Diesel Particulates

Does diesel exhaust exposure affect underground miners' health

Diesel Background

- Diesel exhaust is a complex mixture of gases and particles emitted by diesel – fuelled internal combustion.
- Diesel particulate (DP) emissions have the potential to cause adverse health effects.
- Employees working in underground mines are likely to be exposed to high level of DP exposure BUT not usually targeted in Australia for epidemiological studies related to DP.

The Problem

The complex nature of diesel exhaust

Employees working in underground mines are likely to be exposed to high levels of DP exposure

The lack of a standardised measuring and management plan

CONTAM Database indicates about a quarter of people assessed are exposed to levels greater the designated safe level of 0.1mg/m3

Lack of Studies

Lack of studies on exposure assessment and associated health effects on Western Australian miners, in particular, relationship between exposure and health effects in underground miners

DPM In The Environment

DPM behave similarly to surrounding gases.

DPM have longer residence times in a mine atmosphere

Larger portion of DP are deposited in respiratory tract

Penetrate deeply into regions of the human lung

Health and Safety Consequences

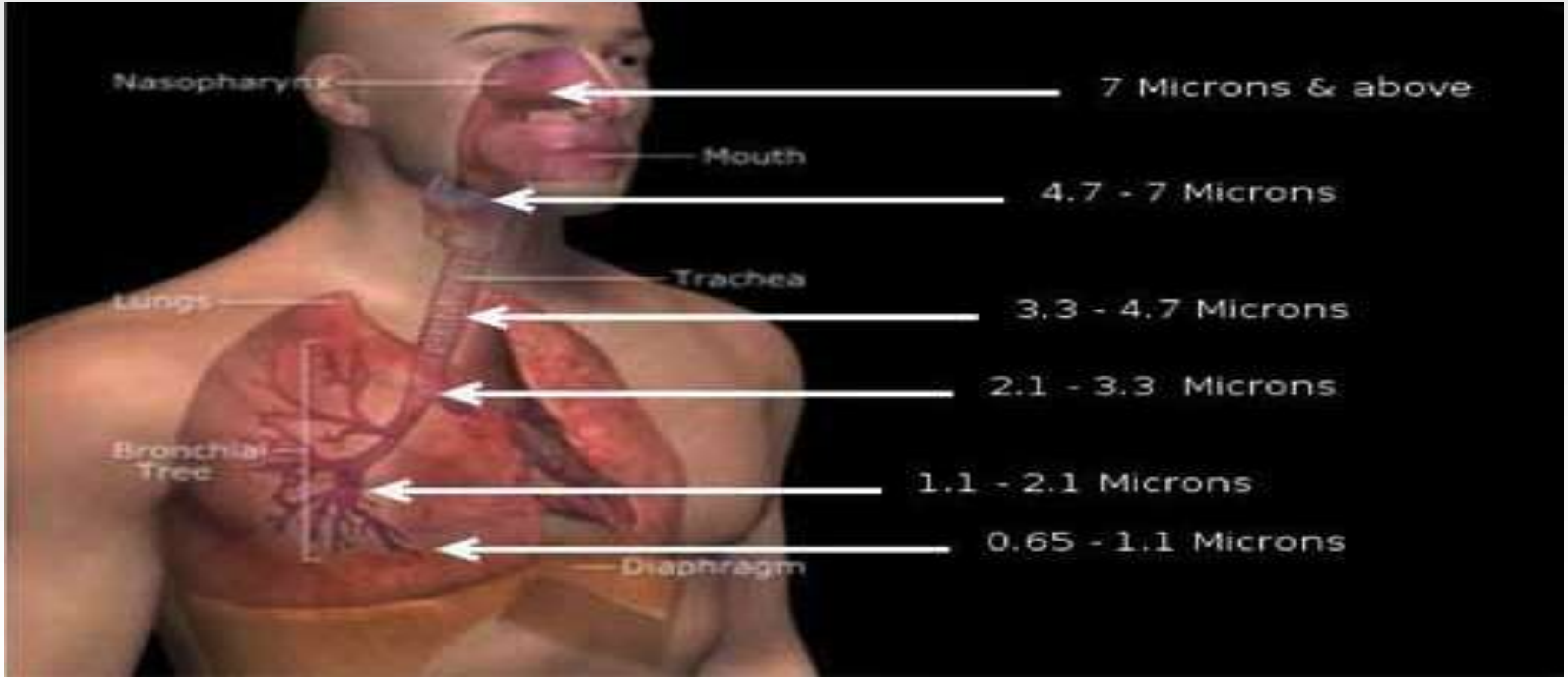
Went from 2b probable carcinogen to 1a carcinogen (cancer causing agent)

Chronic and acute respiratory diseases

Chronic and acute cardiovascular diseases

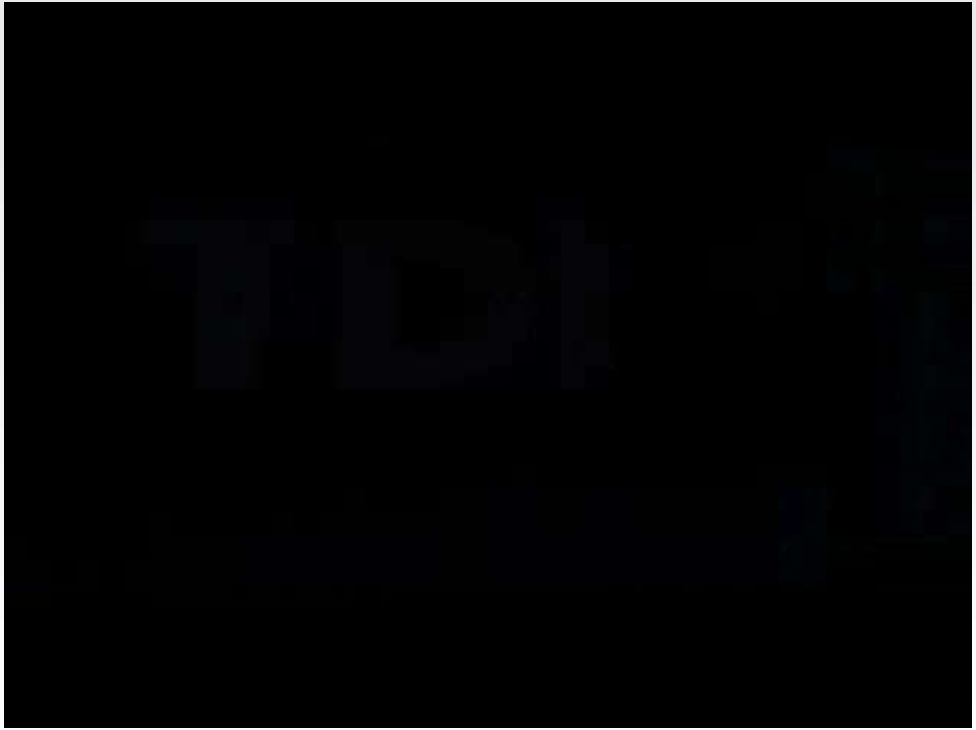
Acute irritation of the nose, eyes and throat and respiratory symptoms

Health and Safety Consequences



Cutaway of penetration zones for nano and ultrafine particles into the lung

Health and Safety Consequences



DP Standards

In 2007 the Australian Institute of Occupational Hygienists (AIOH) stated:

"Notwithstanding the lack of a defined dose response relationship, experience has shown that when workplace exposures are controlled below 0.1 mg/m^3 DP (measured as submicron elemental carbon), irritant effect decreases markedly. In the absence of any more definitive data, the AIOH supports the use of an exposure standard of 0.1 mg/m^3 DP (measured as submicron elemental carbon)"

Study Overview

- Investigate employees' DP exposure patterns in an underground mine
- Potential acute effects caused by DP.
- First research study at an Australia underground mine to investigate DP exposure by using elemental carbon monitoring data while concomitantly reporting on potential irritant effects.
- Will help in providing objective quantitative data for re-evaluation of current recommended DP exposure limit
- Can be used as a foundation for further studies on a larger scale.

Study Method

- This study was designed as an observational, cross-sectional study to investigate workplace DP exposures.
- It was anticipated that this type of study design could assess the prevalence of acute health conditions for a population highly exposed to diesel particulates in a confined workplace.
- Both personal exposure sampling and questionnaire survey methods were used for data collection.
- Collated information was analysed to explore the association of DP and potential irritant effects among current employees working in an underground mine.

The Setting

- Underground metalliferous mines

- Western Australia

The participants

Underground employees at this mine site.

Full time employees of this underground mine

Sampling Method

- The NIOSH recommended thermal optical method (5040) was used to measure personal exposure to DP.
- This method is considered the only validated method to measure elemental carbon, organic carbon and total carbon, with elemental carbon being considered as probably the best indicator or marker for DP exposure
- Air monitoring using NIOSH method 5040 is the standard way of measuring DP concentration in the atmosphere with much research showing it is a reliable and widely accepted validated method

Questionnaire structure

- A structured questionnaire which was validated in DP surveys in a crane and a transport company in W.A was administered to all employees. T

- Included questions on the tasks employees perform, their employment history, general background information and whether they experience certain acute irritant or other health related symptoms.

- The questionnaire used in the study was a structured questionnaire modified from:
  - (1) The Occupational Respiratory Questionnaire
  - (2) “OccIDEAS”, a web-based application tool to assess hazards related to occupational exposure
  - (3) The “Health assessment form” created by the Department of Mines and Petroleum

Exposure conditions

A total of eighty-two personal monitoring results were captured.

The following table documents the average results of specific mine workers' exposure level to DP from a range of job positions.

Personal DPM exposure in different job positions

Job Title	Exposure from highest to lowest	Total Monitored	Precent over TWA	EC* (Mean, mg/m^3)	EC (Median, mg/m^3)	EC (Range, mg /m^3)
Bogger	1	13	84.62%	0.178	0.180	0.006 – 0.35
Charge Up	4	6	66.67%	0.099	0.098	0.006 – 0.19
Grader	9	1	n/a	0.022	0.022	n/a
Jumbo	2	10	70%	0.105	0.120	0.028 – 0.17
Long Hole	8	3	33.33%	0.053	0.045	0.02 – 0.093
Shotcreter	5	2	n/a	0.096	0.096	n/a
Service Crew	3	10	70%	0.093	0.101	0.021 – 0.14
Shift Boss	6	6	50%	0.090	0.084	0.009 – 0.17
Truck	7	31	22.58%	0.055	0.054	0.006 – 0.14
Total		82	51.22%	0.092	0.080	0.006 – 0.35

Results

- From the results it is apparent that truck drivers, long hole operators and grader operators were among the lowest average exposure groups and bogger operators had the highest average exposure.
- Bogger operators, charge up, jumbo operators, service crew and shift bosses all had more than half of the employees in each of these employment positions whose recorded results over the recommended Time Weighted Average (TWA).
- These same roles also had an average exposure that was over the recommended TWA. Nearly 50% of all employees monitored were above the recommended TWA.

Results

- A majority of those monitored were truck drivers.
- When the truck drivers were removed, the percentage over the TWA exposure limit was then 28/34. This equals 82.4% of the miners monitored and provides an average exposure of 0.116 mg/cm^3.
- The average exposure, when all groups were included, was 0.09 mg/cm^3, which was still above the recommended TWA of 0.07 mg/cm^3 assigned to those working a 12 hour shift with 7 days on and 7 days off. This is the most common roster for each job titled in the above table

Acute health effects

There were total 124 questionnaires collected.

The following table documents the employees who responded to questions on acute health effects and the frequencies of the effects distributed in different job positions

Residual DPM after ventilation dilution and vehicle treatment

Response to irritant health effect frequencies in different job positions

Job Title	Eye Sting					Runny Nose					Sore Throat				
	No	Yes	Occ*	Often	Now	No	Yes	Occ	Often	Now	No	Yes	Occ	Often	Now
Bogger	3	9	9	0	0	5	6	6	0	0	5	7	7	0	0
Charge Up	4	5	5	0	0	5	4	3	1	0	5	4	3	1	0
Grader	1	2	2	0	0	1	2	2	0	0	1	2	2	0	0
Jumbo	2	7	5	2	0	2	6	6	0	0	2	7	5	2	0
Long Hole	2	2	2	0	0	2	2	2	0	0	2	2	2	0	0
Shotcreter	0	4	2	2	0	2	2	1	1	0	2	2	0	2	0
Service Crew	8	6	5	1	0	9	5	4	1	0	8	6	6	0	0
Shift Boss	1	4	4	0	0	2	2	2	0	0	2	2	2	0	0
Truck	19	7	6	0	1	18	8	7	0	1	17	9	6	2	1
Other	17	12	11	1	0	17	13	11	1	1	16	12	9	2	1
Total	57	58	51	6	1	63	50	44	4	2	60	53	42	9	2
With W/O	18.701 (0.028)					6.650 (0.673)					6.465 (0.6931)				
Frequency	44.607 (0.018)					20.026 (0.830)					26.025 (0.517)				

Results

- Apparent that truck drivers were among the groups that recorded the least frequency of irritant effects.
- Bogger operators, jumbo operators, shotcreters and shift bosses were among the groups that recorded the highest level of frequency for irritant effects.
- The Chi-square tests showed that there was a statistical significant correlation between job title and eye sting ($p<0.05$)
- There were no statistic significant correlations between job title and runny nose or sore throat ($p>0.05$)

Research Discussion

- In past more of a focus on chronic health effects and therefore little published research was identified in relation to the acute health effects of diesel particulates.

- The 2 groups that recorded the highest DP exposure were bogger operators and jumbo operators. These jobs also recorded some of the higher frequencies of acute health effects compared to truck drivers with average lower DP exposure and lower frequency of acute health effects.

Result Discussion

- In some cases, such as long hole and grader operators, there was a recorded lower DP exposure but a high frequency of acute health effects
- These job group had a lower number of participants, this may contributed to a higher average of acute health effects.
- 124 questionnaires were completed with 115 responses to eye sting and 113 responses to runny nose and sore throat.
- Response rates were between 91.1% and 92.7%.

Past studies

- A study conducted on laboratory mice showed that pathological details of acute pulmonary inflammation and tissue injury induces by intratracheal instillation of various low doses of DP.

- Dose-response pulmonary effect of DP was also revealed.

- Another experimental study performed on mice and results showed that low doses of diesel particles can acutely elicit pulmonary toxicity in mice.

Limited data

- Limited amount of data collected on potential acute health effects of diesel exhaust exposure in humans so laboratory animal studies have been used to identify acute health effects.

- Highlights the relevance of this study as it demonstrates the needs to conduct research in humans to investigate the exposure and acute health effects in real-life work situations

Human Studies

Some studies have used human volunteers in settings that have been developed by the researchers.

Tornqvist, Mills et al (2007) found that in 15 healthy volunteers, 24 hours after inhalation of 300 mu g/m^3 diesel exhaust for 1 hour, mild systemic inflammation and an impairment of vascular endothelial function were observed

Uniqueness of study

Our study uses real-life and real time work situations

Human exposure studies often use different DP concentrations, compared with real-world exposure levels.

Relevance of study

- In many studies there has been a focus on measurable health effects.
- Miner state “Some of the stresses you can feel – you don’t need a gauge to measure this – your burning eyes, nose, throat, your chest irritation. The more you’re exposed to the higher this goes”. (Monforton 2006)
- Important to also look at health effects that are not only measurable but irritable level.

Benefits & Effects

- Health and Safety Benefits
- Data for other studies
- Further look at irritant health
- Pressure for standard management plan and monitoring

Forecasted Outcomes

- Data in determining if there is an issue with Diesel Particulates in relation to irritant health effects.
- Create Diesel Particulate Policy and Management Plans
- Implement more effective diesel particulate control measures
- Work on the development of having an across the board standard for the monitoring of diesel particulates

Conclusion and recommendation

- Further analysis of confounding factors to determine if the acute health effects are directly associated with diesel particulate exposure.
- Distribute questionnaires to determine if response changes with employees paying more attention to irritant health effect after participating in study.
- It is clear that diesel particulate exposure does have an influence on the occurrence of irritant symptom
- Further research on acute health effects on a larger sample size need to be conducted to give more accurate information on the relationship between DP exposure and acute health effects on workplace employees.

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Thankyou

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Diesel Particulates

Importance of standardizing diesel particulate sampling

Diesel Exhaust

Diesel engine has been used in a wide range of industries such as mining, railroad, construction and transportations for more than 80 years.

Diesel exhaust is a complex mixture of gases and particles.

There is no single golden standard method that can be used for assessing the total diesel exhaust

Diesel recommendations

At present the only recommendation for workplace exposure level and monitoring is that worker exposure to diesel particulate (DP) levels should be controlled to below 0.1 mg/m3 measured as submicron elemental carbon.

Paper Overview

- Two sampling methods were used and compared to provide first hand data for future standardizing sampling method in WA mining sectors.
- Method 1 was the common method used by the contracted occupational hygienists for monitoring DP concentration at this mine site
- Method 2 is considered to be more precise in monitoring for diesel particulates and is the popular method of monitoring in other underground settings both metaliferous and non metaliferous mines.
- Method 2 of monitoring was also the method currently used in a study by the research team on this mine to determine if there was a relationship between DP exposure and irritant health effects.

The Setting

Underground gold mine in W.A.

More ideal than a coal mines as coal dusts have to be made accountable when looking at elemental carbon as a benchmark.

Lack of studies in metaliferous mining, most current recommendations are based on coal mining

Focus is currently needed for DP issues in underground metaliferous mining.

Current DP monitoring

- Mine site was experiencing issues with higher levels of diesel particulates exposure than the recommended 0.1mg/m^3.
- Monitoring was done at a more frequent level then most mines.
- Monitoring done by a contracted occupational hygienist
- Monitored differently than some other metaliferous mines

Monitoring Methods

Method 1

- Administered by the company contracted to do the monitoring.
- Cassette was prepared by the laboratory where analysis occurred.
- Sampling train was calibrated before and after the monitoring period by an employee of the contracted occupational hygiene company
- Qualified ventilation technician.

Method 2

- Administered by Curtin University student completing a study on DP.
- Preloaded specialised SKC DPM cassette.
- Sampling train was calibrated before and after the monitoring period by the Curtin student
- Qualified ventilation technician and officer.

Comparisons of two types of DPM monitoring methods

	Method 1	**Method 2**
Sampling Pumps	AirChek 2000	AirChek XR5000
Cassette	Three Piece Styrene	Precision-jeweled impactor
Filter Paper	Heat – treated quartz	2 heat – treated quartz
Cyclone	Plastic cyclone	DPM Cyclone
Flow Rate (l/min)	2.2	2.0

Monitoring Method

- Monitors were:
  - Placed in the same area
  - Side by side
  - Positioned the same way
  - Started and stopped at the same time.

This was done to reduce the effect of confounders.

- Sampling begun just after shift had begun and collected just before the end of that same shift.

- Monitoring both day and night shift

Analysis Method

- Elemental carbon (EC) is considered the best marker for DP exposure
- NIOSH method (5040) was used to measure EC in both monitoring procedures.
- This method is considered the most accurate and the only validated method to measure EC, organic carbon (OC) and total carbon (TC).
- To eliminate measurement bias, samples collected by both monitoring methods were sent to the same lab for analysis of elemental carbon. This lab is accredited to use the NIOSH method 5040.

Sample collection areas

- Travelling down the portal the mine there are two main declines
- The Exhibition decline (EXH) and the North decline (NTH).
- The numbers next to each of the declines represents meters above sea level
- Results with “n” represents the data collected during night shifts.
- Among 11 sample collected, one result was not included in the table as for reasons unknown the pump for method 1 stopped working half way through monitoring

Comparisons of DPM monitoring results by using the two sampling methods

Date	Position	Method 1	Method 2	Difference
22.02.11	EXH **288	0.41	0.31	0.1
22.02.11	EXH 388	0.29	0.21	0.08
22.02.11	EXH 311	0.28	0.23	0.05
13.04.11 n*	NTH*** 300	0.58	0.55	0.03
13.04.11 n	NTH 481	0.2	0.081	0.119
13.04.11 n	NTH 285	0.27	0.38	0.11-
13.04.11 n	EXH 400	0.4	0.16	0.24
15.06.11 n	EXH 270	0.23	0.18	0.05
15.06.11 n	NTH 275	0.12	0.09	0.03
15.06.11 n	EXH 400	0.36	0.53	0.17-
Mean (mg/m^3)	Mean (mg/m^3)	0.314	0.274	0.040
Median (mg/m3)	Median (mg/m^3)	0.285	0.23	0.055
Range (mg/m3)	Range (mg/m^3)	0.12 – 0.58	0.081 – 0.55	0.039 – 0.03

Statistical Results

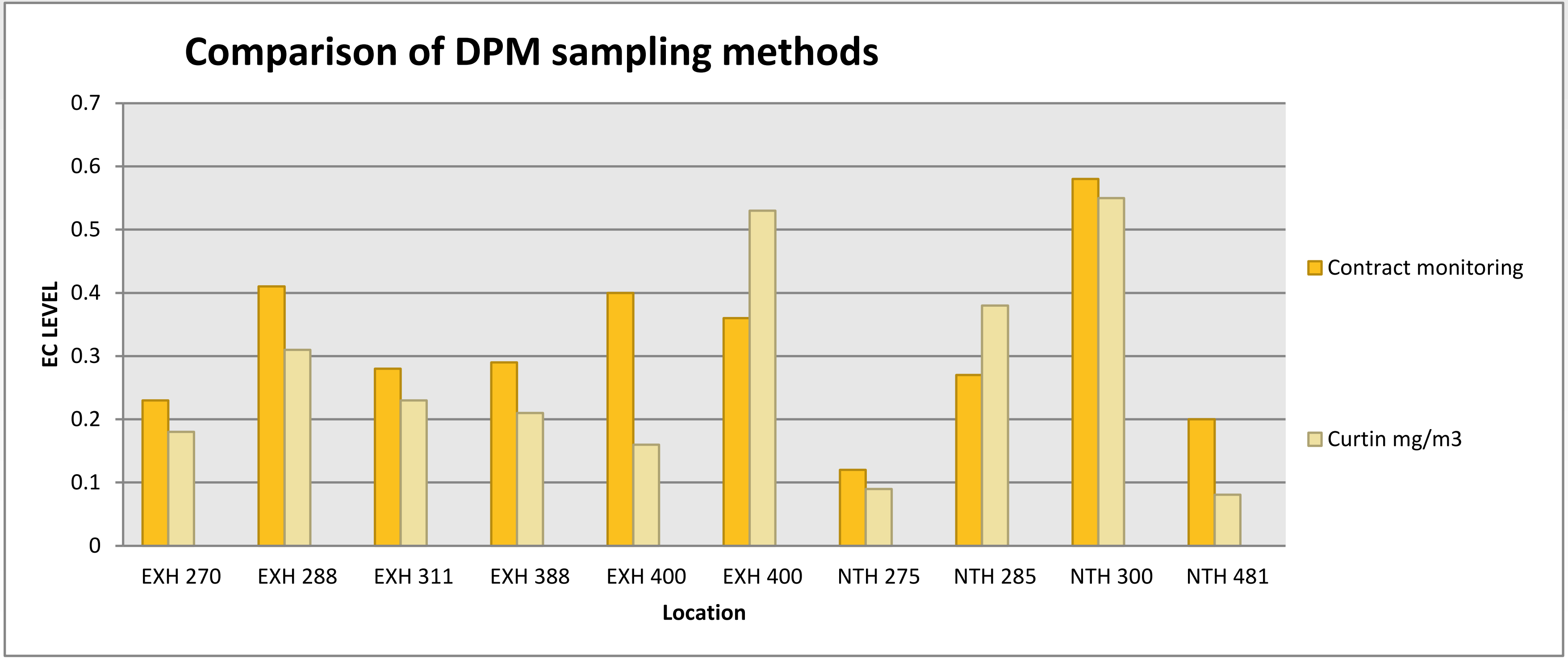
- The paired t test showed that the monitoring results from the two sampling methods had relatively good correlation ($r=0.731$, $P=0.016$) and there was no statistical significant difference between the two methods ($t=0.155$ and $P=0.278$).

- While there seems to be no statistical difference in comparing the two sampling methods, there does seem to be a different trend in results, with some difference being up to 0.119 (mg/m^3)

Overall Results

- Overall the readings recorded in Method 2 were less than those in Method 1.
- However in 2 occasions Method 2 recorded higher readings.
- Another interesting point is that one of the areas where Method 2 recorded a higher reading had monitoring done in the same location just 2 months prior and those results showed Method 2 as having lower readings.

Comparisons of DPM monitoring results by using the two sampling methods



Past Comparative studies

- Ramachandran (2003), conducted a study comparing four different methods to sample and analyse DP in underground mining.

- These methods were:
  - Respirable combustible dust sampling (RCD)
  - Size selective sampling with gravimetric analysis (SSG)
  - Respirable dust sampling with EC analysis
  - Respirable dust sampling with TC analysis.

The researchers discovered that as levels of DP decrease, the necessity to use EC as a marker for exposure of DP increases as it is more sensitive than other methods.

Impact of the Impactor

- Noll (2005) Investigated how DP samples were collected on a quartz filter to measure carbon content using the NIOSH 5040 Method
- Explained the importance of using size-selective samplers to collect DP
- An impactor can be used to separate larger dusts from DP dusts.
- Data on the efficiency of using SKC DPM cassettes is limited.
- Exemplifies that Method 2 is more acceptable and also the need for research using this method

Current Requirements – NIOSH 5040

- Currently there is no standard method of monitoring DP in Australia
- The only requirement - analysis is done using the NOISH Method 5040.
- NIOSH 5040 was specifically developed to measure EC from DP.
- Studies have determined that EC forms a considerable portion of DP therefore is as a suitable marker for DP exposure
- It can also be measured at low amounts

SKC background

- SKC, a company that produces air monitoring equipment
- Claim that other cassettes may meet NIOSH Method 5040 specifications but only the SKC DPM Cassette separates DP from other respirable dust.
- The precision-jeweled impactor screens out and retains respirable particles $\geq$ 1.0 µm
- These cassettes are pre loaded and therefore less errors have the potential of occurring with Method 2.

Inconsistencies

- The variations may be due to a number of reasons :
    - Sampling trains was not working properly due to environmental issues
    - Sampling train may have moved slightly
    - Many different possibilities that are hard to determine unless the sampling trains are observed throughout the whole monitoring process and this is not very practical.

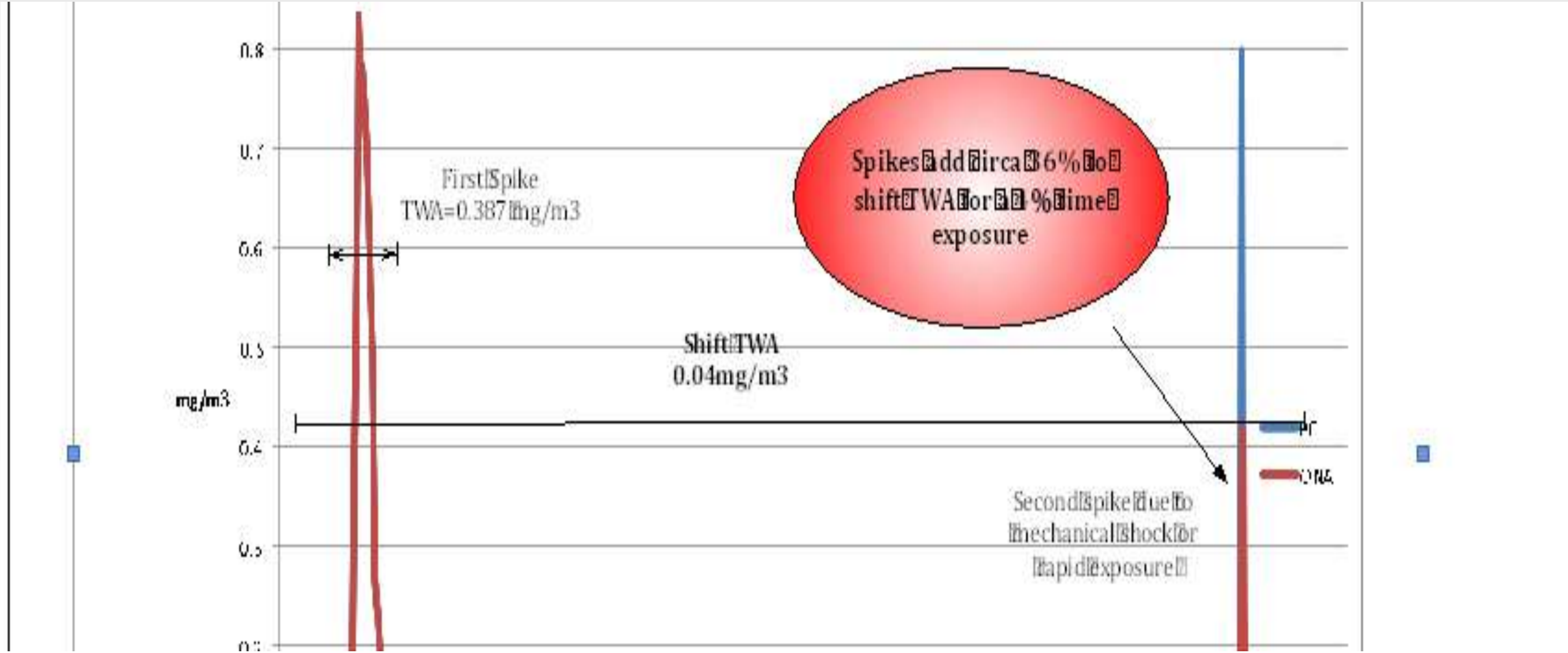
Current most appropriate method

- From the information gathered both from past studies and this study it would seem that Method 2 is more specific to diesel particulates
- Method 1 may collect larger particles as it does not contain the Impactor that is present in Method 2.
- More analysis of all methods for monitoring D.P needs to occur.

Recommendations

- More comparison of both methods need to be conducted in different areas to determine if there is any significant difference.
- Accompanying these comparisons other environmental conditions need to be monitored to determine what affect these may have on the monitoring methods.
- Look at activities that are occurring in the area
- Continual observation of the monitoring equipment during the whole monitoring process.

Need for real time monitoring



Solution - Monitoring

- What to monitor
- Position of the monitoring equipment
- When to monitor
- Monitoring process
- Monitoring equipment

Solution – Training and Education

- Monitoring staff need to alter their testing regimes
- Monitored staff needed to be directed on how to wear monitoring equipment
- Engage employees on environmental air contaminant issues

Solution – Data Capture and Reporting

- More appropriate systems needed so emissions data can be more accurately collected, assembled, and expertly interpreted.
- From here a true accurate picture of emissions can be more confidently disseminated to all stakeholders

Benefits & Effects

- Health and Safety Benefits
- Accurate results
- Fair comparison
- Environmental Benefits

Improving Standards

- Improve on regulatory requirements where possible
- Better understanding of diesel emissions to help significantly reduce its operational costs
- Publicising its findings so other mine operators, regulators, unions and all stakeholders can collectively contribute to create a standardized monitoring system

Forecasted Outcomes

- Determine if there is an issue with Diesel Particulate Emissions on site
- Create Diesel Particulate Policy and Management Plans
- Implement more effective diesel particulate control measures
- Work on the development of having an across the board standard for the monitoring of diesel particulates

Future implications

- The differences shown will help encourage further comparisons and recommendations in the future
- This data can also be used when sampling other methods of monitoring.
- This study supports the need for a standardised method of monitoring.

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Thankyou

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