Minerals Council South Africa

MEMO

SUBJECT: **CHAMBER OF MINES OF SOUTH AFRICA – CERTIFICATE IN MINE ENVIRONMENTAL CONTROL**	EXAMINER**: George Mapele**
PAPER 3 – PLANNING, ECONOMIC, TECHNICAL LITERATURE	MODERATOR: **Aldo Oosthuizen**
SUBJECT CODE: **COMMEC3**	TOTAL MARKS: **[100]**
EXAMINATION DATE:	PASS MARK: **(60%)**
TIME: **14:30 – 17:30 (3 HOURS)**	

NUMBER OF PAGES: 42

SPECIAL REQUIREMENTS:

THIS IS **NOT** AN **OPEN BOOK EXAMINATION**.

FORMULA HANDOUTS ARE AVAILABLE TO CANDIDATES:

1. Answer all 4 questions **legibly** in English.
2. Write your **ID number** on the outside cover of each book used, and on any graph paper or other loose sheets handed in.

NB: Your name **must not** appear on any answer book or loose sheets.

3. Show all calculations and **check calculations on which your answers are based**.
4. Hand-held electronic calculators may be used for calculations.
5. Write **legibly,** in ink, on the **right hand page** only – **left hand pages will not be marked**.
6. Illustrate your answers by means of sketches or diagrams wherever possible.
7. Answers must be given to an accuracy which is typical of practical conditions.

NB: Ensure that the correct unit of measurement (SI unit) is recorded, as marks will be deducted from answers if the incorrect unit is used (even if the calculated value is correct).

8. Please note that you are not allowed to contact the examiner or moderator regarding this examination.
9. Cell phones and any other electronic devices are **NOT** allowed in the examination room.

QUESTION 1 (35 Points)

1.1 Briefly describe the factors to be considered when designing an up-cast shaft and drift. **(6)**

Answer

- *Amount of air required (1) ✓*
- *Economic velocity(18-20m/s) (1) ✓*
- *Critical air velocity between (1) ✓*
- *Up cast shaft are normally concrete lined and free of steel work (1)✓*
- *Up cast velocity to be in excess of 12 m/s necessary to ensure that the water droplet are carried to surface in the air stream where arrangements can be made to trap the water and the drain it away (1) ✓*
- *Area considerations-this is often done by having an expansion chamber in the fan drift to lower the air velocity allowing free moisture fall out (1) ✓*

1.2. During fan performance testing the airflow quantities and pressure reading are recorded. Why is fan performance important? **(7)**

Answer

- *To ensure that new system adheres to particular design requirements (1) ✓*
- *To build up data on systems which work properly for future use in similar circumstances (1) ✓*
- *To determine whether the requirements set by authorities have been met (1) ✓*
- *To balance the system properly (1) ✓*
- *To determine if maintenance or repair is required (1) ✓*
- *To determine quantities (1) ✓*
- *To determine pressure (1) ✓*

1.3. The management of the mine plans to deepen its exiting shaft system by 600m to establish 5 new additional production levels to mine 150 000 tons per month from the deepened section.

Additional information:

- Sinking rate is 6m per 24 hours
- Shaft diameter is 7 plus 10% over break to accommodate the concrete lining
- The rock density is 2780 kg/m^3
- Each level will be considered as a separate ventilation district
- The planned production will split evenly from each production level
- Average air density over the five levels is 1.2kg/m^3

1.3.1 What average service water flow rate will be required during the development stage of the following, if the expected consumption is 1.77 ton of water per ton of rock mined for,

1.3.1.1 The shaft,

1.3.1.2 The production levels

(11)

1.3.2 If a design rate of 5.0 kg /s is planned, what size should the intake and return airways be designed to accommodate the desired flow rate? **(11)**

Answer

The total tons blasted per month during shaft sinking must be determined assume a 24-day month

Ton from shaft$=\frac{\pi D^2}{4}\times$advance per month $\times$density (2) ✓✓

$$=\frac{\pi[7+(0.1\times 7)]^2}{4}\times(6\times 24)\times 2.78$$

=18 641 tons (2) ✓✓

The total service water requirements during shaft sinking can now be established.

Service water needed $=\frac{\text{tons mined}\times\text{water facter}\times 1000_{\text{litre/ton}}}{\text{days in monh}\times\text{hours per day}\times 3600}$ (2) ✓✓

$$=\frac{18\,641\times 1.77\times 1000}{24\times 24\times 3600}$$ =15.9 say 16.0 litres/second (1) ✓

(ii) The total tons productions levels 150 000 tons, the total service water requirements for production can now be established:

Service water needed$=\frac{\text{tons mined}\times\text{water factor}\times 1000_{\text{litre/ton}}}{\text{days in month}\times\text{hour per day}\times 3600}$ (2) ✓✓

$$=\frac{150\,000\times 1.77\times 1000}{24\times 24\times 3600}$$ =128 litres/second (1) ✓

The additional service water requirements for production after shaft sinking, can now be established:

Service water required= 128 -16=112 litres/ second (1) ✓

The maximum air velocity in intake airways to be taken as 5 m/s and for return airways as 7 m/s (2) ✓✓

The tons produced per level $=\frac{150\,000}{5}$ =30 000tons (1) ✓

Air amount required per level$=\frac{30\,000}{1000}\times 5$=150 kg/s (1) ✓

The air density has been given as1.2kg/m³, the air quantity can now be determined:

$Q=\frac{m}{w}=\frac{150}{1.2}$ *=125 m³/s (1)* ✓

Intake airways area$=\frac{Q}{v}=\frac{125}{5}$ *=25 m² (1)* ✓

Return airways area$=\frac{Q}{v}=\frac{125}{7}$ *=17.8 say 18 m² (1)* ✓

Due to practical reason the airways sizes per level should be as follows:

Intake airways=2×12.5 m² (2) ✓✓

Return airways= 2×9.0 m² (2) ✓✓

QUESTION 2 (25 Points)

A mine in West Witwatersrand region, it has been decided to deepen an existing operational mine, to increase their existing life of mine. Access to this portion of the orebody will be through a newly sunk, serving five working levels, each spaced 100 m apart shaft to the reef horizon. The reef will be extracted using a series of single side longwalls. The planning parameters for this project will be:

• Tonnage broken	110 000tons/month
• Ratio reef tons to development tons	5:1
• Average depth below surface	2 800m
• Dip of the ore body	26˚
• Stoping widh	1.8 m
• Average stoping face advance	8.0m/month
• Expected VRT	45˚C
• Density of rock to be mined	2740kg/*m³
• Heat production rate of area to be mined	180W/ton mined
• Chilled water arrival temperature	12˚C
• Return service water temperature	24˚C
• Planned water consumption per ton of rock mined	2ton/ton mined
• Production month consist of	23 days

In addition, 25% of the total downcast volume will be used to ventilate the shaft infrastructure (including ventilation door leakage). All development will be ventilated using established through ventilation to stoping areas.

Given the following environmental requirement:

- Face velocity >1m/s
- Minimum stope air utilisation (air on face supplied at stope entrance)
- Maximum ventilation control distances the face :10m

Calculate the following:

2.1 Total quantity of ventilation required for ventilation of the stoping area's;

2.2 For logistical reason, the newly sunk shaft has a diameter of 7.0 m, will this shaft be adequately sized to carry the required volume of ventilation
Briefly defend your answer.

2.3.1 Determine the heat load of this production area

2.3.2 Calculate the cooling provided through the usage of chilled water

2.3.3 How much additional cooling must be provided to overcome the heat load of this area

2.3.4 Briefly describe (if needed) how you will provide additional cooling

Answer

2.1 The total amount of reef tons hat must be mined must be determined:

Total tonnage reef to waste is 5:1 (given)

Reef tons=Total tons$\times\frac{5}{6}$ *(reef tons to total tons reef ration) (1)* ✓

$=110\ 000\times\frac{5}{6}=91\ 666.7$ *tons SAY 92 000 tons (1)* ✓

The longwall backlength needs to be determined

Longwall backlength$=\dfrac{400_{\text{vertical heght beween deepest and shallow levels}}}{\sin 26^\circ}$ *(1)* ✓

$=912.46$ *say 912m (1)* ✓

Tons per longwall per month=length×face advance/m×SW×rock density

$=912\times8\times1.8\times2.74=35\ 983.8$*tons (1)* ✓

Number of stoping raises$=\frac{92000}{35983.8}=2.55$ *say 3 raise (1)* ✓

The air quantity that needs to be circulated per stope can now be determined, face velocity of 1 m/s is given;

air volume before AUI =Velocity×SW×Strke distance (1) ✓

$=1\times1.8\times10=18\ m^3/s$ *(1)* ✓

But AUI needs to be incorporated$=\frac{18}{0.8}=22.5$ *say 25* m^3/s *(1)* ✓

Three stopes lines will therefore need$=25\times3=75\ m^3/s$ *(1)* ✓

The new shaft area to be determined:

Shaft area$=\frac{\pi D^2}{4}=\frac{\pi\times(7)^2}{4}=38.48$ *say* $38.5m^2$*(1)* ✓

Assume that the downcast volume in the shaft to be a value "a".The leakage/shaft infrastructure will be 0.25 "a" say we call this "b"(0.25"a"="b" .Therefore "a"- "b"=75, he amound need for raises will be75 m^3/s (calculated above). (2)✓✓

The amount of air to be used:
The total downcast volume required: "a" –"0.25"a"=75
0.75"a"=75
"a"=100m^3/s (1) ✓

2.2 The shaft air velocity for the 7m shaft needs to be determined:

$$U=\frac{\text{air quantity required}}{\text{area}}=\frac{100}{38.5}=2.59 \text{ say } 2.6\ m/s(2)\ ✓✓$$

The down cast velocity will be within design specifications and will have a small influence on the total resistance of the mine.(1) ✓

- *2.3.1 Te heat load in the stope face=110 000×180=19 800Kw (1) ✓*
- *2.3.2 The flowrate of the service water needs to be expressed in litres/second. It is important to first establish the total amount in water used per month. The usage of water has been expressed as ton water per ton of rock mined.*
  Ton of water per month=110 000×2
  =220 000 tons of water /month (1) ✓
  Expressed as litres/second $\frac{220\ 000\ 000}{23 \times 24 \times 60 \times 60}$ *=110.7 say 111litres/second (1) ✓*

2.3.3 Cooling from service water= m×cΔt=111×4.187×(24-12)=5577Kw (1) ✓
Additional cooling required=Heat load – service water cooling (1) ✓
=19 800- 5577
=14 223Kw (1) ✓

2.3.4 Additional might be best deployed through placement of shaft BAC system, in this particular shaft 50% of the cooling load based at the shaft BAC's, with the remaining cooling split between level BAC's sited closer to the reef on the main air intake levels and approximately 14 mobile coolers (rate 25kW). (2) ✓✓

QUESTION 3 (20 Points)

A volume of 45m^3/s is delivered to a section through an airway 3m high,3m wide and 800m long.The pressure drop is 320Pa.It has become necessary to increase the quantity from 45m^3/s to 65 m^3/s.The following schemes are being considered.

Scheme 1

Installation of the booster fan to provide the additional pressure required for the increased quantity

Cost of the complete fan installation	R160 000
Fan efficiency	72%

Motor efficiency	94%
Power cost per kW per year	R1100
Life expectancy of section	R16 years

Present value of R1 per year over 16 year is R6.97@12%

OR

Scheme 2

Widening of airway from 3m to 4m, pressure drop would again be 320Pa when the new quantity flows. The cost of increasing the airways size will be approximately R300/m^3.

Assume that none of the above change will affect the operating point of the main fans.Which is the most economic scheme?

Scheme 1

At present a pressure of 320Pa is required to pass 43m^3/s of air through the airway.The pressure required to pass 65m^3/s is as foloows:

Pressure required (P_2)= P_1×$(Q_2/Q_1)^2$=320×$(65/45)^2$=667.6 say 668Pa (2)✓✓

The duty of the booster fan will be 65m^3/s at the pressure of =(668-320)= 348Pa (3)✓✓✓

348Pa is the additional pressure required to supplied by the booster fan

Fan Air power required=pQ/1000=65×348/1000=22.62kW (2) ✓✓

Fan Motor Input power required=Air power/Fan efficiency
=22.62/0.72×0.94=33.4kW (3) ✓✓✓

PV of fam motor power=R(Input power×R/kW/h×PV factor)
=R(33.4×1100×6.97)=R256078 (2) ✓✓

PV of captital cost R160 000 (1) ✓

The total of owning cos scheme 1(TOC)=(256078+160 000) =R416 078 (2) ✓✓

Scheme 2

By widening the airway by 1m, the volume being excavated:

Volume=(1×3×800)=2 400m^3(1) ✓

The capital cost excavation= cost/m^3×volume=R(300×2400)=R720 000

PV of capital cost =R720 000 (1) ✓

There are no running cost involve in this scheme as as te operationg point of the main fans will not be affected

The total owning cost (TOC) scheme 2= R720 000 (2) ✓✓

Scheme 1 is the therefore the more economic (1) ✓

QUESTION 4 (20 Points)

You must choose to answer one of the questions below. You must between 4.1 or 4.2.

4.1. Elaborate on the relevant section in the article *"More effective use of disposable dust masks"* which appeared in the following publication:-
Volume 75 , Number 1 – January to March 2022

The authors discussed the following within the article:

- Introduction
- Objectives
- Literature review
- South African National Standards
- Additional Literature
- Disposable Dust Masks Types
- Effectivenes of Dust Masks
- Technical Review
- Labarotory Fit Test
- Underground Trials
- Conclusions

More effective use of disposable dust masks

M Mokowena, Latona Consulting

ABSTRACT

The wearing of disposable masks has been identified as a major source of discomfort and dissatisfaction. This Coaltech research investigated the current industry standards and practices with respect to distribution and wearing of the dust masks in the continuous miner sections.

Laboratory fit tests and underground tests were conducted, as well as a questionnaire sent out to the mines to gather data in order to identify possible research gaps on the subject, and this technical feedback was combined with the literature review findings.

Dust masks from the LHD operator recorded the highest total mass loading, exceeding 200 mg in an average time of 1.7 hours, whilst the CM, Shuttlecar and Roofbolt operators averaged 3.5 hours, 5 hours and 2 hours respectively. All dust masks failed the laboratory fit tests.

The recommended 8-hour service time limit of the dust mask is too long, the dust masks do not offer adequate protection against leakage and both mines have no set guidelines and procedures with respect to the use and distribution of dust masks.

Mines need to review and implement their own training procedures, consider conducting fit tests and implementing awareness programs educating the workforce on the importance of wearing and proper use of the dust masks.

1. INTRODUCTION

As part of the Coaltech dust project (Task 2.6.1), workshops were held with mine production personnel to help identify specific problem areas regarding dust in Continuous Miner sections. Feedback from the workshops identified the wearing of disposable masks as a major source of discomfort and dissatisfaction. This initiated further research on the current industry standards with respect to distribution and wearing of the dust masks.

The problems resulting from the effects of dust on health and safety of personnel employed in the mining industry is a difficult task which requires attention (Li, Qin, Yang, & Tian, 2011, Ji et al., 2016).

Workers wear nose masks or breathing devices to protect their health in the workplace. These devices are generally referred to as Respirable Protective Equipment (RPE). Respirators filter the air to eliminate harmful substances and provide clean air for the worker to breathe. RPE must be both sufficient/adequate and suitable for the work to be used properly in the mine i.e. it must comfortably fit the wearer whilst providing adequate protection for the specific work environment.

Original paper presented at the second 2021 MVSSA Virtual Conference

Adequate/sufficient protection is classified as the dust mask's capability to reduce the exposure of a harmful substances to a standard level.

There are two types of RPE namely, disposable and reusable respirators. The broad range of RPE provides the mines the freedom to select the level of protection, comfort, style and maintenance options needed to work efficiently, effectively and safely.

2. OBJECTIVES

The objective of this study was to provide a review and guidelines for the use of respirators/nose masks and fit testing to help the South African mining industry in the selection and provision of proper and suitable RPE for mine workers.

3. LITERATURE REVIEW (ONIFADE, 2019)

3.1 Fit and seal testing

A "fit-test" is a 15-20-minute test which examines the seal between the respirator's facepiece and the wearer's face. It is used to evaluate an adequate match between the facepiece of the RPE and the face of the wearer and should not be confused with a user seal-check. Upon passing the fit test, the user is required to use the exact dust mask i.e. make, model, size when performing their daily duties on the job.

performing their daily duties on the job.

A user-seal check is a quick check carried out by the user each time the dust mask is put on. A seal check determines whether the dust masks is fitted properly, or it needs to be readjusted in order to get a proper fit.

If the wearer's facial characteristics change due to weight changes, loss of teeth etc., the standard requires a new fit test be conducted before the dust mask is used.

3.2 Fit test methods

The fit of a facepiece is determined by qualitative or quantitative methods. The qualitative method depends on the wearer's subjective reaction to a sprayed test agent (usually a sweet or bitter tasting substance), whilst the quantitave method provides an objective measure of the fit, by generating a measuring number referred to as a fit factor. A fit factor is defined as the ratio of the concentration of a substance outside the facepiece to the concentration inside the facepiece. There are several quantitative fit testing methods. Test chamber methods used in CE certification testing is considered as the reference standard for fit testing but are neither practical nor cost effective for regular fit testing applications. CE is a certification mark that indicates conformity with health, safety and environmental protection standards for products sold within or outside the European Economic Area (EEA) but have been manufactured to EEA standards (ce marking association, 2014). The most regular quantitative fit testing method in use applies an ambient particle counting device (e.g. PortaCount™), while an alternative method uses controlled negative pressure

(CNP) (e.g. FitTester 3000™). Since these methods use various techniques, they give rise to different fit factors. Studies carried out by Oestenstad and Graffeo (1993) and Crutchfield et al. (1999) compared these methods and found that these methods have strengths and weaknesses. This scenario is the case of striking the right balance between a fit test method that is scientifically standard but regularly not very practical and a method that is easy to use while providing an acceptable evaluation of fit. Although, what is significant is that the fit tester is well informed of the limitations of a specific technique and takes these into account.

3.3 International standards, regulations and guidance

Fit testing has been a requirement in the USA over decades and was introduced in 1969 by the American Standard ANSI Z88.2 (ANSI, 1992), while the OSHA Standard 1910.134 set out accepted fit test protocols. The American National Standard Institution (ANSI) Z88.10-2001 is responsible for the provision of guidance on how to carry out fit testing and suitable methods to be used (ANSI, 2001).

In the UK, fit testing was first introduced into the Control of Asbestos at Work (CAW) Approved Code of Practice back in 1999 and then extended throughout all of industry in 2002, when the fit testing requirement was integrated into the Approved Code of Practices supporting the COSHH (Control of Substance Hazardous to Health) and CLAW (Control of Lead at Work) regulations.

The UK Health and Safety Executive (HSE) issued an information document HSE 282/28 to provide guidance on fit test techniques and procedures (HSE, 2003).3.4 Respiratory Protective Equipment (RPE). RPE is a specific type of Personal Protective Equipment (PPE) which is designed to safeguard the wearer from breathing-in injurious substances or from oxygen-deficient atmospheres when other controls are either not possible or deficient on their own. RPE is obtainable in various sizes to allow for the facial differences of workers. Gender, ethnicity and several other factors mean that one size of facepiece will not fit everyone.

Figure 1. An example of a disposable dust mask

- The wearer must always read and follow the manufacturer's directions when using a disposable dust mask and it must cover both the nose and mouth to prevent the wearer from breathing in mold and dust.
- If the mask does not have a snug fit, it will not work correctly. The correct fit of the mask requires contact with smooth skin. It will not work properly for people with beards or facial hair.
- The wearer must perform a user seal check, including both positive and negative pressure checks, to confirm that the mask has been put on correctly and adjusted to fit correctly.
- As the disposable dust mask gets clogged, it becomes more difficult to breathe. When this arises, the user must throw it out and use a new one. The mask must be discarded if it is wet or dirty on the inside, if it is deformed, or if the filter is torn. A disposable dust mask cannot be cleaned or disinfected.

4. SOUTH AFRICAN NATIONAL STANDARDS

4.1 (SANS 10220:2010)

deficient atmospheres when other controls are either not possible or deficient on their own. RPE is obtainable in various sizes to allow for the facial differences of workers. Gender, ethnicity and several other factors mean that one size of facepiece will not fit everyone.

3.5 Disposable dust masks

A disposable dust mask is a safety device that covers the nose and mouth. This device helps protect the wearer from breathing-in harmful substances. It protects you from breathing in small particles in the air such as dust and mold.

According to Onifade (2019), workers are advised to use a disposable dust mask that is certified by the National Institute for Occupational Safety and Health (NIOSH). Masks that are not certified by NIOSH may not provide adequate protection. It should be used even if the wearer cannot see the particles because they may be too small to see.

General guidelines for the use of RPE's are provided by Onifade (2019) and these include:

- Disposable dust masks do not protect the wearer against chemical vapours, gases, carbon monoxide,gasoline, asbestos, lead or low oxygen environments.

torn. A disposable dust mask cannot be cleaned or disinfected.

4. SOUTH AFRICAN NATIONAL STANDARDS

4.1 (SANS 10220:2010)

The South African National Standards (SANS 10220:2010), derived and copied from EN149:2001, covers the factors affecting the selection of respiratory protective equipment for the protection of the body against harmful substances. The standard also provides recommendations for the use and maintenance of such equipment.

4.1.1 Classification of respiratory equipment

There are various types of RPE considered to suit a variety of work situations and protect the wearer from a variety of hazards. The two major types of RPE are breathing apparatus and respirators.

Respirators use filters to eliminate impurities from the air being breathed in and can be either powered (using a motor channel air through the filter to provide a supply of clean air) or non-powered. Breathing apparatus requires a supply of breathing quality air from an independent source such as an air cylinder or air compressor.

4.1.2 Classification of inhalation hazards

The RPE is designed to give protection against one or more of the following hazards: Oxygen deficient environments, Particulates, Vapours and gaseous contaminants.

4.1.3 Description of respirators

All RPE's designed for protection against particulates, gases or a combination of both contaminants have a quarter mask, half mask, full-face mask or a filtering mask. All of which contain air purifying features designed to remove the contaminant from the surrounding air before it is inhaled by the wearer.

There is respiratory equipment that is designed to give protection against specific contaminants only e.g. particulates only. These types of equipment do not provide universal protection and should only be used in situations where the concentration and the type of contamination is known.

4.1.4 Respirators for particulate matter only

Respirators designed for the use against particulate matter only are ineffective in gas containing environments. The service time of the respirator decreases in environments where the concentration of the contaminant is excessively high and breathing resistance is experienced when used for an increased amount of time.

To reduce the level of contamination, the contaminated air is drawn by the breathing action of the wearer through a filter system before the air is inhaled. The exhaled air is discharged into the atmosphere through the filter media or the second valve of the respirator (if fitted).

4.1.5 Respirators for gases

These types of respirators are designed for protection against specific gases only. The mask is directly connected to cartridge and canister filters where the inhaled air passes through, via a system of non-return valves. The exhaled air passes directly into the atmosphere.

Provision for protection against particulates can be

4.1.9 Moustaches

Moustaches interfere with the peripheral seal of a dust mask and affect the fit of the dust mask.

4.1.10 Sideburns

When sideburns extend below the line drawn through the top of a tragion i.e. the notch in the cartilage of the ear just above and immediately in front of the earhole, it affects the seal of the respirator.

4.1.11 Stubble growth and long hair

When the wearer has long hair or beard stubble, particular care should be taken to ensure that none of the hair or stubble is trapped beneath the face seal.

4.1.12 Wearing of spectacles

A perfect fit may not be obtained with a full-face mask when spectacles are worn. However, special spectacles can be made or adapted to obtain a satisfactory fit.

4.1.13 Communication

Excessive speech causes component or mask leakage and should be limited when wearing a half mask. However, the exhalation valves allow for speech transmission over short distances.

4.1.14 Selection of respiratory equipment

Before any protection equipment can be selected, the hazards, limitations, operational and maintenance requirements that exist in that given operation need to be evaluated. More factors that need to be considered before selecting the suitable respirator for a given operation can be found in the full SANS 10220:220 report.

Once all the factors that determine the most suitable respirator for a given operation have been satisfied, proper implementation and application of RPE's in the workplace plays a pivotal role in assuring more effective use of the dust masks. In the workplace, RPE's should:

Provision for protection against particulates can be
incorporated through the cartridges or canister types, however no protection is provided for any particulate contaminants not specified on the cartridges or canisters.

4.1.6 Limitations of respiratory protective equipment

The sealing capability of the respiratory between the wearer's face and fitting surface of the mask is greatly affected by the wearer's facial features such as beard growth and moustaches. Due to the large variation of the amount in the noses of individuals, difficulty is also obtained in the sealing through the nasal passages when using a respirator with a nose clip.

4.1.7 Facial features

Some facial features reduce the sealing efficiency of RPE's, these include:

4.1.8 Beards

Adequate respiratory protection cannot be achieved with bearded persons due to the hair trapped between the pneumatic cushion and the mask.

In the workplace, RPE's should:

- be used by properly trained people who are supervised.
- be suitable for the proposed use.
- be properly stored, cleaned and checked regularly to ensure it remains effective.
- be CE-marked or of an approved type/standard approved by SABS; and
- sufficiently control inhalation exposure to provide the wearer with effective protection.

4.2 (SANS 50149:2003)

This standard derived and copied from EN149:2001, covers the minimum required specifications for filtering half masks used as protective devices against particles. A respiratory protective device can only be approved when the individual components of the device satisfy the requirements of the test specifications which may be the complete standard or part of the standard. Laboratory and practical performance tests are included for the assessment of compliance with the requirements.

Table 1. The difference between the different types of dust masks. (www.dustmaskdirect.co.za) [Accessed 18 August 2019].

Dust mask	Filter Efficiency	Micron Size	Cost (R/Unit)	Hazard type
FFP1	95%	>5	3.5	Non-toxic dusts, oil-based aerosols
FFP2	99%	2 – 5	9	Toxic dust and metal fumes
FFP3	99.7%	Less than 2	82	Toxic and carcinogenic dusts, metal fumes

5. ADDITIONAL LITERATURE (WWW.CDC.GOV/NIOSH)

The National Institute for Occupational Safety and Health (NIOSH) of the United States of America (USA) uses high filter loading (200mg) in certification tests, to address the potential for filter efficiency degradation by solid-based aerosols in the workplace (Center for Disease Control and Prevention, 2014). In most workplace settings, there is no recommended service time limit for the use for the respirators. However, NIOSH recommends that in dirty workplaces i.e. high aerosol concentrations, the service time limit should only be extended beyond 8 hours of use when an evaluation of the workplace settings demonstrates that:

- The filter efficiency will not be degraded below the certified efficiency level, or
- The total mass loading of the filter does not exceed the recommended 200mg

6 DISPOSABLE DUST MASK TYPES.

(www.dustmaskdirect.co.za)

Table 2. A comparison of the Nominal protection Factor (NPF) to the Assigned protection Factor (APF) (Charlton, 2006).

Dust mask type	Nominal PF	Assigned PF
FFP1	4	4
FFP2	12.5	10
FFP3	50	20
EN 136 (Full face mask)	1000	40

7. EFFECTIVENESS OF THE DUST MASKS. (CHARLTON, 2006)

The effectiveness of the current performance standards of the dust masks can be determined by assessing their presumed protection factors against exposure to harmful substances and the realistic expectations. The mostly widely known international protection factors is the Nominal protection factor and the Assigned protection factor.

6 DISPOSABLE DUST MASK TYPES.

(www.dustmaskdirect.co.za)

There are 3 main types of RPE's that are generally referred to as disposable dust masks. These are governed by the European standards EN149:2001+A1:2009 used to protect against particles in the continuous miner sections, namely, the filtering facepiece for particulates (FFP1, FFP2 and FFP3).

6.1 FFP1 Dust Masks

The FFP1 dust masks provides the lowest level of protection against particulates. This is relatively acceptable depending on the airborne hazard they have been commissioned to protect against. The minimum protection is due to the less amount of filter material they are composed of. They provide the least breathing resisting and usually do not have an exhalation valve.

6.2 FFP2 Dust Masks

The FFP2 dust mask offers a moderate level of protection against hazardous particulates. There is greater breathing resistance associated with these mask types due to the presence of the exhalation valves.

6.3 FFP3 Dust Masks

The FFP3 dust masks provides the highest level of protection against hazardous particulates that a disposable dust mask can offer. It contains thick filter material and an exhalation valve is almost always fitted. Table 1 lists the difference between the dust masks in terms of their filter efficiency, micron sizes, costs and the hazard types. The unit costs given in Table 1 were approximate at the time they were purchased for the research project i.e. August 2019.

the realistic expectations. The mostly widely known international protection factors is the Nominal protection factor and the Assigned protection factor.

7.1 Nominal protection factor (NPF)

The Nominal protection factor can be defined as the ratio of the concentration of the hazardous contaminant outside the dust mask to that inside the dust masks. It was developed by manufacturers from laboratory testing.

The test consisted of a mask that is securely strapped onto the face of a rubber head. To determine the leakage or contamination ingress, a hole is drilled through the back of the rubber head into the face mask and the air is extracted from within the mask.

These initial laboratory tests provided satisfactory seal around the edges and the filter satisfied the design specifications. Therefore, an NPF of 1000 was awarded to an EN136 full-face mask. However, these tests did not strike a balance between a fit test method that is laboratory accepted and a fit test method that is very practical and applicable to the working conditions of the wearer. Therefore, a new fit and use test method needed to be developed.

7.2 Assigned protection factor (APF)

The new fit and use test method took into consideration the different shapes and sizes of the human faces that vary between the sex, race and genetic make-up. The wearer was required to take the test with a clean-shaven face, trained in inspection, fit and application.

The test also required the wearer to undertake various tasks which included talking, turning the head and raising arms etc.

From this test, an Assigned Protection Factor (APF) is now the recognized true value of mask performance. Table 2 shows the full-face mask nominal protection factor of 1000 was reduced to an assigned/actual protection factor of 40.

An APF of 10 means that the dust mask (if used properly) can be safely used in an atmosphere that has a hazardous concentration of up to 10 times the permissible exposure limit PEL) or other exposure limit for that hazard.

One of the disadvantages of this fit test method (ambient particle counting method) is that it cannot differentiate between particles that have leaked around the face seal of the facepiece and those that have been created by the wearer. Fairchild et al. (1987), da Roza et al. (1991) and Clayton (2001) indicated that wearers produce particles during the fit test exercises which reduces the measured fit factors, particularly during the talking exercises. However, this can be minimized by ensuring that the ambient particle count is sufficiently high.

8. TECHNICAL REVIEW

For the technical review, questionnaires were sent out to five different underground coal mines and interviews were conducted with the mine personnel.

8.1 Questionnaires

The questionnaire consisted of the following questions:

1. Does your mine issue disposable dust masks in production sections/areas?
2. How do you identify jobs that require disposable dust masks?
3. Who is responsible to issue the disposable masks?
4. Do you keep records of the disposable dust masks?
5. When do disposable dust masks get replaced?
6. What type of disposable dust masks do you use? Make / style / code / supplier etc.
7. Do you use more than one protection class of disposable dust masks? i.e. FFP1, FFP2, other?

Table 3 - Responses from the questionnaires

Q nr.	Mine A	Mine B	Mine C, D, E1
1	Yes	Yes	Yes
2	All jobs	All jobs	All jobs
3	Supervisors	Supervisors	Supervisors
4	No	No	No
5	Daily	Daily	Daily
6	3M	Honeywell	3M
7	FFP2	FFP2	FFP2
8	Yes	Yes	Yes
9	Yes	Yes	Yes
10	No	No	No
11	One size fits all	One size fits all	One size fits all

- that there are no specific selection criteria determining the jobs require dust masks, all jobs at the mine are issued with dust masks
- that there is no record keeping of the issued dust masks
- that a new pack of dust masks is issued daily with every shift
- that the most used disposable dust mask type is the FFP2 from 3M
- to applying PPE procedures as their standard procedures for the disposable dust masks
- they do have formal training for the use and wearing of disposable dust masks.
- they do not do fit testing for disposable dust masks.
- that they do not have more than one fit size of the disposable dust masks and apply a one size fits all approach with respect to fit sizes.
- inefficiencies of the filter and inadequate sealing of the dust

6. What type of disposable dust masks do you use? Make / style / code / supplier etc.
7. Do you use more than one protection class of disposable dust masks? i.e. FFP1, FFP2, other?
8. Do you have standard procedures for disposable dust masks?
9. Do you have formal training for the use and wearing of disposable dust masks?
10. Do you do fit testing for disposable dust masks?
11. Do you have more than one fit size or type of disposable dust mask, or one mask fits all?

8.2 Findings from questionnaires

Table 3 shows all the responses to the questions listed in section 9.1 of this report that were received from the five underground coal mines.

From Table 3, it can be observed that most of the responses are similar. It can be noted that:

All mines do issue disposable dust masks in the production sections/areas

- that they do not have more than one fit size of the disposable dust masks and apply a one size fits all approach with respect to fit sizes.
- inefficiencies of the filter and inadequate sealing of the dust masks around the edges lead to breathing resistance and fogging of the goggles.

9. LABORATORY FIT TEST

To test whether the dust masks used in the mines i.e. FFP1, FFP2 and FFP3 provided a satisfactory seal around the edges, Latona Consulting (Pty) Ltd conducted its own laboratory fit test at the UNISA Florida Campus with Envirocon.

9.1 Fit test procedure

To accommodate the different human face shapes and sizes, Latona Consulting (Pty) Ltd selected 5 volunteers of different sex, race, gender and face shapes. The volunteers were requested to perform various tasks such as talking, turning the head and raising of arms with the aim of simulating the normal behavior of an operator in a real-life situation in the continuous miner section.

The fit test involved the following:

- FFP1 disposable masks, CE specifications (EN 149:2001 = SANS 50149:2003)
- Non-adjustable straps

Images of the laboratory fit test are depicted in Figure 2.

Figure 2. Latona Consulting laboratory fit test

9.2 Fit test results

All five dust masks from the individuals failed the fit test. This is an indication that the dust masks do not offer adequate protection against leakage around the edges.

10. UNDERGROUND TRIALS

Initial field tests were carried out at two mines (Mine X and Mine Y) over a period of two days, to get preliminary results for dust loading on disposable dust masks. Primary focus was on high-risk dust occupations i.e. Continuous Miner, Shuttle Car, Roofbolt and Load Haul Dump operators.

The objectives of the trials were to determine the loading time i.e. how long it takes the dust masks to reach a total loading (including sweat, moisture etc.) of 200mg and dust loading concentration on the dust mask filter which is the amount of dust on the dust mask filter.

Figure 3 is a flowchart that illustrates the procedure that was

Figure 3 is a flowchart that illustrates the procedure that was followed to obtain these main objectives.

10.1 Underground methods

Before each test, a new set of masks was weighed, numbered and logged at the laboratory. At each mine some masks

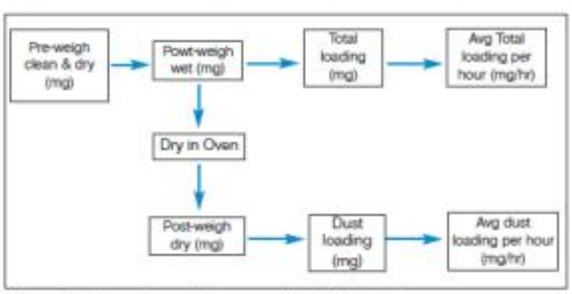


Figure 3. Flowchart of the procedure followed to determine the loading time and the dust concentration

remained sealed and unused as controls, whilst the remaining masks were distributed for use and then sealed individually for return to the laboratory for analysis. After use the masks were reweighed and then dried and weighed again.

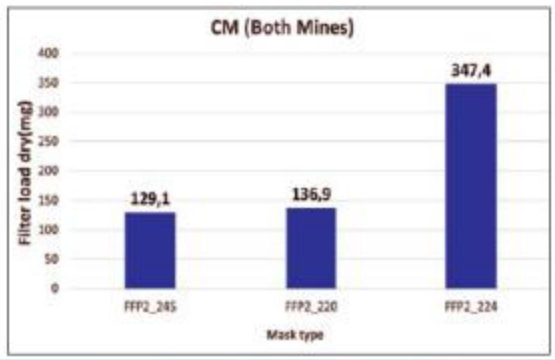
10.2 Underground trial results

The underground trial results are presented in Figures 4 – 7, showing the dry dust loading on each mask. This is less than the total mass loading, which includes moisture and is the indicator for the serviceable life of the mask.

10.3 Continuous miner (CM)

A total number of three CM samples were collected during the investigation phase of the project, two from Mine X (FFP2_224 and FFP2_220) and one from Mine Y (FFP2_245). Samples FFP2_224 and FFP2_220 were both collected on day one during a dayshift, from different sections of the mine. Sample FFP2_245 was collected on day two during a nightshift.

An average dust loading of 52 mg/hr was recorded from the dust mask filters of the CM operators, which would take 4 hours to reach a dust loading of 200mg. However, for the total mass loading, dust masks of the CM operators recorded 60 mg/hr and that would take only 3.5 hours to reach a total mass loading of 200mg. Figure 4 shows the dust loading results from the dust mask filters of the CM operators.



Mask type

Figure 4. Dust loading on CM operator

10.4 Shuttlecar (SC)

A total number of five Shuttlecar samples were collected during the investigation phase of the project, two from Mine X (FFP2_243 and FFP2_270) and three from Mine Y (FFP2_211, FFP2_217 and FFP2_218). Samples FFP2_243 and FFP2_270 were both collected on day one during a dayshift, from different sections of the mine. Samples FFP2_211, FFP2_217 and FFP2_218 were all collected on day two during a nightshift, from different sections.

An average dust loading of 35 mg/hr was recorded from the dust mask filters of the SC operators, which would take 6 hours to reach a dust loading of 200mg. However, for the total mass loading, dust masks of the SC operators recorded 39 mg/hr and that would take only 5 hours to reach a total mass loading of 200mg.

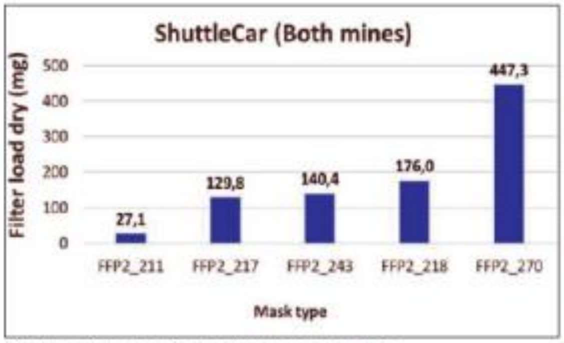


Figure 5. Dust loading on Shuttlecar operator

Figure 5 shows the dust loading results from the dust mask filters of the SC operators.

10.5 Roofbolt (RB)

A total number of six Roofbolt samples were collected during the investigation phase of the project, two from Mine X (FFP2_244 and FFP2_247) and four from Mine Y (FFP2_215, FFP2_221, FFP2_222 and FFP2_223). Samples FFP2_244 and FFP2_247 were both collected on day one during a dayshift, from different sections. Samples FFP2_215, FFP2_221, FFP2_222 and FFP2_223 were all collected on day two during a nightshift, from different sections.

An average dust loading of 46 mg/hr was recorded from the dust mask filters of the RB operators, which would take 4 hours to reach a dust loading of 200mg.

However, for the total mass loading, dust masks of the RB operators recorded 89 mg/hr and that would take only 2 hours to reach a total mass loading of 200mg.

Figure 6 shows the dust loading results from the dust mask filters of the RB operators.

10.6 Load haul dump (LHD)

A total number of four LHD samples were collected during the investigation phase of the project, all of them were collected from mine X. All samples were collected on day one during a dayshift, from different sections.

An average dust loading of 51 mg/hr was recorded from the dust mask filters of the LHD operators, which would take 4 hours to reach a dust loading of 200mg. However, for the total mass loading, dust masks of the LHD operators recorded 116 mg/hr and that would take only 1.7 hours to reach a total mass loading of 200mg.

Figure 7 shows the dust loading results from the dust mask filters of the LHD operators.

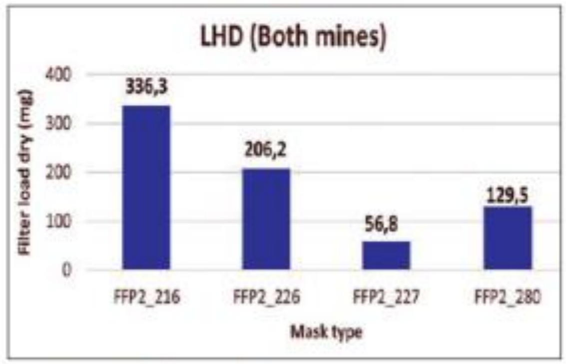


Figure 7. Dust loading on LHD operators

10.7 Findings from underground results

Due to these results being average values, it is evident that some of the dust masks will reach a 200mg dust loading and total mass loading in a much shorter time than the averaged time e.g. FFP2_216 in Figure 7 from the LHD operator will reach

Figure 5 shows the dust loading results from the dust mask filters of the SC operators.

10.5 Roofbolt (RB)

A total number of six Roofbolt samples were collected during the investigation phase of the project, two from Mine X (FFP2_244 and FFP2_247) and four from Mine Y (FFP2_215, FFP2_221, FFP2_222 and FFP2_223). Samples FFP2_244 and FFP2_247 were both collected on day one during a dayshift, from different sections. Samples FFP2_215, FFP2_221, FFP2_222 and FFP2_223 were all collected on day two during a nightshift, from different sections.

An average dust loading of 46 mg/hr was recorded from the dust mask filters of the RB operators, which would take 4 hours to reach a dust loading of 200mg.

However, for the total mass loading, dust masks of the RB operators recorded 89 mg/hr and that would take only 2 hours to reach a total mass loading of 200mg.

Figure 6 shows the dust loading results from the dust mask filters of the RB operators.

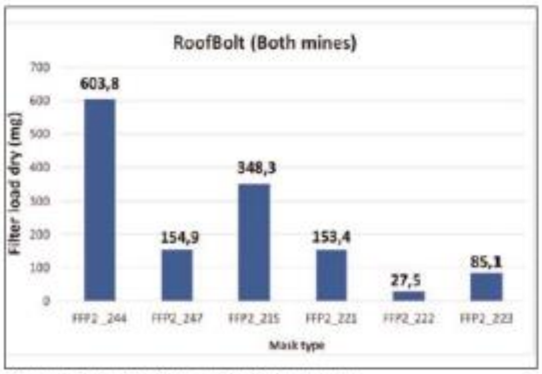


Figure 6. Dust loading on Roofbolt operator

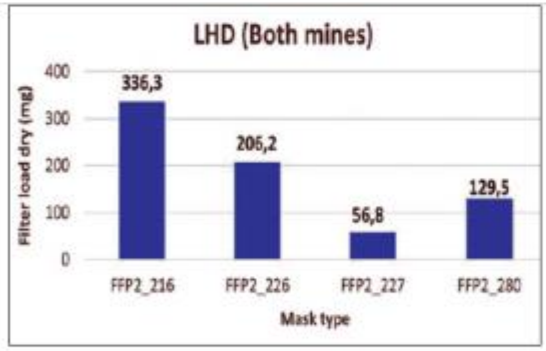


Figure 7. Dust loading on LHD operators

10.7 Findings from underground results

Due to these results being average values, it is evident that some of the dust masks will reach a 200mg dust loading and total mass loading in a much shorter time than the averaged time e.g. FFP2_216 in Figure 7 from the LHD operator will reach 200mg much faster than the averaged 4 hours for the dust loading and 1.7 hours for the total mass loading.

Furthermore, there is no correlation between the recorded highest dust readings from the different occupations i.e. dust readings from FFP2_216(LHD), FFP2_270 (SC), FFP2_224 (CM) and FFP2_244 (RB) and the trial sections. The high dust results were distributed across both the sections.

11. CONCLUSIONS

From the information gathered during the study it can be concluded that:

- The failed laboratory seal tests indicated that the generally used dust mask types, do not offer adequate protection against leakage.
- There are no set guidelines and procedures with respect to the use and distribution of dust masks in the mines.
- The results obtained from the 18 samples from the 2 mines indicate that 8 hours is too long to be set as a required service time limit since the dust masks reach a total mass loading in 2 – 5 hours. See Table 4
- Inefficiencies of the filter and the inadequate sealing of the dust masks around the edges lead to breathing resistance and fogging of the goggles.

Table 4. Average time to 200mg total mass loading

Occupation	Average time to 200mg (hours)
CM	3.5
SC	5
RB	2
LHD	1.7

12. RECOMMENDATIONS

It is recommended that:

- The mines implement programmes that will educate the operators on the importance of proper use.
- The mines conduct fit tests and extend the use of adjustable straps.
- The mines consider using dust masks of different sizes to accommodate the different face shapes and sizes.
- The mines review their current training procedures and implement their own training procedures (in line with the international standards).
- They consider implementing record keeping on the distributions of the dust mask.

REFERENCES

Charlton, J., 2006. Pandemic planning: A review of respirator and mask protection levels. Disaster advice. Beckenham.

Onifade, M., 2019. Initial Literature review - More effective use of disposable dust masks. Johannesburg: University of Witwatersrand. Coaltech.

SANS, 2003. South African National Standards. Respiratory protective devices – Filtering half masks to protect against particles – Requirements, testing, marking. SANS 50149:2003. Pretoria: SABS standards division.

OR

4.2. Elaborate on the relevant section in the article *"Occupational exposure to radon at high altitude Chilean Mining"* which appeared in the following publication:-
Volume 74 , Number 2 – April to June 2021

The authors discussed the following within the article:

- Introduction
- Physiopathological effects to Radon exposure
- Results
- Discussions and recommendations

(20)

Total marks for the question paper **[100]**

Occupational exposure to radon at high altitude Chilean mining:

Discussion on the need for a "Threshold Limit Value" according to the different altitude levels

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ABSTRACT

In this work, we review the impact of occupational exposure to Radon in high altitude mining. We report the lack of regulations and monitoring-system present in Chile. We also provided recommendations to improve the present regulations and suggest actions to be implemented based on the Threshold Limit Value according to different altitudes of the workplaces.

I. INTRODUCTION

Radon is an inert, odorless, and colorless, radioactive gaseous element with an atomic number of 86 which is emitted when the uranium and thorium disintegrated via successive radioactive decays. Radon is the main contributor (approximately half of it) to the natural radiation background on Earth, it is contained in the earth's crust, water, and in many materials used in the building industry; therefore, exposure to radon is unavoidable. to be associated with radioactive gas Radon and short-lived products of its decay, which accumulates in the air of poorly ventilated mines [1-3].

Once the hazard to human health due to Radon was determined it did not take a long time that several investigations were carried out for different kinds of mines, founding high levels of Radon in many of them, and consequently an incrementing number of lung cancer cases. Table 1 shows that different mines (different ores) deliver a considerable amount or Radon to the atmosphere, in addition, Table 1 also shows that both open-pit and underground mines are relevant in the Radon release process.

Table 1. Radon released to the atmosphere at different mining deposit. The table is adapted from Ref. [4].

Metal	Type of mine	Number of Sources	Radon release per source (Bq y-1 x 1010
Uranium	underground	305	25000
Uranium	open-pit	63 7	250
Iron	underground	11	560
	open-pit	57	70
Copper	underground	15	20
	open-pit	46	1500
Zinc	underground	36	850

In the Andes, the highland zone extends from Colombia in the north to central Chile in the south, with mining being one of the

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I. INTRODUCTION

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On the other hand, Radon is the second heaviest of the noble gases (7.5 times denser than air and only lighter than the Oganesson), and its capacity to form compounds is almost zero. Up to now, there are 37 known isotopes of Radon, which are all radioactive. There are three natural radioactive series in which Radon is produced in an intermediate step: the thorium, uranium-radium, and actinium series. In nature, most of the radon occurs in two main forms: in the form of 222Rn, a member of the radioactive 235U -series, and in the form of thoron 220Rn, a member of the radioactive 232Th -series. Radon enters the human body through the respiratory tract, producing irradiation of the mucous tissues of the lungs. Long-term exposure to Radon and its products increases the risk of lung cancer as is reported in the literature [1-3].

In the book of Paracelsus "Uber die Bergsucht und andere Bergkrankeiten", published in 1567, a mysterious disease which affects the miners was described, later called "Schneeberg's pulmonary disease". However, only until the middle of the XIX century, it was identified as lung cancer. During the last decades, it was possible to correlate why lung cancer affects the miners more often than the rest of the population [1,2]. The disease turned out

Keywords: High altitude, Radon occupational exposure, Threshold limit value

mines are relevant in the Radon release process.

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Zinc	underground	36	850

In the Andes, the highland zone extends from Colombia in the north to central Chile in the south, with mining being one of the main economic activities that are developed at high altitude. In this work, we will consider as high altitude any workplace located over 1500 masl (meters above sea level).

In Chile, approximately 80% of mining takes place over 3000 masl [5], and it is known that workers who carry out their activities at high altitude only due to the effect of altitude can present diseases such as: acute mountain sickness, pulmonary hypertension, pulmonary edema, among others [6,7].

Around 13% of copper productions comes from underground mining [8], however, this percentage is growing due to the higher efficiency of underground mines compared with open-pit mines. In addition, the metallic-mining sector has employed around 248803 persons during 2019 [8].

Therefore, and considering the huge number of persons which could (and will) be affected by Radon exposure the creation of proper regulations and monitoring criteria becomes imperative.

In this article, we focus only in studies related to mining industry, mainly in uranium mines: most of these describe the incidence or mortality from lung cancer or its derivatives. It is worth to mention, that we did not find any study evaluating the effects of Radon exposure in miners working at high altitude. We have subdivided the studies related to the effects of Radon exposure, as follows: "Radon and cancer", "synergistic effects of Radon with tobacco", "Exposure to Radon in Working Level Month (WLM) and mortality".

This article is organised in the following way: In section 1 we present the physiopathogical effects to Radon exposure. In section 3 we show the results and in section 4 we discuss and provide recommendations for improving the present regulations in Chile.

2. PHYSIOPATHOLOGICAL EFFECTS TO RADON EXPOSURE

Radon and cancer:

The Radon (^{222}Rn) and its short-lived progeny (^{218}Po, ^{214}Pb, ^{214}Bi, and ^{214}Po) are considered as Group 1 human carcinogens by the International Agency for Research on Cancer (IARC) [9]. The risk of developing lung cancer from exposure to Radon is confirmed in the literature presented below. This risk depends on the gas concentration, the exposure duration, the tobacco consumption, and the individual susceptibility [10].

The dose and the exposure time determine the incidence of the disease and the mortality of it, this is confirmed by studies in uranium miners where chest x-rays and respiratory function tests were analysed [11,12]. The age of the worker is another determining factor, in a study carried out in uranium mines in the Czech Republic it was found that the excess relative risk (ERR) of cancer changed according to age and time since exposure [13].

In studies focused on Chinese miners working in tin mines, it was found that the ERR increase by 1.7% for each level of accumulated work. The ratio of this exposure decreased significantly each year since the last Radon exposure. This indicates that a long-term exposure in low concentrations may be more harmful than a short-term exposure in high concentration [14]. In Czechoslovakia, a cohort of 16434 miners were studied and a high mortality and incidence of lung cancer was founded [15].

Other follow-up studies of mortality in miners conclude that there is a significant increase in the mortality from lung cancer [16,17,18], as well as a statistically significant linear association between mortality from lung cancer and cumulative Radon exposure [19].

However, when performing a trend test ($P = 0.09$) it was not statistically significant. The study found that smokers were 1.8 times more likely to suffer from coronary heart disease than non-smokers [26].

On the other hand, a work carried out by Walsh [16] shows that a relationship between Radon exposure and coronary heart disease cannot be established (ERR per 100 WLM = 0.0003), nor can this exposure be related to cerebrovascular diseases (ERR per 100 WLM = 0.001).

Synergistic effects of Radon with tobacco:

Among the risk factors for developing lung cancer are those that are intrinsic or non-modifiable and those that are extrinsic or modifiable. Smoking is one of the extrinsic factors. The risks founded for the tobacco-lung cancer association are among the highest in the scientific literature. However, in the case of combined exposure to Radon and tobacco, there are much fewer studies, and for combined exposure to Radon with other toxic that cause lung cancer, there are almost none. In this article, it is of great interest to review studies that consider Radon exposure in smokers and non-smokers.

Having evidence on the possible synergistic effects that these two toxic may have would allow proper medical surveillance to be implemented in exposed workers, especially those who are smokers.

In a study on the incidence of lung cancer in Workers at Uranium Mines (WUM) in Canada, it is confirmed that the risk of lung cancer may decrease when quitting smoking [11] and that the factors that aggravate the exposure are smoking or inhaled arsenic [12].

Another study suggests a synergistic or additive effect produced by these cocarcinogens. The appearance of small tumors in young non-smoking miners is mentioned when exposed to Radon levels above 465 WLM, while for smokers there is evidence of the incidence of lung cancer at much lower levels [27].

Mortality in WUM was followed by classifying the study group

Other follow-up studies of mortality in miners conclude that there is a significant increase in the mortality from lung cancer [16,17,18], as well as a statistically significant linear association between mortality from lung cancer and cumulative Radon exposure [19].

Apart from lung cancer, there are others cancer associated with Radon exposure. In various studies in workers at uranium, tin and iron mines, among others, an excess risk for stomach cancer is found [15,16,18,19,20,21], rectal cancer [15], liver cancer [15,16,19], laryngeal cancer [21], bladder cancer [18], and Leukemia [22,23,24].

On the other hand, there are also studies in miners exposed to Radon that examine mortality from diseases of the circulatory and coronary system. The information founded is contradictory and inconclusive.

However, in a study in French miners exposed to low concentrations of Radon, a positive trend was observed between deaths from cerebrovascular diseases and cumulative exposure to Radon with a relative risk per 100 WLM [ERR per 100 WLM 0.49, (95% CI) 0.07-1.23)]. In this study, strong physical activity was identified as a possible modifying factor of the risk-exposure relationship [25].

In the case of coronary heart disease, there is a study in miners working at fluorite mines in Canada, which shows that the high risk of mortality from coronary heart disease after cumulative exposure to Radon every 1000 WLM was (RR 1.5, (95% CI) 0.77-2.751).

non-smoking miners is mentioned when exposed to Radon levels above 465 WLM, while for smokers there is evidence of the incidence of lung cancer at much lower levels [27].

Mortality in WUM was followed by classifying the study group according to the degree of smoker; lung cancer was found to be the main cause of death, and a sub multiplicative relationship between Radon and tobacco [28].

In other works, focused on multiple cohort studies of Chinese, Czech, Canadian, Swedish, French, American, and Australian miners, risk was analysed by grade and type of smokers. Miners exposed to high concentrations of Radon had a high risk of lung cancer, however, in the groups exposed to low concentrations, an evident dependency was not found [29].

In workers at iron mines in Sweden, a quantitative analysis of lung cancer cases was carried out. The results of this study confirmed a considerable risk to get the disease and an additive effect between the combined exposure to Radon and tobacco [30].

Exposure to Radon in WLM and mortality:

This section presents a summary of studies with Radon concentration measurements expressed in WLM, which is applied in uranium mining and is equivalent to an exposure to 3700 Bq/m^3 (WL) for 170 hours per month.

Few mortality follow-up studies are found with measurements of Radon exposure in WLM for smoking and non-smoking miners. A study of this type carried out in WUM confirms that tumours are induced by radiation when the cumulative exposure level is above 300 WLM. The study shows that lung cancer cases in miners exposed to less than 300 WLM can be attributed to smoking, sinceno lung cancer was found in non-smokers exposed to less than 300 WLM. The lowest cumulative exposure suffered by a non-smoking miner who developed lung cancer was 465 WLM [27].

In a study based on three cohorts of WUM, from the Czech Republic, France and Canada, exposed to low concentrations of Radon (<100 WLM) is confirmed that there is a statistically significant linear relationship between exposure and response between the low accumulated exposures to Radon and the mortality from lung cancer for the group of cohorts (ERR / WLM = 0.022; 95% CI 0.013-0.034, trend line P <0.001) [31].

Mortality from lung cancer was followed in a group of 4134 WUM in the United States; There were 617 deaths from lung cancer with a risk rate of 0.67 (95% CI 0.61-0.73). Throughout the follow-up it was shown that limiting the exposure reduced mortality; for this, the exposure levels were lowered, decreasing them from 3.47 WLM to 2 WLM, then to 1 WLM and finally to 0.33 WLM. The result obtained was that mortality was reduced, by 23% for the limit of 2 WLM, by 28% for the limit of 1WLM and by 33% for the limit of 0.33 WLM [32].

In terms of cumulative exposure to Radon in uranium mining, tremendous progress has been made. In several mining companies in Canada, for example, control methods have been implemented that manage to keep exposure to Radon at low levels. The mean annual Radon exposure of Canadian uranium miners ranged from 0.106 to 0.214 WLM between 2005 and 2015: the sum of 10 years of average annual exposure to Radon was 1.8 WLM [31]. However, the problem persists in much of the mining of underdeveloped countries as Chile where an estimate of exposure has been not even tried because there are no national regulations that force them to do so.

while others suggest studying arsenic as an aggravating factor of exposure to Radon [12].

No high altitude mining studies with exposure to Radon have been found; therefore, it is not known how these risk factors behave when they coexist. In mines at high altitude seems urgent to study:

the incidence and mortality from lung cancer associated with exposure to Radon at different working altitudes; the degree of acclimatisation to the altitude in miners exposed to Radon and toxic gases or toxins; the concentration of Radon in the different mines (open-pit mine and underground mine).

In Chile there is a lack of legal norms that regulate occupational exposure to Radon. It is necessary to establish a measurement and monitoring methodology for Radon, and a Threshold Limit Value for exposure to it.

4. DISCUSSION AND RECOMMENDATIONS

According to the revisited bibliography, Radon levels change during the day (see Fig. 9.1 in Ref. [4]). Therefore, it is mandatory to develop a real-time monitoring system, specially at underground mines, which will allow to alert and to prevent miners about huge Radon emanations. We propose to establish a TLV for mining based on an effective dose to Radon, that considers a subdivision according to the altitude at which the mine is placed; for mines located at an altitude equal or lower than 1500 masl it is recommended to use the international limit of 4 WLM [34].

For mines at altitudes higher than 1500 masl, a more restrictive TLV is proposed, since above 1500 masl some physiological problems to altitude adaptation may occur (see Fig. 1 and Ref. [35]), and this, in addition to the exposure to Radon, could bring more serious consequences for the exposed workers. Between 1850 and 2750 masl, some diseases began to appear such as acute mountain sickness, which can affect up to 25% of those who ascend [36].

3. RESULTS

The Radon is present at any working place, only changing the concentration of it. Therefore, the existence of reliable measurements and strong regulations are a must. Radon is seven times heavier than air which implies that ventilation systems at close places (as underground mines) must be designed considering such physical properties.

In the studies analysed, it is confirmed that exposure to Radon increases the risk of developing lung cancer in most of the exposed miners. There is also a probability to get other cancers, such as stomach [15,16,18,19,20,21], liver [15,16,19], and Leukemia [22,23,24].

Cigarettes and Radon have additive or synergistic effects [27,28,30]. In various studies direct relation have been found between exposure to Radon and the increase of lung cancer in smokers.

In the literature reviewed, no studies were found that analyse the combined effects of exposure to Radon with other toxics present in mining processes. Some studies present the need to study the combined effects of exposure to Silica and other workplaces lung carcinogens (polycyclic aromatic hydrocarbons, nickel, Radon) [33]:

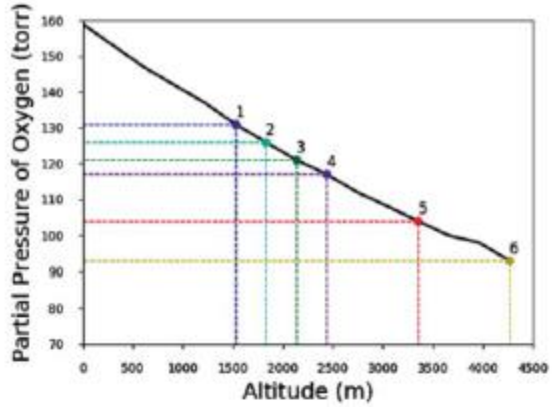

Figure 1. Relation between altitude and Partial Pressure of Oxygen (PPO) and its physiological effects (information collected from [34]). Black line shows the PPO as a function of altitude. Blue lines (point 1) stand for the limits up to where physiological effects have been not reported (1524 masl). Cyan lines (point 2) denote the limit where the loss of dark adaptation can occur (1829 masl). Green lines (point 3) represent the limit where the increment of pulmonary ventilation,

cardiac output, incoordination, and impaired attention and thinking appears (2134 masl). Magenta lines (point 4) stand for the limit where respiratory alkalosis, headache, nausea, and vomiting appear, in unacclimatised individuals; a rapid ascent increases the risk to suffer cerebral and pulmonary edema (2438 masl). The red lines (point 5) determine the limit where abnormal fatigue on exertion, faulty coordination, impaired judgment, and emotional upset and start to appear (3353 masl). Yellow lines (point 6) stand for the limits where impaired respiration, very poor judgment, and coordination, and tunnel vision start to appear (4267 masl).

To determine the TLV with greater precision, it is necessary to carry out studies that consider that the decreased partial pressure of oxygen at altitude causes various physiological changes in exposed workers, depending on their degree of acclimatisation to altitude. Among mechanisms of acclimatisation and compensation to altitude is the increased pulmonary ventilation [37]; this occurs because the volume of air inhaled or the respiratory rate or both increases, consequently increasing the inhalation of the various toxic gases or toxins that may be present in the workplace. Therefore, the behaviour of the respiratory rate is also a factor that must be taken into account to establish an annual effective dose of Radon [38].

From the above, it follows that it is not advisable to consider a single TLV for jobs at different high altitudes. In the particular case of Chilean mining there are processes that take place at more than 4000 masl where the partial pressure of oxygen is approximately 97 torr (see Fig. 1).

The recommendation to establish 1500 masl as the dividing level for the different TLVs is based on the value proposed by the National Institute for Occupational Safety and Health (NIOSH) of USA for the physiological limit that defines an oxygen deficient atmosphere. NIOSH has defined the physiological limit as 60 torr of alveolar oxygen pressure and has denoted the oxygen-deficient atmosphere like that in which the ambient oxygen pressure is less than 132 torr. A minimum sufficient amount of oxygen (considering a margin of safety) to carry out successfully most of the tasks is 19.5% oxygen at sea level (148 torr oxygen pressure, dry air), however, this security margin rapidly decreases while the altitude increase (see Fig. 1).

For the reasons aforementioned, we propose that future studies to determine a TLV for Radon as a function of altitude, consider 1500 masl as a starting point.

On the other hand, due to the geographic isolation conditions in

CONFLICT OF INTERESTS

The authors declare that there are no conflicts of interest.

REFERENCES

[1] Sarah, C., Darby et al, Radon and Cancers Other Than Lung Cancer in Underground Miners: A Collaborative Analysis of 11 Studies, Journal of the National Cancer Institute, 1995.

[2] Field, R.W., Steck, D.J., Smith B.J., et al, The Iowa Radon Lung Cancer Study-phase I: Residential radon gas exposure and lung cancer. Sci Total Environ, 2001.

[3] Hornung, R.W., Health effects in underground uranium miners, Occup Med, 2001.

[4] Johnson, R.H., Jr., et al., in Natural Radiation Environment (Bombay), Wiley Eastern Limited (1982) pp. 182-183.

[5] Departamento de Estudios de la Direccion del Trabajo, Ministerio del Trabajo, Gobierno de Chile. 2011. Una aproximacion a las condiciones de trabajo en la gran mineria de altura. ISBN: 978-956-7978-11-3.

[6] Vearrier, D., Greenberg, M., Occupational health of miners at altitude: adverse health effects, toxic exposures, pre-placement screening, acclimatization, and worker surveillance. Clinical Toxicology. https://doi.org/10.3109/15563650.2011.607169

[7] Escuela de Salud Publica, Universidad de Chile. 2013. Informe Final: Elaboracion de un estudio sobre la poblacion trabajadora de faenas mineras en altura geografica y analisis de riesgos laborales asociados a altitud. https://www.mintrab.gob.cl/wp-content/uploads/downloads/2014/09/Estudio-Exploratorio-Trabajo-en-Altura.pdf

[8] Servicio Nacional de Geologia y Mineria, Anuario de la Mineria en Chile 2019, https://www.sernageomin.cl/pdf/anuario_2019_act100720.pdf

[9] Radiation. IARC monographs on the evaluation of carcinogenic risks to humans. International Agency for Research on Cancer, Lyon (100D). https://publications.iarc.fr/Book-And-Report-Series/Iarc-Monographs-On-The-Identification-Of-Carcinogenic-Hazards-To-Humans/Radiation-2012

[10] Barros Dios, J., 2012. Radon y cancer de pulmon, Santiago de Compostela, Espana, Universidad de Santiago de Compostela. ISBN 978-84-9887-948-3.

For the reasons aforementioned, we propose that future studies to determine a TLV for Radon as a function of altitude, consider 1500 masl as a starting point.

On the other hand, due to the geographic isolation conditions in which, in general, mining deposits are located, it is common for the work regime to be developed in unusual work shifts. A very frequent shift in Chilean mining is the so-called "7x7" which consists of working 7 days in a row for 12 hours a day, and then resting for another 7 days. If we consider that the ACGIH proposes TLVs for 8 hours workdays for 40 weekly hours, it is also necessary to carry out studies to adapt the TLV of the Radon to the Chilean reality where the relation between the number of hours worked in a shift per number of hours resting is very different. We propose to study the problem of geographical altitude and the duration of working shifts independently.

Finally, we think that smoking status should be a contra-indication for working at high altitudes in places with considerable Radon exposure.

To-Humans/Radiation-2012

[10] Barros Dios, J., 2012. Radon y cancer de pulmon, Santiago de Compostela, Espana, Universidad de Santiago de Compostela. ISBN 978-84-9887-948-3.

[11] Finkelstein, M., (1996). Clinical measures, smoking, radon exposure, and risk of lung cancer in uranium miners. Occupational and Environmental Medicine, 53, 697-702.

[12] Kusiak, R., Ritchie, A., Muller, J., Springer, J., (1993). A Mortality from lung cancer in Ontario uranium miners. British Journal of Industrial Medicine, 50, 920-928.

[13] Tomasek, K., Darby, S., (1995). Recent Results from the Study of West Bohemian Uranium Miners Exposed to Radon and Its Progeny. Environmental Health Perspectives, 103, 55-57.

[14] Lubin, J., et al. (1990). Quantitative Evaluation of the Radon and Lung Cancer Association in a Case Control Study of Chinese Tin Miners. Cancer Research, 50, 174-180.

(20)

ABSTRACT

The wearing of disposable masks has been identified as a major source of discomfort and dissatisfaction. This Coaltech

research investigated the current industry standards and practices with respect to distribution and wearing of the dust masks in the continuous miner sections.

Laboratory fit tests and underground tests were conducted, as well as a questionnaire sent out to the mines to gather data in order to identify possible research gaps on the subject, and this technical feedback was combined with the literature review findings.

Dust masks from the LHD operator recorded the highest total mass loading, exceeding 200 mg in an average time of 1.7 hours, whilst the CM, Shuttlecar and Roofbolt operators averaged 3.5 hours, 5 hours and 2 hours respectively. All dust masks failed the laboratory fit tests.

The recommended 8-hour service time limit of the dust mask is too long, the dust masks do not offer adequate protection against leakage and both mines have no set guidelines and procedures with respect to the use and distribution of dust masks.

Mines need to review and implement their own training procedures, consider conducting fit tests and implementing awareness programs educating the workforce on the importance of wearing and proper use of the dust masks.

1. INTRODUCTION

As part of the Coaltech dust project (Task 2.6.1), workshops were held with mine production personnel to help identify specific problem areas regarding dust in Continuous Miner sections. Feedback from the workshops identified the wearing of disposable masks as a major source of discomfort and dissatisfaction. This initiated further research on the current industry standards with respect to distribution and wearing of the dust masks.

The problems resulting from the effects of dust on health and safety of personnel employed in the mining industry is a difficult task which requires attention (Li, Qin, Yang, & Tian, 2011, Ji et al., 2016).

Workers wear nose masks or breathing devices to protect their health in the workplace. These devices are generally referred to as Respirable Protective Equipment (RPE). Respirators filter the air to eliminate harmful substances and provide clean air for the worker to breathe. RPE must be both sufficient/adequate and suitable for the work to be used properly in the mine i.e. it must comfortably fit the wearer whilst providing adequate protection for the specific work environment.

Adequate/sufficient protection is classified as the dust mask’s capability to reduce the exposure of a harmful substances to a standard level.

There are two types of RPE namely, disposable and reusable respirators. The broad range of RPE provides the mines the freedom to select the level of protection, comfort, style and maintenance options needed to work efficiently, effectively and safely

3. LITERATURE REVIEW (ONIFADE, 2019)

3.1 Fit and seal testing

A “fit-test” is a 15-20-minute test which examines the seal between the respirator’s facepiece and the wearer’s face. It is

used to evaluate an adequate match between the facepiece of the RPE and the face of the wearer and should not be confused with a user seal-check. Upon passing the fit test, the user is required to use the exact dust mask i.e. make, model, size when performing their daily duties on the job.
A user-seal check is a quick check carried out by the user each time the dust mask is put on. A seal check determines whether the dust masks is fitted properly, or it needs to be readjusted in order to get a proper fit.
If the wearer's facial characteristics change due to weight changes, loss of teeth etc., the standard requires a new fit test be conducted before the dust mask is used.

3.2 Fit test methods

The fit of a facepiece is determined by qualitative or quantitative methods. The qualitative method depends on the wearer's subjective reaction to a sprayed test agent (usually a sweet or bitter tasting substance), whilst the quantitave method provides an objective measure of the fit, by generating a measuring number referred to as a fit factor. A fit factor is defined as the ratio of the concentration of a substance outside the facepiece to the concentration inside the facepiece. There are several quantitative fit testing methods. Test chamber methods used in CE certification testing is considered as the reference standard for fit testing but are neither practical nor cost effective for regular fit testing applications. CE is a certification mark that indicates conformity with health, safety and environmental protection standards for products sold within or outside the European Economic Area (EEA) but have been manufactured to EEA standards (ce marking association, 2014). The most regular quantitative fit testing method in use applies an ambient particle counting device (e.g. PortaCount™), while an alternative method uses controlled negative pressure (CNP) (e.g. FitTester 3000™). Since these methods use various techniques, they give rise to different fit factors. Studies carried out by Oestenstad and Graffeo (1993) and Crutchfield et al. (1999) compared these methods and found that these methods have strengths and weaknesses. This scenario is the case of striking the right balance between a fit test method that is scientifically standard but regularly not very practical and a method that is easy to use while providing an acceptable evaluation of fit. Although, what is significant is that the fit tester is well informed of the limitations of a specific technique and takes these into account.

3.3 International standards, regulations and guidance

Fit testing has been a requirement in the USA over decades and was introduced in 1969 by the American Standard ANSI Z88.2 (ANSI, 1992), while the OSHA Standard 1910.134 set out accepted fit test protocols. The American National Standard Institution (ANSI) Z88.10-2001 is responsible for the provision of guidance on how to carry out fit testing and suitable methods to be used (ANSI, 2001).
In the UK, fit testing was first introduced into the Control of Asbestos at Work (CAW) Approved Code of Practice back in 1999 and then extended throughout all of industry in 2002, when the fit testing requirement was integrated into the Approved Code of Practices supporting the COSHH (Control of Substance Hazardous to Health) and CLAW (Control of Lead at

Work) regulations.
The UK Health and Safety Executive (HSE) issued an information document HSE 282/28 to provide guidance on fit test techniques and procedures (HSE, 2003).3.4 Respiratory Protective Equipment (RPE). RPE is a specific type of Personal Protective Equipment (PPE) which is designed to safeguard the wearer from breathing-in injurious substances or from oxygendeficient atmospheres when other controls are either not possible or deficient on their own. RPE is obtainable in various sizes to allow for the facial differences of workers. Gender, ethnicity and several other factors mean that one size of facepiece will not fit everyone.

3.4 Disposable dust masks

A disposable dust mask is a safety device that covers the nose and mouth. This device helps protect the wearer from breathing-in harmful substances. It protects you from breathing in small particles in the air such as dust and mold.
According to Onifade (2019), workers are advised to use a disposable dust mask that is certified by the National Institute for Occupational Safety and Health (NIOSH). Masks that are not certified by NIOSH may not provide adequate protection. It should be used even if the wearer cannot see the particles because they may be too small to see.
General guidelines for the use of RPE’s are provided by Onifade (2019) and these include:

• Disposable dust masks do not protect the wearer against chemical vapours, gases, carbon monoxide,gasoline, asbestos, lead or low oxygen environments

• The wearer must always read and follow the manufacturer's directions when using a disposable dust mask and it must cover both the nose and mouth to prevent the wearer from breathing in mold and dust.
• If the mask does not have a snug fit, it will not work correctly. The correct fit of the mask requires contact with smooth skin. It will not work properly for people with beards or facial hair.
• The wearer must perform a user seal check, including both positive and negative pressure checks, to confirm that the mask has been put on correctly and adjusted to fit correctly.
• As the disposable dust mask gets clogged, it becomes more difficult to breathe. When this arises, the user must throw it out and use a new one. The mask must be discarded if it is wet or dirty on the inside, if it is deformed, or if the filter is torn. A disposable dust mask cannot be cleaned or disinfected.

4. SOUTH AFRICAN NATIONAL STANDARDS

4.1 (SANS 10220:2010)

The South African National Standards (SANS 10220:2010), derived and copied from EN149:2001, covers the factors affecting the selection of respiratory protective equipment for the protection of the body against harmful substances. The standard also provides recommendations for the use and maintenance of such equipment.

4.1.1 Classification of respiratory equipment

There are various types of RPE considered to suit a variety of

work situations and protect the wearer from a variety of hazards. The two major types of RPE are breathing apparatus and respirators.
Respirators use filters to eliminate impurities from the air being breathed in and can be either powered (using a motor channel air through the filter to provide a supply of clean air) or nonpowered.
Breathing apparatus requires a supply of breathing quality air from an independent source such as an air cylinder or air compressor

4.1.2 Classification of inhalation hazards

The RPE is designed to give protection against one or more of the following hazards: Oxygen deficient environments, Particulates, Vapours and gaseous contaminants.

4.1.3 Description of respirators

All RPE's designed for protection against particulates, gases or a combination of both contaminants have a quarter mask, half mask, full-face mask or a filtering mask. All of which contain air purifying features designed to remove the contaminant from the surrounding air before it is inhaled by the wearer.
There is respiratory equipment that is designed to give protection against specific contaminants only e.g. particulates only. These types of equipment do not provide universal protection and should only be used in situations where the concentration and the type of contamination is known.

4.1.4 Respirators for particulate matter only

Respirators designed for the use against particulate matter only are ineffective in gas containing environments. The service time of the respirator decreases in environments where the concentration of the contaminant is excessively high and breathing resistance is experienced when used for an increased amount of time.
To reduce the level of contamination, the contaminated air is drawn by the breathing action of the wearer through a filter system before the air is inhaled. The exhaled air is discharged into the atmosphere through the filter media or the second valve of the respirator (if fitted).

4.1.5 Respirators for gases

These types of respirators are designed for protection against specific gases only. The mask is directly connected to cartridge and canister filters where the inhaled air passes through, via a system of non-return valves. The exhaled air passes directly into the atmosphere.
Provision for protection against particulates can be incorporated through the cartridges or canister types, however no protection is provided for any particulate contaminants not specified on the cartridges or canisters.

4.1.6 Limitations of respiratory protective equipment

The sealing capability of the respiratory between the wearer's face and fitting surface of the mask is greatly affected by the wearer's facial features such as beard growth and moustaches.
Due to the large variation of the amount in the noses of individuals, difficulty is also obtained in the sealing through the nasal passages when using a respirator with a nose clip.

4.1.7 Facial features

Some facial features reduce the sealing efficiency of RPE's, these include:

4.1.8 Beards

Adequate respiratory protection cannot be achieved with bearded persons due to the hair trapped between the pneumatic cushion and the mask.

4.1.9 Moustaches

Moustaches interfere with the peripheral seal of a dust mask and affect the fit of the dust mask.

4.1.10 Sideburns

When sideburns extend below the line drawn through the top of a tragion i.e. the notch in the cartilage of the ear just above and immediately in front of the earhole, it affects the seal of the respirator.

4.1.11 Stubble growth and long hair

When the wearer has long hair or beard stubble, particular care should be taken to ensure that none of the hair or stubble is trapped beneath the face seal.

4.1.12 Wearing of spectacles

A perfect fit may not be obtained with a full-face mask when spectacles are worn. However, special spectacles can be made or adapted to obtain a satisfactory fit.

4.1.13 Communication

Excessive speech causes component or mask leakage and should be limited when wearing a half mask. However, the exhalation valves allow for speech transmission over short distances.

4.1.14 Selection of respiratory equipment

Before any protection equipment can be selected, the hazards, limitations, operational and maintenance requirements that exist in that given operation need to be evaluated. More factors that need to be considered before selecting the suitable respirator for a given operation can be found in the full SANS 10220:220 report.

Once all the factors that determine the most suitable respirator for a given operation have been satisfied, proper implementation and application of RPE's in the workplace plays a pivotal role in assuring more effective use of the dust masks. In the workplace, RPE's should:

- be used by properly trained people who are supervised.
- be suitable for the proposed use.
- be properly stored, cleaned and checked regularly to ensure it remains effective.
- be CE-marked or of an approved type/standard approved by SABS; and
- sufficiently control inhalation exposure to provide the wearer with effective protection.

4.2 (SANS 50149:2003)

This standard derived and copied from EN149:2001, covers the minimum required specifications for filtering half masks used as protective devices against particles. A respiratory protective device can only be approved when the individual components of the device satisfy the requirements of the test specifications which may be the complete standard or part of the standard. Laboratory and practical performance tests are included for the assessment of compliance with the requirements.

Table 1. The difference between the different types of dust masks. (www.dustmaskdirect.co.za) [Accessed 18 August 2019].

DUSK MASK	Filter Efficiency	Micron size	Cost(R/Unit)	Hazard type
FFP1	95%	>5	3.5	No toxic dust-Oil based Aerosol
FFP2	99%	2-5	9	Toxic dust and metal fumes

FFP3	99.7%	Less than 2	82	Toxic and carcinogenic dust, metal fumes

5. ADDITIONAL LITERATURE (WWW.CDC.GOV/NIOSH)

The National Institute for Occupational Safety and Health (NIOSH) of the United States of America (USA) uses high filter loading (200mg) in certification tests, to address the potential for filter efficiency degradation by solid-based aerosols in the workplace (Center for Disease Control and Prevention, 2014). In most workplace settings, there is no recommended service time limit for the use for the respirators. However, NIOSH recommends that in dirty workplaces i.e. high aerosol concentrations, the service time limit should only be extended beyond 8 hours of use when an evaluation of the workplace settings demonstrates that:

• The filter efficiency will not be degraded below the certified efficiency level, or

• The total mass loading of the filter does not exceed the recommended 200mg

6 DISPOSABLE DUST MASK TYPES.

(www.dustmaskdirect.co.za)

There are 3 main types of RPE's that are generally referred to as disposable dust masks. These are governed by the European standards EN149:2001+A1:2009 used to protect against particles in the continuous miner sections, namely, the filtering facepiece for particulates (FFP1, FFP2 and FFP3).

6.1 FFP1 Dust Masks

The FFP1 dust masks provides the lowest level of protection against particulates. This is relatively acceptable depending on the airborne hazard they have been commissioned to protect against. The minimum protection is due to the less amount of filter material they are composed of. They provide the least breathing resisting and usually do not have an exhalation valve.

6.2 FFP2 Dust Masks

The FFP2 dust mask offers a moderate level of protection against hazardous particulates. There is greater breathing resistance associated with these mask types due to the presence of the exhalation valves.

6.3 FFP3 Dust Masks

The FFP3 dust masks provides the highest level of protection against hazardous particulates that a disposable dust mask can offer. It contains thick filter material and an exhalation valve is almost always fitted. Table 1 lists the difference between the dust masks in terms of their filter efficiency, micron sizes, costs and the hazard types. The unit costs given in Table 1 were approximate at the time they were purchased for the research project i.e. August 2019

From this test, an Assigned Protection Factor (APF) is now the recognized true value of mask performance. Table 2 shows the full-face mask nominal protection factor of 1000 was reduced to an assigned/actual protection factor of 40.

An APF of 10 means that the dust mask (if used properly) can be safely used in an atmosphere that has a hazardous concentration of up to 10 times the permissible exposure limit PEL) or other exposure limit for that hazard.

One of the disadvantages of this fit test method (ambient particle counting method) is that it cannot differentiate between particles that have leaked around the face seal of the facepiece and those that have been created by the wearer. Fairchild et al.

(1987), da Roza et al. (1991) and Clayton (2001) indicated that wearers produce particles during the fit test exercises which reduces the measured fit factors, particularly during the talking exercises. However, this can be minimized by ensuring that the ambient particle count is sufficiently high.

Table 2. A comparison of the Nominal protection Factor (NPF) to the Assigned protection Factor (APF) (Charlton, 2006).

Dusk mask Type	Nominal PF	Assigned PF
FF1	4	4
FF2	12.5	10
FF2	50	20
EN 136(full face mask)	1000	40

7.1 Nominal protection factor (NPF)

The Nominal protection factor can be defined as the ratio of the concentration of the hazardous contaminant outside the dust mask to that inside the dust masks. It was developed by manufacturers from laboratory testing.

The test consisted of a mask that is securely strapped onto the face of a rubber head. To determine the leakage or contamination ingress, a hole is drilled through the back of the rubber head into the face mask and the air is extracted from within the mask.

These initial laboratory tests provided satisfactory seal around the edges and the filter satisfied the design specifications. Therefore, an NPF of 1000 was awarded to an EN136 full-face mask. However, these tests did not strike a balance between a fit test method that is laboratory accepted and a fit test method that is very practical and applicable to the working conditions of the wearer. Therefore, a new fit and use test method needed to be developed

7.2 Assigned protection factor (APF)

The new fit and use test method took into consideration the different shapes and sizes of the human faces that vary between the sex, race and genetic make-up. The wearer was required to take the test with a clean-shaven face, trained in inspection, fit and application.

The test also required the wearer to undertake various tasks which included talking, turning the head and raising arms etc.

8. TECHNICAL REVIEW

For the technical review, questionnaires were sent out to five different underground coal mines and interviews were conducted with the mine personnel.

8.1 Questionnaires

The questionnaire consisted of the following questions:

1. Does your mine issue disposable dust masks in production sections/areas?
2. How do you identify jobs that require disposable dust masks?
3. Who is responsible to issue the disposable masks?
4. Do you keep records of the disposable dust masks?
5. When do disposable dust masks get replaced?
6. What type of disposable dust masks do you use? Make / style / code / supplier etc.
7. Do you use more than one protection class of disposable dust masks? i.e. FFP1, FFP2, other?
8. Do you have standard procedures for disposable dust masks?

9. Do you have formal training for the use and wearing of disposable dust masks?
10. Do you do fit testing for disposable dust masks?
11. Do you have more than one fit size or type of disposable dust mask, or one mask fits all?

8.2 Findings from questionnaires

Table 3 shows all the responses to the questions listed in section 9.1 of this report that were received from the five underground coal mines.

From Table 3, it can be observed that most of the responses are similar. It can be noted that:

All mines do issue disposable dust masks in the production sections/areas.

Table 3 - Responses from the questionnaires

Question Nbr	Mine A	Mine B	Mine C,D, E1
1	Yes	Yes	Yes
2	All jobs	All jobs	All Jobs
3	Supervisors	Supervisors	Supervisors
4	No	No	No
5	Daily	Daily	Daily
6	3M	Honeywell	3M
7	FFP2	FFP2	FFP2
8	Yes	Yes	Yes
9	Yes	Yes	Yes
10	No	No	No
11	One Size fit all	One Size fit all	One size fit all

• that there are no specific selection criteria determining the jobs require dust masks, all jobs at the mine are issued with dust masks
• that there is no record keeping of the issued dust masks
• that a new pack of dust masks is issued daily with every shift
• that the most used disposable dust mask type is the FFP2 from 3M
• to applying PPE procedures as their standard procedures for the disposable dust masks
• they do have formal training for the use and wearing of disposable dust masks.
• they do not do fit testing for disposable dust masks.
• that they do not have more than one fit size of the disposable dust masks and apply a one size fits all approach with respect to fit sizes.
• inefficiencies of the filter and inadequate sealing of the dust masks around the edges lead to breathing resistance and fogging of the goggles.

9. LABORATORY FIT TEST

To test whether the dust masks used in the mines i.e. FFP1, FFP2 and FFP3 provided a satisfactory seal around the edges, Latona Consulting (Pty) Ltd conducted its own laboratory fit test at the UNISA Florida Campus with Envirocon.

9.1 Fit test procedure

To accommodate the different human face shapes and sizes, Latona Consulting (Pty) Ltd selected 5 volunteers of different sex, race, gender and face shapes. The volunteers were requested to perform various tasks such as talking, turning the head and raising of arms with the aim of simulating the normal behavior of an operator in a real-life situation in the continuous miner section.

The fit test involved the following:

• FFP1 disposable masks, CE specifications (EN 149:2001 = SANS 50149:2003)

• Non-adjustable straps

9.2 Fit test results

All five dust masks from the individuals failed the fit test. This is an indication that the dust masks do not offer adequate protection against leakage around the edges.

10. UNDERGROUND TRIALS

Initial field tests were carried out at two mines (Mine X and Mine Y) over a period of two days, to get preliminary results for dust loading on disposable dust masks. Primary focus was on high-risk dust occupations i.e. Continuous Miner, Shuttle Car, Roofbolt and Load Haul Dump operators.

The objectives of the trials were to determine the loading time i.e. how long it takes the dust masks to reach a total loading (including sweat, moisture etc.) of 200mg and dust loading concentration on the dust masks which is the amount of dust on the dust mask filter.

Figure 3 is a flowchart that illustrates the procedure that was followed to obtain these main objectives.

10.1 Underground methods

Before each test, a new set of masks was weighed, numbered and logged at the laboratory. At each mine some masks

Figure 3. Flowchart of the procedure followed to determine the loading time and the dust concentration

remained sealed and unused as controls, whilst the remaining masks were distributed for use and then sealed individually for return to the laboratory for analysis. After use the masks were reweighed and then dried and weighed again.

10.2 Underground trial results

The underground trial results are presented in Figures 4 – 7, showing the dry dust loading on each mask. This is less than the total mass loading, which includes moisture and is the indicator for the serviceable life of the mask.

10.3 Continuous miner (CM)

A total number of three CM samples were collected during the investigation phase of the project, two from Mine X (FFP2_224 and FFP2_220) and one from Mine Y (FFP2_245). Samples FFP2_224 and FFP2_220 were both collected on day one during a dayshift, from different sections of the mine. Sample FFP2_245 was collected on day two during a nightshift.

An average dust loading of 52 mg/hr was recorded from the dust mask filters of the CM operators, which would take 4 hours to reach a dust loading of 200mg. However, for the total mass loading, dust masks of the CM operators recorded 60 mg/hr and that would take only 3.5 hours to reach a total mass loading of 200mg. Figure 4 shows the dust loading results from the dust mask filters of the CM operators.

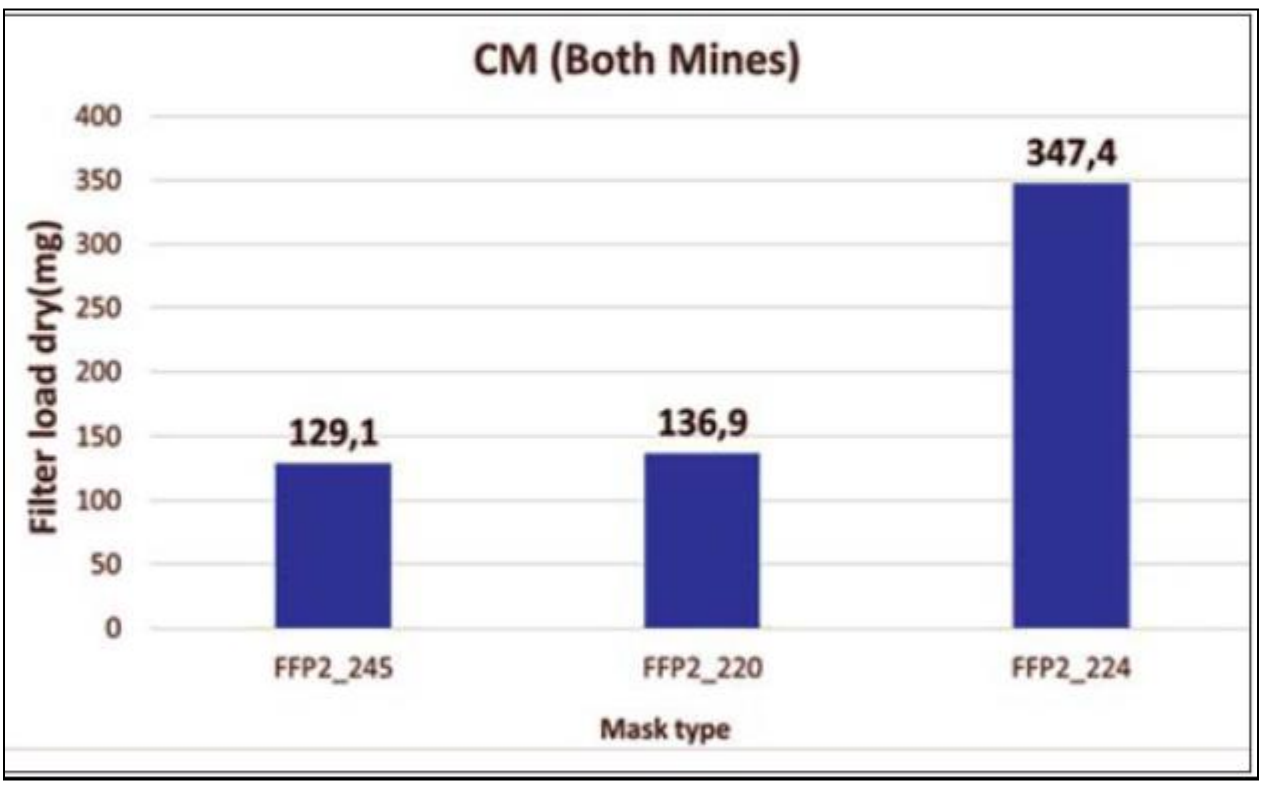

Figure 4. Dust loading on CM operator

10.4 Shuttlecar (SC)

A total number of five Shuttlecar samples were collected during the investigation phase of the project, two from Mine X (FFP2_243 and FFP2_270) and three from Mine Y (FFP2_211, FFP2_217 and FFP2_218). Samples FFP2_243 and FFP2_270 were both collected on day one during a dayshift, from different sections of the mine. Samples FFP2_211, FFP2_217 and FFP2_218 were all collected on day two during a nightshift, from different sections.

An average dust loading of 35 mg/hr was recorded from the dust mask filters of the SC operators, which would take 6 hours to reach a dust loading of 200mg. However, for the total mass loading, dust masks of the SC operators recorded 39 mg/hr and that would take only 5 hours to reach a total mass loading of 200mg.

Figure 5. Dust loading on Shuttlecar operator

Figure 5 shows the dust loading results from the dust mask filters of the SC operators.

10.5 Roofbolt (RB)

A total number of six Roofbolt samples were collected during the investigation phase of the project, two from Mine X (FFP2_244 and FFP2_247) and four from Mine Y (FFP2_215, FFP2_221, FFP2_222 and FFP2_223). Samples FFP2_244 and FFP2_247 were both collected on day one during a dayshift, from different sections. Samples FFP2_215, FFP2_221, FFP2_222 and FFP2_223 were all collected on day two during a nightshift, from different sections.

An average dust loading of 46 mg/hr was recorded from the dust mask filters of the RB operators, which would take 4 hours to reach a dust loading of 200mg.

However, for the total mass loading, dust masks of the RB operators recorded 89 mg/hr and that would take only 2 hours to reach a total mass loading of 200mg.

Figure 6 shows the dust loading results from the dust mask filters of the RB operators

Figure 6. Dust loading on Roofbolt operator

10.6 Load haul dump (LHD)

A total number of four LHD samples were collected during the investigation phase of the project, all of them were collected from mine X. All samples were collected on day one during a dayshift, from different sections.

An average dust loading of 51 mg/hr was recorded from the dust mask filters of the LHD operators, which would take 4 hours to reach a dust loading of 200mg. However, for the total mass loading, dust masks of the LHD operators recorded 116 mg/hr and that would take only 1.7 hours to reach a total mass loading of 200mg.

Figure 7 shows the dust loading results from the dust mask filters of the LHD operators.

Figure 7. Dust loading on LHD operators

10.7 Findings from underground results

Due to these results being average values, it is evident that some of the dust masks will reach a 200mg dust loading and total mass loading in a much shorter time than the averaged time e.g. FFP2_216 in Figure 7 from the LHD operator will reach

200mg much faster than the averaged 4 hours for the dust loading and 1.7 hours for the total mass loading. Furthermore, there is no correlation between the recorded highest dust readings from the different occupations i.e. dust readings from FFP2_216(LHD), FFP2_270 (SC), FFP2_224 (CM) and FFP2_244 (RB) and the trial sections. The high dust results were distributed across both the sections.

11. CONCLUSIONS

From the information gathered during the study it can be concluded that:

- The failed laboratory seal tests indicated that the generally used dust mask types, do not offer adequate protection against leakage.
- There are no set guidelines and procedures with respect to the use and distribution of dust masks in the mines.

- The results obtained from the 18 samples from the 2 mines indicate that 8 hours is too long to be set as a required service time limit since the dust masks reach a total mass loading in 2 – 5 hours. See Table 4
- Inefficiencies of the filter and the inadequate sealing of the dust masks around the edges lead to breathing resistance and fogging of the goggles

Table 4. Average time to 200mg total mass loading

Uccupation	Average ime to 200mg (hour)
CM	3.5
SC	5
RB	2
LHD	1.7

12. RECOMMENDATIONS

It is recommended that:

- The mines implement programmes that will educate the operators on the importance of proper use.

- The mines conduct fit tests and extend the use of adjustable straps.
- The mines consider using dust masks of different sizes to accommodate the different face shapes and sizes.
- The mines review their current training procedures and implement their own training procedures (in line with the international standards).
- They consider implementing record keeping on the distributions of the dust mask.

OR

4.2. Elaborate on the relevant section in the article *“Occupational exposure to radon at high altitude Chilean Mining”* which appeared in the following publication:-
Volume 74 , Number 2 – April to June 2021

The authors discussed the following within the article:

- Introduction
- Physiopathological effects to to Radon exposure
- Results
- Discussions and reccomendations

(20)

Total marks for the question paper **[100]**