is selected on the instrument.
- Setting for building vibration would be the same as for whole body vibration.
- Attach the accelerometer to the seat pad
- Ensure that you have all the necessary PPE required for the particular area that you selected, including a completed risk assessment card.
- Proceed to the area selected for measurement.
- Notify the responsible person of your intentions.
- Before commencing with any measurement, explain the procedure and purpose.
- Identify the direction of measurement.
- Take your measurement while person is performing their normal daily duties

10.1 Important Parameters To Be Considered When Taking Your Measurement

a) <u>Parameters related to the source of vibration</u>

- Ascertain main source of vibration if any are present
- Note the daily start and finish times of the activity of the vibration source during the period of measurement
- Also note the following:
  - Permanent source: day, night, or both
  - Intermittent source: duration + number of events per day
  - Isolated or infrequent source
  - Character of vibration: continuous, shocks
  - It is also very important to note the approximate exposure time of the occupant in the building on a daily basis.

b) <u>Associated phenomena</u>

- **Structure-borne noise** – This noise is related to the vibration present. This should be measured at that location in the room where its effect is considered to be most disturbing.
- **Induced rattling** – Effects such as the rattle of windows may be due to vibration. This should be <u>reported</u>.
- **Visual effects** – Any visual effects must be <u>reported</u>.

After the taking of a measurement the results will be displayed in the Result Menu on the instrument. Follow the steps set out on *Page 23* in the instrument manual to retrieve the measurement results. Record results on the table provided and than onto the OH & E Management database. Remember to update the area map accordingly.

11.0 FINAL ASSESSMENT REPORT

Summarize your findings in a report that will be submitted to the H & E Management Co-ordinator.

Your report should include the following:

- Date of assessment
- Description of area – a map of the building indicating the rooms surveyed should be set up and included in the report as an appendix.
- Clear purpose of the assessment
- Methodology followed to obtain data
- Results in table format
- Discussion
- Recommendations if necessary
- References

A hard copy of the report should be forwarded to the line manager of the area surveyed and to the document controller for filing.

12.0 RE-ASSESSMENT

12.1 Re-assessment of the levels of vibration should be performed at least every two years,

12.2 When there are changes or replacements in equipment or in the production process,

With the re-assessment, the whole-body vibration map for building vibration should also be updated accordingly.

13.0 REFERENCES

13.1 **SABS ISO 2631-1:1997**, Mechanical vibration and shock: Evaluation of human exposure to whole-body vibration, **Part one**: General Requirements

13.2 **MVI Technologies, INRS**, **MAESTRO** 4 channel vibration measurements user manual, 2000

13.3 **ISO 2631-2: 2003**, Mechanical vibration and shock: Evaluation of human exposure to whole-body vibration, **Part two**: Vibration in buildings (1Hz to 80Hz)

APPENDIX ONE

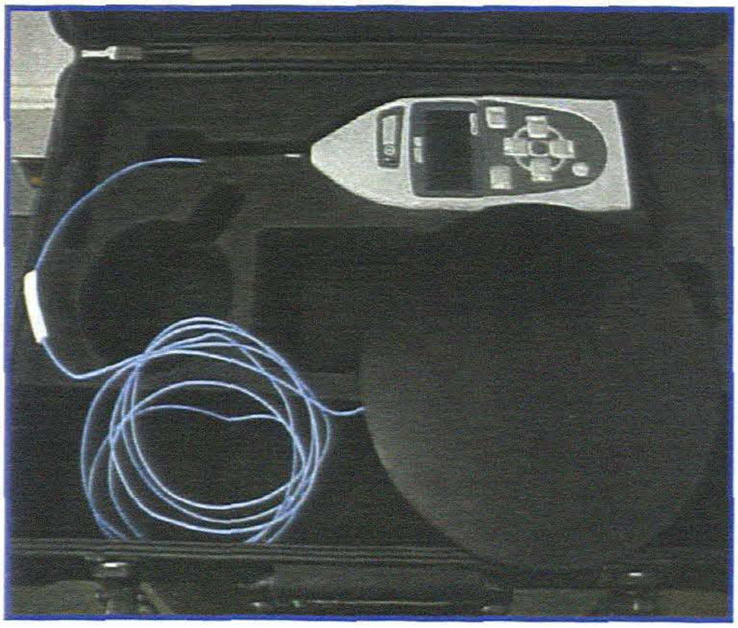
THE RECORDING OF WHOLE BODY VIBRATION MEASUREMENTS

	EQUIPMENT TYPE	DURATION OF MEASUREMENT	POSITION OF SEAT PAD e.g. floor, back or seat	DIRECTION OF MEASUREMENT + RESULT	Aeq
				X:	
				Y:	
				Z:	

APPENDIX TWO

MEASURING EQUIPMENT FOR HUMAN RESPOSNSE TO BUILDING VIBRATION

Figure 2: MEASURING EQUIPMENT



PENINSULA TECHNIKON

Research Project:

WHOLE-BODY AND HAND-ARM VIBRATION STUDY AT RöSSING URANIUM LTD, NAMIBIA
2003/4

APPENDIX 5

LETTER OF CONSENT

1. Title of research project

Whole-body and hand-arm vibration: *Quantifying the risk of exposure to human vibration at Rössing Uranium Ltd, Namibia.*

(A copy of the completed research summary submitted to the above-mentioned Tertiary Educational Institution is attached for your convenience.)

2. Purpose of the research

The purpose of this study is to evaluate the occurrence of Whole body and Hand-arm vibration at Rössing Uranium Ltd with reference to job characteristics, administrative and technological practices in order to develop a sustainable human vibration occupational health and safety management system.

Vibration induced diseases are recognised and well documented in various parts of the world. In Namibia, however, no historical records about vibration exposure and its effects are available. This can be attributed to a lack of national legislation and ignorance about the subject. It is therefore imperative that research be conducted to quantify exposure and develop a sustainable monitoring and control programme. Hence, a baseline study will be conducted on the mine.

3. Short description of research project

a) Administering of a structured questionnaire

Before commencing with human vibration measurements, a structured questionnaire will be administered on all participants in the study. Questions relating to type and duration of job tasks, type of equipment handled and behavioural characteristics (worker habits) during operation will be included in the structured questionnaire.

b) Collection of measurement data

The study comprises two separate sets of measurements, namely whole -body and hand-arm vibration. The measurement procedures will be explained and the consent of the study participants will be obtained prior to the taking of any measurements.

c) Whole-body vibration measurements

Collection of field data will take place during normal work operations. The sample population will consist of workers whose overall work activities involves driving or operating transportation equipment.

In some instances employees operating in specific employment areas perceived to be at increased odds of exposure would be included in the study for the sake of comparison.

d) Hand-arm vibration measurements

The sample population for this type of vibration measurement will mainly consist of workers whose work involves the operation of vibrating hand-held power tools.

4. Expected benefits to the mine

- The knowledge that we will obtain from this study will help the mine define the extent of the problem and to develop control programmes/measure to reduce employee exposure.
- Research findings will ensure compliance to the Occupational Health standard as specified by Rio Tinto.
- Data obtained from the study will identify risk areas; extent of the risk, measures to reduce/eliminate exposure, which in turn will reduce the risk of compensation threats.

5. Confidentiality of information collected

After completion of the research study, a written executive summary of the research findings will be submitted to the company management. It is imperative to note that for ethical reasons, the research findings will only be made public with the consent of the mine and such findings and data will be used only for matters pertaining to the research project.

6. Contact persons related to this study

The following persons may be contacted for answers to further questions about the research.

Peninsula Technikon Researchers:

I.	Ms Fulencia Burns	[M.Tech.: Environmental Health Candidate]
	Telephone number:	081 2707 998
II.	Mr Emmanuel Rusford	[M.Tech.: Environmental Health Supervisor]
	Telephone numbers:	0027 21 9596366

7. Documentation of the consent

One copy of this signed document will be kept together with our research records for this study. A copy of the proposal summary will be given to you for record keeping purposes.

8. Consent from the Mine

I have read the above-mentioned information on behalf of the company and I have a clear understanding of the contents and its meaning.

By signing this form, I do hereby grant consent to the research candidate to embark on this Whole body and Hand vibration study amongst the employees on the mine for the duration of this research project until its full completion.

Willem van Rooyen [Manager OHSE & Risk Management] **Date**

Fulencia Naomi Burns [M.Tech.: Environmental Health Candidate] **Date**

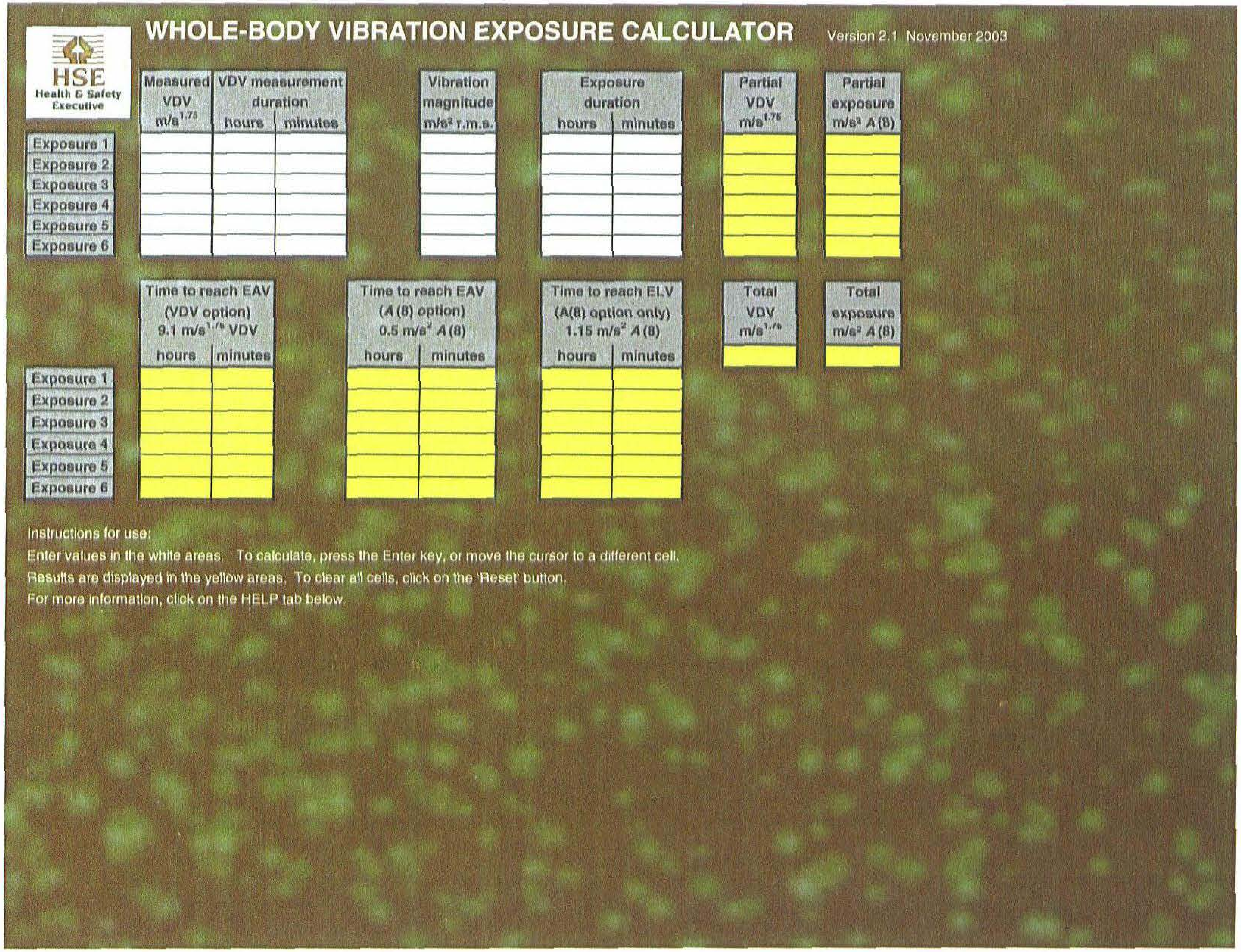
Emmanuel Rusford [M.Tech.: Environmental Health Supervisor] **Date**

RÖSSING

OH & E MANAGEMENT PROCEDURES		**Reference:** ENV/OHS/029	**Revision:** 0.0
		Page: 1	**Date:** June 2004
Compiled: F. Burns	**Reviewed:** J. Hassall	**Approved:** A. Abrahams	**Authorised:** W. Van Rooyen
SUBJECT: The Measurement of Whole body Vibration in Buildings			

APPENDIX 6

Whole-Body Vibration Exposure Calculator



HSE
Health & Safety Executive

WHOLE-BODY VIBRATION EXPOSURE CALCULATOR

Version 2.1 November 2003

	Measured VDV $m/s^{1.75}$	VDV measurement duration hours	VDV measurement duration minutes	Vibration magnitude m/s^2 r.m.s.	Exposure duration hours	Exposure duration minutes	Partial VDV $m/s^{1.75}$	Partial exposure m/s^2 *A* (8)
Exposure 1								
Exposure 2								
Exposure 3								
Exposure 4								
Exposure 5								
Exposure 6								

	Time to reach EAV (VDV option) 9.1 $m/s^{1.75}$ VDV hours	Time to reach EAV (VDV option) 9.1 $m/s^{1.75}$ VDV minutes	Time to reach EAV (*A* (8) option) 0.5 m/s^2 *A* (8) hours	Time to reach EAV (*A* (8) option) 0.5 m/s^2 *A* (8) minutes	Time to reach ELV (A(8) option only) 1.15 m/s^2 *A* (8) hours	Time to reach ELV (A(8) option only) 1.15 m/s^2 *A* (8) minutes
Exposure 1						
Exposure 2						
Exposure 3						
Exposure 4						
Exposure 5						
Exposure 6						

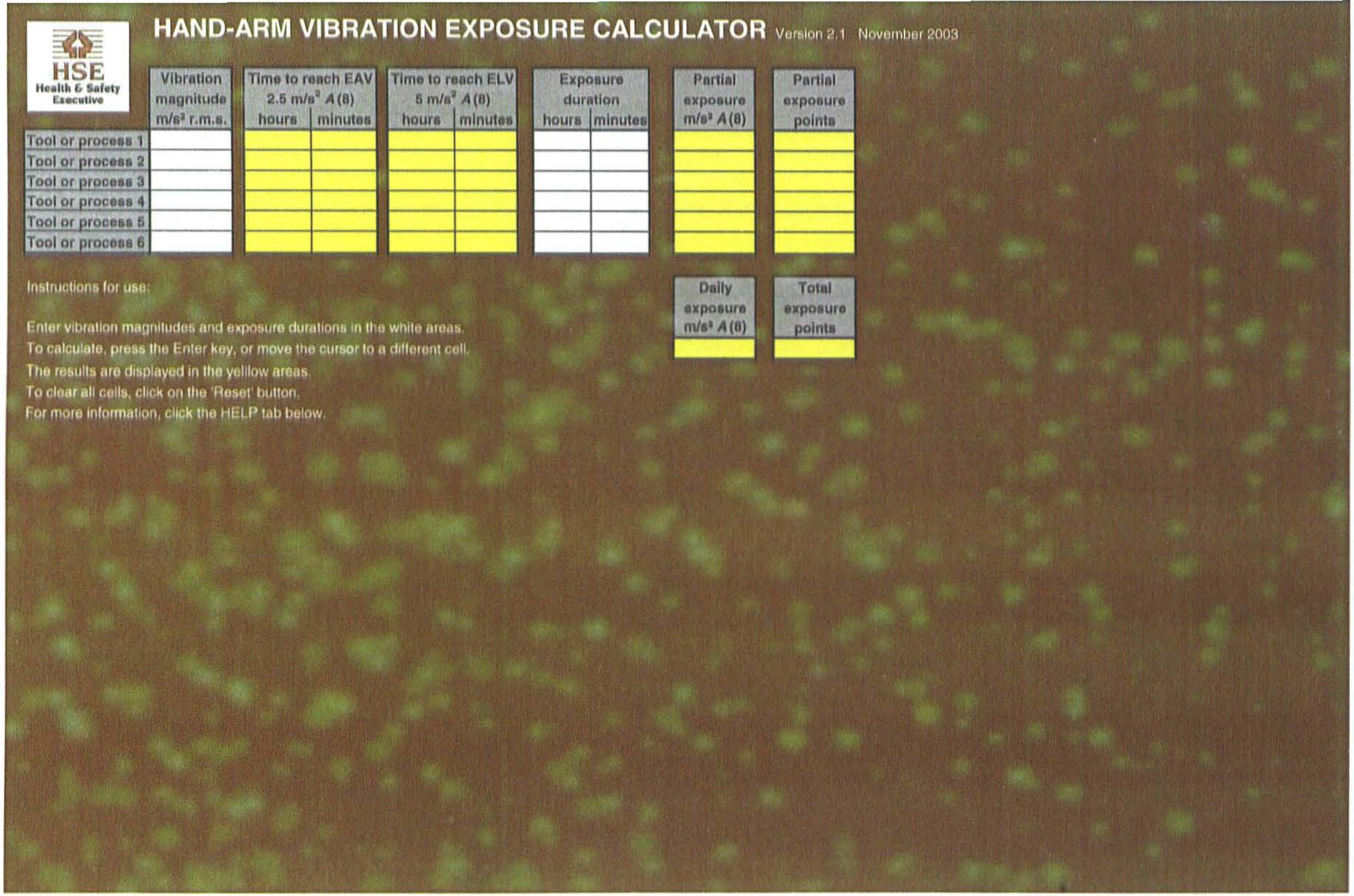
Total VDV $m/s^{1.75}$	Total exposure m/s^2 *A* (8)

Instructions for use:

Enter values in the white areas. To calculate, press the Enter key, or move the cursor to a different cell.
Results are displayed in the yellow areas. To clear all cells, click on the 'Reset' button.
For more information, click on the HELP tab below.

APPENDIX 7

Hand-Arm Vibration Exposure Calculator



HAND-ARM VIBRATION EXPOSURE CALCULATOR Version 2.1 November 2003

	Vibration magnitude m/s^2 r.m.s.	Time to reach EAV 2.5 m/s^2 $A(8)$		Time to reach ELV 5 m/s^2 $A(8)$		Exposure duration		Partial exposure m/s^2 $A(8)$	Partial exposure points
		hours	minutes	hours	minutes	hours	minutes		
Tool or process 1									
Tool or process 2									
Tool or process 3									
Tool or process 4									
Tool or process 5									
Tool or process 6									

Daily exposure m/s^2 $A(8)$	Total exposure points

Instructions for use:

Enter vibration magnitudes and exposure durations in the white areas.
To calculate, press the Enter key, or move the cursor to a different cell.
The results are displayed in the yellow areas.
To clear all cells, click on the 'Reset' button.
For more information, click the HELP tab below.

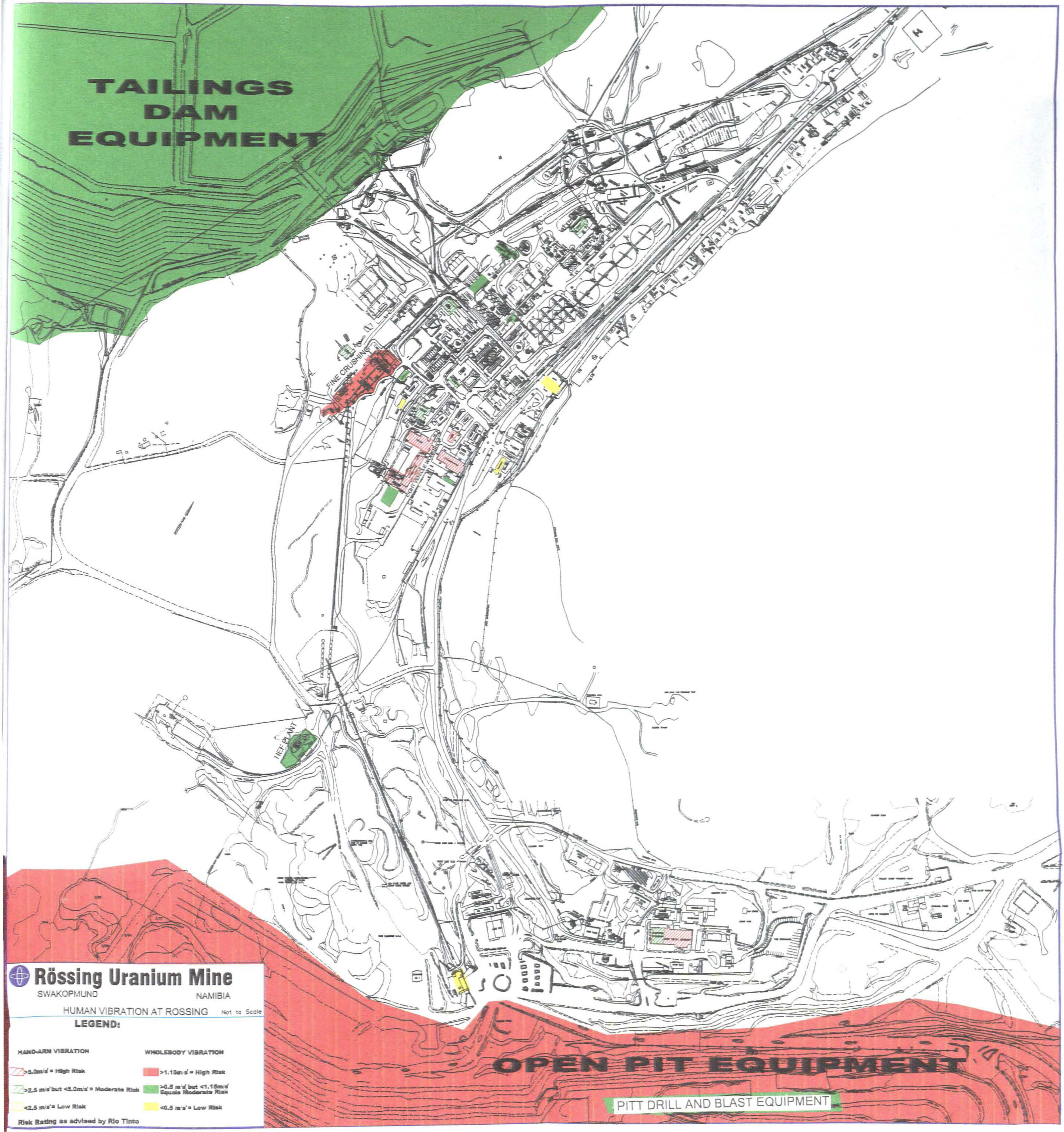
RÖSSING URANIUM VIBRATION EXPOSURE RISK RESULTS, 2004

No.	Similarly Exposed Group	Occupations	Tools or Equipment present within occupational groups	*n* sampl	Vibration Risk	A(8) Results	Risk Rating	Nature of Proposed Remedial Action
1	Pit Equipment Operators	Equipment Operators	Shovel, Haultrucks, Rubber Tyredozers, Trackdozers, Graders, Front-end Loaders, Watertruck	17	Whole Body	1.39	High	Engineering, Administrative, Medical Surveillance
2	Pit Drill and Blasters	Drill Operators, Hef plant Controller, Hef truck operator	GD-120 drills, Halco Drill 1 & 2, Forklift, Bobcat, Heftruck	10	Whole Body	0.19 to 1.01	Moderate	Administrative, Medical Surveillance
3	Mine Maintenance Workers	Fitters, Boilermakers, Diesel/motor mechanics, Welders	Different size air operated impact tools, air drills, Grinders,	8	Hand-Arm	3.0 to 6.0	High	Engineering, Administrative, Medical Surveillance & PPE
4	Reduction Operators	Primary and Fine Crushing Area Operators	Plant Area	6	Whole Body	0.05 to 1.43	High	Engineering, Administrative, Medical Surveillance
5	Reduction Maintenance Workers	Fitters, Boilermakers, Welders, MIT	Different size air operated impacts, air drills, Grinders,	8	Hand-Arm	3.0 to 4.0	Moderate	Administrative, Medical Surveillance & PPE
6	Extraction Operators	Rodmills, MNO^2 Operators	Plant Area, Forklift, Front-end Loader, Bell truck	5	Whole Body	0.36 to 1.22	Moderate	Administrative, Medical Surveillance
7	Extraction Maintenance	Fitters, Boilermakers	Electric & Air Grinders, Pipe Grinders, welding machine, Air operated Impact tools, Niblers, needle Scalers	8	Hand-Arm	3.0 to 4.0	Moderate	Administrative, Medical Surveillance & PPE
8	Tailings Dam Equipment Operators	Equipment Operators	(CAT)Back Actors, (CAT)Front End Loaders, (CAT)Grader, (CAT)Trackdozer, (CAT)Diesel Truck	6	Whole Body	0.72	Moderate	Administrative, Medical Surveillance
9	Engineering Workshops and Maintenance	Fitters, Boilermakers, Welders, Turners, Carpenters, Bricklayers, MIT, Bus driver, IVECO driver	Different size air operated impact tools, air drills, Grinders, Jackhammer, sanding machine , IVECO, bus	28	Hand-Arm & Wholebody	0.3 to 11.4	Low - High	Engineering, Administrative, Medical Surveillance & PPE
10	Rubberliner Workshop	Rubberliners	Different size Grinders, Sticher, Rubber mallet	5	Hand-Arm	1.9	Moderate	Administrative, Medical Surveillance & PPE
11	Mobile Equipment Operators	Equipment Operators	110 ton DEMAG crane, 75 ton P&H crane, Oshkosh truck, Luggerbin truck, 35 ton GROVE crane	5	Whole Body	0.85	Moderate	Administrative, Medical Surveillance
12	Vehicle Maintenance workers	Diesel & Motor Mechanics, Panel beaters	Small air operated impact, break shoe tool, air drill, Impact wrench, 1 inch impact tool, Grinder, Air Torque tool, Needle scaler, Grinder, sanding Machine	6	Hand-Arm	3.2 to 6.0	High	Engineering, Administrative, Medical Surveillance & PPE
13	Electricians and Instrumentation	Assistant Electricians, Instrument technicians, Plant Electricians, Auto Electricians	Air operated Hand drills, Large Electrical Bosch Grinders, Impact Tools	11	Hand-Arm	0.3 to 2.6	Moderate	Administrative, Medical Surveillance & PPE
14	Field Workers	H&E Field Support	Light Vehicles	2	Whole Body	0.48	Low	Awareness Training
15	Office Personnel (Controls)	H&E Co-ordinators, Health Promotion Officer, Editorial Officer, Safety Advisors, Lab Technicians, FLM: Primary Crushers	Inside office settings	10	Whole Body	0.04 to 0.10	Low	Awareness Training

RÖSSING

H & E MANAGEMENT PROCEDURES		**Reference:** ENV/OHS/	**Revision:** 0.0
		Page: 1	**Date:** June 2003
Compiled: F.Burns	**Reviewed:** A. Abrahams	**Approved:** A .Abrahams	**Authorised:** W. Van Rooyen
SUBJECT: Whole Body & Hand-Arm Vibration Risk Areas			

APPENDIX 9



Rössing Uranium Mine

SWAKOPMUND
NAMIBIA

HUMAN VIBRATION AT ROSSING Not to Scale

LEGEND:

HAND-ARM VIBRATION	WHOLEBODY VIBRATION
▨ $>5.0 m/s^2$ = High Risk	🟥 $>1.15 m/s^2$ = High Risk
▨ $>2.5 m/s^2$ but $<5.0 m/s^2$ = Moderate Risk	🟩 $>0.5 m/s^2$ but $<1.15 m/s^2$ Equals Moderate Risk
▨ $<2.5 m/s^2$ = Low Risk	🟨 $<0.5 m/s^2$ = Low Risk

Risk Rating as advised by Rio Tinto